

Medium and Low Voltage Quality Improvement with Shunt Bank Capacitor and Transformer Tap on Morocco Tapung Feeder Duri

Sepannur Bandri¹, Liliana², Rafika Andari^{3✉}, Zuriman Anthony⁴

^{1,3,4} Department of Electrical Engineering, Institut Teknologi Padang, Indonesia

² Department of Electrical Engineering, Universitas Islam Negeri Sultan Syarif Kasim, Riau, Pekanbaru, Indonesia

✉ **Corresponding Author** : Rafika Andari (e-mail: rafika.andari09@gmail.com)

Article Information	ABSTRACT
Article History Received : May 07, 2025 Revised : May 22, 2025 Published : July 02, 2025	Voltage and frequency quality are paramount in 20 kV distribution systems that supply both medium and low voltage feeders. This study explores the significant voltage deficiency in the Maroko Tapung extension of PT PLN (PERSERO), ULP Duri, which dropped 16% from the nominal value. The main objective is to implement a comprehensive voltage restoration strategy to improve the efficiency of the 20 kV distribution system so that it reaches a better standard. The restoration was carried out by setting tap changers, installing shunt capacitor banks, and gradually increasing the tap settings on distribution transformers. Simulation results show a significant improvement in the minimum voltage level across the network, with the lowest voltage on the medium voltage side increasing to 91.69% and on the low voltage side to 90.47%. These outcomes demonstrate that the implemented multi-stage restoration procedures effectively brought the voltage quality within the acceptable limits defined by SPLN 1: 1987 standards, which permit a deviation of +5% and -10% from the nominal voltage. This study highlights the effectiveness of combined tap adjustments and shunt capacitor installation in mitigating voltage drops and ensuring compliance with regulatory standards in distribution systems.
Keywords: <i>Distribution transformer; Shunt bank capacitor; Tap of transformer; Voltage drop; Voltage quality.</i>	

INTRODUCTION

Voltage drops during electric power distribution can result in power losses if the voltage that reaches the electrical equipment falls short of the nominal voltage limit (Gokbayrak & Avci, 2020). Power providers and consumers may experience electrical equipment interference due to voltage drops in the distribution system. This electrical provider's voltage drop might lead to malfunctions in control devices including auxiliary relays, automatic valves, and magnetic switches (Chou et al., 2017); (Shekhar et al., 2018). In the meanwhile, a voltage drop will result in suboptimal performance from electrical equipment on the customer's end. For example, it will cause a loss in torque when the electric motor is started (starting torque) and a fall in lighting equipment's light intensity (Arief & Nappu, 2017).

The Duri Customer Service Unit has a feeder whose voltage drop is outside the standard limits of the State Electricity Company (PLN). The voltage drop occurred in the Maroko feeder in the direction of Tapung. The measurement results on July 3, 2020, on the medium voltage network side with a nominal voltage of 20 kV are in the R-S phase with a voltage value of 17.3 kV, the R-

T phase with a voltage value of 16.7 kV, and in the S-T phase with a voltage value of 16.4 kV (Arief & Nappu, 2017). From the measurement results, it can be concluded that the average voltage drop between phases is 16.8 kV or a voltage drop of 16% of the nominal voltage of 20 kV. The percentage result of this voltage drop exceeds the standard SPLN 1: 1987 which is a maximum of 10% (Utomo et al., 2017).

The cause of the voltage fall in Maroko feeder majoring in Tapung due to wide distribution services. Tapung major is the longest channel, compared to other majors in Maroko feeder. The feeder itself is an express feeder (no load network) used to supply electrical power from the load center (substation) directly to link substation. Maroko feeder are divided into 3 majors, among others, Sukatani, Kandis City, and Tapung. Based on data from State Electricity Company, the total length of each major, among others, Sukatani 44.6 kms, Tapung 103.6 kms, and Kandis City 31.3 kms. With the total total length of the network is 103.6 kms, it has a major influence on the magnitude of the voltage fall value on the feeder (Liliana et al., 2024).

Apart from being due to extensive distribution services, the Maroko feeder majoring in Tapung has electricity customers with large power. There are three customers of the Palm Oil Mill (PKS) industry, namely, PKS Naga Mas, PKS Nagasakti Mill, and PKS Kijang Mill. Industrial customers use PLN's power supply to drive electric motors for generation. This customer is a customer with an inductive load. Inductive load is a load that absorbs the reactive power of the system so that it affects the magnitude of the system voltage drop (Arief & Nappu, 2017).

Attempts to increase voltage have been made thus far by earlier scholars in related articles. Among them is to configure the network by operating switching, smart meter (Bula et al., 2016). Furthermore, it provides compensation by placing a shunt bank capacitor and a distributed generation (Jung et al., 2018); (Kim et al., 2017); (Balu & Mukherjee, 2020), optimizing (Zeinalzadeh et al., 2015); (Chen & Li, 2016); (Mosbah et al., 2017), coordination (Aryanezhad, 2018), and analyzing the economy (Zeinalzadeh et al., 2015); (Sadeghian et al., 2021). Next is the operation of the transformer by changing the tap which can be done on power transformers and distribution transformers (Seo et al., 2017); (Z. Li et al., 2018); (Ku et al., 2019); (C. Li et al., 2020).

The feeder's condition has attempted to raise the voltage by installing a bank of capacitors, but this has not improved the voltage's quality in accordance with standards. Through the modification of the transformer tap and the optimization of the capacitor bank's positioning on the line, this study aims to raise the voltage. Additionally, the utilization of capacitor banks will be reduced by repairs involving transformers and tap changes. As a result, capacitor bank repairs may be less expensive. Both the medium voltage network side (20 kV) and the low voltage network side (380 V) of the feeder were subjected to these two attempts to reduce the voltage drop.

RESEARCH METHODS

This research was conducted at the Maroko Feeder in the Tapung Department at PT. PLN (PERSERO) ULP Duri, Sub Belutu. It is one of the majors in the Maroko Feeder (feeder express). The Feeder from the Tapung Department is located at Jl. Belutu, Kec. Kandis, Kab. Siak, Riau Province. The Moroccan feeder from the Tapung Department gets an electric power supply from the Power Transformer Unit 1 of the Balai Pungut Substation with a capacity of 60 MVA Indonesia.

The data used in this study is secondary data belonging to PT. PLN (PERSERO) Duri Customer Service Unit (ULP), PT. PLN (PERSERO) Belutu Kandis and the Balai Pungut Substation. The data needed in this study include Single Line Diagram (SLD) data for the Maroko Feeder, Tapung Department, load data and load location, line length data, power transformer data and capacitor data and capacitor locations. Power flow simulation using Newton Raphson method. While the standard voltage limit is set based on SPLN 1: 1987, namely +5% and -10% of the nominal voltage.

Voltage quality improvement initiatives are methodically executed in three stages. The objective of these stages is to ascertain the most efficacious voltage quality improvement outcomes. The stages of this process include, firstly, the transformer changing the tap (power transformer), followed by the placement of the shunt bank capacitor in stage two, and culminating in further improvement in stage three with the transformer changing the tap.

1) First Stage

The Maroko feeder from the Tapung Department is supplied by a Unit 1 GiBalaiPungut power transformer with the On Load Tap Changer (OLTC) type or a loaded tap changer system. OLTC is a type of tap on a transformer that can be changed the position of the tap under load or voltage without breaking the circuit. At this stage, the power transformer is increased by 5% on the secondary side. This means that there is an additional secondary side winding, so that the voltage on the secondary side will increase from the nominal voltage of 20 kV to 21 kV (Bao et al., 2020).

2) Second Stage

In the second repair stage, it aims to improve the quality of the voltage on the medium-voltage network and on the low-voltage network. Placement of shunt bank capacitors using the optimization of the Genetic Algorithm Method. In this research, optimization by genetic algorithm method uses the Optimal Placement Capacitor (OPC) tool on ETAP 12.6.0 software. The variables of the optimization search results include, among others, the location, quantity, capacity and cost of the shunt bank capacitors that will be placed in the Maroko Feeder in the Tapung Department (Arlenny et al., 2019).

3) Third Stage

In the Maroko feeder, there are 75 distribution transformers with the type of Off Load Tap Changer or a system to change the tap to no load. Off Load Tap Changer is a type of tap on a transformer that cannot be changed when the tap is under load, so it can be done by disconnecting the circuit first. At this stage, the distribution transformer is tapped once by 2.5% of the nominal voltage on the secondary side. If the secondary side voltage is still not within the tolerance limit, the tap will be increased twice by 5% of the nominal voltage on the secondary side. Increasing the tap on the secondary side means that there is an additional secondary side winding, so that the voltage on it or the voltage received by the consumer will increase (Lee et al., 2023).

RESULTS AND DISCUSSION

The case study was conducted in the distribution system of the Maroko Feeder, Tapung Department, Customer Service Unit Duri. In the feeder circuit, there are two networks that are divided based on the nominal voltage value, namely the Medium Voltage (MV) 20 kV and the Low Voltage (LV) network 0.38 kV. The LV consists of 114 buses and the LV consists of 75 buses.. Meanwhile, the standard voltage limit is set based on SPLN 1: 1987, namely +5% and -10% of the nominal voltage.

The Quality of The Existing Voltage

After simulating the Moroko feeder in the Tapung direction, in the initial conditions before making repairs, the simulation results obtained data in the form of the voltage value (%) of each bus in the medium voltage and low voltage network as shown in Figure 1 and Figure 2.

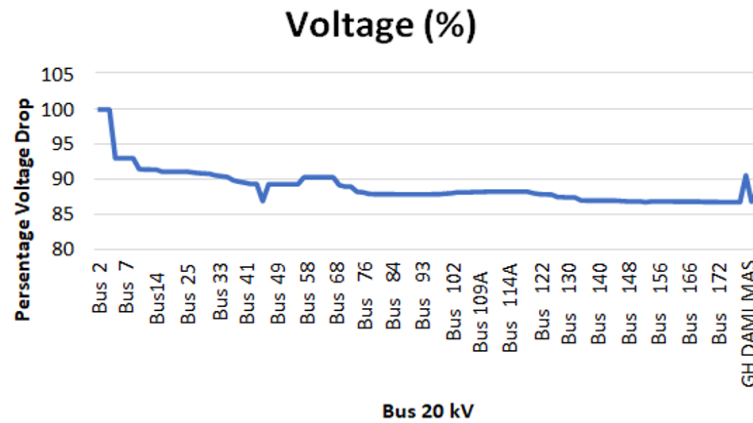


Figure 1. The quality of the existing low voltage

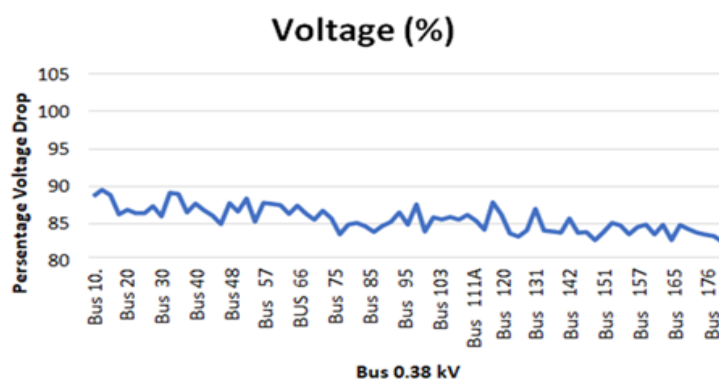


Figure 2. The quality of the existing medium voltage

In analyzing the voltage quality of the electrical distribution system, as depicted in Figure 1 and Figure 2, significant trends emerge for both low voltage (20 kV) and medium voltage (0.38 kV) networks. Figure 1 illustrates that the voltage levels across the 20 kV bus experience a gradual decline, with most measurements remaining between 85% and 95%. However, several initial bus points exhibit substantial voltage drops, indicating potential issues with power distribution efficiency. Conversely, Figure 2 reveals that the medium voltage bus consistently operates at lower quality, with voltage levels approaching 80% at some points. This indicates a more pronounced degradation in voltage stability compared to the 20 kV network. The 20 kV network often experiences significant voltage drops, especially at the ends of the distribution network. This is due to the length of the distribution lines, uneven load, and physical damage to the distribution cables (Subhan et al., 2023). Additionally, voltage dips result in real power losses in distribution lines and transformers, meaning electrical energy is lost during distribution. This reduces the system's efficiency and results in financial losses for the electricity provider (Darmawan et al., 2023).

Stage 1. Voltage Quality Improvement with Tap Transforamator Changing

The first step is to improve the quality of the voltage by increasing the secondary side tap by 5% on the 1 GI BP unit power transformer as shown in Figure 3. After increasing the secondary tap, the nominal voltage on the secondary side increases to 21 kV which was previously 20 kV. The increase in voltage occurs due to the addition of the secondary side winding, so that the nominal voltage on the secondary side of the power transformer will increase.

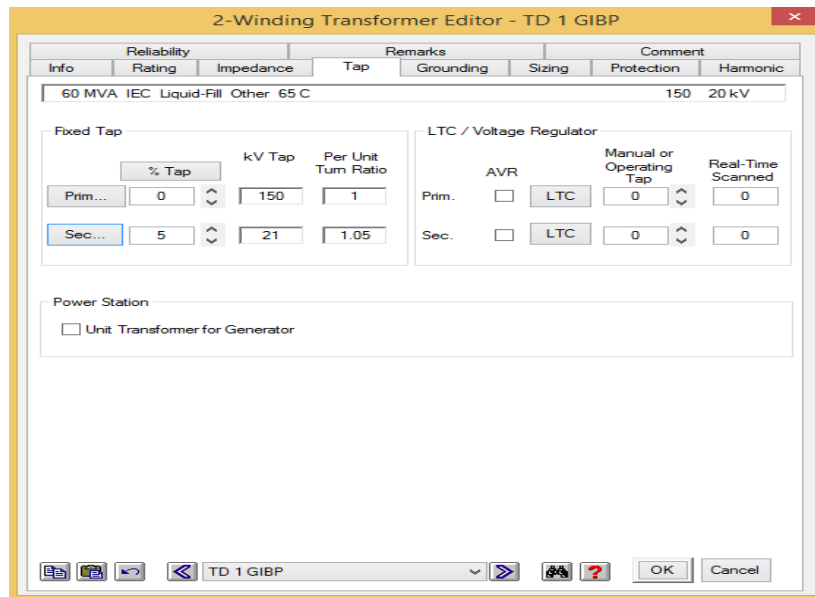


Figure 3. Simulation Increase Tap 5% On Power Transformer Unit 1 GI BP

This is proven based on the working principle equation of transformer tap. This increased secondary side voltage of the transformer will cause an increase in the supply voltage on the medium and low voltage network. Figure comparison of voltage (%) before repairing and after improving the quality of the voltage with the transformer changing the tap of the power transformer in this first stage, can be seen in Figures 4 and Figure 5.

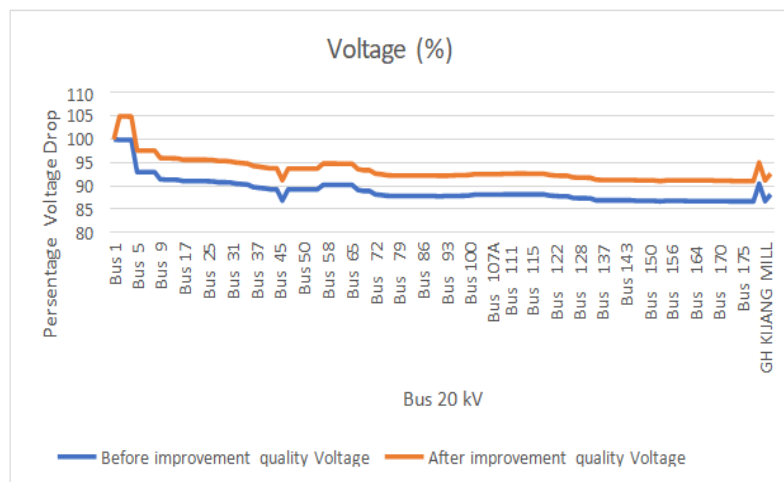


Figure 4. The improvement quality voltage stage 1 with transformator tap changing in medium voltage network

Based on Figure 4 above, before making improvements to the quality of the voltage there are 85 buses in the MV network with a voltage (%) of less than 90%. After performing step 1 voltage quality improvement, there are no more buses whose voltage (%) is less than 90%. Meanwhile, before improving the quality of the voltage, the bus with the lowest voltage (%) was bus number 175 with a voltage of 86.73%. After improving the quality of the voltage, the bus value with the lowest voltage (%) is bus number 175, which is 91.06%.

Changing transformer taps to improve voltage quality causes changes in the voltage and current profiles inside the transformer. These changes can lead to an increase in internal losses and contact resistance in the tap changer, thus causing an increase in transformer temperature. Therefore, tap settings must be optimized and accompanied by monitoring of the temperature and physical condition of the transformer to maintain safe and efficient operation (Nurrahmat et al., 2020); (Sumarno et al., 2022).

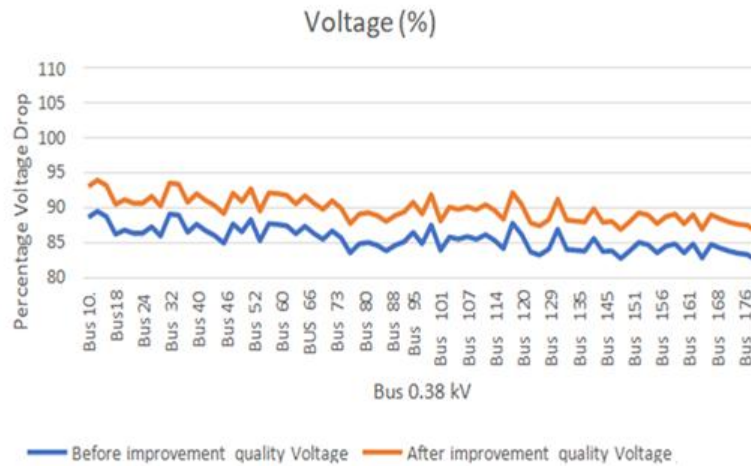


Figure 5. The improvement quality voltage stage 1 with transformer tap changing in low voltage network

Based on the Figure 5 above, before improving the quality of the voltage, there are 72 buses in the LV network with a voltage (%) of less than 90%. After performing stage 1 voltage quality improvement, there are 42 buses remaining voltage (%) is less than 90%. Meanwhile, before improving the quality of the voltage, the bus with the lowest voltage (%) was bus number 181 with a voltage of 82.58%. After improving the quality of the voltage stage 1, the value of the bus with the lowest voltage (%) is bus number 181 which is 86.73%. Previous studies have shown that changing the tap changer can improve the voltage drop on the conductor or cable. For example, in transformer LMR 0325, the voltage increased from 0.359 kV (89.75%) to 0.381 kV (95.25%) after the tap change (Apriliyanto et al., 2023).

Stage 2. Voltage Quality Improvement with Optimal Placement Shunt Capacitor Bank

In this second stage, the repair is continued by placing a shunt bank capacitor on the side of the Medium Voltage Network. The placement of capacitors is carried out with the Optimal Placement Capacitor (OPC) feature in the ETAP software 12.6.0. This feature places the capacitor bank optimally using the Genetic Algorithm technique. At the beginning of the mutation and crossover good characteristics are selected to be carried to the next generation. The optimal solution can be achieved through iterative generation. In this study the feeder network is divided into 2 to get optimization results that do not take a long time. The study conducted on the Optimal Placement Capacitor (OPC) feature, among others, first was to determine the bus candidate to be placed in the capacitor. The selected bus candidate has the lowest voltage value. In this study the researchers chose 5 buses, it can be seen that the bus candidates selected in Table 1.

Table 1. Determination of Bus Candidates

Candidate Bus	
IDBus	kV
171A	20
180	20
172	20
175	20
178	20
174	20

Next is to determine the optimal location and capacity of the capacitor. Placement is done automatically using simulation and optimization software such as ETAP with the Optimal Capacitor Placement (OCP) method. This software can automatically calculate the optimal capacity and location of capacitor bank installation to improve the power factor and voltage profile of the system (Buton et al., 2023); (Al Firdausi et al., 2024). The optimal location chosen is bus

172. Furthermore, we can see the results of the report in the form of details of the capacity, location, and total capacitor banks that must be installed on the Maroko Tapung Department, as shown in Table 2.

Table 2. Location, Capacity, And Total Capacitor Banks

IDBus	Banks(kVAR)	RatingVoltage (kV)	Total Banks	Total Banks (kVAR)
Bus 171A	-	-	-	-
Bus172	400	20	1	400
Bus174	-	-	-	-
Bus175	-	-	-	-
Bus178	-	-	-	-
Bus 180	-	-	-	-

After placing a 1×400 kVAR shunt capacitor bank on bus 172, there was an increase in the voltage on the Maroko feeder line to Tapung. The installation of a shunt bank capacitor will produce a leading current (I_c) which will compensate for the lagging current (I_L) absorbed by the load. So that it will have the effect of canceling each other out between the two current values ($I_c - I_L$) and reducing the total current flowing to the load. The total current is reduced thereby reducing the line load, so that the voltage drop can be minimized. Placement of capacitors at the right point can improve the voltage profile of the entire network (Rosihan et al., 2023). The increase in medium and low voltage network by placing a shunt bank capacitor in this second stage compared to the improvement in stage 1 (previous), can be seen in Figure 6. and Figure 7.

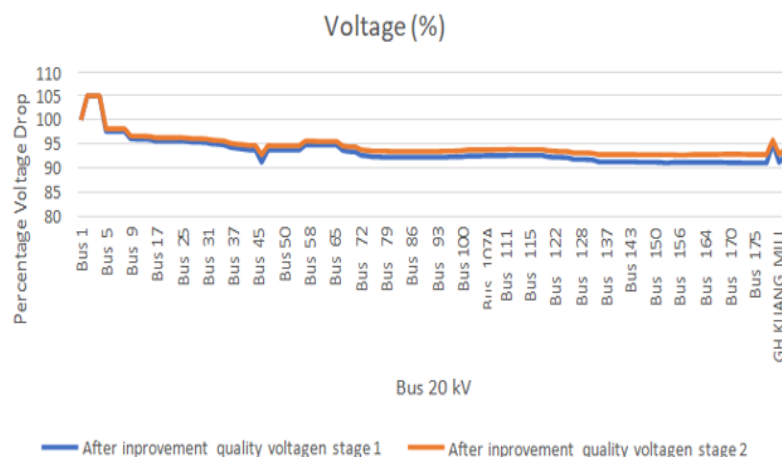


Figure 6. The improvement quality voltage comparison stage 1 and stage 2 in medium voltage network

As illustrated in Figure 6, following the enhancement of voltage quality in Stage 2, there is an observed increase in voltage within the MV network when compared to the results subsequent to the Stage 1 improvement. Following the enhancement of voltage quality in stage 1, bus number 175 has been identified as the bus with the lowest voltage percentage, exhibiting a voltage of 91.06%. Subsequent to the implementation of the second stage of voltage quality enhancement, the bus value exhibiting the least voltage percentage is designated as bus number 156, with a percentage of 92.72%.

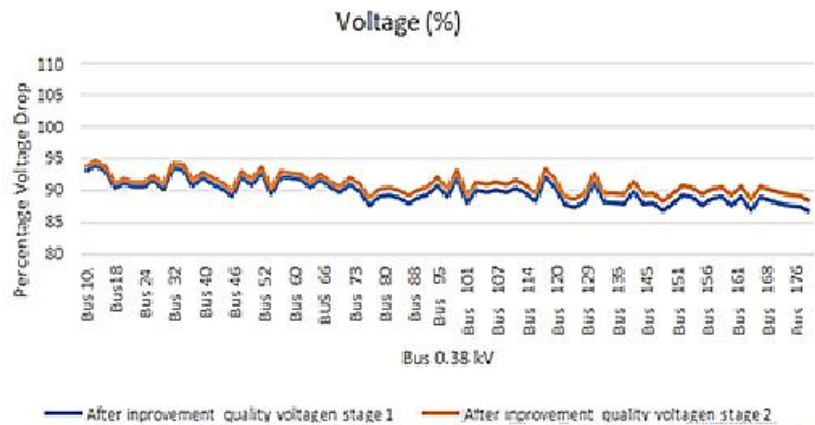


Figure 7. The improvement quality voltage comparison stage 1 and stage 2 in low voltage network

According to Figure 7 above, after enhancing the voltage quality of stage 1, there are 42 buses in the LV network with a voltage (%) less than 90%. After enhancing the quality of stage 2 voltage, 21 buses remain with voltages (%) less than 90%. Meanwhile, after improving the quality of voltage 1, bus number 181 has the lowest voltage (%), at 82.58%. After enhancing the quality of the voltage stage 2, bus number 149 has the lowest voltage (%), at 88.37%.

The quality of the voltage at the medium voltage Moroko Feeder in the Tapung direction improved as a result of transformer repairs, which included repairing the tap (power transformer) and installing a shunt bank capacitor. This is because increasing the tap on the secondary side of the power transformer by 5% raises the nominal voltage to 21 kV from 20 kV, increasing the voltage. The placement of a shunt bank capacitor generates a leading current (I_c), which compensates for the load's trailing current (I_L). The total current is reduced thereby reducing the line load, so that the voltage drop can be minimized (Jung et al., 2018); (Balu & Mukherjee, 2020).

Stage 3. Voltage Quality Improvement

The third stage is to increase voltage quality by altering the tap transformer (distribution transformer). At this point, the distribution transformers that are tapped once on the secondary side are 2.5% and 5%, respectively, totaling 45 transformers. Among them, raising the tap 2.5% from the initial winding value on 32 distribution transformers numbered 117, 125, 73, 165, 199, 201, 260, 124, 256, 122, 171, 131, 133, 167, 235, 129, 169, 234, 130, 236, 89, 277, 127, 134, 120, 116, 259, 254, 105, 276, 231, 253. Increase the tap 5% from the initial winding value at 13 distribution transformers with numbers 200, 175, 128, 121, 119, 120, 174, 132, 126, 250, 173, 172, 118, and 166.

The comparison of the voltage between the improvement of the voltage quality with the transformer changing the tap (distribution transformer) in stage 3 compared to the improvement in stage 2 (previous), can be seen in the graphs of Figure 8. and Figure 9.

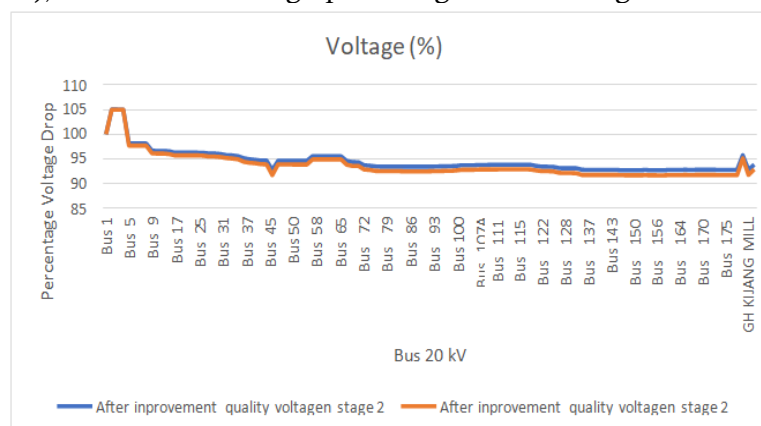


Figure 8. The improvement quality voltage comparison stage 2 and stage 3 in medium voltage network

As illustrated in Figure 8, the enhancement of voltage quality in Stage 3 led to a decline in the voltage of the MV network in comparison to the post-repair scenario in Stage 2. Subsequent to the enhancement of voltage quality in stage 2, the bus exhibiting the lowest voltage percentage was identified as bus number 152, with a recorded voltage of 92.72%. Following the enhancement of the voltage stage 3 quality, the bus value exhibiting the lowest voltage percentage is bus number 156, with a percentage of 91.69%.

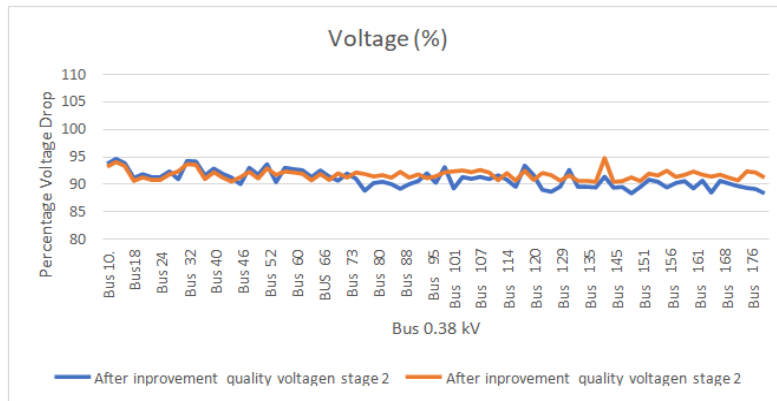


Figure 9. The improvement quality voltage comparison stage 2 and stage 3 in low voltage network

According to the graph in Figure 9. above, 21 buses in the LV network have a voltage (%) of less than 90% following improvements in stage 2 voltage quality. Once the stage 3 voltage quality has been improved, no buses remain with a voltage (%) below 90%. Bus number 149 has the lowest voltage (%) after upgrading the quality of voltage 2, with a voltage of 88.37%. Following the improvement of the voltage stage 3 quality, bus number 145, which has the lowest voltage (%), is 90.47%. Based on the analysis, it can be concluded that the voltage after carrying out the third stage of repair meets the voltage standard limits specified in SPLN 1:1987. According to this standard, the acceptable voltage range is within +5% and -10% of the nominal voltage. This means the acceptable voltage range is from 90% (nominal voltage minus 10%) up to 105% (nominal voltage plus 5%) of the nominal voltage value (Handayani et al., 2016); (Husin & Sirait, 2022).

CONCLUSION

This research successfully demonstrated a multi-stage approach to enhance voltage quality in the Maroko Feeder system. An initial assessment revealed a significant voltage drop, which was addressed in the first stage by adjusting the power transformer tap, notably improving minimum voltage levels in the medium voltage network above 90%. The subsequent placement of a shunt capacitor bank in the second stage further enhanced voltage profiles through reactive power compensation. Final optimization in the third stage, utilizing distribution transformer tap adjustments, led to improved voltage quality in the low voltage network, meeting SPLN 1: 1987 standards, despite a slight decrease in medium voltage. In conclusion, the combined strategy of transformer tap changing and shunt capacitor bank placement proves to be an effective solution for mitigating voltage drops and improving voltage quality in distribution systems, offering a framework for system optimization and regulatory compliance.

ACKNOWLEDGMENT

Thanks to the Department at PT. PLN (PERSERO) ULP Duri who has facilitated in providing data related to research and support from UIN Suska Riau and ITP Padang to the author.

REFERENCES

- Al Firdausi, B. I., Auliq, M. A., & Fitriana, F. (2024). Analisis Kebutuhan Bank Kapasitor Untuk Perbaikan Faktor Daya di PT Beras Rajawali Menggunakan Optimal Capacitor Placement ETAP 19. *Jurnal Listrik, Instrumentasi, Dan Elektronika Terapan*, 5(1), 39. <https://doi.org/10.22146/juliet.v5i1.89376>.
- Apriliyanto, I., Utomo, R. M., Wirawan, A. P., Hardjanto, A., Hani, F., Mulawarman, U., Daya, A. A., & Tegangan, J. (2023). Analisis Jatuh Tegangan Pada Penyulang S-1 Di Gardu Induk Manggar Sari Balikpapan. *Seminar Nasional Inovasi Teknologi Terapan (SNITT)*.
- Arief, A., & Nappu, M. B. (2017). Voltage drop simulation at Southern Sulawesi power system considering composite load model. *Proceedings - 2016 3rd International Conference on Information Technology, Computer, and Electrical Engineering, ICITACEE 2016*, 169–172. <https://doi.org/10.1109/ICITACEE.2016.7892432>.
- Arlenny, A., Zondra, E., & Zulfahri, Z. (2019). Optimation of Capacitor Bank Placement in Electric Network Using Genetic Algorithm. *Journal of Physics: Conference Series*, 1351(1). <https://doi.org/10.1088/1742-6596/1351/1/012005>.
- Aryanezhad, M. (2018). Management and coordination of LTC, SVR, shunt capacitor and energy storage with high PV penetration in power distribution system for voltage regulation and power loss minimization. *International Journal of Electrical Power and Energy Systems*, 100(February), 178–192. <https://doi.org/10.1016/j.ijepes.2018.02.015>.
- Balu, K., & Mukherjee, V. (2020). Siting and Sizing of Distributed Generation and Shunt Capacitor Banks in Radial Distribution System Using Constriction Factor Particle Swarm Optimization. *Electric Power Components and Systems*, 48(6–7), 697–710. <https://doi.org/10.1080/15325008.2020.1797935>.
- Bao, L., Yuan, Y., Lei, Y., Zhu, Q., Zhang, W., & Zhao, L. (2020). Simulation and Experimental Study of Switching Transient Process of On-load Tap Changer of Converter Transformer. *7th IEEE International Conference on High Voltage Engineering and Application, ICHVE 2020 - Proceedings*, 20–23. <https://doi.org/10.1109/ICHVE49031.2020.9279460>.
- Bula, I., Hoxha, V., Shala, M., & Hajrizi, E. (2016). Minimizing non-technical losses with point-to-point measurement of voltage drop between “SMART” meters. *IFAC-PapersOnLine*, 49(29), 206–211. <https://doi.org/10.1016/j.ifacol.2016.11.103>.
- Buton, S., Krismanto, A. U., Elektro, T., Itn, S., & Indonesia, M. (2023). Penempatan Kapasitor Bank OCP Untuk Meningkatkan Profil Tegangan di Jaringan Distribusi PT.PLN (PERSERO) Area Ambon Rayon Namlea. *Magnetika*, 07(2), 7–17.
- Chen, L., & Li, H. (2016). Optimized reactive power supports using transformer tap stagger. *IEEE Transactions on Smart Grid*, 1–10.
- Chou, M. H., Su, C. L., Lee, Y. C., Chin, H. M., Parise, G., & Chavdarian, P. (2017). Voltage-drop calculations and power cable designs for harbor electrical distribution systems with high voltage shore connection. *IEEE Transactions on Industry Applications*, 53(3), 1807–1814. <https://doi.org/10.1109/TIA.2016.2646658>.
- Darmawan, H., Kurnianto, R., Gianto, R., Yusuf, I., & Purwoharjono. (2023). Analisis Sistem Jaringan Tegangan Menengah 20 kV di Kawasan Industri Kelapa Sawait PT. Bumitama Gunajaya Agro. *Jurnal Darma Agung*, 30(3), 414–429.
- Gokbayrak, K., & Avci, H. (2020). A voltage drop limited decentralized electric power distribution network. *Computers and Operations Research*, 118, 104907. <https://doi.org/10.1016/j.cor.2020.104907>.
- Handayani, F. I., Yuningtyastuti, & Nugroho, A. (2016). Analisis Jatuh Tegangan Dan Rugi Daya Pada Jaringan Tegangan Rendah Menggunakan Software Etap 12.6.0. *Transient: Jurnal*

- Ilmiah Teknik Elektro*, 5(1), 56–61.
<https://ejournal3.undip.ac.id/index.php/transient/article/view/11888>.
- Husin, F., & Sirait, B. (2022). Quality Improvement of 20 KV Voltage Profile Of PT. PLN (Persero) Ketapang According to SPLN No.72 Of 1987. *Elkha*, 14(1), 7. <https://doi.org/10.26418/elkha.v14i1.48511>.
- Jung, T. H., Gwon, G. H., Kim, C. H., Han, J., Oh, Y. S., & Noh, C. H. (2018). Voltage Regulation Method for Voltage Drop Compensation and Unbalance Reduction in Bipolar Low-Voltage DC Distribution System. *IEEE Transactions on Power Delivery*, 33(1), 141–149. <https://doi.org/10.1109/TPWRD.2017.2694836>.
- Kim, Y. J., Park, H. W., Hyun, S. D., Kim, H. J., Kim, K. Do, Lee, Y. H., Moon, T., Lee, Y. Bin, Park, M. H., & Hwang, C. S. (2017). Voltage Drop in a Ferroelectric Single Layer Capacitor by Retarded Domain Nucleation. *Nano Letters*, 17(12), 7796–7802. <https://doi.org/10.1021/acs.nanolett.7b04008>.
- Ku, T. T., Lin, C. H., Chen, C. S., & Hsu, C. T. (2019). Coordination of transformer on-load tap changer and pv smart inverters for voltage control of distribution feeders. *IEEE Transactions on Industry Applications*, 55(1), 256–264. <https://doi.org/10.1109/TIA.2018.2870578>.
- Lee, H. O., Kim, D. J., Kim, C. S., & Kim, B. (2023). Optimal Voltage Control Method for a Step Voltage Regulator Considering the Under-Load Tap Changer in a Distribution System Interconnected with a Renewable Energy Source. *Energies*, 16(16). <https://doi.org/10.3390/en16166039>.
- Lei, E., Yin, X., Zhang, Z., & Chen, Y. (2018). An Improved Transformer Winding Tap Injection DSTATCOM Topology for Medium-Voltage Reactive Power Compensation. *IEEE Transactions on Power Electronics*, 33(3), 2113–2126. <https://doi.org/10.1109/TPEL.2017.2698207>.
- Li, C., Disfani, V. R., Haghi, H. V., & Kleissl, J. (2020). Coordination of OLTC and smart inverters for optimal voltage regulation of unbalanced distribution networks. *Electric Power Systems Research*, 187. <https://doi.org/10.1016/j.epsr.2020.106498>.
- Li, Z., Li, Q., Wu, Z., Yu, J., & Zheng, R. (2018). A Fault Diagnosis Method for on Load Tap Changer of Aerospace Power Grid Based on the Current Detection. *IEEE Access*, 6(c), 24148–24156. <https://doi.org/10.1109/ACCESS.2018.2825219>.
- Liliana, Aini, Z., & Bandri, S. (2024). Voltage Quality Improvement with Shunt Bank Capacitor and Transformer Tap. *Engineering and Technology Journal*, 09(08), 4863–4870. <https://doi.org/10.47191/etj/v9i08.35>.
- Mosbah, M., Mohammadi, R. D., Arif, S., & Hellal, A. (2017). Optimal of shunt capacitor placement and size in Algerian distribution network using particle swarm optimization. *Proceedings of 2016 8th International Conference on Modelling, Identification and Control, ICMIC 2016*, 192–197. <https://doi.org/10.1109/ICMIC.2016.7804297>.
- Nurrahmat, R., Karim, S., Teknik, F., Kalimantan, U. I., Profil, P., Sistem, T., Listrik, T., Menggunakan, S., Perhitungan, A., Daya, S., Dengan, E., Kurva, P., Susut, P., Listrik, E., Pln, P., Mode, M. F., Analisis, E., Zondra, E., Kecepatan, P., ... Energi, D. (2020). *Pengaruh Perubahan Tap Trafo Gardu Distribusi Terhadap Susut Energi (Kwh) Pada Gardu Cbd-0693 (Tbr-0020) Di Pt . Pln (Persero)*. 0693, 1–2.
- Rosihan, A. N., Wartana, I. M., & Sulistiawati, I. B. (2023). Optimasi Penempatan Kapasitor Untuk Memperbaiki Profil Tegangan dan Mereduksi Rugi-Rugi Daya pada Jaringan Distribusi 20kV Penyulang Lambitu , Kalampa , dan. In *Institut Teknologi Nasional Malang*. <http://eprints.itn.ac.id/id/eprint/13238>.
- Sadeghian, O., Oshnoei, A., Tarafdar-Hagh, M., & Khezri, R. (2021). A clustering-based technoeconomic analysis for wind farm and shunt capacitor allocation in radial

- distribution systems. *International Transactions on Electrical Energy Systems*, 31(1), 1–17. <https://doi.org/10.1002/2050-7038.12708>.
- Seo, J., Ma, H., & Saha, T. K. (2017). A Joint Vibration and Arcing Measurement System for Online Condition Monitoring of Onload Tap Changer of the Power Transformer. *IEEE Transactions on Power Delivery*, 32(2), 1031–1038. <https://doi.org/10.1109/TPWRD.2016.2531186>.
- Shekhar, A., Ramirez-Elizondo, L., Bandyopadhyay, S., Mackay, L., & Bauera, P. (2018). Detection of series arcs using load side voltage drop for protection of low voltage DC Systems. *IEEE Transactions on Smart Grid*, 9(6), 6288–6297. <https://doi.org/10.1109/TSG.2017.2707438>.
- Subhan, Fauzi, Asyadi, T. M., Muliadi, Syukri, & Masrurha, F. (2023). Perbaikan Tegangan Ujung Pada Jaringan Distribusi 20 kV Di GH Tangse ULP Beureunuen. *JTT (Jurnal Teknologi Terpadu)*, 11(1), 40–47. <https://doi.org/10.32487/jtt.v11i1.1570>.
- Sumarno, R. N., Muntasiroh, L., & Mariani, D. (2022). Pengaruh Setting Tap Transformator Terhadap Profil Tegangan Pada Jaringan IEEE 14 Bus. *Jambura Journal of Electrical and Electronics Engineering*, 4(2), 154–158. <https://doi.org/10.37905/jjee.v4i2.14324>.
- Utomo, T., Hasanah, R. N., & Madjid, M. F. (2017). Single-loop optimization for losses minimization in medium- voltage power distribution system. *International Journal on Advanced Science, Engineering and Information Technology*, 7(4), 1347–1352. <https://doi.org/10.18517/ijaseit.7.4.3135>.
- Zeinalzadeh, A., Mohammadi, Y., & Moradi, M. H. (2015). Optimal multi objective placement and sizing of multiple DGs and shunt capacitor banks simultaneously considering load uncertainty via MOPSO approach. *International Journal of Electrical Power and Energy Systems*, 67, 336–349. <https://doi.org/10.1016/j.ijepes.2014.12.010>.