Study of Transformer Lifetime Due to Loading Process on 20 KV Distribution Line

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Abstract Power transformer is very important in electric power system due to its function to raise or lower the voltage according to its designation. On the power side, the power transformer serves to raise voltage to be transmitted to the transmission line. On the transmission side, the power transformer serves to distribute the voltage between the main substations or down to the distribution voltage. On the distribution side, the stresses are channeled to large customers or lowered to serve small and medium customers. As the power transformer is so importance, it is necessary to protect against disturbance, as well as routine and periodic maintenance, so that the power transformer can operate in accordance with the planned time. Some factors that affect the duration of the power transformer is the ambient temperature, transformer oil temperature, and the pattern of load. Load that exceeds the maximum efficiency of the transformer which is 80% of its capacity will cause an increase in transformer oil temperature. Transformer oil, other than as a cooling medium also serves as an insulator. Increasing the temperature of transformer oil will affect its ability as an isolator that is to isolate the parts that are held in the transformer, such as iron core and the coils. If this is prolonged and not handled properly, it will lead to failure / breakdown of insulation resulting in short circuit between parts so that the power transformer will be damaged. PLN data indicates that the power transformer is still burdened exceeding maximum efficiency especially operating in the work area of PLN South Bali Area. The results of this study, on distribution transformers with different loads, in DS 137, DS 263 and DS 363, show that DS 363 transformer with loading above 80% has the shortest residual life time compared to DS 263 and DS 137 which loading less than 80%.

***Index Terms*— Current, Voltage, Duration of Time, Distribution Transformer.**

I. INTRODUCTION

Power transformer is used to transform power. In power plant, this is used to increase power transferred to transmission line. In transmission line, however, this is used to transfer power between substations. In the distribution side, power is distributed to main customers or reduced to become low power to serve middle-level or low-level customer. As power transformer is so importance, it is highly required to protect and maintain it, therefore, their lifetime can be extended.

There are factors to influence lifetime of power transformer: ambient temperature, transformer's oil temperature, and loading pattern. Loading process in distribution transformer influences voltage and current in transformer's coil. In ideal condition, transformer is loaded up to 80% of its capacity due to its efficiency and losses. Power transformer management is related to the routine maintenance, for preventive, corrective, or detective. Shorten lifetime or damaged transformer caused by isolation fail in parts of transformer such as iron core and coils. This can happen due to the function of isolation to break parts with voltage to avoid flash over or spark over. Isolation fail can be caused by some factors, such as time, reduced-

dielectric strength, extra voltage and high current. Extra voltage in isolator, is a stress that must be counter by isolator for not being fail when isolating current. Inside isolation, electrons hardly link to their molecule, where this link forces stress caused by voltage. If this link is broken, isolation is disappeared, and it is fulfilled with power, there are moving electrons from one molecule to the others, where therefore, leaked current is created. On the other hand, High voltage that constantly flows inside coils cause temperature escalation.

PLN Area Bali Selatan says that in 2016, there are distribution transformers with load more than 80%, exceeds their capacity. Based on these facts, this research aims to analyze effect of loading to life time of power transformer by comparing power transformer with load of 50% - 60%, 70% - 80%, and 80% - 90% of its capacity. Results of this research can be used as a base of power transformer replacement or mutation, therefore power transformer damage that influences service continuity can be minimized.

There are previous studies related to power transformer lifetime and its load factor:

1. Janny Olny Wuwung, 2010. Here, effect of loading process to temperature increment in oil-submerged transformer is studied. Results of this study show that increment of loading factor raises aging factor that decrease the lifetime of a transformer.
2. Syafriyudin, 2011. In this study, transformer time of use prediction is calculated from daily voltage and current. Results of this study is that time of use of a transformer is reduced 8 months out of its normal time.
3. Sofyan and Afryastuti Herawati, 2015, studied effect of, loading process to efficiency and lifetime of transformer based on IEC 60076-7. Results of their research show that the highest efficiency of 96.66% occurs in peak load.
4. Winarso, 2014. Time of use of a transformer is predicted from daily voltage and current calculation. Results of this paper shows that for transformer with 5 years lifetime, it can be used for only 4 years and 7 months.

II. BASIC CONCEPT

Transformer is a robust magnetoelectric tool used to change voltage. In general, Transformer composed by core formed by iron plate and two coils, primary and secondary coil. Ratio of voltage change depends ratio of those two coils (Abdul Kadir). Turn ratio of transformer is a deciding factor of the transformer type. If the turn ratio is lower than one, it is a step-up transformer. Otherwise, turn ratio that is higher than one means that the transformer is a step down one (Sumanto).

Distribution transformer used to distribute power to customers. A proper election of distribution transformer capacity is highly decided by the supplied load; therefore, it can support the continuity of service, reliability, and transformer lifetime. Distribution transformer reach maximum efficiency when it is loaded until 80 percent of its capacity. When the load is too high, it is required to change the transformer, to insert new transformer, or to shift transformer (low-loaded transformer is shifted to serve high-loaded transformer or vice versa). Equation 1 is used to calculate distribution transformer rating where pf is power factor (cos phi = 0.85).

Distribution transformer rating (KVA) = Load (KW)/pf (1)

Prediction of Transformer lifetime can be analyzed through error value of transformer load. Error value of transformer is counted by using Equation 2.

$$E = \frac{P - P*}{P} x\,100\,\% \quad (2)$$

where :
E = Error value (%)
P = Threshold value of transformer usage (80%)
P* = I (%) + V (%) + P (%)

Meanwhile, each percentage value of I, V, and P can be calsulated by these methods:

$$I\,(\%) = \frac{Inom - Ibeban}{Inom} x\,100\ \ (\%) \quad (3)$$

$$V\,(\%) = \frac{Vinput - Voutput}{Vinput} x\,100\ \ (\%) \quad (4)$$

$$P\,(\%) = \frac{Pnomi - Pbeban}{Pnom} x\,100\ \ (\%) \quad (5)$$

$$Inom = \frac{S}{\sqrt{3}V} \quad (6)$$

Where :
S = Pnom = Power of power transformer (KVA)
Inom = Phase current (A)
V = Vinput = Phase voltage (V)
Voutput = V_L = Load voltage from experiment (V)
Ibeban = I_L = Current from experiment (A)
Pbeban = Load power (KW)

Load power is calculated by using equation 7.

$$P_{beban} = \sqrt{3} V_L I_L \cos\phi \quad (7)$$

If load current I_L is current that transfers power to load in a balance mode, therefore, in the curent power transmission with unbalance mode, value of load current can be stated with a, b, and c coefficients as it are shown in equation 8 where I_R, I_S, dan I_T are load current in each phase, R, S, and T.

$$\begin{aligned}[I_R] &= a[I] \\ [I_S] &= a[I] \\ [I_T] &= a[I]\end{aligned} \tag{8}$$

If power factors in these three phases is equal, even each current is different, transmitted power can be stated by equation 9.

$$P_{beban} = (a+b+c)\sqrt{3}V_L I_L \cos\phi \tag{9}$$

Due to the imbalanced load in each phase of secondary transformer, it is current to traverse the neutral of transformer, where this current causes losses. Losses value in the neutral of transformer can be calculated using equation 10. In this equation, P_N is losses in the neutral conductor of transformer (Watt), I_N is current arises in neutral conductor (Ampere), and R_N is resistance in neutral conductor (Ohm)

$$P_N = {I_N}^2 R_N \tag{10}$$

Afterwards, percentage of transformer lifetime is calculated through equation 11

$$\text{Transformer lifetime (\%)} = 100(\%) - E(\%) \tag{11}$$

If it is predicted that transformer can be used until 10 years, therefore its lifetime is calculated as folows. Lifetime (day) is lifetime(%) multiply by 3600 days. Or it can be calculated by lifetime (year) which is lifetime(day) divide by 3600 days.

III. METHODOLOGY

This research was conducted in three distribution transformers: DS 137 located in Tirta Nadi street, DS 263 in Danau Tamblingan street, and DS 363 which is located in Pulau Serangan street. These transformers are selected due to the early data from PT. PLN Bali South Regian in 2016., which is corresponding to the loading criteria of this research, 50% - 60%, 70% - 80%, and 80% - 90%. Data of each transformer is:

- DS 137 brand of B.D, installed in 2011, capacity of 250 KVA, 380/220 V, load of 47.91%.
- DS 263 brand of Unindo, installed in 2011, capacity of 250 KVA, 380/220 V, load of 71.37%.
- DS 363 brand of Trafindo, installed in 2011, capacity of 250 KVA, 380/220 V, load of 83.24%.

Measurement was conducted from 19.00 until 20.00, which is time of peak load. This schedule was repeated for seven days. The tool used is Clamp Power Meter.

IV. RESULTS

Results of our research are shown in Table 1, 2, and 3, for DS 137, DS 263, and DS 363 respectively.

Table 1
Measurement results of DS 137

Day	MEASUREMENT RESULTS									
	CURRENT (AMPERE)				VOLTAGE (VOLT)					
					PHASE			NEUTRAL PHASE		
	IR	IS	IT	IN	RS	RT	ST	RN	SN	TN
1	163	178	185	57	391	401	398	227	225	231
2	184	193	205	47	391	400	397	227	225	229
3	114	124	223	95	398	390	400	223	231	227
4	98	67	81	37	403	397	409	228	235	231
5	193	151	163	58	387	398	395	225	223	229
6	193	151	163	58	387	398	395	225	223	229
7	123	48	122	80	394	387	401	223	230	226
Total	**1068**	**912**	**1142**	**432**	**2751**	**2771**	**2795**	**1578**	**1592**	**1602**
Average	**152.57**	**130.29**	**163.14**	**61.714**	**393**	**395.86**	**399.29**	**225.43**	**227.43**	**228.86**

Table 2
Measurement results of DS 263

DAY	MEASUREMENT RESULTS									
	CURRENT (AMPERE)				VOLTAGE (VOLT)					
					PHASE			NEUTRAL PHASE		
	IR	IS	IT	IN	RS	RT	ST	RN	SN	TN
1	282	265	251	46	385	397	392	223	221	227
2	196	246	260	90	383	394	391	223	220	225
3	199	216	269	91	395	387	397	224	226	225
4	324	257	186	143	389	403	398	227	225	230
5	259	258	273	112	388	380	397	220	227	226
6	266	339	266	125	380	397	387	224	218	227
7	267	197	303	164	388	380	396	219	229	224
Total	**1793**	**1778**	**1808**	**771**	**2708**	**2738**	**2758**	**1560**	**1566**	**1584**
Average	**256.14**	**254.00**	**258.29**	**110.14**	**386.86**	**391.14**	**394.00**	**222.86**	**223.71**	**226.29**

Table 3
Measurement results of DS 363

DAY	MEASUREMENT RESULTS									
	CURRENT (AMPERE)				VOLTAGE (VOLT)					
					PHASE			NEUTRAL PHASE		
	IR	IS	IT	IN	RS	RT	ST	RN	SN	TN
1	323	301	284	134	402	397	405	224	233	231
2	300	362	318	103	391	387	397	223	227	224
3	253	339	375	158	399	404	401	232	228	232
4	291	370	306	123	396	390	398	225	226	228
5	300	318	384	135	391	383	396	222	228	223
6	389	296	401	130	390	398	395	228	224	227
7	375	378	308	174	395	392	401	224	230	228
Total	**2231**	**2364**	**2376**	**957**	**2764**	**2751**	**2793**	**1578**	**1596**	**1593**
Average	**318.71**	**337.71**	**339.43**	**136.71**	**394.86**	**393**	**399.00**	**225.43**	**228**	**227.57**

V. DISCUSSION

Results of lifetime calculation in each distribution transformer are shown in Table 4, 5, and 6, for DS 137, DS 263, and DS 363 respectively.

Table 4
DS 137 with 50% - 60% load

Pnominal, (250 KVA = 250000 VA)	250,000.00	VA
	294,117.65	Watt
Power faktor	0.85	
V input	220.00	V/phase
I nominal (eq. 6)	379.69	A/phase
I load	148.67	A/phase
Voutput	227.24	V/phase
Pload (eq. 7)	49,677.50	Watt
	49.68	KW
Percentage value :		
I (%), eq. 3	60.84	%
V (%), eq. 4	(3.29)	%
P (%), eq. 5	83.11	%
P*, e1. 6	140.66	%
Error, eq 1	(75.83)	%
Lifetime, eq 11	175.83	%
Lifetime in day	6,329.90	day
Lifetime in year	17.58	year

Table 5. DS 263 with 70% - 80% load

Pnominal, (250 KVA = 250000 VA)	250,000.00	VA
	294,117.65	Watt
Power faktor	0.85	
V input	220.00	V/phase
I nominal (eq. 6)	379.69	A/phase
I load	256.14	A/phase
Voutput	224.29	V/phase
Pload (eq. 7)	84,479.02	Watt
	84.48	KW
Percentage value :		
I (%), eq. 3	32.54	%
V (%), eq. 4	(1.95)	%
P (%), eq. 5	71.28	%
P*, e1. 6	101.87	%
Error, eq 1	(27.33)	%
Lifetime, eq 11	127.33	%
Lifetime in day	4,584.03	day
Lifetime in year	12.73	year

Table 6
DS 363 with 80% - 90% load

Pnominal, (250 KVA = 250000 VA)	250,000.00	VA
	294,117.65	Watt
Power faktor	0.85	
V input	220.00	V/phase
I nominal (eq. 6)	379.69	A/phase
I load	331.95	A/phase
Voutput	227.00	V/phase
Pload (eq. 7)	110,806.87	Watt
	110.81	KW
Percentage value :		
I (%), eq. 3	12.57	%
V (%), eq. 4	(3.18)	%
P (%), eq. 5	62.33	%
P*, e1. 6	71.72	%
Error, eq 1	10.36	%
Lifetime, eq 11	89.64	%
Lifetime in day	3,227.21	day
Lifetime in year	8.96	year

These calculation results show that the higher the given load, affects to the diminished of lifetime of distribution transformer. Finally, Figure 1 shows the relations between lifetime and loading factor of power transformer.

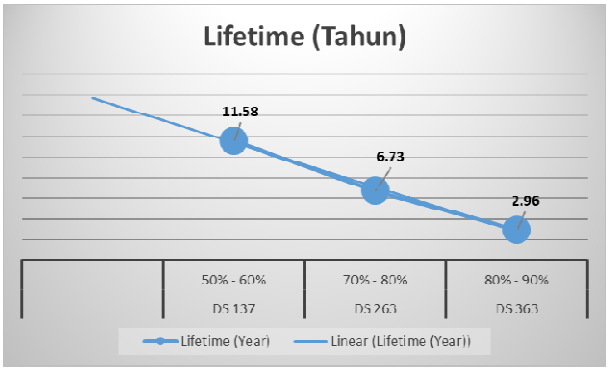

Fig. 1. Relation between loading factor and lifetime.

VI. CONCLUSIONS

Loading in power transformer affects lifetime. The higher the load the shorter the lifetime. If it is assumed that power transformer can be used for 10 years, transformer DS 137 with brand of B.D then can be used for 11.58 years when it is loaded only 50% to 60% of its capacity. Meanwhile, DS 263 with brand of Unindo with load of 70% to 80% of its capacity, can be used for 6.73 years. Lastly, DS 363 with brand of Trafindo, where it is loaded with 80% to 90% of its capacity, its lifetime is only 2.96 years.

VII. ACKNOWLEDGMENT

We would like to express our sincere gratitude to:

1. Rector of Udayana University, through Dean of Faculty of Engineering for the grant with value of 25.000.000 IDR, where therefore this research can be finished.
2. Head and secretary of the Electrical Engineering Department, students, colleges who have collaborated to finish this research.

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