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Equipment Maintenance Effect on Energy Losses Reduction at Medium Voltage Distribution Network

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Abstract. The energy loss is one of primary problems at medium voltage distribution network. The declining quality of distribution network equipment is main factor of energy losses. The equipment maintenance has a significant correlation with energy losses reduction. This research discussed the effect of equipment maintenance on energy losses reduction at medium voltage distribution network. The research object was a feeder of 20 kV medium voltage overhead line at Bontoala Substation, Makassar. The research method was the quantitative calculation of energy losses in a month based on empirical formulas, with and without maintenance condition. The calculation was performed on three distribution network equipment: connector, transformer, and insulators. Based on the calculation results, the total energy losses without maintenance were 118,373.429 kWh. With maintenance, the value of losses can be reduced to 36,960.339 kWh or equal with 68.776% reduction. The research result shows the significant impact on equipment maintenance to distribution network energy losses.

1. Introduction

The electric power system consists of three main parts, namely: generation, transmission and distribution [1, 2]. The distribution system consists of medium voltage (MV) distribution network and low voltage (LV) distribution network [3, 4]. In Indonesia, the MV distribution network uses 20 kV voltage [5]. In other hand, the LV distribution network uses 380/220 Volt voltage. Generally, the MV distribution networks supply large scale customers while LV distribution networks supply small scale customers and households. Based on construction, the MV distribution network consists of MV overhead lines and MV cable line.

The energy loss is one of main problems at a MV distribution network [6]. One of energy losses caution is deteriorating conditions of electrical equipment. The lack of maintenance will lead to the life shortening of electrical equipment. The periodically maintenance needs to be conducted so that the distribution network will operate well and continuously.

The equipment condition which is properly operated and maintained perfectly is called as an ideal condition. If the electrical equipment is operated continuously, it will experience wear and tear performance compared with its initial conditions or commissioning-test condition. Maintenance is intended as an effort to maintain the equipment ideal conditions. It affects to the reliability, efficiency and economic life of network.

Based on the above explanation, this research takes the topic of equipment maintenance effect on energy losses reduction at medium voltage distribution network. This research aims to determine the value of energy losses in MV overhead lines, especially at connector, transformer and insulator equipment. Another objective is to analyze the relationship between maintenance and energy loss reduction.

2. Basic theory

2.1. Electrical power distribution system equipment

In this study, energy loss was only calculated on three components of distribution network, namely connector, transformer and insulator. The connector is a device to connect two conductors. The connector will join the two conductors in such a way that the connection contact resistance maintaining as small as possible. The distribution transformer is operated to transform MV level to the LV level, for example from 20 kV to 380/220 V.

The insulator is a component that useful for separating voltage part from another part that should not have voltage and also from the ground. The insulator in distribution network is also to support the conductor wires on electric poles. The insulator is also used to separate electrically two or more wires to prevent leakage current or flash over.

2.2. Energy loss on MV overhead line

The energy loss in distribution network is electrical energy lost due to various causes in certain unit of time. In general, energy loss can be classified into two parts, namely technical loss and non-technical loss. The technical loss is energy lost as heat in conductor, transformer and other equipment containing resistive and reactive elements. Non-technical loss is energy lost due to non-technical factors such as error reading of measuring instruments, administrative errors, etc.

2.3. Loss on connector

The power loss on a conductor is directly proportional to the resistance value and the square of current. This power loss is also often called conductor dissipation power [7]. The power loss is expressed by the following formula:

$$P_{loss}=I^2_{line} x R_{conductor} \quad (1)$$

I = current (Ampere)
R = conductor resistance (Ω)

The conductor internal resistance is influenced by temperature and expressed by the following formula [8]:

$$R_t=R_{20}\times\frac{234,5+t}{254,5}\times\frac{L}{1000} \text{ for copper} \quad (2)$$

$$R_t=R_{20}\times\frac{228+t}{248}\times\frac{L}{1000} \text{ for aluminium} \quad (3)$$

For the the connector loss calculation, it is assumed that on each branch, there is a bad connector. The connector power loss value is calculated using equation (1). The resistance value for good connector R_k is expressed by equation (4). Meanwhile, the resistance value for bad connector uses equation (5).

$$R_k=\left(\frac{1\text{ m}}{1000\text{ m}} x R_t\right) \quad (4)$$

$$R_k=\left(\frac{11\text{ m}}{1000\text{ m}} x R_t\right) \quad (5)$$

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2.4. Loss on distribution transformer

The distribution transformers loss consists of iron loss, copper loss and insulation loss. The iron loss is caused by flux at the core and it is constant. While copper loss depends on load current changes. Another source of loss is insulation dielectric loss, but this loss type is usually small and negligible. Thus, the transformer power loss is written as the following equation:

$$P_{transformer} = \left[P_{iron} + P_{copper} \times \left(\frac{kVA_{load}}{kVA_{rated}}\right)^2\right] \quad (6)$$

The transformer total loss in kVA expressed with:

$$S_{transformer} = \frac{P_{transformer}}{pf} \quad (7)$$

with::

$P_{transformer}$ = transformer loss (kW)
P_{iron} = iron loss (kW)
P_{copper} = copper loss (kW)
kVA_{load} = transformer load (kVA)
kVA_{rated} = transformer capacity (kVA)
$S_{transformer}$ = transformer total loss (kVA)
pf = power factor

Generally, the standard value of iron and copper loss at a distribution transformer is determined based on the measurement results [9]. The value is proportional to the capacity (kVA). The power loss in the core and conductor of transformer is difficult to be suppressed. This is also coupled with its position in transformer tube body which is tightly closed.

2.5. Loss on insulator

The power loss occurs due to insulators inability to withstand electrical stress perfectly. This is indicated by the presence of leakage current, whose value is influenced by:

- pollution level and insulator wet/dry surface condition
- shape/type of insulator

On normal insulator at clean and dry condition, the leakage current is negligible. However, if the surface is polluted, especially in wet conditions, the leakage current will increase significantly. The shape/type of insulator also affects the level of pollution. The insulator itself can be distinguished by type, namely pin type and pin post type. The leakage current values for clean and polluted insulators (wet and dry conditions) are shown at Table 1 [10].

Table 1. Leakage current value for clean and polluted insulator

Type	**Leakage current (clean)**		**Leakage current (polluted)**	
	Wet (mA)	**Dry (mA)**	**Wet (mA)**	**Dry (mA)**
Pin type	2.5	0	2.4	26.7
Pin post type	2.5	0	2.3	27.8

2.6. Maintenance on distribution network

There are several types of distribution networks maintenance [11]:

- Preventive maintenance. Maintenance is carried out between certain intervals to reduce the equipment possibility to experience changing condition.
- Corrective maintenance. Maintenance is conducted to restore the equipment to its normal condition (including equipment adjustment/repair that has deviated from normal condition). This maintenance sometimes is done outside of the plan activity.

- Emergency maintenance. Maintenance is needed immediately to prevent greater damage.
- Running maintenance. Maintenance is carried out when the equipment still in operation.
- Stopped maintenance. Maintenance is performed when the equipment not in operation.
- Repair. It is carried out after the damage occurred, but it was predicted beforehand, so that preparations for repairs had been made

3. Research method

3.1. Research object

This research object is a 20 kV medium voltage feeder from Bontoala Substation (SS), Makassar. Based on sampling method, one feeder was selected based on number of distribution substations and the line length. Based on these criteria, Polda feeder was selected from 91 feeders of Bontoala SS. The feeder is connected to transformer 1 of Bontoala SS. The feeder has a length of 9 km and 42 distribution substations. Specifically, the data collected for this research are:

- Single line diagram of feeder.
- Technical data of distribution line components: impedance, insulator, conductor and transformer data.
- The length of line and line current data.
- The transformer load data

3.2. Feeder conductor data

The feeder conductor data in the form of current, temperature, conductor length and resistance obtained from PLN measurements. The current value is the load current flowing into conductor. Temperature is the conductor temperature when the load current flows. Conductor resistance is resistance when the conductor temperature is 75°C. Meanwhile, the line is assumed to work at power factor (pf) = 0.85. The conductor data is shown in Table 2. The distribution transformer data are shown in Table 3. While, the insulators data is shown in Table 4.

Table 2. Feeder conductor data

No.	Distribution SS		Current (A)	Temperature (°C)	Power (kW)	Length (m)	R_t (Ohm)
	From	To					
1	GI	UBB	229.1667	75	6747.778	80	0.01974
2	UBB	UBAZ	175.6667	75	5172.479	140	0.03455
3	UBAZ	UPAH	401.3333	75	11817.200	80	0.01974
4	UPAH	UPAG	145.8333	75	4294.041	186	0.0459
5	UPAG	UPBW	26.46667	75	779.307	500	0.1234
6	UPBW	UPDP	236.3333	75	6958.800	227,8	0.05622
7	UPJB	UWBJ	348	75	10246.808	80	0.01974
8	UPBW	UPDW	324	75	9540.131	400	0.09872
9	UPDW	UPBH	18	75	530.0073	37	0.00913
10	UPBX	UPAY	331.6	75	9763.912	130	0.03208
11	UPAY	UPBG	486.3333	75	14320.012	159	0.03924
12	UPBG	UPDE	249.5667	75	7348.453	160	0.03949
13	UPAY	UPCF 1	108	75	3180.044	80	0.01974
14	UPCF 1	UPCF	256.6667	75	7557.512	80	0.01974

15	UPCF	UPDF	142.3	75	4190.002	290	0.15413
16	UPDF	UPAV	168.9	75	4973.235	80	0.04252
17	UPCF	UPAC	313.6667	75	9235.868	295	0.15678
18	UPAC	UPAC 1	13.66667	75	402.413	40	0.02126
19	UPAC	UPAQ	165.6667	75	4878.030	360	0.19133
20	UPAC 1	UPDX	313.3333	75	9226.053	120	0.06378
21	UPAC 1	UPDX 1	22.33333	75	657.6017	80	0.04252
22	UPDF	UPAD	148.3333	75	4367.653	120	0.02962
23	UPCM	UPAZ	72.33333	75	2129.844	120	0.06378
24	UPAZ	UPDH	141.6667	75	4171.354	206	0.10948
25	UPDH	UPDI 1	88.66667	75	2610.777	80	0.04252
26	UPDI 1	UPDI	170.3333	75	5015.439	40	0.02126
27	UPCM 1	UPAO	307.3333	75	9049.384	90	0.04783
28	UPCM 1	UPDG	172	75	5064.514	120	0.02962
29	UPDG 1	UPAE	366.8333	75	10801.352	160	0.03949
30	UPAE	UPDL	45.66667	75	1344.648	80	0.01974
31	UPDL	UPAE 1	108.6667	75	3199.674	41	0.01012
32	UPAE 1	UPDL 1	128.1667	75	3773.848	177	0.04368
33	UPAE	UPBM	315.6667	75	9294.758	80	0.01974
34	UPBM	UPBM 1	89.33333	75	2630.407	160	0.03949
35	UPBM 1	UPBM 2	187.5	75	5520.909	80	0.01974
36	UPBM 2	UPDJ	164.6667	75	4848.585	410	0.2179
37	UPDJ	UPBZ	120.6667	75	3553.012	94	0.04996
38	UPBM 2	UPDK	262.3333	75	7724.366	480	0.11846
39	UPDK	UPDK 1	87.83333	75	2586.239	30	0.01594
40	UPDK	UPBP	352.3333	75	10374.402	120	0.02962
41	UPBP	UPCJ	465.6667	75	13711.485	200	0.04936

Table 3. Distribution transformer iron and copper loss

No.	Distribution SS	Capacity (kVA)	Average load (kVA)	Iron loss (Watt)	Copper loss (Watt)
1	UBB	200	137.55	355	2350
2	UBAZ	200	102.44	355	2350
3	UPAH	400	291.26	595	3850
4	UPAG	160	107.19	300	2000
5	UPBW	315	12.18	500	3250
6	UPDP	250	137.06	420	2750
7	UWBJ	400	222.83	595	3850
8	UPDW	250	141.26	420	2750
9	UPBH	250	8.25	420	2750
10	UPAY	250	143.24	420	2750
11	UPDE	200	54.78	355	2350

12	UPBG	400	216.91	595	3850
13	UPCF	200	112.93	355	2350
14	UPCF 1	100	16.06	210	1420
15	UPAV	160	119.2	300	2000
16	UPDF	250	97.29	420	2750
17	UPAQ	160	72.89	300	2000
18	UPAC	250	138.01	420	2750
19	UPAC 1	50	6.07	125	800
20	UPDX	250	135.98	420	2750
21	UPDX 1	50	9.83	125	800
22	UPAD	160	79.53	300	2000
23	UPAO	250	137.69	420	2750
24	UPAZ	100	15.91	210	1420
25	UPDH	160	65.16	300	2000
26	UPDI	250	78.01	420	2750
27	UPDI 1	400	50.87	595	3850
28	UPBN	630	77.74	835	5400
29	UPDL	100	19.91	210	1420
30	UPDL 1	160	72.06	300	2000
31	UPAE	315	251.68	500	3250
32	UPAE 1	160	49.11	300	2000
33	UPBM	250	138.89	420	2750
34	UPBM 1	160	20.28	300	2000
35	UPBM 2	160	123.69	300	2000
36	UPCJ	400	316.17	595	3850
37	UPDK	250	165.98	420	2750
38	UPDK 1	160	62.01	300	2000
39	UPDJ	250	35.323	420	2750
40	UPBZ	250	25.680	420	2750
41	UPBP	400	49.607	595	3850

Table 4. Insulator data

Pole type	**Number of pole**	**Number of insulator/pole**		**Total of insulator**	
		Pin post	***Pin type***	***Pin post***	***Pin type***
Main line pole	124	3	-	372	-
End pole	3	-	3	-	9
Branching pole	10	-	6	-	60
Corner pole	8	-	6	-	49
Main line DSS pole	18	6	3	108	54
Branch DSS pole	6	-	3	-	18
End DSS pole	31	-	6	-	186
Total	**200**			**480**	**375**

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4. Results and discussion

4.1. Energy loss calculation on connector

For a feeder load of 243,592.337 kW, it will produce loss values for good and bad connectors as shown in Table 5. The total power loss is 118.328 Watt for good connector and 1,301.603 Watt for bad connector.

Table 5. Good and bad connector loss value

No.	Distribution SS		Power (kW)	Good connector Loss (Watt)	Bad connector loss (Watt)	Loss deviation (Watt)
	From	To				
1	GI	UBB	6747.778	1.036693	11.403623	10.3669301
2	UBB	UBAZ	5172.479	1.0661712	11.727883	10.66171177
3	UBAZ	UPAH	11817.200	3.1794906	34.974396	31.79490565
4	UPAH	UPAG	4294.041	0.9761714	10.737886	9.761714288
5	UPAG	UPBW	779.307	0.0864398	0.9508378	0.864398022
6	UPBW	UPDP	6958.800	3.1400798	34.540877	31.40079761
7	UPJB	UWBJ	10246.808	2.390593	26.296523	23.9059296
8	UPBW	UPDW	9540.131	10.363231	113.99554	103.6323072
9	UPDW	UPBH	530.0073	0.0029581	0.0325393	0.0295812
10	UPBX	UPAY	9763.912	3.5274706	38.802177	35.27470605
11	UPAY	UPBG	14320.012	9.2810479	102.09153	92.81047888
12	UPBG	UPDE	7348.453	2.4595769	27.055346	24.59576906
13	UPAY	UPCF 1	3180.044	0.2302474	2.532721	2.3024736
14	UPCF 1	UPCF	7557.512	1.3004277	14.304704	13.00427671
15	UPCF	UPDF	4190.002	3.1210231	34.331254	31.21023068
16	UPDF	UPAV	4973.235	1.212977	13.342747	12.12976969
17	UPCF	UPAC	9235.868	15.425082	169.67591	154.250823
18	UPAC	UPAC 1	402.413	0.0039709	0.0436799	0.039708975
19	UPAC	UPAQ	4878.030	5.251139	57.762529	52.51138999
20	UPAC 1	UPDX	9226.053	6.2617773	68.879551	62.61777334
21	UPAC 1	UPDX 1	657.6017	0.021208	0.2332883	0.212080248
22	UPDF	UPAD	4367.653	0.651722	7.1689418	6.517219849
23	UPCM	UPAZ	2129.844	0.333704	3.6707442	3.337040159
24	UPAZ	UPDH	4171.354	2.1972038	24.169242	21.97203812
25	UPDH	UPDI 1	2610.777	0.3342828	3.677111	3.342828162
26	UPDI 1	UPDI	5015.439	0.6168256	6.7850815	6.168255875
27	UPCM 1	UPAO	9049.384	4.5177232	49.694955	45.17723211
28	UPCM 1	UPDG	5064.514	0.8762781	9.6390589	8.7627808
29	UPDG 1	UPAE	10801.352	5.3140378	58.454416	53.14037798
30	UPAE	UPDL	1344.648	0.0411667	0.4528335	0.411666793
31	UPDL	UPAE 1	3199.674	0.1195015	1.3145168	1.195015311
32	UPAE 1	UPDL 1	3773.848	0.7175184	7.8927023	7.175183866
33	UPAE	UPBM	9294.758	1.9670015	21.637016	19.67001489
34	UPBM	UPBM 1	2630.407	0.3151477	3.466625	3.151477276
35	UPBM 1	UPBM 2	5520.909	0.6939844	7.6338281	6.93984375

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36	UPBM 2	UPDJ	4848.585	5.9083851	64.992236	59.08385103
37	UPDJ	UPBZ	3553.012	0.7274402	8.0018423	7.274402063
38	UPBM 2	UPDK	7724.366	8.1522703	89.674974	81.52270344
39	UPDK	UPDK 1	2586.239	0.1229722	1.3526944	1.229722201
40	UPDK	UPBP	10374.402	3.6769899	40.446889	36.76989902
41	UPBP	UPCJ	13711.485	10.703493	117.73842	107.0349267
Total			243.592.337	118.32542	1301.5797	1183.254235

Thus, the energy loss in 1 month (30 days) for good connector is:
= 118.325 Watt x 30 x 24 = 85,194.305 Wh or 85.194 kWh
Meanwhile, the energy loss in 1 month (30 days) for a bad connector is:
= 1,301.580 Watt x 30 x 24 = 937,137.35 Wh or 937.137 kWh

4.2. Transformer loss calculation

The transformer loss is calculated based on iron loss, copper loss, transformer capacity and average load per hour. The value of power losses based on calculation is shown in Table 6 below:

Table 6. Transformer loss value

No.	Distribution SS	Capacity (kVA)	Loss (kW)
1	UBB	200	1.466550147
2	UBAZ	200	0.971519774
3	UPAH	400	2.636279327
4	UPAG	160	1.197632508
5	UPBW	315	0.504859111
6	UPDP	250	1.246559518
7	UWBJ	400	1.789780339
8	UPDW	250	1.297993054
9	UPBH	250	0.42299475
10	UPAY	250	1.322778694
11	UPDE	200	0.531299844
12	UPBG	400	1.727139376
13	UPCF	200	1.104249613
14	UPCF 1	100	0.246625151
15	UPAV	160	1.41005
16	UPDF	250	0.83647514
17	UPAQ	160	0.715074383
18	UPAC	250	1.258057444
19	UPAC 1	50	0.136790368
20	UPDX	250	1.233584658
21	UPDX 1	50	0.155921248
22	UPAD	160	0.794142258
23	UPAO	250	1.254175588
24	UPAZ	100	0.24594419

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25	UPDH	160	0.631705125
26	UPDI	250	0.687764644
27	UPDI 1	400	0.6572679
28	UPBN	630	0.917224593
29	UPDL	100	0.26628995
30	UPDL 1	160	0.705675281
31	UPAE	315	2.574720814
32	UPAE 1	160	0.488421258
33	UPBM	250	1.268779012
34	UPBM 1	160	0.332131125
35	UPBM 2	160	1.495251258
36	UPCJ	400	3.00037097
37	UPDK	250	1.632171858
38	UPDK 1	160	0.600409383
39	UPDJ	250	0.47489943
40	UPBZ	250	0.449016346
41	UPBP	400	0.65421431
	Total	9,710	**41.34278974**

The total power loss of the transformer is 41.343 kW. Meanwhile, the transformer energy losses for 1 month (30 days) are:
= 41.343 kW x 30 x 24 = 29,766.809 kWh

4.3. *Loss calculation on insulator*

The loss calculation of insulator used the assumption that percentage of wet and dry conditions (or the ratio of rainy and dry days) is 40% and 60%.

a. Clean Insulator

The average leakage current (I_b) is calculated as follows:

- Pin type
  I_b = 375 x ((40% x 2.5) + (60% x 0)) mA = 375 mA = 0.375 A
- Pin post
  I_b = 480 x ((40% x 2.5) + (60% x 0)) mA = 480 mA = 0.48 A

The value of energy loss caused leakage current at insulator in 1 month (30 days) is:

- Pin type
  = (0.375 A) x (20 kV/√3) x 30 x 24
  = 3,117.691 kWh
- Pin post
  = (0,48 A) x (20 kV/√3) x 30 x 24
  = 3,990.645 kWh

Thus the total energy loss of insulators in clean conditions is 7,108,336 kWh / month

b. Polluted Insulator

The average leakage current (I_b) is calculated as follows:

- Type pin type:
  I_b = 375 x (40% x 26.7 + 60% x 2.4) mA = 4,545 mA = 4.545 A
- Type pin post:
  I_b = 480 x (40% x 27.8 + 60% x 2.3) mA = 6000 mA = 6.000 A

The value of energy loss caused leakage current at insulator in 1 month (30 days) is:

- Type pin type
  = (4.545 A) x (20 kV/√3) x 30 x 24
  = 37,786.420 kWh
- Type pin post
  = (6 A) x (20 kV/√3) x 30 x 24
  = 49,883.063 kWh

Thus the total energy loss of insulators in polluted conditions is 87,669.483 kWh/month.

The recapitulation of feeder energy loss value is shown in Table 7 below. The data was arranged based on each equipment energy loss calculation.

Table 7. Comparison of energy loss

No	Equipment	Loss with maintenance (kWh/month)	Loss without maintenance (kWh/month)	Loss deviation (kWh/month)
1	Connector	85.194	937.137	851.943
2	Transformer	29,766.809	29,766.809	0
3	Insulator			
	Pin Type	3,117.691	37,786.420	34,668.729
	Pin Post Type	3,990.645	49,883.063	45,892.418
		36,960.339	118,373.429	81,413.090

5. Conclusion

The connector energy loss without maintenance is 937.137 kWh and can be reduced to 85.194 kWh with maintenance. The energy loss in the distribution transformer is 29,766.809 kWh. The insulators loss without maintenance is 87,669.48 kWh and can be reduced to 7,108.34 kWh through maintenance. With equipment maintenance, the total energy loss in feeder can be reduced from 118,373.429 kWh to 36,960.339 kWh. The energy loss reduction value is 81,413.090 kWh or equal with 68.776%.

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