The 2nd International Conference on Multidisciplinary Engineering
(2nd ICOMDEN 2024)

The 2nd International Conference on Multidisciplinary Engineering: ***00068*** (2024)
Volume 2, 2024
eISSN: xxxx-xxxx
https://doi.org/10.29103/icomden.v2.xxxx

Research Original Article

Power Quality Analysis of a 20kV Primary Distribution Line Using ETAP Power Station 12.6.0 at Sidikalang Substation

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Abstract

The rapid economic growth and population increase in Indonesia have significantly raised the demand for electrical energy. The electricity distribution system, having the highest rate of disruptions among power system components, has become the primary focus for improvement efforts. This study aims to evaluate the quality of electricity distribution lines at the Sidikalang Substation using ETAP Power Station 12.6.0. The analysis is crucial for understanding power usage efficiency, identifying potential disturbances, and evaluating distribution system performance. The main challenge lies in effectively evaluating distribution line quality, involving the monitoring of critical parameters such as voltage, current, and power factor. Utilizing ETAP Power Station 12.6.0 enables in-depth analysis, aids decision-making, and facilitates future planning. This research draws upon scientific literature and industry guidelines to provide a strong theoretical foundation. The study's findings are expected to contribute to enhancing the quality and reliability of electricity distribution systems in Indonesia, thereby supporting the nation's sustainable development goals in the energy sector.

Keywords: power distribution; ETAP; power quality; substation; energy efficiency

Introduction

At this time, electricity has become a primary necessity for modern human life to carry out social and economic activities to achieve a better standard of living [1]. Thus, the level of electricity consumption can also be considered a benchmark for the level of income and prosperity of a country or region [2]. In line with the economic growth rate and the increase in Indonesia's population, the demand for electrical energy continues to rise [3]. To meet the electricity needs of the community, PT.PLN (Persero) continues to strive to improve the quality and reliability of the electricity supply [4]. Electricity is the most beneficial and efficient energy source for humans in the modern era [5]. Electric energy plays an important role in meeting the needs and electrical services of consumers today. Compared to other components of the power system, the distribution system has the highest level of disturbances due to its proximity to customers [6]. The distribution network consists of a cable network that connects customers to the distribution substation [7], [8]. Electricity is supplied to customers through this distribution network. The power distribution system consists of two parts, namely the primary distribution system and the secondary distribution system [9], [4].

In the current electrical conditions, power outages still occur frequently, both planned and caused by natural disturbances [10]. It is important to assess the reliability of electricity distribution to customers in order to improve service quality or predict suboptimal electrical performance [11]. To achieve that goal, a comparison can be made between the reliability index results and the reference index used in Indonesia, specifically the PLN Standard [12], [13].

In this context, distribution network analysis aims to understand the efficiency of electricity usage, identify potential disruptions, and evaluate the performance of the electricity distribution system [14]. The electricity distribution industry plays an important role in ensuring a stable and efficient energy supply for the community [15]. In this context, the Sidikalang Substation becomes the central point in the electricity distribution network in the area [16]. The analysis of the distribution line quality at the Sidikalang Substation is crucial to ensure that the electricity supply can be distributed well and of high quality to the end consumers [17], [18].

The main challenge faced in this research is to evaluate the quality of the distribution channels effectively and efficiently [19]. This involves monitoring critical parameters such as voltage, current, and power factor, as well as identifying potential issues that may occur in the distribution line [20]. Disruptions in power quality, such as voltage fluctuations or frequent outages, can interfere with the operation of many electronic devices and systems that rely on a stable power supply [21], [22]. Unstable voltage can also potentially damage electronic equipment or even cause fires if not detected quickly [23]. Therefore, it is important to conduct an analysis of the distribution network system to ensure that the voltage and frequency of electricity remain within safe limits [24].

Literature Review

This research adopts a descriptive statistical approach as an analysis technique to describe and summarize data without making inferences about a broader population. In this study, descriptive statistics are used to process data from power quality measurements. This method includes calculating the mean, median, standard deviation, and frequency distribution of various power quality parameters, including voltage, current, active power, reactive power, and power factor. The purpose of using descriptive statistics is to provide a comprehensive overview of the power quality conditions on the 20kV primary distribution line at the Sidikalang Substation, without generalizing to a larger population. This analysis is a crucial first step in identifying patterns and potential issues, thus serving as a foundation for future system improvements and developments.

Materials & Methods

On the 20 kV distribution line, the feeder SD 01 has 38 transformers with various capacities: 3 units of 16 kVA, 4 units of 25 kVA, 17 units of 50 kVA, 9 units of 100 kVA, 3 units of 160 kVA, and 2 units of 200 kVA. The total transformer capacity is 2,918 kVA and the total transformer load is 1,997.2608 kVA. The load on the SD 01 feeder is considered heavy because it leads to densely populated areas and serves everything from household loads to institutional buildings. In the feeder SD 01, most of the cables used are AAAC 150 mm2 for SUTM, which are made of aluminum alloy and serve as conductors between poles. The length of the 20 kV distribution line on feeder SD 01 is 25.852 kilometers.

This research uses the power flow analysis approach of the ETAP Power Station 12.6.0 software to determine power losses and voltage drops on the distribution line. Then determine the capacity of the capacitor bank using the following equation:

$$Q_c = P\ x\ (tan\theta_1 - tan\theta_2) \tag{1}$$

And determines the number of bank capacitors to be installed using the following equation:

$$\boldsymbol{n} = \frac{\boldsymbol{Qc}}{\boldsymbol{Rating\ kapasitor}} \tag{2}$$

Then determine the value of the bank capacitor compensation using the following equation:

$$\boldsymbol{K} = \frac{\boldsymbol{Qc}}{\boldsymbol{Q}} \tag{3}$$

Then determine the optimal location for placing the bank capacitor using the following equation:

$$X_i = [(1 - \frac{(2i - l)}{2n}) \times k] \times 1 \tag{4}$$

Results and Discussion

On the 20 kV distribution line, the feeder SD 01 has 38 transformers with various capacities: 3 units of 16 kVA, 4 units of 25 kVA, 17 units of 50 kVA, 9 units of 100 kVA, 3 units of 160 kVA, and 2 units of 200 kVA. The power and load data of the transformers on the feeder SD 01 can be seen in Table 1.

Tabel 1. Transformer data and transformer load

No	Transformer data and transformer load			
	Transformer Name	**transformer power (kVA)**	**Transformer Load (kVA)**	**Cos φ**
1	BTB02-1	315	252	0,8
2	BTB.05-1	200	137,862	0,8
3	BTB.05-2	100	42,624	0,8
4	BTB.06-1	50	43,734	0,8
5	SD 507-1	25	6,4	0,8
6	SD 508-1	25	3,108	0,8
7	SD 510-1	25	8,9688	0,8
8	BTB.07-1	50	27,084	0,8
9	PERUM BOANG MANALU	50	48	0,8
10	BTB.08-1	50	61,272	0,8
11	BTB.08-2	100	67,266	0,8
12	BTB.10-3	100	40,404	0,8

13	BTB.10-2	100	50,394	0,8
14	BTB.10-1	160	41,292	0,8
15	BTB.10	160	157	0,8
16	BTB.09-1	50	17,316	0,8
17	PJN.05-1	25	24	0,8
18	PJN.06-1	25	24	0,8
19	PJN.01-1	50	47,952	0,8
20	PJN.01-2	50	34,632	0,8
21	TOWER	50	6,882	0,8
22	PJN.02-1	16	17,538	0,8
23	SD 516-1	25	12,432	0,8
24	BTB.06-1	50	48	0,8
25	BTB.06-1	50	48	0,8
26	SDT01-1	160	143,4	0,8
27	SDT01-1i	200	160	0,8
28	SDT02-1	50	37,1	0,8
29	PERUMAHAAN	100	23,3	0,8
30	KRG.06-1	100	62,4	0,8
31	KRG.07-1	100	53,9	0,8
32	SDT.03-1	50	49,3	0,8
33	SDT.04-1	16	16,7	0,8
34	SDT.05-1	16	10	0,8
35	SDT.03-2	50	48	0,8
36	SDT.06-1	100	53	0,8
37	TOWER	25	24	0,8
38	TOWER	50	48	0,8
Total		2918	1997,2608	

To evaluate power quality, including power losses, voltage drop, and power factor on feeder SD 01, a simulation can be conducted using ETAP software. This simulation utilizes the data that has been obtained and employs equipment rating settings that conform to the specifications of the Sidikalang Substation. Load flow analysis is then conducted to obtain comprehensive results regarding the condition of the studied electricity distribution system.

Tabel 2. Power losses and voltage drops

CKT / Branch	**Losses**		**Vd**
ID	**kW**	**kvar**	**% in Vmag**
BTB02-1	4,7	7,0	3,10
BTB.05-2	0,4	0,6	1,63
BTB.05-1	2,2	3,3	2,66
BTB.06-1	0,9	1,3	3,39
BTB.06-1i	1,1	1,6	3,74
BTB.06-1ii	1,1	1,6	3,74
Perum Boang Manalu	1,1	1,6	3,74
BTB.07-1	0,3	0,5	2,09
BTB.08-1	1,8	2,7	4,81
BTB.08-02	1,1	1,6	2,60
BTB.09-1	0,1	0,2	1,33

BTB.10	3,6	5,5	3,83
BTB.10-01	0,2	0,4	0,99
BTB.10-2	0,6	0,9	1,94
BTB.10-3	0,4	0,6	1,55
KRG.06-1	0,9	1,4	2,41
KRG.07-1	0,7	1,0	2,07
Perumahan	0,1	0,2	0,89
PJN.01-1	1,1	1,6	3,74
PJN.01-2	0,6	0,8	2,68
PJN.02-1	0,5	0,7	4,28
PJN.05-1	0,5	0,8	3,74
PJN.06-1	0,5	0,8	3,74
SD 507-1	0,0	0,1	0,98
SD 508-1	0,0	0,0	0,47
SD 510-1	0,1	0,1	1,38
SD 516-1	0,1	0,2	1,91
SDT01-1	3,0	4,5	3,47
SDT01-1i	3,0	4,5	3,10
SDT02-1	0,6	1,0	2,87
SDT.03-1	1,1	1,7	3,84
SDT.03-2i	1,6	2,5	4,61
SDT.04-1	0,4	0,6	4,08
SDT.05-1	0,1	0,2	2,41
SDT.06-1	0,2	0,4	1,24
TOWER	0,0	0,0	0,53
TOWERi	0,5	0,8	3,74
TOWERii	1,1	1,6	3,74
BTB02-1 - BTB.05-1	0,3	0,4	0,05
BTB02-1 - SD 516-1	0,3	0,4	0,05
GI-BTB02-1	1,6	2,1	0,12
BTB.05-1 - BTB.05-2	0,1	0,1	0,02
BTB.05-2 - BTB.06-1	0,2	0,3	0,04
BTB.06-1 - PERUM BOANG MA	0,2	0,2	0,04
BTB.06-1 - SD 507-1	0,0	0,0	0,00
BTB.06-1i - BTB.06-1ii	0,0	0,0	0,00
SD 516-1- BTB.06-1i	0,0	0,0	0,01
SD 510-1 - BTB.07-1	0,0	0,0	0,00
BTB.08-1 - BTB.08-02	0,1	0,1	0,03
PERUM - BTB.08-1	0,1	0,2	0,04
BTB.08-2 - BTB.10-3	0,1	0,1	0,03
BTB.09-1 - PJN.05-1	0,0	0,0	0,01
BTB.10 - BTB.09-1	0,0	0,0	0,01
BTB.10-1 - BTB.10	0,0	0,1	0,02
BTB.10-2 - BTB.10-1	0,1	0,1	0,02
BTB.10-3 - BTB.10-2	0,1	0,1	0,03
GI	1,0	20,7	0,66
KRG.06-1 - KRG.07-1	0,0	0,0	0,00

PJN 01-1 - KRG.06-1	0,0	0,0	0,01
PJN 01-1 - SDT.03-1	0,0	0,0	0,02
SDT02-1i - Perumahan	0,0	0,0	0,02
SDT 02-1 - PJN.01-2	0,0	0,0	0,00
PJN.06-1 - PJN.01-1	0,0	0,0	0,01
PJN.01-2 - TOWER	0,0	0,0	0,00
TOWER - PJN.02-1	0,0	0,0	0,00
PJN.05-1 - PJN.06-1	0,0	0,0	0,01
SD 507-1 - SD 508-1	0,0	0,0	0,00
SD 508-1 - SD 510-1	0,0	0,0	0,00
SD 516-1 - SDT01-1	0,2	0,3	0,05
BTB.06-1i - SDT01-1	0,1	0,2	0,04
SDT01-1 - SDT01-1i	0,1	0,1	0,03
SDT.03-1 - SDT.03-2	0,0	0,0	0,01
SDT.03-1 - SDT.04-1	0,0	0,0	0,00
SDT.03-2 - SDT.06-1	0,0	0,0	0,01
SDT.04-1 - SDT.05-1	0,0	0,0	0,00
SDT.06-1 - TOWERi	0,0	0,0	0,00
TOWERi -TOWERii	0,0	0,0	0,00
Total	41,4	80,6	1,36

After conducting a load flow analysis, the data obtained shows active power losses on the feeder SD 01 amounting to 41.1 kW and reactive power losses of 80.6 kVAR with an average voltage drop of 1.36%. The largest voltage drop occurred at transformer BTB.08-1 with a value of 4.81%. And with the following power factor values:

Tabel 3. Faktor daya sebelum perbaikan

CKT / Branch ID	**Cos φ**
Bus BTB02-1	0,793
Bus BTB.05-2	0,793
Bus BTB.05-1	0,793
Bus BTB.06-1	0,796
Bus BTB.06-1i	0,796
Bus BTB.06-1ii	0,796
Bus Perum Boang Manalu	0,796
Bus BTB.07-1	0,796
Bus BTB.08-1	0,793
Bus BTB.08-02	0,794
Bus BTB.09-1	0,793
Bus BTB.10	0,793
Bus BTB.10-01	0,793
Bus BTB.10-2	0,792
Bus BTB.10-3	0,793
Bus KRG.06-1	0,793
Bus KRG.07-1	0,793
Bus Perumahan	0,793
Bus PJN.01-1	0,794
Bus PJN.01-2	0,793
Bus PJN.02-1	0,791

Bus PJN.05-1	0,791
Bus PJN.06-1	0,793
Bus SD 507-1	0,792
Bus SD 508-1	0,792
Bus SD 510-1	0,793
Bus SD 516-1	0,793
Bus SDT01-1	0,793
Bus SDT01-1i	0,792
Bus SDT02-1	0,796
Bus SDT.03-1	0,796
Bus SDT.03-2i	0,792
Bus SDT.04-1	0,795
Bus SDT.05-1	0,795
Bus SDT.06-1	0,794
Bus TOWER	0,792
Bus TOWERi	0,792
Bus TOWERii	0,792
Average	0,793

It can be seen that the feeder bus SD 01 has an average power factor of only 0.793. This is beyond the tolerance limit allowed by SPLN 1985, where the minimum power factor must be 85%. Therefore, improvements need to be made by increasing the power factor value.

Power Quality Improvement

To carry out repairs, it is necessary first to calculate the active and reactive load power on the feeder SD 01. From the data obtained, the author can calculate the values of active load power and reactive load power as follows:
On transformer BTB02-1

It is known,
$S = 252$ kVA
$\cos \theta = 0{,}793$
$\text{Acos } 0{,}793 = 37{,}53^\circ$
$\sin 37{,}53^\circ = 0{,}6$
So,
$P = S \times \cos \theta$
$= 252 \times 0{,}793$
$= 199{,}836$ kW
$Q = S \times \sin \theta$
$= 252 \times 0{,}6$
$= 151{,}2$ kVar

The same calculations were performed on each transformer in the SD 01 feeder, resulting in the following outcomes:

Tabel 4. Load capacity

Transformer Name	Load Capacity	
	kW	kVar
BTB02-1	199,836	151,2
BTB.05-1	109,324566	82,7172
BTB.05-2	33,800832	25,5744
BTB.06-1	34,812264	26,2404
SD 507-1	5,0944	3,84
SD 508-1	2,473968	1,8648
SD 510-1	7,1391648	5,38128
BTB.07-1	21,558864	16,2504
PERUM BOANG MANALU	38,064	28,8

BTB.08-1	48,649968	36,7632
BTB.08-2	53,341938	40,3596
BTB.10-3	32,040372	24,2424
BTB.10-2	39,962442	30,2364
BTB.10-1	32,703264	24,7752
BTB.10	124,501	94,2
BTB.09-1	13,731588	10,3896
PJN.05-1	19,032	14,4
PJN.06-1	19,032	14,4
PJN.01-1	38,073888	28,7712
PJN.01-2	27,463176	20,7792
TOWER	5,443662	4,1292
PJN.02-1	13,872558	10,5228
SD 516-1	9,858576	7,4592
BTB.06-1	38,016	28,8
BTB.06-1	38,016	28,8
SDT01-1	113,7162	86,04
SDT01-1i	126,88	96
SDT02-1	29,4203	22,26
PERUMAHAAN	18,4536	13,98
KRG.06-1	49,6704	37,44
KRG.07-1	42,9044	32,34
SDT.03-1	39,0456	29,58
SDT.04-1	13,2765	10,02
SDT.05-1	7,95	6
SDT.03-2	38,112	28,8
SDT.06-1	41,976	31,8
TOWER	19,008	14,4
TOWER	38,016	28,8
Total	1.584,27149	1.198,35648

Then, the required capacitor bank capacity needs to be calculated with the assumption of increasing the power factor from an average of 0.793 to 0.95 using equation (1), which is in accordance with SPLN 70-1:1985, where the minimum power factor value must be more than 85%.

To calculate the capacitor bank capacity as follows:

Diketahui,:

$\cos \theta a = 0.793$

$\text{acos } 0.793 = 37{,}53^{\circ}$

$\cos \theta b = 0.95$

$\text{acos } 0.95 = 18.20^{\circ}$

So, to calculate Qc from the BTB02-1 transformer as follows:

It is known,

P = 199,836 kW

So,

$Qc = 199{,}836 \times (0{,}76 - 0{,}33)$

$= 199{,}836 \times 0{,}43$

= 86,211249 kVar

The same calculation was performed on all transformers in the SD 01 feeder, resulting in a total capacitor bank capacity of 685.3261 kVar. Therefore, to raise the power factor to 95% from the initial 79.3%, a capacitor capacity of 685.3261 kVar is required. Installing a capacitor bank with the correct capacity can significantly improve the power factor, which will subsequently enhance the efficiency and power quality of the distribution system.

Determining The Optimum Location of a Capacitor Bank

To determine the optimum location for the placement of the capacitor bank, it can be calculated using equation (4). The length of the line on feeder SD 01 is 25.852 km. First, we need to determine the number of capacitors to be installed, if the capacitors to be used have a rating of 250 kVAR. Then, the number of capacitors to be installed is calculated using the following equation:

$$\boldsymbol{n = \frac{Qc}{Rating\ kapasitor}}$$

Where:
Qc = Power factor correction value
n = Number of capacitors
Then:

$$n = \frac{Qc}{Rating\ kapasitor}$$
$$n = \frac{685{,}3261\ \text{kVAR}}{250\ kVAR}$$
$$n = 2{,}6852392$$

Thus, the value n = 2.7413044 is rounded to n = 3.
Next, calculate the compensation factor (K) of the capacitor bank using the following equation (3):

$$\boldsymbol{K = \frac{Qc}{Q}}$$

Where:
QC = Power Factor Correction Value (kVAR)
K = Reactive Compensation Value
Q = Reactive Power (kVAR)
Then:

$$K = \frac{685{,}3261\ \text{kVAR}}{1.198{,}35648\ kVAR}$$
$$K = 0{,}571888342$$

So, from the calculations, the value of K = 0.571888342 was obtained.
Then we will use equation (4) to determine the optimal location for placing the capacitor bank as follows:

- For the first placement location, it is as follows:

$$X_1 = (\,1 - \frac{2 \cdot 1 - 1}{6}) \times 0{,}571888342 \times 25{,}852$$
$$X_1 = \frac{5}{6} \times 0{,}571888342 \times 25{,}852$$
$$X_1 = 12{,}32$$

Therefore, the optimum placement location for the first position is at 12.32 km.

- For the second placement location, it is as follows:

$$X_2 = \left(1 - \frac{2 \cdot 2 - 1}{6}\right) \times 0{,}571888342 \times 25{,}852$$
$$X_2 = \frac{1}{2} \times 0{,}571888342 \times 25{,}852$$
$$X_2 = 7{,}39$$

Maka, untuk lokasi optimum penempatan ke-2 adalah di 7,39 kms.

- For the third placement location, it is as follows:

$$X_3 = (\,1 - \frac{2 \cdot 3 - 1}{6}) \times 0{,}571888342 \times 25{,}852$$
$$X_3 = \frac{1}{6} \times 0{,}571888342 \times 25{,}852$$
$$X_3 = 2{,}46$$

Therefore, the optimum location for the 3rd placement is at 2.46 km.

Analysis of Power Quality Comparison After Improvement

After the installation of the capacitor bank at the determined optimum location, the power losses, voltage drop, and power factor on the SD 01 feeder bus can be seen in the table below:

Table 5. Comparison of power quality after repair

Explanation	Before The Repair	After the Repair
Cos φ	0,793	0,858
Active power loss (P)	41,4 kW	39,68 kW
Reactive power loss (Q)	80,6 kVAR	72,19 kVAR
Drop voltage	1,36%	1,34%

After the installation of the capacitor bank, there was a decrease in active power losses by 4.30%, from initially 41.4 kW to 39.68 kW. The reduction in active power losses after the improvement indicates better efficiency in power transmission. Reactive power losses decreased by 11.67%, from initially 80.6 kVAR to 72.19 kVAR. The significant reduction in reactive power losses indicates an improvement in the system's reactive power management. The voltage drop decreased by 0.89% from initially 1.36% to 1.34%. Although the decrease in voltage drop is small, it indicates better voltage stability along the distribution line.and successfully increased the power factor at the sender's base from initially 78.8% to 95.4% and the average power factor to 85.8%. And it is already in accordance with the PLN 1985 standard where the minimum power factor is 85%.

The improvements made to the SD 01 feeder have resulted in a significant increase in power quality, particularly in terms of power factor and reduction of power losses. This has the potential to enhance operational efficiency and the overall quality of electrical service.

Conclusions

On the feeder SD 01, the active power loss is 41.4 kW, the reactive power loss is 80.6 kVAR, and the voltage drop is 1.36%. The average power factor is 0.793, which is below the SPLN 1985 standard. The installation of 3 capacitor banks with a capacity of 250 kVAR each reduced the active power loss by 4.30%, the reactive power loss by 11.67%, and the voltage drop by 0.89%, resulting in an increase in the average power factor to 0.856. The placement of capacitor banks using the correct method is effective in reducing power loss and improving power factor. With the installation of the capacitor bank, the power quality on feeder SD 01 has met the PLN 1985 standards.

Acknowledgments

The deepest gratitude to Allah SWT for His grace and guidance, and to Mr. Muchlis Abdul Muthalib, ST., M.Eng., Ph.D, Mr. Arnawan Hasibuan, S.T., M.T., Ph.D, Mr. Muhammad, S.T., M.Sc, Mr. Dedi Fariadi, S.T., M.Pd, for their invaluable assistance and support in the writing of this scientific journal. I would also like to express my gratitude to my family for their unwavering patience and support. The contributions of all parties are invaluable and have provided priceless guidance at every step of this research. I hope this collaboration continues and brings greater benefits to the development of science.

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