STUDY OF LOCATION AND CAPACITY OF CAPACITOR BANK ON DURIAN 4'S FEEDER OF PT. PLN (PERSERO) ULP RASAU JAYA

Yudik Anggara[1], M. Iqbal Arsyad[2], Zainal Abidin[3]
yudikanggara3@gmail.com[1], iqbal.arsyad@ee.untan.ac.id[2], zainal.abidin@teknik.untan.ac.id[3]
Universitas Tanjungpura Pontianak

ABSTRACT

Durian 4 PT PLN (Persero) ULP Rasau Jaya is a radial structure with a length of 234.391 km, has 131 distribution transformers with a total of 151 buses, so the voltage drop on the line is unavoidable. This research aims to improve the voltage profile through the installation of capacitor banks by determining the location and capacity of capacitor banks and analysing the effect of capacitor bank installation on voltage drops. The research methodology involves power flow analysis current injection method and voltage stability index Fast Voltage Stability Index (FVSI) method, Line Stability Factor (LQP), and Loss Sensitivity Factor (LSF) method for capacitor bank location determination. From the initial measurement results, the voltage drop percentage of Durian 4 repeater has exceeded the SPLN T6.001 2013 standard limit (± 10%). Where in the existing condition the percentage of voltage drop is 21.071% with a minimum bus voltage of 15.7858 kV and a total active power loss of 365.560 kW. In scenario 1, the minimum bus voltage is 16.5548 kV with a voltage drop percentage of 17.226% and active power losses of 292.248 kW. In scenario 2, the minimum bus voltage is 17.6373 kV with a voltage drop percentage of 11.814% and active power losses of 281.220 kW. In scenario 3, the voltage profile has met SPLN T6.001 Year 2013, where the minimum voltage is 18.1183 kV with a voltage drop percentage of 9.408%, and active power losses of 276.528 kW. The capacitor bank placement strategy using the FVSI, LQP, and LSF methods is effective in improving the voltage profile, ensuring all buses meet SPLN T6.001 Year 2013, and reducing active power losses significantly.

Keywords: *Voltage Profile, Current Injection Power Flow, Voltage Stability Index, Loss Sensitivity Factor And Capacitor Banks.*

INTRODUCTION

In today's modern world, almost every aspect of daily life cannot be avoided from the use of electrical energy. Electricity is a very important element in various aspects of life, such as electricity needs in households, economic development, transportation, education, social and industry. In households, electricity is used for various purposes such as lighting, use of electronic devices, cooking, and cooling or heating. This is followed by the rapid growth of electric transport, such as electric cars, which also adds new demand to electricity supply. Electricity is also a very important part of the industrial world, this is because every manufacturing and production process requires a large supply of electricity to run machinery and equipment.

The electric power distribution network is a component of the electric power system that functions as a distributor of electrical energy from the substation to consumers. The distribution network consists of a primary distribution network that has a working voltage of 20 kV and a secondary distribution network that has a working voltage of 380/220 Volts[1]. The increasing need for electrical energy sometimes makes the quality of distribution decrease. This becomes consumer dissatisfaction with the distributed electrical energy. The condition of the distribution network that is not optimal will result in less effective services as well, one of which is due to voltage drops and electrical power losses. So, by looking at this problem it should be noted that the quantity and quality of electrical energy supplied must be able to increase simultaneously by always prioritising reliability

and efficiency in the distribution system.

Durian 4 is one of the repositories under the auspices of PT PLN (Persero) ULP Rasau Jaya which gets a source from Kuala Dua Substation with a sending voltage of 20 kV. Durian 4 is the longest radial structure in PT PLN (Persero) ULP Rasau Jaya with a network length of 234.391 Kms and there are 131 distribution transformer units with a total of 151 buses. From the results of voltage measurements on the Durian 4 extension under existing conditions, the minimum bus voltage is 15.7858 kV, this shows a voltage drop of around 4.2142 kV or the percentage of voltage drop has reached 21.071%. Based on SPLN No T6.001 Year 2013, the voltage drop of Duran 4 repeater has exceeded the standard permissible limit, where the highest voltage and lowest voltage difference should not be greater than ± 10% of the nominal voltage of the system, or the highest voltage of the system is not more than 22 kV and the lowest voltage of the system is not less than 18 kV[2].

From the explanation above, efforts that can be made to improve the voltage profile of the Durian 4 repeater are by installing capacitor banks, so that services to consumers remain of high quality and the voltage profile can meet SPLN T6.001 Year 2013. This research will discuss the study of the location and capacity of capacitor banks in Durian 4 PT PLN (Persero) ULP Rasau Jaya. To determine the effect of installing a capacitor bank, a power flow analysis will be carried out before and after the installation of the capacitor bank, which is expected to obtain a clear picture of the effectiveness of installing a capacitor bank in improving the voltage profile on the Durian 4 PT. PLN (Persero) ULP Rasau Jaya.

RESEARCH METHODOLOGY

This research has a research methodology to facilitate the process of work by the author. The data that the author uses is single line diagram data, loading data and channel data on Durian 4 PT PLN (Persero) ULP Rasau Jaya.

In this study, the matlab application will be used to help test the results of analysis and calculation of voltage drop on Durian 4 and determine the location of the installation of capacitor banks to be installed on the repeater. Power flow analysis uses the current injection method while for the installation location of capacitor banks using Fast Voltage Stability Index (FVSI), Line Stability Factor (LQP), Loss Sensitivity Factor (LSF) with a combination of normalised values (NORM).

The power flow formula for the current injection method is explained in the equation below:

$$[\Delta V] = [\mathrm{BCBV}]\,[\mathrm{BIBC}]\,[\mathrm{I}] \quad (10)$$

The [ΔV] matrix is a matrix that describes the voltage drop from the source bus to the load bus in the system.

$$\left[V_i^{(k+1)}\right] = [V_1] - \left[\Delta V_i^{(k+1)}\right] \quad (11)$$

Where:

BIBC = Bus Injection-Branch Current

BCBV = Branch Current-Bus Voltage

$V_i^{(k)}$ = Voltage of the i-th bus at the kth iteration

V_i = Voltage of the i-th bus

V_1 = Bus voltage to source

Fast Voltage Stability Index (FVSI) and Line Stability Factor (LQP) using the formula in the equation below:

$$\mathrm{FVSI} = \frac{4Z^2 Q_j}{V_i^2 X} \quad (13)$$

$$LQP = 4\left[\frac{X}{V_i^2}\right]\left[\frac{X}{V_i^2}P_i^2 + Q_j\right] \quad (14)$$

Where:

Z = Line impedance (Ohm)

P_i = Active power at the send side end (kW)

X = Line reactance (Ohm)

Q_j = Reactive power at the receiving end (kVar)

V_i = Voltage on the send side (kV)

Loss Sensitivity Factor (LSF) with reference to the normalised value (NORM) using the formula in the equation below:

$$LSF = \frac{2Q_j R}{V_j^2} \quad (15)$$

$$NORM = \frac{V_j}{V_{min}} \quad (16)$$

Where:

R = Line resistance between bus i and j (Ohm)

V_j = Voltage at bus j (kV)

P_j = Active power load at bus j (kW)

Q_j = Reactive power load at bus j (kVAR)

RESULTS AND DISCUSSION

The power flow calculation uses the current injection method with the help of the Matlab application, using the basic voltage input of 20 kV, basic power of 1 MVA, tolerance value 0.00001. The voltage of each bus from the calculation of the Durian 4 PT PLN (Persero) ULP Rasau Jaya power flow in existing conditions using the current injection method with the help of the Matlab application is shown in Table 1.

Table 1. Durian 4 Bus Voltage Existing condition.

No Bus	Voltage (p.u)	Voltage (kV)	Active Power (kW)	Reactive Power (kVAR)	Injection QShunt (kVAR)	VDrop (%)
1	1,0000	20,0000	0,000	0,000	0,000	0,000
2	0,9493	18,9868	31,076	19,260	0,000	5,066
3	0,9480	18,9600	37,264	23,095	0,000	5,200
4	0,9357	18,7149	34,264	21,236	0,000	6,425
5	0,9300	18,6002	13,592	8,424	0,000	6,999
6	0,9240	18,4808	26,614	16,494	0,000	7,596
7	0,9234	18,4672	52,071	32,272	0,000	7,664
8	0,9233	18,4658	1,301	0,806	0,000	7,671
9	0,9181	18,3622	45,832	28,405	0,000	8,189
10	0,9130	18,2606	0,000	0,000	0,000	8,697
11	0,9116	18,2325	42,313	26,224	0,000	8,837
12	0,9075	18,1498	27,379	16,968	0,000	9,251
13	0,9053	18,1068	49,972	30,971	0,000	9,466
14	0,9041	18,0824	9,707	6,016	0,000	9,588
15	0,9025	18,0498	16,941	10,499	0,000	9,751
16	0,8996	17,9915	29,844	18,496	0,000	10,043
17	0,8926	17,8514	23,120	14,329	0,000	10,743
18	0,8915	17,8299	0,000	0,000	0,000	10,851
19	0,8862	17,7234	37,757	23,401	0,000	11,383
20	0,8845	17,6907	0,000	0,000	0,000	11,547

No Bus	Voltage (p.u)	Voltage (kV)	Active Power (kW)	Reactive Power (kVAR)	Injection QShunt (kVAR)	VDrop (%)
21	0,8774	17,5489	28,543	17,690	0,000	12,255
22	0,8740	17,4803	0,000	0,000	0,000	12,598
23	0,8726	17,4520	20,375	12,628	0,000	12,740
24	0,8687	17,3745	0,000	0,000	0,000	13,127
25	0,8664	17,3288	0,000	0,000	0,000	13,356
26	0,8611	17,2226	58,735	36,402	0,000	13,887
27	0,8608	17,2169	0,000	0,000	0,000	13,916
28	0,8600	17,1991	51,374	31,840	0,000	14,005
29	0,8592	17,1843	31,323	19,413	0,000	14,079
30	0,8590	17,1809	2,278	1,412	0,000	14,095
31	0,8566	17,1327	3,222	1,997	0,000	14,336
32	0,8550	17,1008	0,000	0,000	0,000	14,496
33	0,8506	17,0130	8,441	5,231	0,000	14,935
34	0,8464	16,9286	25,347	15,709	0,000	15,357
35	0,8441	16,8820	14,374	8,908	0,000	15,590
36	0,8435	16,8703	13,175	8,166	0,000	15,649
37	0,8388	16,7762	8,619	5,342	0,000	16,119
38	0,8357	16,7140	13,005	8,060	0,000	16,430
39	0,8351	16,7015	0,000	0,000	0,000	16,493
40	0,8330	16,6608	16,507	10,231	0,000	16,696
41	0,8306	16,6123	14,382	8,914	0,000	16,939
42	0,8300	16,5999	19,712	12,217	0,000	17,001
43	0,8295	16,5904	19,363	12,001	0,000	17,048
44	0,8289	16,5781	9,495	5,884	0,000	17,110
45	0,8285	16,5702	33,235	20,598	0,000	17,149
46	0,8284	16,5681	8,993	5,574	0,000	17,159
47	0,8283	16,5663	2,754	1,707	0,000	17,168
48	0,8283	16,5651	17,179	10,647	0,000	17,175
49	0,9300	18,5995	7,293	4,520	0,000	7,003
50	0,9233	18,4661	16,082	9,967	0,000	7,670
51	0,9130	18,2600	8,602	5,331	0,000	8,700
52	0,9074	18,1484	0,000	0,000	0,000	9,258
53	0,9074	18,1475	4,267	2,645	0,000	9,262
54	0,9073	18,1460	21,097	13,075	0,000	9,270
55	0,9073	18,1458	5,109	3,166	0,000	9,271
56	0,9073	18,1466	27,855	17,263	0,000	9,267
57	0,9024	18,0489	19,873	12,317	0,000	9,755
58	0,8914	17,8281	33,312	20,646	0,000	10,859
59	0,8914	17,8276	6,613	4,099	0,000	10,862
60	0,8844	17,6888	16,448	10,194	0,000	11,556
61	0,8736	17,4724	5,619	3,482	0,000	12,638
62	0,8734	17,4671	19,695	12,206	0,000	12,664
63	0,8731	17,4615	7,727	4,789	0,000	12,693
64	0,8729	17,4576	29,376	18,206	0,000	12,712
65	0,8687	17,3742	9,537	5,911	0,000	13,129
66	0,8687	17,3736	2,941	1,823	0,000	13,132
67	0,8664	17,3273	8,730	5,410	0,000	13,364
68	0,8658	17,3159	24,506	15,188	0,000	13,420

No Bus	Voltage (p.u)	Voltage (kV)	Active Power (kW)	Reactive Power (kVAR)	Injection QShunt (kVAR)	VDrop (%)
69	0,8657	17,3131	0,000	0,000	0,000	13,435
70	0,8656	17,3122	29,325	18,175	0,000	13,439
71	0,8656	17,3117	6,690	4,146	0,000	13,441
72	0,8606	17,2122	22,627	14,024	0,000	13,939
73	0,8605	17,2092	11,152	6,912	0,000	13,954
74	0,8604	17,2074	8,645	5,358	0,000	13,963
75	0,8608	17,2167	4,369	2,708	0,000	13,916
76	0,8608	17,2157	12,665	7,849	0,000	13,921
77	0,8608	17,2168	5,993	3,714	0,000	13,916
78	0,8550	17,1000	17,791	11,026	0,000	14,500
79	0,8349	16,6975	31,025	19,228	0,000	16,513
80	0,8328	16,6568	0,000	0,000	0,000	16,716
81	0,8325	16,6510	34,323	21,272	0,000	16,745
82	0,8315	16,6306	0,000	0,000	0,000	16,847
83	0,8314	16,6271	17,247	10,689	0,000	16,865
84	0,8312	16,6248	8,849	5,484	0,000	16,876
85	0,8302	16,6042	15,895	9,851	0,000	16,979
86	0,8301	16,6018	40,639	25,187	0,000	16,991
87	0,8327	16,6543	11,135	6,901	0,000	16,729
88	0,8315	16,6294	5,806	3,598	0,000	16,853
89	0,8302	16,6046	23,120	14,329	0,000	16,977
90	0,8301	16,6025	11,807	7,317	0,000	16,988
91	0,8300	16,5994	17,731	10,989	0,000	17,003
92	0,8978	17,9561	16,915	10,483	0,000	10,219
93	0,8827	17,6550	0,000	0,000	0,000	11,725
94	0,8801	17,6029	25,364	15,720	0,000	11,986
95	0,8679	17,3585	45,858	28,421	0,000	13,208
96	0,8558	17,1156	14,722	9,124	0,000	14,422
97	0,8551	17,1025	22,840	14,155	0,000	14,488
98	0,8528	17,0559	16,201	10,041	0,000	14,720
99	0,8505	17,0103	30,430	18,860	0,000	14,949
100	0,8501	17,0021	0,000	0,000	0,000	14,989
101	0,8492	16,9839	0,000	0,000	0,000	15,081
102	0,8488	16,9769	14,918	9,245	0,000	15,115
103	0,8479	16,9573	22,704	14,071	0,000	15,213
104	0,8465	16,9304	33,762	20,925	0,000	15,348
105	0,8463	16,9263	27,039	16,758	0,000	15,368
106	0,8439	16,8788	4,097	2,539	0,000	15,606
107	0,8377	16,7544	8,662	5,368	0,000	16,228
108	0,8295	16,5894	44,056	27,304	0,000	17,053
109	0,8263	16,5267	23,868	14,793	0,000	17,367
110	0,8241	16,4816	19,941	12,359	0,000	17,592
111	0,8188	16,3757	13,728	8,508	0,000	18,121
112	0,8159	16,3177	13,507	8,371	0,000	18,411
113	0,8094	16,1884	18,607	11,532	0,000	19,058
114	0,8047	16,0935	0,000	0,000	0,000	19,533
115	0,8037	16,0748	24,378	15,109	0,000	19,626
116	0,8032	16,0649	3,307	2,049	0,000	19,676

No Bus	Voltage (p.u)	Voltage (kV)	Active Power (kW)	Reactive Power (kVAR)	Injection QShunt (kVAR)	VDrop (%)
117	0,8031	16,0618	19,142	11,864	0,000	19,691
118	0,8028	16,0561	17,519	10,857	0,000	19,720
119	0,7996	15,9912	33,023	20,466	0,000	20,044
120	0,7992	15,9844	13,042	8,083	0,000	20,078
121	0,7977	15,9548	33,898	21,009	0,000	20,226
122	0,7976	15,9528	13,728	8,508	0,000	20,236
123	0,7968	15,9355	33,890	21,004	0,000	20,322
124	0,7959	15,9181	10,957	6,791	0,000	20,410
125	0,7955	15,9091	17,655	10,942	0,000	20,454
126	0,7946	15,8916	8,373	5,189	0,000	20,542
127	0,7944	15,8888	9,554	5,921	0,000	20,556
128	0,7928	15,8553	20,307	12,585	0,000	20,723
129	0,7925	15,8500	13,779	8,540	0,000	20,750
130	0,7907	15,8137	0,000	0,000	0,000	20,931
131	0,7905	15,8098	16,320	10,115	0,000	20,951
132	0,7902	15,8047	15,207	9,425	0,000	20,976
133	0,7897	15,7930	18,964	11,753	0,000	21,035
134	0,7896	15,7919	15,105	9,361	0,000	21,040
135	0,7893	15,7862	25,883	16,041	0,000	21,069
136	0,7893	15,7858	13,524	8,381	0,000	21,071
137	0,8824	17,6474	25,704	15,931	0,000	11,763
138	0,8822	17,6436	11,254	6,975	0,000	11,782
139	0,8819	17,6373	9,775	6,058	0,000	11,814
140	0,8816	17,6322	0,000	0,000	0,000	11,839
141	0,8816	17,6317	19,754	12,243	0,000	11,842
142	0,8815	17,6305	16,422	10,178	0,000	11,847
143	0,8557	17,1148	10,515	6,517	0,000	14,426
144	0,8499	16,9985	32,929	20,409	0,000	15,007
145	0,8491	16,9830	31,382	19,450	0,000	15,085
146	0,8188	16,3753	8,840	5,479	0,000	18,124
147	0,7954	15,9076	13,073	8,102	0,000	20,462
148	0,7954	15,9087	10,965	6,796	0,000	20,457
149	0,7927	15,8540	12,810	7,939	0,000	20,730
150	0,7905	15,8107	20,239	12,543	0,000	20,947
151	0,7905	15,8091	8,645	5,358	0,000	20,955
TOTAL			**2538,075**	**1573,0100**	**0,0000**	

Based on Table 1 above, the voltage profile graph of Durian 4 PT PLN (Persero) ULP Rasau Jaya in existing conditions is shown in Figure 5.

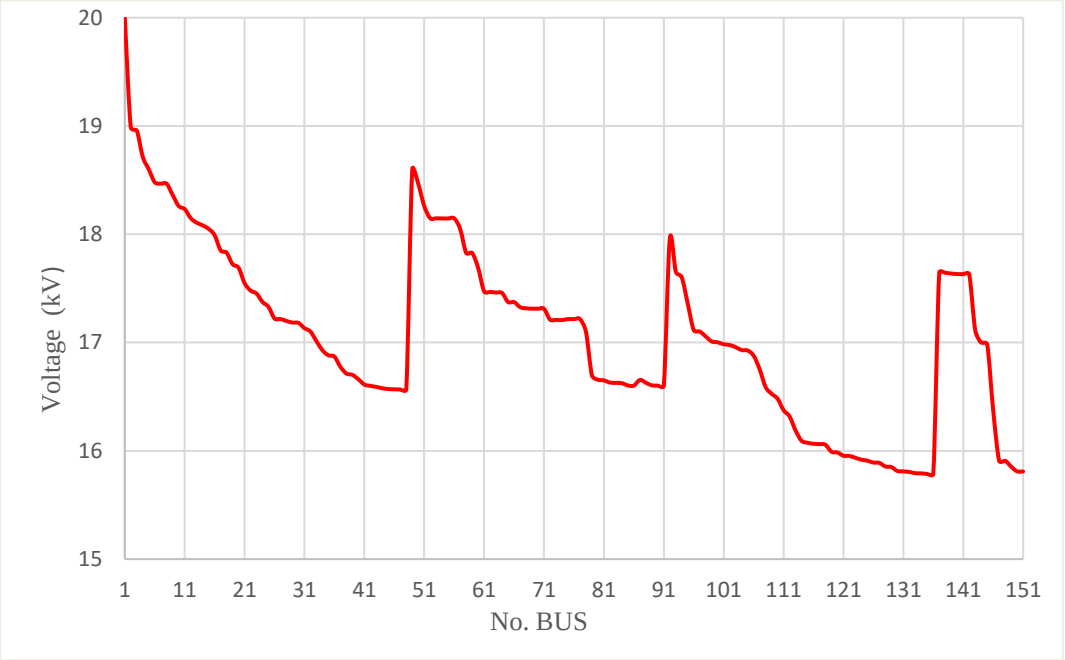

Figure 5: Voltage profile graph of durian rectifier 4 existing condition

Based on SPLN T6.001 Year 2013, the highest voltage increase and the lowest voltage drop in the 20 kV distribution network system, the difference should not be greater than ± 10% of the nominal voltage of the system or the highest voltage should not be more than 22 kV and the lowest voltage should not be less than 18 kV. From the calculation results shown in table 1, the bus voltage on the Durian 4 extension of PT PLN (Persero) ULP Rasau Jaya in the existing conditions that still meet the SPLN T6.001 2013 standard, namely the percentage of voltage drop is not less than 10% or the bus voltage is not less than 18 kV there are 24 buses, while the bus voltage that does not meet the SPLN T6.001 2013 standard is 127 buses. The minimum bus voltage that occurs in the Durian 4 PT PLN (Persero) in the existing condition occurs at bus 136 (RJ 0027 AP) which is 0.7893 p.u or 15.7858 kV with a voltage drop percentage of 21.071%. %. Seeing these conditions, efforts to improve voltage quality will be carried out by installing capacitor banks which are expected to increase the voltage in order to meet the SPLN T6.001 2013 standard.

Capacitor Bank Placement and Capacity Candidate.

Capacitor bank placement candidates are determined based on the fast voltage stability index (FVSI) method with equation (13), the line satability factor (LQP) method with equation (14), the loss sensitivity factor (LSF) method with equation (15) with reference to the normalised value (NORM) with equation (16) and the amount of capacitor bank capacity calculated with equation (12). From the results of the calculations that have been carried out, the candidate locations for the placement of capacitor banks and the amount of capacity of each capacitor bank are shown in Table 2.

Table 2. Candidate Placement and Capacitor Bank Capacity

Scenario	**Location**	**Injection (kVAR)**	**Total Injection (kVAR)**
1	Bus 93	900	900
2	Bus 93 & Bus 108	900 & 900	1800
3	Bus 93, Bus 108 & Bus 26	900, 900 & 800	2600

Based on Table 2, 3 capacitor bank installation scenarios will be carried out, where in scenario 1, 1 capacitor bank unit will be installed at bus 93 (POINT 14) with a capacity of

900 kVAR, scenario 2 will install 2 capacitor bank units at bus 93 (POINT 14) and bus 108 (RJ 0011PL) with a capacity of 1800 kVAR, and scenario 3 will install 3 capacitor bank units at bus 93 (POINT 14), bus 108 (RJ 0011PL) and bus 26 (RJ 0021 TL) with a capacity of 2600 kVAR. The following is a single line diagram of the Durian 4 repeater after installing the capacitor bank.

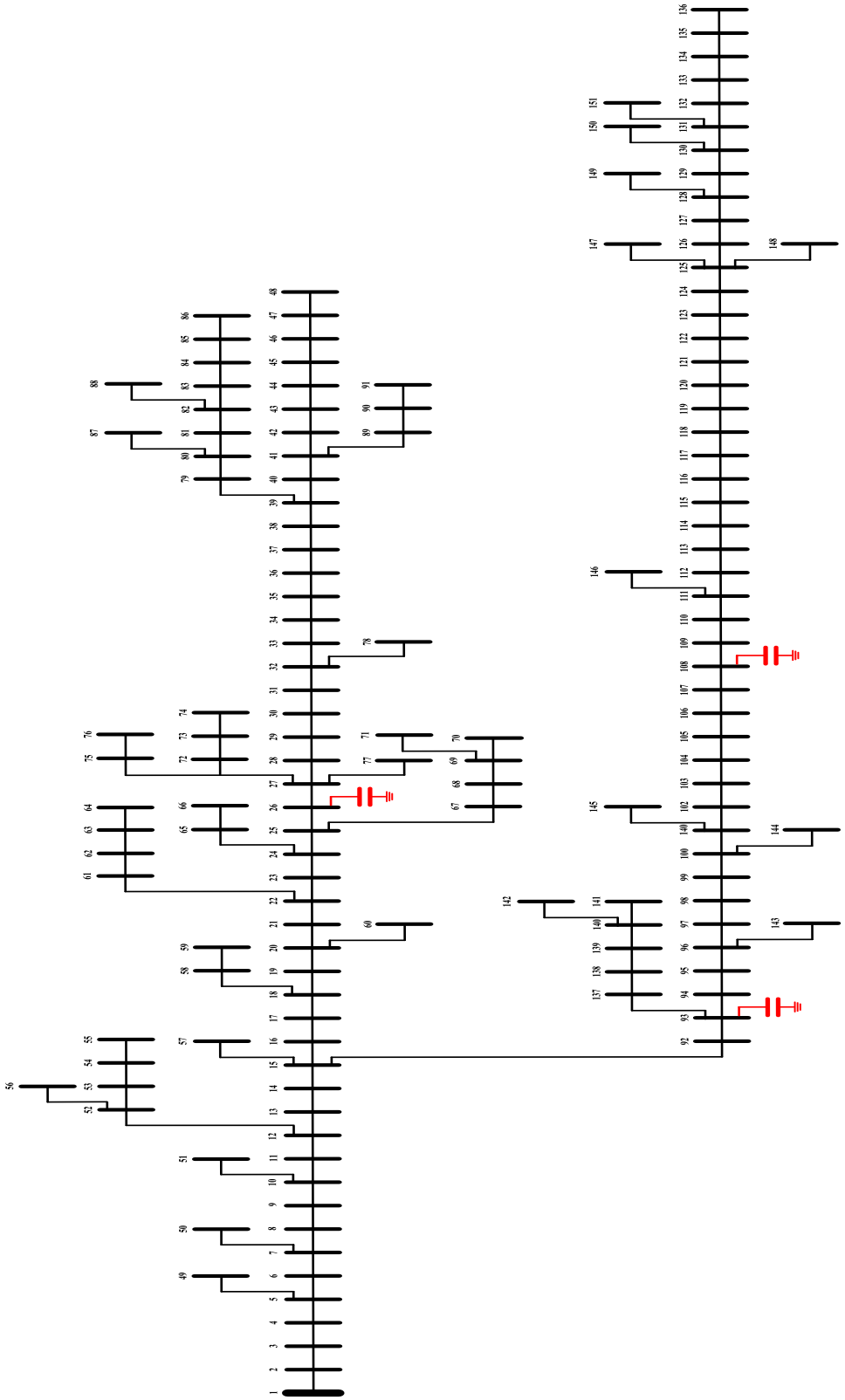

Figure 6. Single line diagram of Durian 4 after the capacitor bank is installed.

Comparison of Voltage Profiles Before and After Installation of Capacitor Banks.

The comparison of the voltage profile of each bus in Durian 4 before and after installing the capacitor bank is shown in Table 3, below.

Tabel 3. Perbandingan Profil Tegangan Setelah di Pasang Bank Kapasitor

No. Bus	Existing (kV)	Scenario 1 (kV)	Scenario 2 (kV)	Scenario 3 (kV)
1	20,0000	20,0000	20,0000	20,0000
2	18,9868	19,2659	19,5169	19,7321
3	18,9600	19,2467	19,5046	19,7258
4	18,7149	19,0725	19,3946	19,6711
5	18,6002	18,9916	19,3444	19,6475
6	18,4808	18,9078	19,2931	19,6241
7	18,4672	18,8983	19,2873	19,6215
8	18,4658	18,8973	19,2867	19,6213
9	18,3622	18,8259	19,2446	19,6045
10	18,2606	18,7565	19,2046	19,5899
11	18,2325	18,7374	19,1937	19,5860
12	18,1498	18,6815	19,1624	19,5760
13	18,1068	18,6530	19,1471	19,5722
14	18,0824	18,6370	19,1388	19,5705
15	18,0498	18,6157	19,1278	19,5685
16	17,9915	18,5593	19,0732	19,5288
17	17,8514	18,4240	18,9419	19,4344
18	17,8299	18,4032	18,9217	19,4201
19	17,7234	18,3005	18,8220	19,3503
20	17,6907	18,2688	18,7913	19,3291
21	17,5489	18,1320	18,6586	19,2386
22	17,4803	18,0657	18,5944	19,1955
23	17,4520	18,0384	18,5679	19,1784
24	17,3745	17,9636	18,4953	19,1322
25	17,3288	17,9195	18,4526	19,1052
26	17,2226	17,8169	18,3531	19,0460
27	17,2169	17,8114	18,3478	19,0409
28	17,1991	17,7943	18,3312	19,0249
29	17,1843	17,7800	18,3173	19,0116
30	17,1809	17,7768	18,3142	19,0086
31	17,1327	17,7303	18,2692	18,9652
32	17,1008	17,6995	18,2393	18,9366
33	17,0130	17,6148	18,1573	18,8576
34	16,9286	17,5334	18,0784	18,7818
35	16,8820	17,4885	18,0349	18,7400
36	16,8703	17,4772	18,0239	18,7294
37	16,7762	17,3864	17,9360	18,6449
38	16,7140	17,3265	17,8779	18,5891
39	16,7015	17,3144	17,8662	18,5778
40	16,6608	17,2752	17,8283	18,5414
41	16,6123	17,2284	17,7829	18,4977
42	16,5999	17,2165	17,7714	18,4866
43	16,5904	17,2073	17,7625	18,4781
44	16,5781	17,1954	17,7510	18,4670

No. Bus	Existing (kV)	Scenario 1 (kV)	Scenario 2 (kV)	Scenario 3 (kV)
45	16,5702	17,1878	17,7436	18,4599
46	16,5681	17,1859	17,7417	18,4581
47	16,5663	17,1841	17,7400	18,4565
48	16,5651	17,1829	17,7388	18,4554
49	18,5995	18,9908	19,3437	19,6468
50	18,4661	18,8972	19,2862	19,6205
51	18,2600	18,7559	19,2040	19,5893
52	18,1484	18,6802	19,1611	19,5747
53	18,1475	18,6793	19,1602	19,5739
54	18,1460	18,6778	19,1588	19,5725
55	18,1458	18,6777	19,1586	19,5723
56	18,1466	18,6785	19,1594	19,5731
57	18,0489	18,6149	19,1270	19,5677
58	17,8281	18,4016	18,9201	19,4185
59	17,8276	18,4011	18,9196	19,4180
60	17,6888	18,2670	18,7896	19,3275
61	17,4724	18,0580	18,5869	19,1883
62	17,4671	18,0529	18,5819	19,1835
63	17,4615	18,0475	18,5766	19,1784
64	17,4576	18,0437	18,5730	19,1748
65	17,3742	17,9632	18,4950	19,1318
66	17,3736	17,9628	18,4945	19,1314
67	17,3273	17,9180	18,4511	19,1038
68	17,3159	17,9070	18,4405	19,0935
69	17,3131	17,9042	18,4378	19,0909
70	17,3122	17,9034	18,4370	19,0901
71	17,3117	17,9029	18,4365	19,0897
72	17,2122	17,8069	18,3434	19,0367
73	17,2092	17,8040	18,3406	19,0339
74	17,2074	17,8023	18,3389	19,0323
75	17,2167	17,8113	18,3477	19,0408
76	17,2157	17,8103	18,3467	19,0398
77	17,2168	17,8113	18,3477	19,0408
78	17,1000	17,6987	18,2385	18,9358
79	16,6975	17,3105	17,8625	18,5742
80	16,6568	17,2714	17,8245	18,5377
81	16,6510	17,2657	17,8190	18,5325
82	16,6306	17,2461	17,8001	18,5142
83	16,6271	17,2427	17,7967	18,5110
84	16,6248	17,2405	17,7946	18,5090
85	16,6042	17,2206	17,7753	18,4904
86	16,6018	17,2183	17,7731	18,4883
87	16,6543	17,2689	17,8221	18,5355
88	16,6294	17,2449	17,7989	18,5131
89	16,6046	17,2210	17,7757	18,4908
90	16,6025	17,2190	17,7738	18,4890
91	16,5994	17,2160	17,7709	18,4862
92	17,9561	18,5498	19,0866	19,5285

No. Bus	Existing (kV)	Scenario 1 (kV)	Scenario 2 (kV)	Scenario 3 (kV)
93	17,6550	18,3401	18,9601	19,4058
94	17,6029	18,2902	18,9267	19,3732
95	17,3585	18,0565	18,7721	19,2229
96	17,1156	17,8242	18,6231	19,0778
97	17,1025	17,8116	18,6152	19,0702
98	17,0559	17,7671	18,5876	19,0433
99	17,0103	17,7235	18,5608	19,0173
100	17,0021	17,7157	18,5561	19,0127
101	16,9839	17,6983	18,5460	19,0028
102	16,9769	17,6916	18,5422	18,9992
103	16,9573	17,6729	18,5317	18,9890
104	16,9304	17,6472	18,5177	18,9753
105	16,9263	17,6433	18,5157	18,9734
106	16,8788	17,5979	18,4928	18,9512
107	16,7544	17,4791	18,4338	18,8938
108	16,5894	17,3216	18,3576	18,8197
109	16,5267	17,2617	18,3013	18,7649
110	16,4816	17,2187	18,2609	18,7255
111	16,3757	17,1177	18,1659	18,6330
112	16,3177	17,0623	18,1139	18,5824
113	16,1884	16,9389	17,9980	18,4695
114	16,0935	16,8483	17,9129	18,3867
115	16,0748	16,8305	17,8961	18,3703
116	16,0649	16,8210	17,8873	18,3617
117	16,0618	16,8181	17,8845	18,3591
118	16,0561	16,8126	17,8794	18,3540
119	15,9912	16,7507	17,8212	18,2974
120	15,9844	16,7442	17,8151	18,2915
121	15,9548	16,7160	17,7886	18,2656
122	15,9528	16,7141	17,7869	18,2639
123	15,9355	16,6976	17,7714	18,2489
124	15,9181	16,6810	17,7558	18,2337
125	15,9091	16,6724	17,7477	18,2258
126	15,8916	16,6557	17,7320	18,2105
127	15,8888	16,6530	17,7295	18,2081
128	15,8553	16,6211	17,6996	18,1789
129	15,8500	16,6161	17,6948	18,1743
130	15,8137	16,5815	17,6623	18,1427
131	15,8098	16,5777	17,6588	18,1393
132	15,8047	16,5729	17,6543	18,1349
133	15,7930	16,5617	17,6438	18,1246
134	15,7919	16,5607	17,6428	18,1237
135	15,7862	16,5552	17,6377	18,1187
136	15,7858	16,5548	17,6373	18,1183
137	17,6474	18,3327	18,9530	19,3989
138	17,6436	18,3291	18,9495	19,3955
139	17,6373	18,3230	18,9437	19,3897
140	17,6322	18,3182	18,9389	19,3851

No. Bus	Existing (kV)	Scenario 1 (kV)	Scenario 2 (kV)	Scenario 3 (kV)
141	17,6317	18,3176	18,9384	19,3846
142	17,6305	18,3165	18,9373	19,3835
143	17,1148	17,8234	18,6223	19,0771
144	16,9985	17,7123	18,5528	19,0095
145	16,9830	17,6974	18,5451	19,0020
146	16,3753	17,1172	18,1655	18,6327
147	15,9076	16,6709	17,7463	18,2245
148	15,9087	16,6720	17,7473	18,2254
149	15,8540	16,6198	17,6983	18,1778
150	15,8107	16,5785	17,6596	18,1400
151	15,8091	16,5770	17,6582	18,1386

Based on Table 3 above, the voltage comparison graph in the existing conditions and after the installation of the capacitor bank is shown in Figure 7.

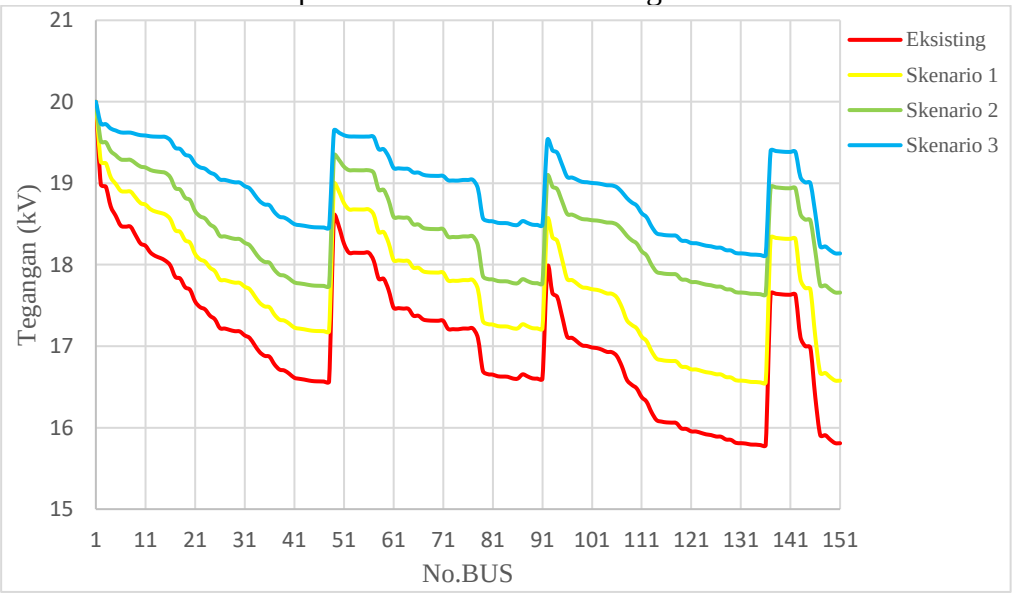

Figure 7 Comparison graph of voltage profile before and after installing capacitor banks

Based on Table 3, the number of buses in Durian 4 PT PLN (Persero) ULP Rasau Jaya is 151 buses. From the results of the power flow calculation using the current injection method with the help of the matlab application in the existing condition, the minimum bus voltage is 15.7858 kV, where there are only 24 buses or around 15.894% of the bus voltage that meets the SPLN T6.001 Year 2013 standard. In scenario 1 after the installation of 1 unit of capacitor bank with a capacity of 900 kVAR at bus 93 (POINT 14), the minimum bus voltage is 16.5548 kV, where the bus voltage that meets the SPLN T6.001 Year 2013 standard has increased by 25 buses or increased 16.556% from 24 buses (existing conditions) to 49 buses with a percentage of bus voltage that meets the standard of 32.450%. In scenario 2 with the installation of 2 units of 1800 kVAR capacitor banks on bus 93 (POINT 14) and bus 108 (RJ 0011 PL), the minimum bus voltage is 17.6373 kV, where the bus voltage that meets the SPLN T6.001 2013 standard has increased by 73 bus voltages or increased 48.344% from 24 buses (existing conditions) to 97 buses with a percentage of bus voltages that meet the standards of 64.238%. While in scenario 3 after the installation of 3 units of capacitor banks with a capacity of 2600 kVAR at bus 93 (POINT 14), bus 108 (RJ 0011 PL) and bus 26 (RJ 0021 TL), the minimum bus voltage is 18.1183 kV. Based on

SPLN T6.001 Year 2013, the voltage profile on the Durian 4 extension of PT PLN (Persero) ULP Rasau Jaya has met the standard, which according to SPLN T6.001 Year 2013 explains that, the minimum voltage on a 20 kV system must not be less than 18 kV.

Comparison of Voltage Drop Percentage Before and After Installation of Capacitor Banks.

A comparison of the voltage drop percentage of each bus in the existing condition and after the installation of capacitor banks through three scenarios is shown in Table 4, below.

Table 4. Comparison of Voltage Drop Percentage Before and After Installation of Capacitor Banks

No. Bus	Exsisting VDrop (%)	Scenario 1 VDrop (%)	Scenario 2 VDrop (%)	Scenario 3 VDrop (%)
1	0,0000	0,000	0,000	0,000
2	5,0661	3,671	2,416	1,339
3	5,1998	3,766	2,477	1,371
4	6,4253	4,638	3,027	1,644
5	6,9990	5,042	3,278	1,763
6	7,5960	5,461	3,535	1,880
7	7,6641	5,509	3,563	1,892
8	7,6710	5,513	3,566	1,894
9	8,1890	5,871	3,777	1,978
10	8,6968	6,217	3,977	2,051
11	8,8373	6,313	4,032	2,070
12	9,2511	6,592	4,188	2,120
13	9,4661	6,735	4,264	2,139
14	9,5882	6,815	4,306	2,147
15	9,7510	6,922	4,361	2,158
16	10,0427	7,203	4,634	2,356
17	10,7431	7,880	5,291	2,828
18	10,8507	7,984	5,391	2,900
19	11,3829	8,498	5,890	3,249
20	11,5467	8,656	6,043	3,354
21	12,2554	9,340	6,707	3,807
22	12,5983	9,671	7,028	4,022
23	12,7399	9,808	7,161	4,108
24	13,1274	10,182	7,523	4,339
25	13,3559	10,403	7,737	4,474
26	13,8872	10,915	8,234	4,770
27	13,9157	10,943	8,261	4,796
28	14,0047	11,029	8,344	4,876
29	14,0787	11,100	8,413	4,942
30	14,0953	11,116	8,429	4,957
31	14,3363	11,349	8,654	5,174
32	14,4959	11,502	8,803	5,317
33	14,9351	11,926	9,214	5,712
34	15,3569	12,333	9,608	6,091
35	15,5898	12,557	9,825	6,300
36	15,6487	12,614	9,881	6,353
37	16,1192	13,068	10,320	6,775
38	16,4301	13,368	10,610	7,055
39	16,4926	13,428	10,669	7,111

No. Bus	Exsisting VDrop (%)	Scenario 1 VDrop (%)	Scenario 2 VDrop (%)	Scenario 3 VDrop (%)
40	16,6958	13,624	10,859	7,293
41	16,9387	13,858	11,086	7,511
42	17,0005	13,918	11,143	7,567
43	17,0482	13,964	11,188	7,610
44	17,1097	14,023	11,245	7,665
45	17,1492	14,061	11,282	7,700
46	17,1593	14,071	11,291	7,709
47	17,1685	14,080	11,300	7,718
48	17,1746	14,086	11,306	7,723
49	7,0026	5,046	3,281	1,766
50	7,6697	5,514	3,569	1,898
51	8,7001	6,221	3,980	2,054
52	9,2579	6,599	4,194	2,126
53	9,2625	6,604	4,199	2,131
54	9,2701	6,611	4,206	2,138
55	9,2709	6,612	4,207	2,138
56	9,2668	6,608	4,203	2,135
57	9,7553	6,926	4,365	2,162
58	10,8594	7,992	5,400	2,908
59	10,8620	7,995	5,402	2,910
60	11,5559	8,665	6,052	3,363
61	12,6381	9,710	7,066	4,059
62	12,6645	9,735	7,090	4,083
63	12,6927	9,763	7,117	4,108
64	12,7122	9,781	7,135	4,126
65	13,1292	10,184	7,525	4,341
66	13,1318	10,186	7,527	4,343
67	13,3637	10,410	7,745	4,481
68	13,4203	10,465	7,798	4,533
69	13,4347	10,479	7,811	4,546
70	13,4389	10,483	7,815	4,549
71	13,4414	10,485	7,818	4,552
72	13,9389	10,965	8,283	4,817
73	13,9542	10,980	8,297	4,830
74	13,9629	10,988	8,305	4,838
75	13,9163	10,943	8,262	4,796
76	13,9214	10,948	8,266	4,801
77	13,9162	10,943	8,261	4,796
78	14,5002	11,507	8,807	5,321
79	16,5127	13,447	10,688	7,129
80	16,7158	13,643	10,877	7,311
81	16,7452	13,672	10,905	7,338
82	16,8468	13,769	11,000	7,429
83	16,8646	13,787	11,016	7,445
84	16,8760	13,798	11,027	7,455
85	16,9792	13,897	11,123	7,548
86	16,9911	13,909	11,135	7,558
87	16,7285	13,655	10,889	7,323
88	16,8528	13,775	11,005	7,434

No. Bus	Exsisting VDrop (%)	Scenario 1 VDrop (%)	Scenario 2 VDrop (%)	Scenario 3 VDrop (%)
89	16,9772	13,895	11,122	7,546
90	16,9875	13,905	11,131	7,555
91	17,0030	13,920	11,146	7,569
92	10,2194	7,251	4,567	2,357
93	11,7250	8,300	5,199	2,971
94	11,9857	8,549	5,367	3,134
95	13,2076	9,718	6,139	3,886
96	14,4222	10,879	6,885	4,611
97	14,4877	10,942	6,924	4,649
98	14,7204	11,164	7,062	4,784
99	14,9487	11,383	7,196	4,914
100	14,9894	11,421	7,219	4,936
101	15,0805	11,509	7,270	4,986
102	15,1155	11,542	7,289	5,004
103	15,2133	11,635	7,341	5,055
104	15,3482	11,764	7,412	5,123
105	15,3685	11,784	7,422	5,133
106	15,6060	12,010	7,536	5,244
107	16,2281	12,604	7,831	5,531
108	17,0529	13,392	8,212	5,902
109	17,3666	13,691	8,494	6,176
110	17,5919	13,906	8,696	6,372
111	18,1213	14,412	9,170	6,835
112	18,4115	14,689	9,431	7,088
113	19,0579	15,305	10,010	7,652
114	19,5326	15,758	10,436	8,067
115	19,6261	15,848	10,519	8,148
116	19,6757	15,895	10,564	8,192
117	19,6908	15,909	10,577	8,205
118	19,7197	15,937	10,603	8,230
119	20,0440	16,246	10,894	8,513
120	20,0781	16,279	10,924	8,543
121	20,2261	16,420	11,057	8,672
122	20,2360	16,429	11,066	8,680
123	20,3224	16,512	11,143	8,756
124	20,4096	16,595	11,221	8,832
125	20,4543	16,638	11,261	8,871
126	20,5422	16,722	11,340	8,947
127	20,5562	16,735	11,352	8,960
128	20,7234	16,894	11,502	9,105
129	20,7499	16,920	11,526	9,128
130	20,9313	17,093	11,688	9,286
131	20,9508	17,111	11,706	9,303
132	20,9763	17,136	11,729	9,326
133	21,0350	17,192	11,781	9,377
134	21,0404	17,197	11,786	9,381
135	21,0692	17,224	11,812	9,407
136	21,0712	17,226	11,814	9,408
137	11,7631	8,336	5,235	3,006

No. Bus	Exsisting VDrop (%)	Scenario 1 VDrop (%)	Scenario 2 VDrop (%)	Scenario 3 VDrop (%)
138	11,7819	8,354	5,252	3,023
139	11,8135	8,385	5,282	3,052
140	11,8388	8,409	5,305	3,075
141	11,8417	8,412	5,308	3,077
142	11,8474	8,417	5,313	3,082
143	14,4261	10,883	6,888	4,614
144	15,0074	11,439	7,236	4,952
145	15,0851	11,513	7,274	4,990
146	18,1236	14,414	9,172	6,837
147	20,4622	16,645	11,268	8,878
148	20,4567	16,640	11,263	8,873
149	20,7302	16,901	11,508	9,111
150	20,9467	17,107	11,702	9,300
151	20,9546	17,115	11,709	9,307

Sumber : Hasil Perhitungan (2024)

Based on Table 4 above, the graph of the percentage of voltage drop before and after the installation of the capacitor bank is shown in Figure 8.

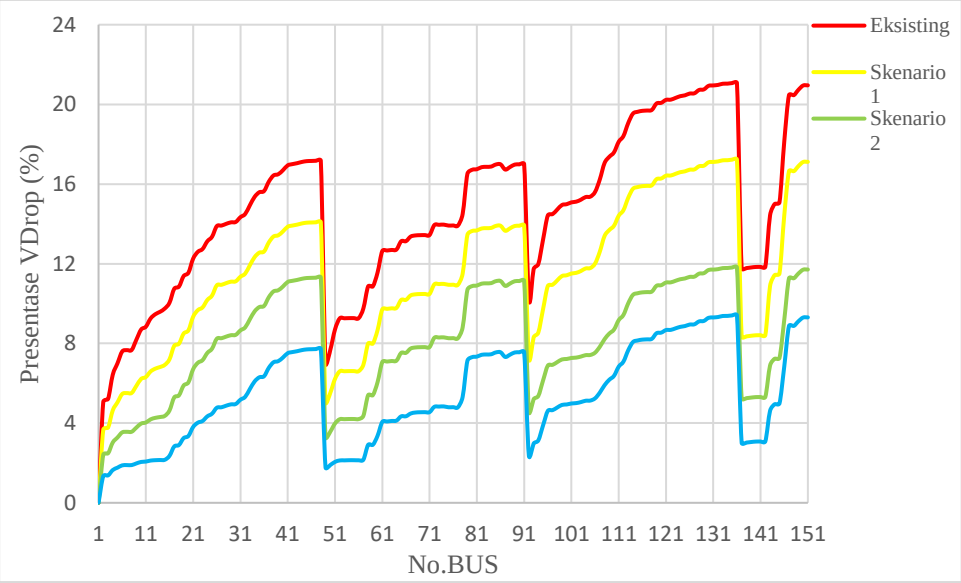

Figure 8. Comparison chart of voltage drop percentage before and after installing capacitor banks

Based on Table 4, the maximum voltage drop percentage that occurs at bus 136 (RJ 0027 AP) under existing conditions is 21.071% or a maximum voltage drop of 4.2142 kV. Based on SPLN T6.001 Year 2013, the voltage drop percentage has not met the standard. In scenario 1 after the installation of a 900 kVAR capacitor bank, the maximum voltage drop percentage decreased by 3.845% from 21.071% (existing conditions) to 17.226% or the maximum voltage drop of 3.4452 kV. In scenario 2 after installing a capacitor bank with a capacity of 1800 kVAR, the maximum voltage drop percentage decreased by 9.257% from 21.071% (existing conditions) to 11.814% or a maximum voltage drop of 2.3628 kV. Based on SPLN T6.001 Year 2013, the voltage drop percentage has not met the standard. In scenario 3 after the installation of a 2600 kVAR capacitor bank, the maximum voltage drop percentage is 9.408% or the maximum voltage drop value is 1.8816 kV which occurs at bus 136 (RJ 0027 AP). Based on SPLN T6.001 Year 2013, the percentage of voltage drop that occurs in Durian 4 PT PLN (Persero) ULP Rasau Jaya has met the standard.

CONCLUSION

Based on the results of the power flow calculations carried out in the Durian 4 PT PLN (Persero) Rasau Jaya ULP using the current injection method with the help of matlab software, several conclusions are obtained as follows:

1. In the existing condition, there are only 24 out of 151 buses that meet SPLN T6.001 Year 2013, with the minimum bus voltage occurring at bus 136 (RJ 0027 AP) of 15.5878 kV with a voltage drop percentage of 21.071% and a total active power loss of 365.560 kW.
2. Based on the FVSI, LQP and LSF methods with a combination of normalised values, the optimal location of placement and capacity of capacitor banks is located at bus 93 (POINT 14) with a capacity of 900 kVAR, at bus 93 (POINT 14) and bus 108 (RJ 0011 PL) with a capacity of 1800 kVAR, and at bus 93 (POINT 14), bus 108 (RJ 0011 PL) and bus 26 (RJ 0021 TL) with a capacity of 2600 kVAR.
3. In scenario 1, the installation of a 900 kVAR capacitor bank at bus 93 (POINT 14) increases the number of buses that meet SPLN T6.001 Year 2013 to 49 buses and increases the minimum voltage at bus 136 (RJ 0027 AP) to 16.5548 kV with a voltage drop percentage of 17.226%, and reduces active power losses to 292.248 kW.
4. In scenario 2, the installation of capacitor banks with a capacity of 1800 kVAR at bus 93 (POINT 14) and bus 108 (RJ 0011 PL), increases the number of buses that meet SPLN T6.001 Year 2013 to 97 buses and increases the minimum voltage at bus 136 (RJ 0027 AP) to 17.6373 kV or with a voltage drop of 11.814%, and reduces active power losses to 281.220 kW.
5. In Scenario 3, the installation of capacitor banks with a capacity of 2600 kVAR at bus 93 (POINT 14), bus 108 (RJ 0011 PL), and at bus 26 (RJ 0021 TL), makes all buses meet SPLN T6.001 Year 2013, increases the minimum voltage at bus 136 (RJ 0027 AP) to 18.1183 kV or with a voltage drop percentage of 9.408%, and reduces active power losses to 276.528 kW.
6. Capacitor bank placement strategies using the FVSI, LQP, and LSF methods are effective in improving the voltage profile, ensuring all buses meet SPLN T6.001 Year 2013, and reducing active power losses significantly.

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