

# Performance of Electrical Power Distribution Network Under Dynamic Loading

Ramadoni Syahputra<sup>\*1</sup>, Taufiq Akbar<sup>1</sup>, and Faaris Mujaahid<sup>1</sup>

<sup>1</sup>Department of Electrical Engineering, Universitas Muhammadiyah Yogyakarta  
Jl. Lingkar Selatan, Tamantirto, Kasihan, Yogyakarta, Indonesia

\*Corresponding author, e-mail: ramadoni@ugm.ac.id

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**Abstract** - This paper presents the performance of the electrical power distribution network under dynamic loading. The performance of a distribution system can be seen from the power losses generated by the network. If the power losses are low, then it can be said that network performance is excellent. Another parameter is the distribution network voltage profile. The voltage profile is significant in the distribution network. A very long distribution line will cause a voltage drop at the end of the network. This condition is very undesirable, so efforts must be made to improve the distribution network voltage profile. The method for correcting the voltage profile is by installing capacitors or reconfiguring the network. In this study, an evaluation of the performance of the distribution network at PLN Temanggung was conducted. The results showed that several network points experienced below-standard voltage drops. Therefore it is recommended to install power capacitors or reconfigure the networks.

**Keywords:** Distribution network, performance, power losses, voltage profile

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## I. Introduction

In the current era of globalization, humans have a dependency on electricity [1]. Electricity has become a basic need inherent in everyday life. Almost all equipment that helps or supports daily activities uses electricity; this is evident when the electricity goes out, then all of our activities will be disrupted [2]-[5]. The use of electricity continues to increase over time. This is related to population growth and the economic growth of an area so that the distribution of electrical energy must be guaranteed [6].

Based on Law No. 30 of 2009, it states that state-owned company (in the case of PT PLN) is the chief executor of the electricity supply business. So that the distribution of electrical energy PT PLN demanded reliable because, in the distribution network, voltage and power losses must occur [7].

Voltage drop is the difference between the source voltage and the load or receiver voltage. This voltage drop is the product of the current flowing in

the line and the line impedance [8]-[11]. The higher the value of current and impedance, the more significant the voltage drop. So for more extensive networks and load currents, the higher the voltage drop, the greater [12]. During the day, the power usage is relatively small, and the currents are small so that the voltage drops are getting smaller, conversely when at night the use of immense power and the current is getting bigger, so the voltage drop is getting bigger too.

Power losses are the loss of power in the process of electricity from substations to consumers. This power loss is the product of the square of the current with line resistance. The higher the current flowing in a prisoner, the greater the loss of power [13]. The higher the cross-sectional area of a line, the smaller the power losses. During the day, the power usage is relatively small; then, the current flowing is also small so that the power losses are small. Conversely, when at night the load is getting bigger, the current is also higher so that the power losses are also more significant [14]-[18].

An excellent electric power system must have a

voltage value that does not exceed the tolerance limits and small power losses. Based on SPLN No. 72 of 1987, the allowable tolerance for voltage drop is  $\leq 5\%$  of the nominal value, and based on the SPLN No. 10-A of 1996; tolerance losses cannot exceed  $\leq 10\%$  of the power delivered [19]. Constant voltage values will optimize the performance of electrical equipment used by consumers and can reduce financial losses that occur during the transmission and distribution process [20]-[22].

These conditions must not be allowed, because voltage drops and power losses are one of the benchmarks of the efficiency of a distribution network system. To reduce the amount of voltage drop and power losses, one of them is by using Load Tap Chargers, Bank Capacitors, and cable replacement in distribution networks [23]-[25].

The objectives of this study are:

1. Knowing the condition of the medium voltage power system distribution network at PT PLN Temanggung.
2. Knowing the voltage profile and power losses in PT PLN Temanggung.
3. Determine efforts to improve the voltage profile and power losses of medium voltage networks by using Load Tap Chargers, Bank Capacitors, and replacing feeder cables in distribution networks.
4. Knowing the voltage profile and power losses in the feeder after a simulation of repairs.

## II. Literature Study

### II.1 General

The distribution network is part of the electric power system in the form of a conduit that connects the load center substation and the customer. The function of the distribution network is to distribute electrical energy to customers according to the required power and voltage. Based on the voltage level, the distribution network is divided into two, namely the medium voltage distribution network and the low standing distribution network [26].

Medium voltage distribution networks mostly use a 3-phase 4-wire network, 3-phase wire, and one neutral wire with a 20kV phase inter-stand, while other parts are 2-phase 1-wire network with 11.5 kV voltage. The low voltage distribution network partly uses a 3 phase 4 wire network similar to a medium voltage distribution network to serve 3 phase customers with a phase voltage of 380 V, while

others use a 1 phase 3 wire network with a voltage of 220 V [29]. Between the low-pressure distribution network and the distribution network Medium voltage distribution transformers are installed according to needs, some are using 3-phase transformers, some are using 1-phase to. The medium voltage distribution network is used to connect between substations with distribution transformers or with medium voltage customers. In contrast, the low voltage distribution network is used to connect the distribution transformer with the low-voltage customer. When a low-voltage network and a medium-voltage network use the same pole, the neutral wire used is just one, as a neutral wire with the two systems.

For customers who use a large enough power, for example, industry, hospital, or campus, usually subscribe to 3 phases with a medium voltage of 20 kV. In the interest of reducing the voltage and its distribution, the customer manages his distribution substation. In contrast, customers with relatively small load power use low voltage and are served by a low voltage distribution network that is connected to a distribution transformer [27]. Figure 1 shows the electrical power system.

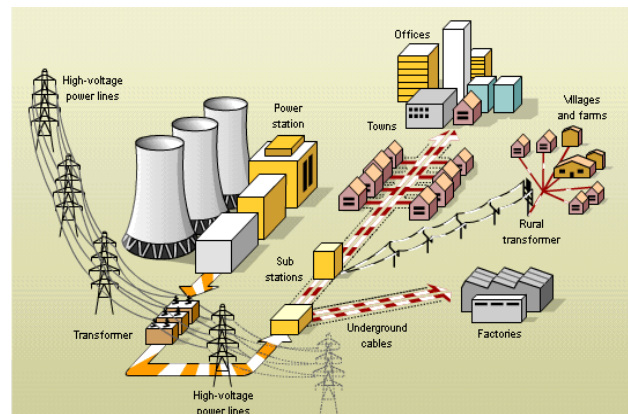


Fig. 1. Electrical power system

Distribution network topologies are grouped into two groups, namely radial networks and loop networks.

### II.2 Radial Distribution Network

The radial distribution network is the simplest network structure, both in terms of planning and effort. The distribution of electric power from feeders is in one direction. As a result, if there is interference at one point in the circuit will cause the entire network will be affected. Thus the continuity of electricity distribution on networks with structures like this is terrible. Because if there is a

repair at one point will cause the entire network must be extinguished. Figure 2 shows the radial distribution network.

### II.3 Loop Distribution Network

Circle distribution network structure is a closed distribution network structure that starts from considerable resources, then passes through several distribution substations and then returns to the source.

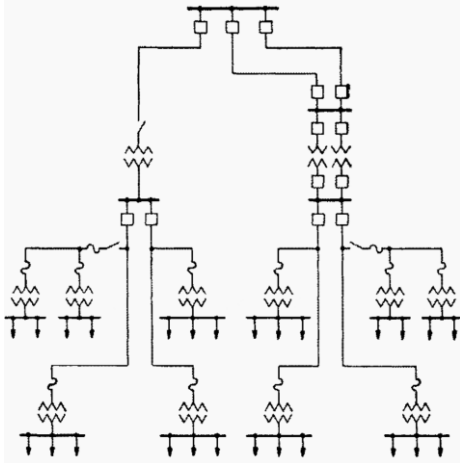


Fig. 2. Radial distribution network

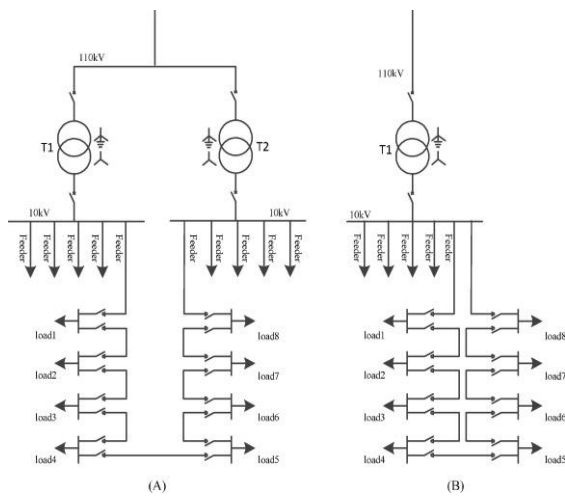


Fig. 3. Loop distribution network

The main advantage of this distribution network structure is that if a disturbance occurs, then the disturbance can be isolated so that it does not interfere with the distribution network as a whole. This can happen because, in this circle distribution network structure, two points can be connected alternately or simultaneously so that the continuity of the distribution is good enough. Even if there is interference at many points in a series or simultaneously, then the entire network can be

disturbed as well. Figure 2 shows the radial distribution network, while Figure 3 shows the loop distribution network.

### II.4 Electrical Power

Active power is the power used by actual energy or the power used by consumers; the active power unit is watts. The active power equation can be seen in the following equation [27]:

$$P = V I \cos \phi \tag{1}$$

where,

- P = Active Power (Watts)
- V = phase voltage (Volt)
- I = phase current (Ampere)
- $\phi$  = Power factor

Reactive power is the amount of power needed to form a magnetic field. From the formation of a magnetic field, a magnetic field flux is formed, the reactive power unit is VAR. The reactive power equation can be seen in the following equation [27]:

$$Q = V I \sin \phi \tag{2}$$

where,

- Q = Reactive Power (VAR)
- V = phase voltage (Volt)
- I = phase current (Ampere)
- $\phi$  = Power factor

The apparent power is the power generated by the multiplication of RMS voltage and RMS current in a network or power, which is the sum of active trigonometric power and reactive power. The real power unit is VA.

## III. Methodology

In this study, the tools used are as follows:

### 1. Hardware

The hardware used by the author is 1 unit of Asus A456QR laptop, 1 unit of the printer and 16 GB flash storage

### 2. Software

The software used is Microsoft Word 2016, Microsoft Exel 2016, and ETAP software.

3. Material for data collection in PT. PLN Temanggung, journals, conferences, and research supporting books.

The authors conducted research and data collection of time and place on May 17, 2018 to June 17, 2018 at PT PLN Rayon Temanggung, located on Jalan Jendral Sudirman, Kowangan, Temanggung, Central Java province, Indonesia.

## IV. Results and Discussion

### IV.1 Network Structure

TABLE I  
DATA OF DISTRIBUTION TRANSFORMER

No.	Transformer Code	Transformer Capacity (kVA)	Load (kVA)
1	T2	350	150
2	T3	550	230
3	T4	555	264
4	T5	675	362
5	T6	750	336
6	T7	275	79
7	T8	425	168
8	T9	475	184
9	T11	775	317
10	T12	565	217
11	T13	625	223
12	T14	625	279
13	T15	775	303
14	T16	500	261
15	T17	525	246
16	T18	450	222
17	T19	750	96
18	T20	100	90
19	T21	210	33
20	T23	825	290
21	T24	375	65
22	T25	600	105

At this stage, the simulation results of the stress profile and power loss program simulation will be explained using the Newton-Rapson flow method. The data collected is based on PLN's report during 2017, while the data on the type of delivery size follows the SPLN standard No. 064 of 1985. After all the data is filled in ETAP 12.6.0, the first simulation is a simulation of the initial state of the SCG 05 feeder and after it is known to have a voltage drop and power losses. There are three methods used in repairing the voltage profile and power losses, namely the first repair using Load Tap Changer, the second repair using a capacitor bank, the third repair using cable replacement. After a simulation of improvement of the three methods will then be compared, which method is most suitable to use.

The SCG 05 feeder is a radial primary 20kv distribution network supplied from the transformer GI 60 MV substation Secang, Central Java. This feeder has a total load of distribution transformer of 11,730 KVA spread over the SCG 05 feeder network.

The distribution network used in SCG 05 feeders is a 3-phase distribution network where all distribution transformers are used using 3-phase

transformers. Distribution network construction consists of a 20 kV Medium Voltage Network. Data of distribution transformer in Temanggung distribution system wa shown in Table I.

### IV.2 ETAP Simulation

From the results of the calculation of power losses using the existing formula with the results of the ETAP 12.6 simulation program, the same results can be obtained; although there is a difference, the difference is minimal. This proves that there is no difference between the existing formula and ETAP 12.6 simulation results, as seen in Figure 4.

To find the total active and reactive power losses in SCG 05 feeders is to add the conductor power losses with the power losses in the distribution transformer.

Furthermore, to improve the performance of the distribution network, cable replacement methods can also be performed. In this method, the repair is done by replacing the distribution network cable with a cross-sectional area of 150 mm<sup>2</sup> to 240 mm<sup>2</sup>, where the value of the impedance of the cable with a cross-sectional area of 240 mm<sup>2</sup> has a smaller impedance compared to cables with a cross-sectional area of 150 mm<sup>2</sup>. After changing the cable, the simulation is performed again to see the voltage profile data and power losses in the SCG 05 feeder.

From the comparative data of the difference in voltage profile and power losses between methods it can be concluded that the method of repair that is able to improve the voltage profile and reduce significant power losses is the method of installing bank capacitors, where this method has a profile on bus 40 of 19,352 kV even though at the load tap changer arrangement method has a larger voltage profile, but the voltage profile for the capacitor bank installation method is already within tolerance limits. As well as active power losses of 108.8 kW and reactive power losses of 191.8 kVar, this reduction in power losses are the largest of all methods used.

The total length of SCG 05 feeders in the Temanggung distribution system is 40.5 km using 240 mm and 150 mm XLPE cables. Data on cable length and specifications used in the Temanggung distribution system can be seen in Table II. Furthermore, power losses in the introduction of the Temanggung distribution system during the existing conditions can be seen in Table III, while the

voltage drop was shown in Table IV. These power losses and voltage drop are obtained using ETAP simulation software, as shown in Figure 4.

TABLE II  
TOTAL CONDUCTOR RESISTANCE DATA USED IN THE TEMANGGUNG SYSTEM DISTRIBUTION NETWORK

No.	from	to	Length (km)	Cross-sectional area	Z (Ω/km)		Total (Ω)	
					R	X	R	X
1	Bus 3	Bus 4	5	240 mm <sup>2</sup>	0.125	0.097	0.625	0.485
2	Bus 4	Bus 5	1.4	240 mm <sup>2</sup>	0.125	0.097	0.175	0.1358
3	Bus 5	Bus 6	3.5	240 mm <sup>2</sup>	0.125	0.097	0.438	0.3395
4	Bus 6	Bus 7	1.5	240 mm <sup>2</sup>	0.125	0.097	0.188	0.1455
5	Bus 7	Bus 8	2.7	150 mm <sup>2</sup>	0.206	0.104	0.556	0.2808
6	Bus 8	Bus 9	2	150 mm <sup>2</sup>	0.206	0.104	0.412	0.208
7	Bus 9	Bus 38	0.8	150 mm <sup>2</sup>	0.206	0.104	0.165	0.0832
8	Bus 6	Bus 10	2.4	240 mm <sup>2</sup>	0.125	0.097	0.300	0.2328
9	Bus 10	Bus 12	1.4	240 mm <sup>2</sup>	0.125	0.097	0.175	0.1358
10	Bus 12	Bus 13	1.7	240 mm <sup>2</sup>	0.125	0.097	0.213	0.1649
11	Bus 13	Bus 14	4	240 mm <sup>2</sup>	0.125	0.097	0.500	0.388
12	Bus 13	Bus 15	1.7	240 mm <sup>2</sup>	0.125	0.097	0.213	0.1649
13	Bus 15	Bus 16	6	240 mm <sup>2</sup>	0.125	0.097	0.750	0.582
14	Bus 16	Bus 17	3	150 mm <sup>2</sup>	0.206	0.104	0.618	0.312
15	Bus 16	Bus 18	3.4	240 mm <sup>2</sup>	0.125	0.097	0.425	0.3298
16	Bus 18	Bus 19	2	150 mm <sup>2</sup>	0.206	0.104	0.412	0.208
17	Bus 19	Bus 20	4	150 mm <sup>2</sup>	0.206	0.104	0.824	0.416
18	Bus 20	Bus 22	0.4	150 mm <sup>2</sup>	0.206	0.104	0.082	0.0416
19	Bus 20	Bus 21	0.7	150 mm <sup>2</sup>	0.206	0.104	0.144	0.0728
20	Bus 21	Bus 40	1	150 mm <sup>2</sup>	0.206	0.104	0.206	0.104

TABLE III  
POWER LOSSES OF THE TEMANGGUNG SYSTEM DISTRIBUTION NETWORK AT EXISTING CONDITION

No.	from and to	Length (km)	Electrical Current (A)	Measured Losses		Calculated Losses	
				kW	kVar	kW	kVar
1	Bus 3 - Bus 4	5	134.7	32.4	26.4	34.045	26.419
2	Bus 4 - Bus 5	1.4	130.3	9.1	7.4	8.915	6.918
3	Bus 5 - Bus 6	3.5	123.8	19.1	15.5	20.025	15.539
4	Bus 6 - Bus 7	1.5	38.7	0.8	0.7	0.842	0.653
5	Bus 7 - Bus 8	2.7	28.1	1.3	0.7	1.319	0.666
6	Bus 8 - Bus 9	2	17.3	0.4	0.2	0.370	0.187
7	Bus 9 - Bus 38	0.8	7.3	0.0	0.0	0.026	0.013
8	Bus 6 - Bus 10	2.4	79.7	5.4	4.4	5.717	4.436
9	Bus 10 - Bus 12	1.4	74.7	2.8	2.3	2.930	2.273
10	Bus 12 - Bus 13	1.7	68.2	2.8	2.3	2.965	2.301
11	Bus 13 - Bus 14	4	10.5	0.2	0.1	0.165	0.128
12	Bus 13 - Bus 15	1.7	57.6	2.0	1.6	2.115	1.641
13	Bus 15 - Bus 16	6	48.2	5.0	4.1	5.227	4.056
14	Bus 16 - Bus 17	3	6.5	0.0	0.0	0.078	0.040
15	Bus 16 - Bus 18	3.4	41.7	2.1	1.7	2.217	1.720
16	Bus 18 - Bus 19	2	35.1	1.4	0.8	1.523	0.769
17	Bus 19 - Bus 20	4	23.6	1.3	0.7	1.377	0.695
18	Bus 20 - Bus 22	0.4	9.1	0.0	0.0	0.020	0.010
19	Bus 20 - Bus 21	0.7	14.5	0.1	0.0	0.091	0.046
20	Bus 21 - Bus 40	1	6.7	0.0	0.0	0.028	0.014
Total				86.3	69	89.995	68.524

TABLE IV  
VOLTAGE DROP OF THE TEMANGGUNG SYSTEM DISTRIBUTION NETWORK AT EXISTING CONDITION

No.	from and to	Length (km)	Electrical Current (A)	Sending Voltage (kV)	Receiving Voltage (kV)	Measured Voltage Drop (kV)	Percentage of Voltage Drop (%)
1	Bus 3 - Bus 4	5	134.75	19.848	19.672	0.176	0.89
2	Bus 4 - Bus 5	1.4	130.31	19.672	19.621	0.051	0.26
3	Bus 5 - Bus 6	3.5	123.52	19.621	19.508	0.113	0.58
4	Bus 6 - Bus 7	1.5	38.68	19.508	19.493	0.015	0.08
5	Bus 7 - Bus 8	2.7	28.12	19.493	19.464	0.029	0.15
6	Bus 8 - Bus 9	2	17.3	19.464	19.45	0.014	0.07
7	Bus 9 - Bus 38	0.8	7.3	19.45	19.448	0.002	0.01
8	Bus 6 - Bus 10	2.4	79.7	19.508	19.458	0.05	0.26
9	Bus 10 - Bus 12	1.4	74.7	19.458	19.431	0.027	0.14
10	Bus 12 - Bus 13	1.7	68.2	19.431	19.4	0.031	0.16
11	Bus 13 - Bus 14	4	10.5	19.4	19.389	0.011	0.06
12	Bus 13 - Bus 15	1.7	57.6	19.4	19.375	0.025	0.13
13	Bus 15 - Bus 16	6	48.2	19.375	19.299	0.076	0.39
14	Bus 16 - Bus 17	3	6.5	19.299	19.299	0	0.00
15	Bus 16 - Bus 18	3.4	41.7	19.299	19.262	0.037	0.19
16	Bus 18 - Bus 19	2	35.1	19.262	19.235	0.027	0.14
17	Bus 19 - Bus 20	4	23.6	19.235	19.199	0.036	0.19
18	Bus 20 - Bus 22	0.4	9.1	19.199	19.197	0.002	0.01
19	Bus 20 - Bus 21	0.7	14.5	19.199	19.195	0.004	0.02
20	Bus 21- Bus 40	1	6.7	19.195	19.192	0.003	0.02

TABLE V  
VOLTAGE DROP OF THE TEMANGGUNG SYSTEM DISTRIBUTION NETWORK AFTER CONDUCTOR REPLACEMENT

No.	Identity of Bus	Voltage Before Conductor Replacement (kV)	Voltage After Conductor Replacement (kV)	Percentage of Voltage Profile (%)	$\Delta V$ (kV)	$\Delta V'$ (kV)	Percentage of Drop Voltage Improvement (%)
1	Bus 3	19.848	19.848	0	-	-	-
2	Bus 4	19.672	19.672	0	0.176	0.176	0
3	Bus 5	19.621	19.621	0	0.051	0.051	0
4	Bus 6	19.508	19.508	0	0.113	0.113	0
5	Bus 7	19.493	19.493	0	0.015	0.015	0
6	Bus 8	19.464	19.473	0.046	0.029	0.02	31.034
7	Bus 9	19.45	19.464	0.072	0.014	0.009	35.714
8	Bus 10	19.458	19.458	0	0.050	0.05	0
9	Bus 12	19.431	19.431	0	0.027	0.027	0
10	Bus 13	19.4	19.4	0	0.031	0.031	0
11	Bus 14	19.389	19.389	0	0.011	0.011	0
12	Bus 15	19.375	19.375	0	0.025	0.025	0
13	Bus 16	19.299	19.299	0	0.076	0.076	0
14	Bus 17	19.299	19.299	0	0.000	0	0
15	Bus 18	19.262	19.262	0	0.037	0.037	0
16	Bus 19	19.235	19.244	0.047	0.027	0.018	33.333
17	Bus 20	19.199	19.219	0.104	0.036	0.025	30.556
18	Bus 21	19.195	19.217	0.115	0.004	0.002	50
19	Bus 22	19.197	19.218	0.109	0.002	0.001	50
20	Bus 38	19.448	19.463	0.077	0.002	0.001	50
21	Bus 40	19.192	19.215	0.120	0.003	0.002	33.333

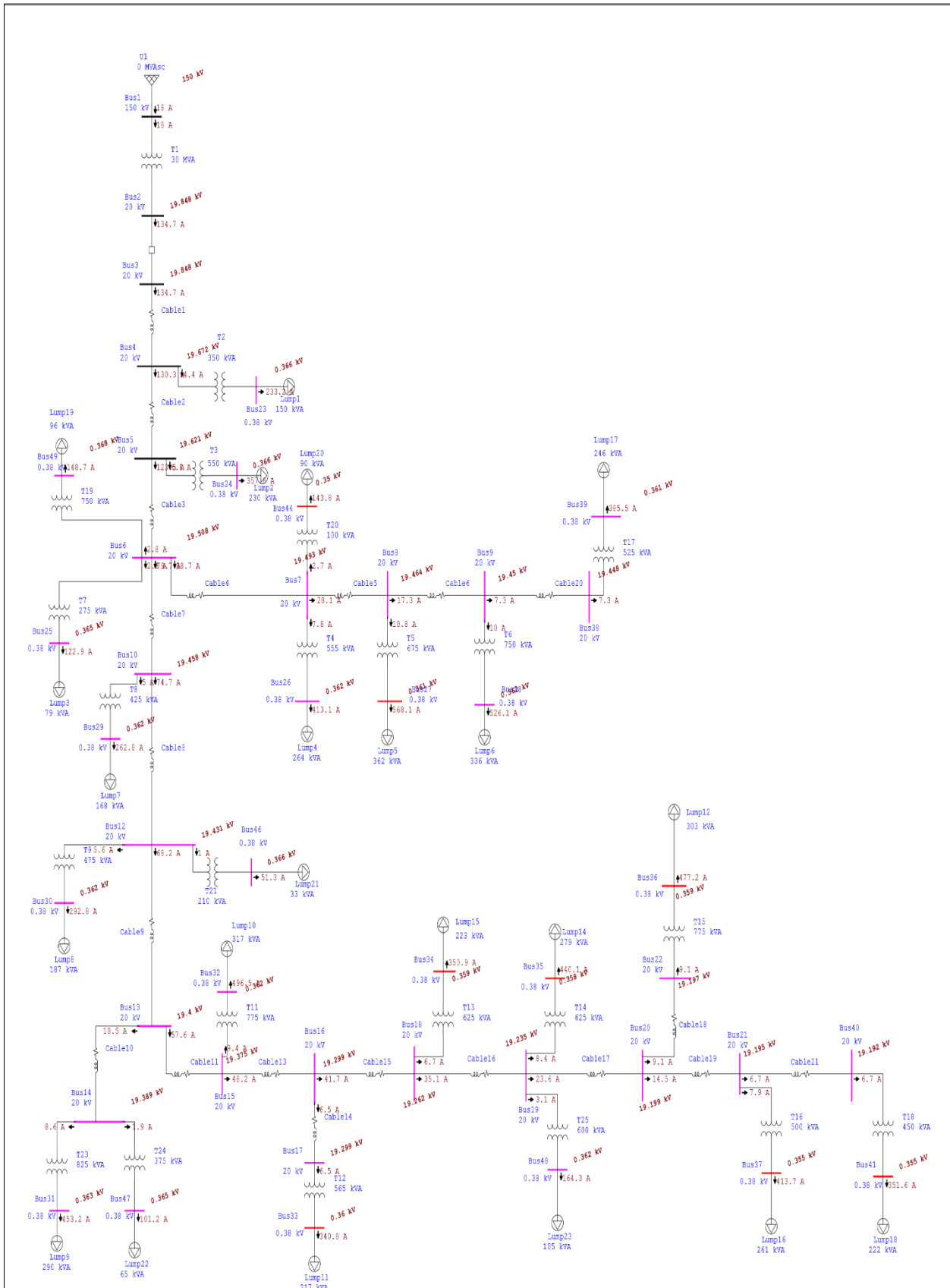


Fig. 4. ETAP simulation results of power losses of the Temanggung distribution system existing conditions

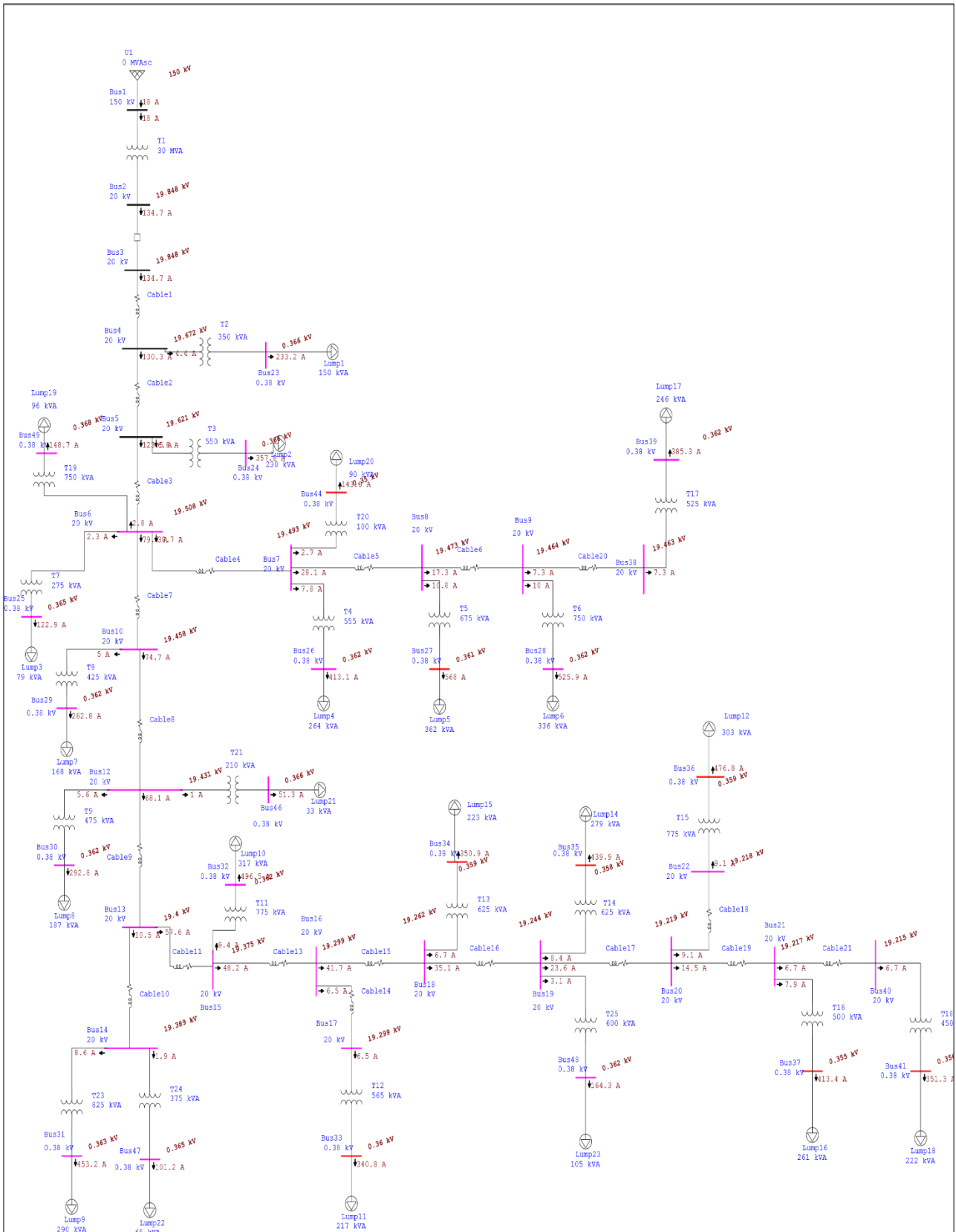


Fig. 5. ETAP simulation results of power losses of the Temanggung distribution system after conductor replacement



ETAP simulation results of power losses of the Temanggung distribution system after conductor replacement was shown in Figure 5. This simulation produces voltage profile data before and after the replacement of the distribution network conductor. The voltage profile before and after the conductor replacement in the Temanggung distribution system is shown in Table V.

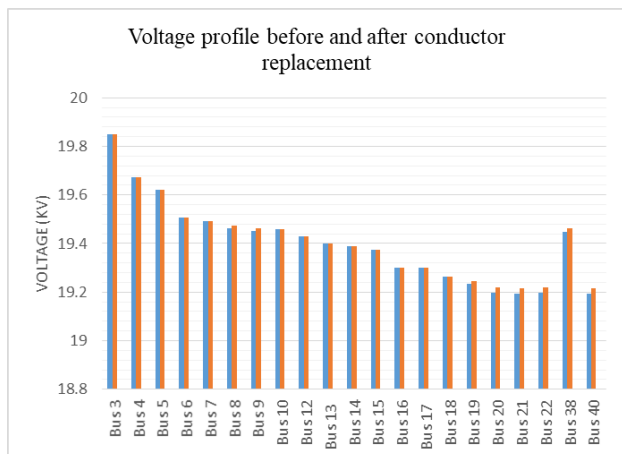


Fig. 6. Voltage profile before and after conductor replacement of Temanggung distribution system

As can be seen in Table V, that after repairs have been made through replacement of the conduit on the distribution network, an increase in the voltage profile on the bus 8, 9, 19, 20, 21, 22, 38, and bus 40. This increase also improves the network voltage on the buses, where before the conductor replacement experiences a voltage drop.

The condition after the repair scenario is done by replacing the SCG 05 feeder cable, some buses have dropped, and some have not changed. However, this voltage drop is only slightly due to cable replacement only replacing cables that still use a 150 mm<sup>2</sup> cross-sectional area. Current flowing in the feeder only slightly decreases wherein the initial condition the current flowing by 134.75 A decreases to 134.71 A. This decrease causes a decrease in voltage drop not to have a significant effect.

From the improvement scenarios above it can be seen that the increase in pad voltage of bus 8 is 0.046%, bus 9 is 0.072%, bus 19 is 0.047%, bus 20 is 0.104%, bus 21 is 0.115%, bus 22 is 0.109%, bus 38 is 0.077%, and bus 40 by 0.12% from the existing condition. Because cable replacement is carried out in part, ie, on a cable whose cross-sectional area is 150 mm<sup>2</sup> to 240 mm<sup>2</sup>, some buses on the SCG 05 feeder also experience variable voltage profile increases, especially on buses whose cables are replaced. Voltage profile before and after

conductor replacement of Temanggung distribution system was shown in Figure 6. In the figure, it can be seen that in general, after cable replacement, the distribution system voltage profile is getting better.

## V. Conclusion

From the results of simulations and analyses that have been made, the following conclusions can be drawn. In the existing condition, SCG 05 feeders have decreased voltage to the end of the network, namely bus 40 by 19,192 kV and active power losses by 121.3 kW and reactive power losses by 202.7 kVar. Cross-sectional area replacement is performed on a network that still uses a 150 mm<sup>2</sup> cross-sectional area. After the simulation, the result of the voltage at the end of the network is bus 40 equal to 19,215 kV, the bus that experiences a voltage increase is only on the bus whose cable has been replaced only while the bus that has not changed. Active power losses of 119.5 kW and reactive power losses of 202.5 kVar.

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## Authors' information



**Ramadoni Syahputra** received B.Sc. degree from Institut Teknologi Medan in 1998, M.Eng. degree from Department of Electrical Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia in 2002, and Ph.D degree at the Department of Electrical Engineering, Faculty of Industrial Technology, Institut Teknologi Sepuluh

Nopember, Surabaya, Indonesia in 2015.

Dr. Ramadoni Syahputra is a Lecturer in Department of Electrical Engineering, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta, Indonesia. His research interests are in computational of power system, artificial intelligence in power system, power system control, the application of fuzzy

logic in power system, optimization, distributed energy resources, and renewable energy.



**Taufiq Akbar** received B.Sc. degree from Department of Electrical Engineering, Universitas Muhammadiyah Muhammadiyah Yogyakarta, Yogyakarta, Indonesia in 2019. His research interests are in operation of power system and power system planning.



**Faaris Mujaahid** hold a bachelor degree in 2010 from Electrical and Electronics Engineering Department, Saxion University of Applied Sciences, the Netherlands. He received a master degree in Sustainable Energy Technologies in 2016 from University of Southampton, UK. ing. Faaris Mujaahid, M.Sc is currently a lecturer in the Department of Electrical Engineering, Faculty of Engineering, Universitas Muhammadiyah Yogyakarta, Indonesia. His main research interest is in LabVIEW and renewable energy (mainly in solar cell material and fabrication technologies).