ANALYSIS OF VOLTAGE DROP AND POWER LOSSES ON MEDIUM VOLTAGE 20 KV DISTRIBUTION SYSTEM KOTAMOBAGU AREA SUPPLIED FROM PLTD KOTAMOBAGU

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ABSTRACT

Drop voltage and power loss at the distribution system of electricity power in the Kotamobagu Area are caused by several factors, a namely far distance of a place that is distributed by electricity power from the source, imbalance load, equipment age, the diameter of the conductor, a distance of powerhouse to the consumer is too far and connection point are caused for technical loss. If it keeps happening, it will decrease the reliability of the electric power system and the distributed quality of the electricity power as well as it can damage the equipment. Therefore, unbalanced loading should be decreased at the phase, and overloading at the network will cause PT PLN (Persero) loss in the Kotamobagu Area. This research aims to analyze voltage drop, percentage of voltage drop, and power loss at every medium voltage feeder of 20 KV that is supplied from PLTD (Steam Power Plant) Kotamobagu until every transformer of distribution at peak load. After it is analyzed, the feeder OK 1, OK 2, OK 3, OK 4, OK 5 obtain the most significant value of drop voltage for 7.221 KV, 1.94 KV, 6.472 KV, 5.04 KV, 4.878 KV, respectively, with a percentage value of 56.507%, 10.742%, 47.841%, 33.689 %,32.257%. All OK happen at powerhouse K-153 (Kobo Besar), K-158 (RS. Monompia Kotamobagu), K-187 (Poopo I), K-201 (Motoboi Kecil), K-287 (Moyag I), respectively. The most significant power loss of 11.890 KW, 4.820 KW, 9.819 KW, 7.311 KW, 10.533 KW happen at powerhouse K-140 (Matali I), K-158 (RS. Monompia Kotamobagu), K-167 (Bilalang V), K-201 (Motoboi Kecil) and K-287 (Moyag I), respectively.

Keywords: *Voltage Drop, Power Loss, Steam Power Plant, Kotamobagu*

1. INTRODUCTION

PT PLN (Persero) is a state-owned enterprise that provides electricity to all levels of society, with increasing demand along with technological advances and improvements in people's living standards. Voltage drop is a condition in which the amount of voltage supplied is not the same as the voltage received by consumers [1]. Factors causing voltage drop include distance from the power source, load imbalance, equipment age, conductor diameter, and others. Voltage drop cannot be completely eliminated, but it can be minimized.

Loss situation in the power distribution network is a condition where there is a large voltage drop [2]. The causes can be the distance from the substation to the consumer that is too far, the cable cross section that is too small, and the problematic connection point. If left unchecked, this condition will reduce the reliability of the power system and the quality of energy supplied, as well as cause damage to related equipment. Research related to voltage drop and power losses has been carried out in many previous studies, such as analysis of voltage drop and power losses in electric submersible pump motor installations [3], analysis of voltage drop and power losses in tantui up substation [4], analysis of voltage drop in office building lighting system [5], and effect of bank capacitor placement related to voltage drop increase [6]. This problem results in a decrease in the number of electricity services received by customers. Therefore, severe treatment is needed by conducting research experiments to deal with voltage drops and power losses.

In this research, we solve this problem using a measurement experiment. Measures are needed to reduce unbalanced loading on the phase and overloading on the network [3]. One of the power plants that provides energy for PT PLN Kotamobagu Area and its surroundings is PLTD Kotamobagu [4]. In each extension, voltage drops and power losses also occur. Therefore, it is necessary to analyze the voltage drop and power loss on each extension in PLTD Kotamobagu as one of the plants that supply electrical energy needs in the Kotamobagu City area and its surroundings.

2. RESEARCH METHODOLOGY

The research was conducted by collecting primary data on each medium voltage network extension supplied from PLTD Kotamobagu. The data collected includes Single Line Diagram (SLD), number of distribution substations, distribution substation transformer capacity, distribution line length, and type of conductor. The measurement of base current and end current is carried out through the secondary side distribution substation on each extension. Furthermore, the data is processed and analyzed to obtain the value of voltage drop and power loss on each transformer of the JTM line of the electricity distribution system of PLN Kotamobagu Area. This calculation uses formulas that are in accordance with the State Electricity Company Standards (SPLN) and considers asset data such as channel length, distance between load points, and type of conductor [5], [6]. This research was conducted at PLN Kotamobagu Area with the aim of knowing the amount of power losses in the distribution system and identifying potential improvements to increase system efficiency [7].

The method used to calculate voltage drop and power loss in medium voltage networks is to use the voltage drop equation and the power loss equation [8]–[10]. Calculations are made based on the load current of each transformer obtained from measurements on each transformer and the length of the line. The data obtained is then used to calculate the voltage drop and power loss that occurs in the Medium Voltage Distribution Network. The following are the calculation steps taken:

1. Calculating the average current of the secondary side load with the assumption of a balanced load using the equation $I_{Rata-rata} = \frac{I_R I_S I_T}{3}$
2. After the average current of the secondary side load of the transformer is known, to determine the voltage drop and power loss, the primary side current of the transformer is needed. To find out the value of the primary current in the transformer, a comparison of the value of the high voltage side with the value of the low voltage side of the transformer is used, known as the transformer ratio, where the voltage ratio ratio is 20000 Volts / 400 Volts and uses the equation $\frac{V_{TM}}{V_{TR}} = \frac{I_{TR}}{I_{TM}}$ so that it is obtained $I_{TM} = \frac{V_{TR} \times I_{TR}}{V_{TM}}$ where V_{TM}: voltage on the high voltage side, V_{TR}: voltage on the low voltage side, I_{TM}: high voltage side current, I_{TR}: low voltage side current.
3. After the primary side current and line length of each transformer are known, we can calculate the voltage drop value using the equation $\Delta V = I (R \cos \theta + X \sin \theta)\, l$ where ΔV: voltage drop (KV), I: current on the primary side of the transformer (Ampere), (R cos θ + X sin θ): line impedance, and l: line length (Km).
4. Calculating the receiving voltage at each transformer branching point is by using the equation Vr = Vs- ΔV where Vr: receiving voltage, Vs: sending voltage, ΔV: voltage drop.
5. Calculating the percentage of voltage drop is by using the equation $\Delta V(\%) = \frac{\Delta V}{V_r} \times 100\%$
6. Calculating the power loss on the line is by using the equation $P_{\text{Saluran}} = I^2 . r . 1$ where PSaluran: power loss on the line (Kw), I: medium voltage side current (Ampere), r: conductor resistance (Ohm/Km), l: line length (Km).

3. RESULTS AND DISCUSSIONS

3.1 Kotamobagu Area Electricity System

PT PLN (Persero) SULUTTENGGO Region Kotamobagu Area is a state-owned enterprise that provides electricity to the community, with needs that continue to increase along with technological advances and living standards. This area is interconnected with the SULUTGO system through Otam, Lolak, and Boroko substations, serving the areas of Central, North, East, South Bolaang Mongondow Regency, Kotamobagu Municipality, and parts of South Minahasa Regency. PT PLN (Persero) Kotamobagu Area operates a Diesel Power Plant (PLTD) and a Micro Hydro Power Plant (PLTMH). In Kotamobagu City, electricity is supplied by PLTD Kotamobagu and Otam Substation, with PLTD distributing power through 5 main and 2 express feeders, and Otam Substation through 3 main and 2 express feeders, with only 2 feeders supplying Kotamobagu City.

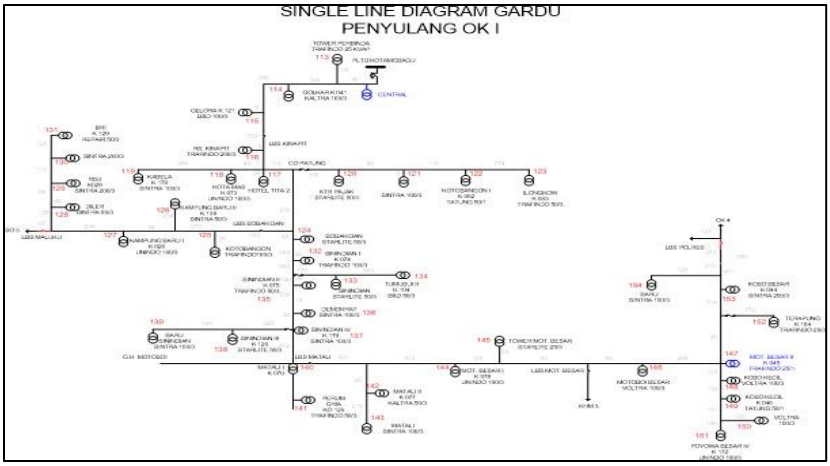

Figure 1. Single line of OK extension

3.2 Result of Measuring the End Current Value of The Distribution Transformer and The Distance Between The Generation Side and Each Transformer on OK 1 Feeder.

The OK 1 extension in Kotamobagu gets its electricity supply from the local PLTD. This line is a priority because it serves several important institutions, business places, and is divided into 42 transformers spread across 3 sub-districts. Calculation of load current with the assumption of unbalanced load, for example at substation K-113 (Tower Behind PLTD) on the OK 1 extension has a load of I_R = 7 Amperes; I_S = 0 Amperes; I_T = 0 Amperes, then the loading is not balanced using the following equation:

$$I_{Rata-rata} = \frac{I_R I_S I_R}{3}$$

$$I_{Rata-rata\ Gardu\ K-113} = \frac{I_R I_S I_T}{3}$$

$$= \frac{7+0+0}{3}$$

$$= 2.3\ Amperes$$

To calculate the total low-voltage side current of each transformer on the OK 1 feeder, it is done in the same way. The result is presented in Table 1.

Table 1. Low voltage side transformer current values in OK 1 repeater

No.	Substation No.	Location	Capacity (KVA)	Distance (Km)	Low Voltage Current (A)
1	K-113	Tower behind the power plant	25	0,085	2,33
2	K-114	Jl. Golkar Biga	160	0,354	73,33
3	K-115	Behind Gelora Togop	100	1,018	81,33
4	K-116	RSU.Kinapit JL. S. Parman	200	1,721	6,67
5	K-117	Hotel Tita 2 JL. Soetoyo	100	1,737	89,67
6	K-118	Kota Mas JL. Soetoyo	160	1,761	100
7	K-119	Kabela JL. Soetoyo	100	2,015	90
8	K-120	Tax Office	50	2,246	10
9	K-121	Dream Hotel Kotobangon	100	2,335	94
10	K-122	Kotobangon 1	50	2,436	17,33
11	K-123	Ilongkow Kotobangon	50	3,210	19
12	K-124	Bobakidan Kotobangon	50	2,231	45,67
13	K-125	Kotobangon Masjid	160	2,552	128,33
14	K-126	Kampung Baru 2	50	3,062	68,33
15	K-127	Kampung Baru 1	160	2,846	193
16	K-128	Hasjrat Dealer	50	3,264	8
17	K-129	Ex RSU. Datoebinangkang	200	3,300	71
18	K-130	Sisip Ex RSU. Datoebinangkang	200	3,413	28,67
19	K-131	BRI beside PN	50	3,538	62

No.	Substation No.	Location	Capacity (KVA)	Distance (Km)	Low Voltage Current (A)
20	K-132	Sinindian I KPU	100	2,641	221
21	K-133	JL. Ibantong Sinindian	50	3,333	20,67
22	K-134	Tumubui II	50	3,836	59,67
23	K-135	Sinindian II	50	3,336	68,33
24	K-136	Sinindian Democrats	100	3,556	6
25	K-137	Sinindian IV	100	3,576	93
26	K-138	Sinindian III	50	3,901	16,67
27	K-139	New Sinindian Settlement	100	4,046	70
28	K-140	Matali I	200	4,090	187,33
29	K-141	Perum Griya Pobundayan	100	4,200	61,33
30	K-142	Matali II	50	4,647	54,67
31	K-143	Matali III	100	4,862	98,33
32	K-144	Motoboi Besar I	100	5,515	82,33
33	K-145	Big Motoboi Tower	25	5,683	12,67
34	K-146	Big Motoboi Insert	100	5,799	80,67
35	K-147	T-junction of Big Motoboi Floating Route	50	6,084	41
36	K-148	Kobo Kecil II Field	100	6,219	52
37	K-149	Small Kobo I	50	6,354	50
38	K-150	Small Kobo Insert	100	6,633	95,67
39	K-151	Poyowa Besar IV	160	6,645	84,33
40	K-152	Big Motoboi Float	25	6,884	18
41	K-153	Large Kobo	200	6,826	139
42	K-154	Tumubui I	100	7,361	72,33

3.3 Calculating the High Voltage side Current of The Feeder End Using the Transformer Voltage Ratio on the OK 1 Feeder.

In order to calculate the voltage drop and power losses on the repeater, the current on the medium voltage side at the end of the repeater is required. To get the value of this current, we need to compare the transformer voltage ratio with the 20,000 Volt/400 Volt voltage ratio.

$$\frac{V_{TM}}{V_{TR}} = \frac{I_{TR}}{I_{TM}}$$

Thus obtained:

$$I_{TM} = \frac{V_{TR} \times I_{TR}}{V_{TM}}$$

$$I_{TR\ Gardu\ K-113} = 2{,}3\ A$$

$$V_{TM} = 2000\ Volt$$

$$V_{TR} = 400\ Volt$$

Then:

$$I_{TM\ Gardu\ K-113} = \frac{400 \times 2{,}3}{20000} = 0{,}047\ Ampere$$

The average value of the transformer load current in the substation tower behind the PLTD on the medium voltage side is 0.047 Ampere. The total medium voltage side current of each transformer on the OK 1 feeder is calculated by the same method and the results can be seen in the Table 2.

Table 2. Current value of 20 kv medium voltage side transformer on OK 1 extension.

No.	Substation No.	Location	Capacity (KVA)	Distance (Km)	Medium Voltage Current (A)
1	K-113	Tower behind the power plant	25	0,085	0,047
2	K-114	Jl. Golkar Biga	160	0,354	1,467
3	K-115	Behind Gelora Togop	100	1,018	1,627
4	K-116	RSU.Kinapit JL. S. Parman	200	1,721	0,133
5	K-117	Hotel Tita 2 JL. Soetoyo	100	1,737	1,793

No.	Substation No.	Location	Capacity (KVA)	Distance (Km)	Medium Voltage Current (A)
6	K-118	Kota Mas JL. Soetoyo	160	1,761	2
7	K-119	Kabela JL. Soetoyo	100	2,015	1,8
8	K-120	Tax Office	50	2,246	0,2
9	K-121	Dream Hotel Kotobangon	100	2,335	1,88
10	K-122	Kotobangon 1	50	2,436	0,347
11	K-123	Ilongkow Kotobangon	50	3,210	0,38
12	K-124	Bobakidan Kotobangon	50	2,231	0,913
13	K-125	Kotobangon Masjid	160	2,552	2,567
14	K-126	Kampung Baru 2	50	3,062	1,367
15	K-127	Kampung Baru 1	160	2,846	3,86
16	K-128	Hasjrat Dealer	50	3,264	0,16
17	K-129	Ex RSU. Datoebinangkang	200	3,300	1,42
18	K-130	Sisip Ex RSU. Datoebinangkang	200	3,413	0,573
19	K-131	BRI beside PN	50	3,538	1,24
20	K-132	Sinindian I KPU	100	2,641	4,42
21	K-133	JL. Ibantong Sinindian	50	3,333	0,413
22	K-134	Tumubui II	50	3,836	1,193
23	K-135	Sinindian II	50	3,336	1,367
24	K-136	Sinindian Democrats	100	3,556	0,12
25	K-137	Sinindian IV	100	3,576	1,86
26	K-138	Sinindian III	50	3,901	0,333
27	K-139	New Sinindian Settlement	100	4,046	1,4
28	K-140	Matali I	200	4,090	3,667
29	K-141	Perum Griya Pobundayan	100	4,200	1,227
30	K-142	Matali II	50	4,647	1,093
31	K-143	Matali III	100	4,862	1,967
32	K-144	Motoboi Besar I	100	5,515	1,467
33	K-145	Big Motoboi Tower	25	5,683	0,253
34	K-146	Big Motoboi Insert	100	5,799	1,613
35	K-147	T-junction of Big Motoboi Floating Route	50	6,084	0,82
36	K-148	Kobo Kecil II Field	100	6,219	1,04
37	K-149	Small Kobo I	50	6,354	1
38	K-150	Small Kobo Insert	100	6,633	1,913
39	K-151	Poyowa Besar IV	160	6,645	1,687
40	K-152	Big Motoboi Float	25	6,884	0,36
41	K-153	Large Kobo	200	6,826	2,78
42	K-154	Tumubui I	100	7,361	1,447

3.4 Calculating the Voltage Drop that Occurs in the OK 1 Feeder.

The voltage drop calculation is based on measurement data calculated from the source point to the calculated point (load point) according to the length of the feeder so that the voltage drop is obtained at the location of the PLTD Rear Tower substation:

$$\Delta V = I \times (R \ \cos\varphi) + \sin\varphi) \times l$$
$$\cos\varphi = 0{,}95$$
$$\sin\varphi = 0{,}53$$

Then from the above equation, the calculation of the voltage drop results is obtained as follows:

$$\Delta V = I(R\, cos\,\varphi + X\, sin\,\varphi)l$$
$$\Delta V = 0{,}047(0{,}2162 \times 0{,}95 + 0{,}3305 \times 0{,}53)0{,}085$$
$$\Delta V = 0{,}047(0{,}20539 + 0{,}17516)0{,}085$$
$$\Delta = 0{,}047(0{,}38055)085$$
$$\Delta V = 0{,}00152\ KV$$

The sending voltage at PLTD Kotamobagu is 20 KV, so the receiving voltage at the transformer at the branching point of Substation K-113 (PLTD Rear Tower) is:

$$V_r Gardu\ K-113 = V_s - \Delta V$$
$$= 20 - 0{,}00152$$
$$= 19{,}998\ KV$$

Then from the above equation, the calculation of the percentage of voltage drop is obtained as follows:

$$\Delta V(\%) = \frac{\Delta V}{V_r} \times 100\%$$
$$\Delta V(\%) = \frac{0{,}00152}{19{,}998} \times 100\%$$
$$\Delta V(\%) = 0{,}0076\%$$

To calculate the percentage value of each transformer on the OK 1 extension, it is done in the same way. The result is presented in Table 3.

Table 3. Calculation results of voltage drop in OK 1 repeater

No.	**Substation No.**	**Distance (Km)**	**Delivery Voltage (KV)**	**ΔV (KV)**	**Receive Voltage (KV)**	**ΔV (%)**
1	K-113	0,085	20	0,00152	19,998	0,00715
2	K-114	0,354	20	0,198	19,802	0,999
3	K-115	1,018	20	0,63	19,37	3,252
4	K-116	1,721	20	0,087	19,913	0,436
5	K-117	1,737	20	1,185	18,815	6,298
6	K-118	1,761	20	1,34	18,66	7,181
7	K-119	2,015	20	1,38	18,62	7,411
8	K-120	2,246	20	0,171	19,829	0,862
9	K-121	2,335	20	1,67	18,33	9,111
10	K-122	2,436	20	0,322	19,678	1,636
11	K-123	3,210	20	0,464	19,536	2,375
12	K-124	2,231	20	0,775	19,225	4,031
13	K-125	2,552	20	2,493	17,507	14,24
14	K-126	3,062	20	1,593	18,407	8,654
15	K-127	2,846	20	4,18	15,82	26,422
16	K-128	3,264	20	0,199	19,801	1,005
17	K-129	3,300	20	1,783	18,217	9,787
18	K-130	3,413	20	0,744	19,256	3,864
19	K-131	3,538	20	1,669	18,331	9,105
20	K-132	2,641	20	4,442	15,558	28,551
21	K-133	3,333	20	0,524	19,476	2,69
22	K-134	3,836	20	1,741	18,259	9,535
23	K-135	3,336	20	1,735	18,265	9,499
24	K-136	3,556	20	0,162	19,838	0,817
25	K-137	3,576	20	2,531	17,469	14,488
26	K-138	3,901	20	0,494	19,506	2,532
27	K-139	4,046	20	2,155	17,845	12,076
28	K-140	4,090	20	5,707	14,295	39,923
29	K-141	4,200	20	1,961	18,039	10,871
30	K-142	4,647	20	1,938	18,062	10,729
31	K-143	4,862	20	3,639	16,361	22,242
32	K-144	5,515	20	3,457	16,543	20,897
33	K-145	5,683	20	0,547	19,453	2,812
34	K-146	5,799	20	3,559	16,441	21,647
35	K-147	6,084	20	1,898	18,102	10,485
36	K-148	6,219	20	2,461	17,539	14,031
37	K-149	6,354	20	2,418	17,582	13,753

38	K-150	6,633	20	4,828	15,172	31,822
39	K-151	6,645	20	4,266	15,734	27,113
40	K-152	6,884	20	0,943	19,057	4,948
41	K-153	6,826	20	7,221	12,779	56,507
42	K-154	7,361	20	4,053	15,947	25,415

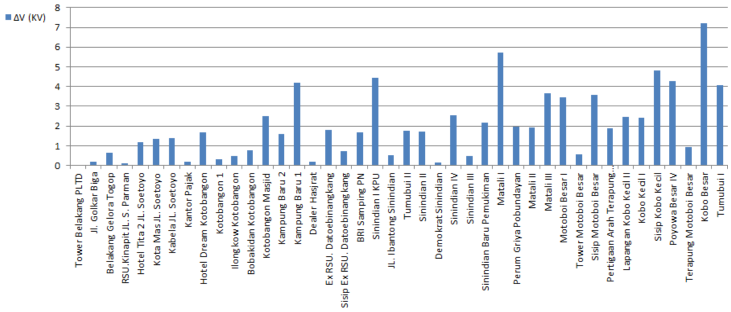

Figure 2. Voltage drop diagram for OK 1 extension.

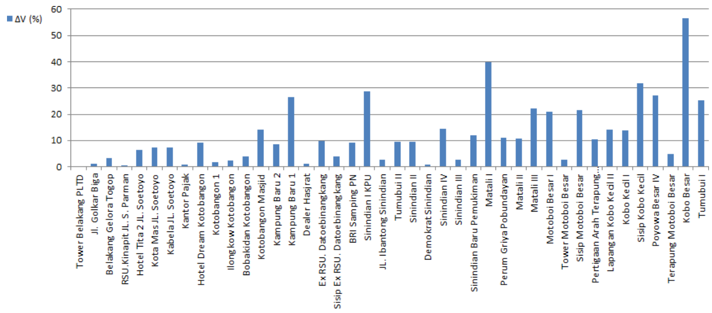

Figure 3. Diagram of the percentage of voltage drop in OK 1 repeater

The calculation results show that the voltage drop in the distribution network is influenced by the length of the line and the load current on each transformer in the OK 1 extension. As a result, the largest voltage drop occurs at substation K-153 (Kobo Besar) of 7.221 KV with a percentage of 56.507%. Details can be seen in Figure 2 and Figure 3.

3.5 Calculating Power Losses Occurring in OK 1 Feeder.

The power losses on the OK 1 conductor as an example of Substation K-113 (Tower Behind PLTD) can be calculated as follows:

$$I_{TM} = 0{,}047A$$
$$R = 0{,}2162 \times 0{,}085 = 0{,}018377\Omega$$
$$p_{Saluran} = I^2.r.1$$
$$P_{Saluran} = (0{,}047^2)0{,}018377$$
$$= 0{,}000040595KW$$

To calculate the power loss value of each transformer on the OK 1 extension, the same method is used. The result is presented in Table 4.

Table 4. The results of the calculation of power losses on the OK 1 penyulang

No.	Substation No.	Distance (Km)	Channel (KW)
1	K-113	0,085	0,000040595
2	K-114	0,354	0,165
3	K-115	1,018	0,583
4	K-116	1,721	0,0066
5	K-117	1,737	1,207
6	K-118	1,761	1,523
7	K-119	2,015	1,411
8	K-120	2,246	0,019

9	K-121	2,335	1,784
10	K-122	2,436	0,063
11	K-123	3,210	0,1002
12	K-124	2,231	0,402
13	K-125	2,552	3,636
14	K-126	3,062	1,237
15	K-127	2,846	9,168
16	K-128	3,264	0,0181
17	K-129	3,300	1,439
18	K-130	3,413	0,242
19	K-131	3,538	1,176
20	K-132	2,641	11,155
21	K-133	3,333	0,123
22	K-134	3,836	1,1803
23	K-135	3,336	1,348
24	K-136	3,556	0,0111
25	K-137	3,576	2,675
26	K-138	3,901	0,0935
27	K-139	4,046	1,7145
28	K-140	4,090	11,890
29	K-141	4,200	1,3671
30	K-142	4,647	1,2002
31	K-143	4,862	4,067
32	K-144	5,515	2,566
33	K-145	5,683	0,0786
34	K-146	5,799	3,262
35	K-147	6,084	0,884
36	K-148	6,219	1,454
37	K-149	6,354	1,374
38	K-150	6,633	5,248
39	K-151	6,645	4,089
40	K-152	6,884	0,1929
41	K-153	6,826	11,405
42	K-154	7,361	3,332

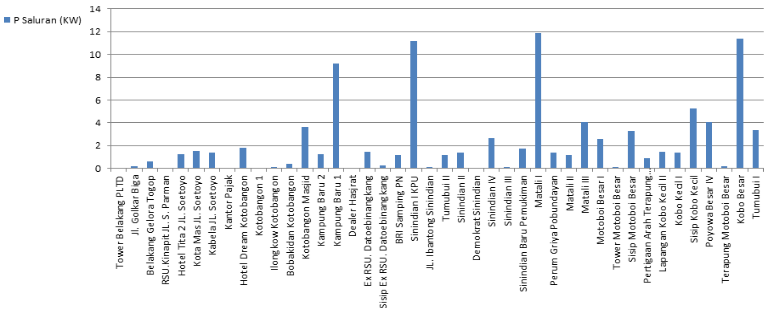

Figure 4. Diagram of power loss in OK 1

The calculation results show that the power loss in the distribution network is caused by the length of the extension, the resistance value, and the load current on each transformer in the OK 1 extension. The largest power loss occurred at substation K-140 (Matali I) of 11.890 KW, as presented in Figure 4. For other calculations on feeder OK-2, OK-3, OK-4 and OK-5 can be calculated in the same way as for feeder OK-1.

4. CONCLUSION

Based on the analysis of the calculation of voltage drops and power losses on five 20 KV medium voltage feeders at the Kotamobagu PLTD discussed in the previous chapter, the authors conclude that in OK 1 the largest voltage drop occurs at substation K-153 (Kobo Besar) with a voltage drop value of 7.221 KV and a percentage value of 56.507% and power losses in the largest OK 1 extension occurs at substation K-140 (Matali I) with a power loss value of 11.890 KW. In the OK 2 extension, the largest voltage drop occurs at substation K-158 (Monompia Kotamobagu Hospital) with a voltage drop value of 1.94 KV and a percentage value of 10.742% and the power loss on the largest OK 2 extension occurs at K-158 (Monompia Kotamobagu Hospital) with a power loss value of 4.820 KW. In OK 3 the biggest voltage drop occurs at substation K-187 (Poopo I) with a voltage drop value of 6.472 KV and a percentage value of 47.841% and the power loss on the largest OK 3 extension occurs at substation K-167 (Bilalang V) with a power loss value of 9.819 KW. In OK 4 the largest voltage drop occurs at substation K-201 (Motoboi Kecil) with a voltage drop value of 5.04 KV and a percentage value of 33.689% and power losses in the largest OK 4 repeater occurs at substation K-201 (Motoboi Kecil) with a power loss value of 7.311 KW. In the OK 5 extension, the largest voltage drop occurs at substation K-287 (Moyag I) with a voltage drop value of 4.878 KV and a percentage value of 32.257% and power losses on the largest OK 5 extension occurs at substation K-287 (Moyag I) with a power loss value of 10.533 KW.

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