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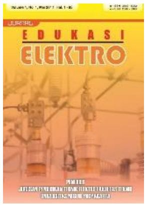

Estimated Cost of Power Losses Due to Imbalance, No-Load and On-Load on Transformers in 2023-2033

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Abstract— The greater the power losses, the higher the loss costs for the transformer. These losses can occur due to load, no-load, and load imbalance factors. This study aims to obtain the cost of losses incurred due to these three factors for ten years (2023-2033). The estimated cost of losses due to unbalance is obtained from the calculation of power losses in the neutral of the transformer, the cost of no-load losses is obtained from the losses of the iron core in the transformer, in contrast the cost of load losses is influenced by the development of the load and the interest rate for each year. As a result, the greatest power losses occur under unbalanced conditions with an average load for ten years of 88.68%, followed by no-load conditions of 11.10% and 0.21% load. The total power losses for ten years amounted to Rp. 3,029,196,416.64.

Keywords: cost of power losses, load, no-load, on-load imbalance, transformer

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1 Introduction

The transformer is the main equipment in the distribution of electric power from generation to customers. The transformer functions to lower or increase the voltage according to the desired needs in the distribution of both high voltage networks (JTT), medium voltage networks (JTM), and low voltage networks (JTR). Continuity of power distribution must be supported by reliable and efficient transformer performance with a lifetime according to standards [1] [2]. Reliable means the ability of the transformer to work all the time without or at least failing to work [3]. Efficient means that the transformer distributes optimal power without or at a minimum occurring power losses [4].

Achievement of performance in accordance with the characteristics of a transformer with a capacity that should often experience problems in its implementation. Power losses are still being experienced by the State Electricity Company (PLN) in supplying electricity to customers. Losses that occur can be caused by two transformer conditions when not loaded and loaded [1] [5] . Losses when no-load conditions are caused by losses that occur in the iron core [2] [6]. Alternating current flowing continuously on the iron plate can cause excessive heating. The current flowing in the iron core is called the Eddy Current (Eddy Current) [7] [8]. Meanwhile, load losses occur in the copper windings of the transformer which are electrified due to the given loading. These losses are called Copper losses. The increase in power losses in both no-load and no-load conditions can directly affect the cost of power losses [9].

The unbalanced load on the transformer also increasing power losses. Imbalance affects the flow of current to the neutral point of the transformer [10]. The current flowing into the neutral of the transformer is caused by an imbalance in the loading on each phase so that the amount of current flowing is also unbalanced [11]. This results in the flow of current in the neutral of the transformer resulting in power losses [12] . Power losses cause the cost of power losses to also increase [13].

The 1 MVA transformer at UIN Suska Riau which was damaged in 2020. This transformer was first used in 2007. The lifetime of the transformer is only 13.55 years old. Based on standard transformer lifetime, it is 20.55 years or 180,000 hours. Solving the problem previously carried out by replacing a new transformer unit at the same capacity. Transformer damage had an impact on the the academic activities of the UIN Suska Riau campus community. For the PLN itself, it has an impact on bearing replacement costs and experiencing financial losses because electric power is not used. This problem can be minimized by paying attention of transformers in serving loading so that they do not recur. It is necessary causes of damage to the transformer. First, we will review the amount of power loss that occurs when no-load and load conditions. The cost of power losses over the next 10 years can also be predicted. The increase in load and unbalanced load also has the potential to become hot so that it can cause an increase in temperature and increase power losses [14] . In summary, the problem in this study is to analyze the magnitude of the power loss costs caused by load imbalance, no-load and load losses during 2023-2033 in the 1 MVA transformer at UIN Suska Riau. The aim of the research is to obtain the cost of losses incurred by the three causes mentioned above for the next ten year.

2 Method

The steps to obtain transformer loss costs can be seen in Figure 1.

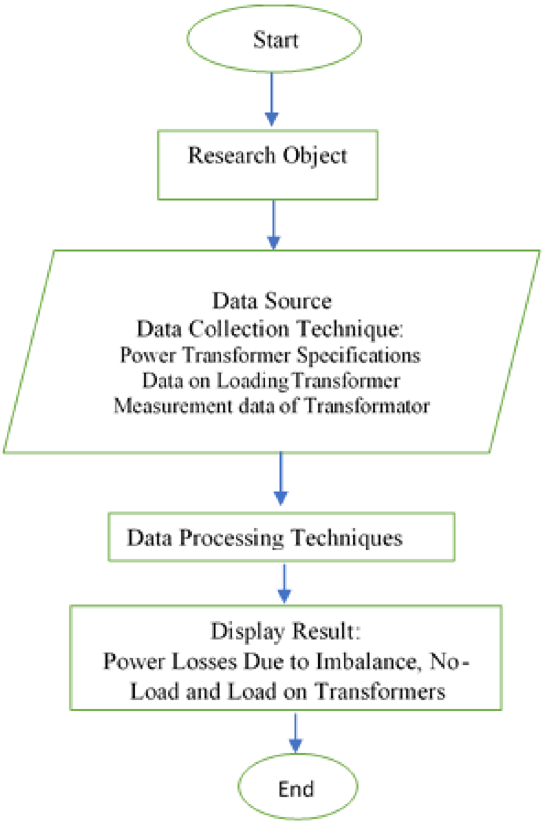

Fig. 1. Research Method

3.1 Research Object

This research produces loss costs for transformers with a capacity of 1000 kVA located at Sulthan Syarif Kasim University, Riau. It was based on the condition that the transformer had experienced damage, which resulted in problems with academic and administrative services in 12 buildings on this campus. The buildings on the channel of the transformer consist of the Library building, Male Dormitory building, Economics and Psychology Laboratory building, Animal Science Laboratory building, Animal Feed Laboratory building, Faculty of Science and Technology Laboratory, Faculty of Science and Technology building, Female Dormitory building. , the Faculty of Psychology building, the Faculty of Social Sciences building, the Faculty of Economics building, and the Computer Center building. Based on the results of observations by PLN, it was found that the medium voltage network voltage (JTM) entering the primary side of the transformer of 20 kVA was appropriate. However, at the position of the low-voltage network (JTR), the three-phase voltage measurement results on the RS, S-T and T-S are unbalanced. Unbalance can be caused by the transformer load on each phase being unequal can also increase losses in the transformer neutral. Losses can also increase due to losses in the iron core and windings in the copper. Based on the results of an interview with one of the technicians who handles the electricity system at UIN Suska Riau.

3.2 Data Source

Research conducted using Quantitative methods. The data used in this study include primary data and secondary data. Primary data were obtained from direct measurements in the form of current, voltage, power, and power factor values for each transformer phase for the average value and peak value every day for eight days. While the secondary data needed consists of 1 MVA transformer specification data and loading distribution data for each phase of 12 buildings at UIN Suska Riau.

3.3 Data Collection Technique

This study obtains research results based on four objectives, namely the magnitude of the cost of transformer losses due to unbalanced loads, transformer losses without load, losses because of loading and total losses for the next 10 years. Based on the research objectives, the required research data is presented in Table 1 to Table 4 below.

Table 1. Power Transformer Specifications

Brand	Starlite
Power/kVA	1000 kVA
Load	Continous
Standart	SPLN 50:1997
Cooling	ONAN
Oil Weight	705 kg
Maximum Oil Temperature Rise	50^0 C
No-load Loss	2300 watt
Load Loss	12100 watt
Impedance	5%
Vector Group	Dyn5
Dimension (L*W*H)	1865*1010*1969 mm
Mass	3400 kg

Table 2. Data on loading distribution of the 1000kVA transformer at UIN Suska Riau

Building	**Apparent Power/phase (kVA)**		
	R	***S***	***T***
Library	11.5	11.8	11.6
Male Dormitory	9.6	7.9	7.9
Economics and Psychology Laboratory	9.7	8.8	8.9
Animal Science Laboratory	8.4	8.0	8.1
Animal Feed Laboratory	11.7	11.8	11.9

Building	**Apparent Power/phase (kVA)**		
	R	***S***	***T***
Faculty of Science and Technology Laboratory	21.4	21.0	20.9
Faculty of Sains dan Technology	17.9	18.0	19.9
Female Dormitory	9.6	7.9	7.9
Faculty of Psychology	13.4	13.4	13.3
Faculty of Social Science	16.5	16.4	16.5
Faculty of Economic	19.9	17.6	15.5
Computer Center	6.2	6.4	6.3
Total Apparent Power/Phase (kVA)	155.7	148.8	148.4
I/ Phase R, S. T (A)	707.7	676.4	674.7
Total I (A)	2058.8		

Table 3. Measurement data of voltage, current, power and average power factor of a 1000 kva transformer UIN Suska Riau (21-28 March 2023)

Day	**Voltage/phase (V)**			**Current/phase (A)**			**I tot (A)**	**P (kW)**	**Q (kVar)**	**S (kVA)**	**Pf**
	Vr	***Vs***	***Vt***	***Ir***	***Is***	***It***					
1	233.8	235.2	236.6	414.0	396.7	167.1	977.9	179.3	102.8	206.9	0.86
2	233.8	235.5	236.8	190.0	137.6	80.7	408.3	76.2	42.2	87.2	0.87
3	232.9	234.3	236.0	192.9	146.8	84.9	424.6	79.2	44.1	90.7	0.87
4	232.0	233.7	235.0	412.5	368.4	163.9	944.8	177.7	93.0	200.7	0.88
5	232.1	233.6	235.0	203.7	167.0	87.9	458.6	83.3	48.8	96.6	0.86
6	233.6	235.1	236.5	192.1	155.0	93.1	440.1	77.7	50.9	93.0	0.84
7	232.0	233.5	234.9	424.0	385.6	210.9	1020.5	186.4	106.0	214.6	0.86
8	231.1	232.6	234.1	428.1	402.6	222.5	1053.2	194.4	105.6	221.4	0.87
Average	232.7	234.2	235.6	307.2	270.0	138.9	716.0	131.8	74.2	151.4	0.86

Table 4. Peak load measurement data per day for the 1000 kVA transformer at UIN Suska Riau (21-28 March 2023)

Day	**Voltage/phase (V)**			**Current/phase (A)**			**I total (A)**	**P (kW)**	**Q (kVar)**	**S (kVA)**	**Pf**
	Vr	***Vs***	***Vt***	***Ir***	***Is***	***It***					
1	229.5	230.9	232.3	718.0	717.3	300.2	1735.5	317.2	176.6	363.0	0.9
2	233.1	235.0	236.0	221.2	146.0	82.0	449.2	83.8	46.5	95.8	0.9
3	232.3	233.7	235.4	211.5	156.2	99.8	467.5	84.4	52.5	99.4	0.8
4	230.9	233.1	234.4	887.9	792.4	415.2	2095.5	398.8	202.5	447.2	0.9
5	232.3	233.8	235.3	219.1	181.5	86.0	486.6	90.1	49.2	102.7	0.9
6	234.3	235.7	237.2	199.7	180.4	100.9	481.0	84.8	56.4	101.9	0.8
7	229.5	231.8	232.6	840.5	746.3	426.1	2012.9	374.8	196.4	423.2	0.9
8	228.1	230.6	231.2	818.8	721.4	371.4	1911.6	356.7	178.2	398.8	0.9

3.4 Data Processing Techniques

The initial stage of the research is to generate losses due to unbalanced load on the transformer, the steps are described as follows[15].

a. Calculate the full load current on the transformer, with the equation

$$I_{fl} = \frac{S}{\sqrt{3}V} \qquad (1)$$

Explanation:
I_{fl} = transformator full load current (A)
S = transformator power capacity (VA)
V = transformator voltage/phase (V)

b. Determine the average current of the transformer

$$I_{average} = \frac{I_r+I_s+I_t}{3} \qquad (2)$$

Explanation:

$I_{average}$= transforator average current (A)
I_r = phase current R (A)
I_s = phase current S (A)
I_t = phase current T (A)

c. Calculating the percentage of transformer loading

$$\% P_r = \frac{I_{rata-rata}}{I_{fl}} \tag{3}$$

Explanation:

%P_r = transformator loading Persentage (%)

d. Calculating the unbalance coefficient

$$a = \frac{I_r}{I_{average}} \tag{4}$$

$$\mathrm{b} = \frac{\mathrm{I_s}}{\mathrm{I_{average}}} \tag{5}$$

$$\mathrm{c} = \frac{\mathrm{I_t}}{\mathrm{I_{average}}} \tag{6}$$

e. Calculates the percentage of imbalance

$$\% Kt = \frac{[|a-1|+|b-1|+|c-1|]}{3}\ x\ 100\% \tag{7}$$

where

%Kt = transformator percentage imbalance (%)

f. Calculate the neutral current of the transformer

$$I_n = \sqrt{(I_r^2 + I_s^2 + I_t^2) - (I_r x\ I_s) - (I_r x\ I_t) - (I_s x\ I_t)} \tag{8}$$

where

In = transformator neutral current (A)

g. Calculate transformer power losses due to neutral currents

$$P_n = I_n^2\ x\ R_n \tag{10}$$

Explanation:

P_n = Losses due to the neutral current of the transformer (W)
Rn= Transformer neutral conductor resistance (Ω)

Cost of losses incurred due to the condition of the transformer without load, load and imbalance for the next ten years [16]

h. Cost of losses due to imbalances

$$B_{pn} = btl\ x\ P_n \tag{11}$$

Explanation:

B_{pn} = Transformer neutral power loss costs (Rp)
btl = electricity tariffs (Rp)

The cost of power losses due to unbalanced loads on each phase for each year is assumed to be constant. Furthermore, the research resulted in losses on the transformer at no load due to losses in the iron core. Losses can be calculated based on the following equation.

$$B_{pib} = t\ x\ btl\ x\ P_{ib} \tag{12}$$

Explanation:

B_{pib} = no load cost (Rp)
t = number of hours in 1 year (hours)
Pib = no load power loss (W)
Cost and loss without burden for each year is constant.

Furthermore, the calculation of the amount of costs when the condition of the transformer has been loaded. Losses when this condition occurs in the copper winding. The steps to determine the amount of the cost of losses can be described as follows.

a. Calculate the load factor

$$F_b = \frac{P_0}{P_p} \tag{13}$$

Explanation:

F_b = load factor
P_0 = First year average power of transformer (W)
P_p = peak power (W)

b. Calculating the loss factor

$$F_r = F_b\ x\ c + (1 - c) * F_b^2\ (14)$$

Explanation:

F_r = loss factor
c = The constant for the distribution system is 0.15 and the transmission system is 0.3

c. Calculate the load growth constant

$$\mathrm{k} = \frac{[(1+r)^2[(1+i)^n-(1+r)^{2n}]].i}{[(1+i)-(1+r)^2][(1+i)^n-1}(15)$$

Explanation:

k = load growth constant
r = load growth (%)
i = annual interest rate (%)

d. Calculate the ^{n}th year load power

$$P_b = P_0\ x\ (1 + r)^n \qquad (16)$$

Explanation:

P_b = Nth year load power (W)

e. Loaded transformer loss costs

$$B_{ptb} = F_r\ x\ t\ x\ btl\ x\ P_{ib}\ x\ \left(\frac{P_b}{S}\right)^2\ x\ k \tag{17}$$

Explanation:

B_{ptb} = Transformer power loss costs (Rp)
So, the total cost of losses on the transformer

$$B_{pt} = B_{pn} + B_{pib} + B_{ptb}\ (18) \tag{18}$$

Explanation:

B_{pt} = The cost of the total power losses of the transformer (Rp)

3.5 Display Result

The research results are presented in 4 Tables. The first table displays the results of calculating the cost of transformer power losses due to load imbalance which causes current to flow to the transformer neutral. The second table presents the results of the no-load costs due to losses in the iron core. The third table presents the results of calculating the cost of losses due to transformer loading. The fourth table is the accumulation of the three costs and losses above for the next 10 years from 2023 to 2033.

The analysis carried out in this study was based on the four results of the study. First perform an analysis of the cost of power losses generated due to load imbalance. The second is to analyze the cost of power losses due to iron core losses in the transformer. The third analyzes the cost of power losses due to loading on the transformer. All three costs will be estimated over the next 10 years. The fourth analysis is carried out on the results of the total power losses due to the three losses occurring over the next ten years.

3 Result and Discussion

The research that has been carried out shows that the cost of power losses in the transformer is due to load imbalance, zero load conditions and when the transformer is loaded. The cost of power losses due to unbalance is influenced by the magnitude of the channel current value for each phase which has a different value for two or more for each phase. The cost of power losses under zero load conditions results from the loss of the iron core in the transformer. While the cost of power losses under loaded conditions is found in copper which is affected by transformer loading. The total cost of power losses in the transformer for the three losses above for 10 years (2023-2033) is presented next.

Table 5. Cost of power losses due to load imbalance

Day	Pr (%)	a	b	c	Kt (%)	In (A)	Pn (kW)	W (kWh)	Bpn (Rp)/year
1	37.26	0.42	0.41	0.17	66.67	238.76	39.00	936.07	268,641,611.25
2	15.56	0.47	0.34	0.20	66.67	94.73	6.14	147.36	
3	16.18	0.45	0.35	0.20	66.67	93.92	6.04	144.84	
4	36.00	0.44	0.39	0.17	66.67	229.75	36.12	866.80	
5	17.48	0.44	0.36	0.19	66.67	102.45	7.18	172.36	
6	16.77	0.44	0.35	0.21	66.67	86.61	5.13	123.18	
7	38.89	0.42	0.38	0.21	66.67	196.70	26.47	635.33	
8	40.13	0.41	0.38	0.21	66.67	194.03	25.76	618.18	

Table 5 describes the cost of power losses due to load imbalance. The second column presents the percentage of loading on the transformer when the condition is unbalanced. The third column is the unbalance constant for each phase. The fourth column calculates the total magnitude of the imbalance, the fifth column produces the current flowing in the neutral of the transformer resulting in dsya losses, transformer density, and the amount of energy losses that occur up to the cost of the resulting losses due to this imbalance factor in columns five and six.

Table 5. Generates power loss costs due to load imbalance on the 1 MVA transformer at UIN Suska Riau. These losses are caused by the loading in each phase is not balanced. Based on Table 3. The greater the imbalance current, the greater the losses that occur. The smaller power factor with reduced real power that can be utilized by electricity customers in this transformer. Based on the theory related to the amount of losses generated due to load imbalance is directly proportional to the amount of imbalance in each phase of the transformer [17]. The greater the imbalance, the greater the resulting losses.

Tabel 6. No-load power loss cost

Year	Pib (kW)	Bpib (Rp)/year
1	2.3	33,637,690.44

Table 6 describes the cost of power losses of the iron core at no-load conditions. The calculation of power losses is carried out for the first year which is presented in the second column. The results of the power losses are presented in the third column. Table 6. Generates loss-free costs. The losses that occur in this condition are caused by losses in the iron core [18]. These losses always occur in transformers based on the type and size of the transformer capacity. Based on Table 1, the no-load losses on the 1 MVA transformer at UIN Suska Riau have a value of 2300 watts. So that the cost of power losses generated due to these losses has the same value every year.

Table 7. Load power loss cost

Year	Po (kW)	Pr (%)	Pp (kW)	Fb	Fr	K	Ptb (kW)	Bptb (Rp)
1	131.80	27.28	398.80	0.33	0.14	1.12	0.03	491,498.24
2						1.12	0.04	541,261.29
3						1.12	0.04	567,271.40
4						1.11	0.04	594,454.26
5						1.11	0.04	622,854.26
6						1.11	0.05	652,516.44
7						1.10	0.05	683,486.41
8						1.10	0.05	715,810.14
9						1.10	0.05	749,533.79
10						1.09	0.06	784,703.51

Table 7 describes the cost of power loss when the transformer is loaded. Calculations based on the peak load conditions that have been experienced by the transformer. The calculation of the cost of losses is based on the average power loading of the transformer in the first year which is presented in the second column and calculates the average loading percentage in the third column. The peak power that occurred in the first year is presented in the fourth column. The value of the loading factor and loss factor in the fifth and sixth columns. Load growth constants are presented in the seventh column so that the amount of power losses under load conditions is generated in the eighth column and the amount of loss costs in the last column. Table 3 presents the cost of losses for ten years assuming a load growth of 2.5% per year. With constant expense growth every year, even though the constant growth of expenses is getting smaller, the cost of losses generated every year has increased. Increasing the load on the transformer results in increased power losses so that the cost of losses also increases [19].

Table 8. Total cost of transformer power losses for 10 years (2023-2033)

Year	Bpn (Rp)	Bpib (Rp)	Bptb (Rp)	Bpt(Rp)	Bpn (%)	Bpib (%)	Bptb (%)
1	268,641,611	33,637,690	491,498	302,770,800	88.73	11.11	0.16
2	268,641,611	33,637,690	541,261	302,820,563	88.71	11.11	0.18
3	268,641,611	33,637,691	567,271	302,846,574	88.71	11.11	0.19
4	268,641,611	33,637,690	594,454	302,873,756	88.70	11.11	0.20
5	268,641,611	33,637,692	622,854	302,902,158	88.69	11.11	0.21
6	268,641,611	33,637,690	652,516	302,931,818	88.68	11.10	0.22
7	268,641,611	33,637,693	683,486	302,962,791	88.67	11.10	0.23
8	268,641,611	33,637,690	715,810	302,995,112	88.66	11.10	0.24
9	268,641,611	33,637,694	749,534	303,028,839	88.65	11.10	0.25
10	268,641,611	33,637,690	784,704	303,064,005	88.64	11.10	0.26
Total	2,686,416,112	336,376,914	6,403,390	3,029,196,417	88.68	11.10	0.21

Table 8. Presents the total loss costs from the costs of losses due to unbalanced loads, no-load losses and loaded losses on the transformer. Presentation of estimated loss costs for 10 years from 2023 to 2033. Loss costs are displayed annually. There is an increase in the cost of losses every year. The biggest losses occur due to load imbalance, then followed by losses due to no-load losses and then followed by losses due to load growth. The difference in cost losses due to this imbalance is so significant compared to other causes. Unbalance causes current to flow in the neutral of the transformer which the customer can no longer use. This neutral current causes power losses in the transformer.

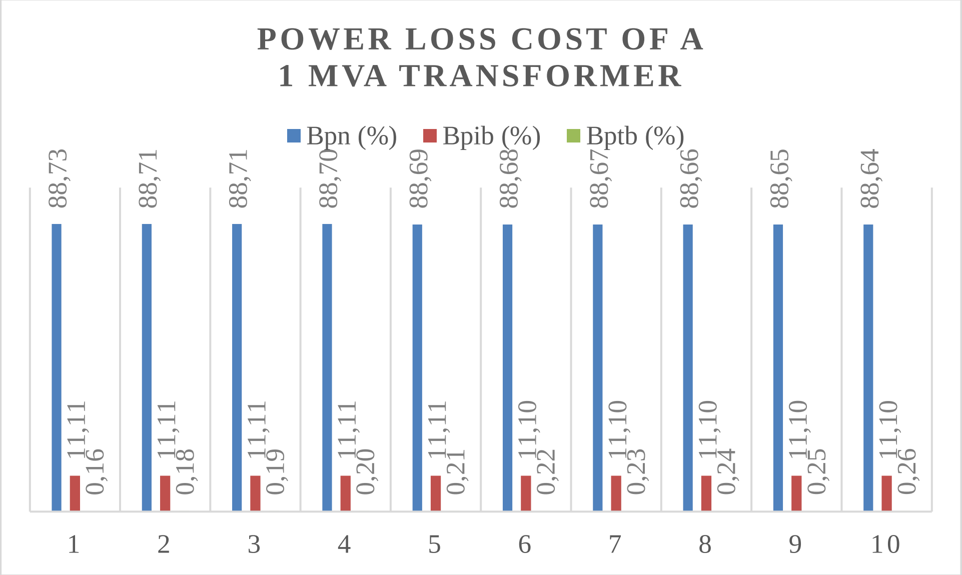

Fig. 2. Percentage comparison of power loss costs for 1 MVA transformer UIN Suska Riau in 2023-2033

4 Conclusions

Cost of power losses that occur in 3 phase 1 MVA power transformers at UIN Suska Riau caused by load imbalance, no-load and load transformer conditions. Losses due to load imbalance result in current flowing in the neutral of the transformer. Losses in the no-load condition of the transformer are caused by losses in the iron core. Meanwhile, losses under load conditions cause additional losses in copper. Every year the losses that occur are increasing. The estimated cost of losses generated within a period of 10 years (2003-2033) is Rp. 303,064,00za5.02. The biggest losses were caused by the occurrence of imbalances which reached 88.68% of the total loss, then followed by losses during no-load conditions which reached 11.1% and loaded conditions of 0.21%.

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