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Voltage Quality Improvement with Shunt Bank Capasitor and Transformer Tap

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ABSTRACT: Morocco Feeder Tapung Department is 20 kV feeder with the largest voltage drop in the PT. PLN (PERSERO), ULP Duri. The voltage drop was 16% of the nominal voltage. This study conducted voltage repairs on the medium and low voltage sides to strive for voltage increase to achieve standardization. The first stage of repair was to increase the tap by 5% on the secondary side of the Unit 1 distribution transformer of the Balai Pungut Substation. The second stage of repair was by placing a shunt capacitor bank with a capacity of 400 kVAR on bus 172. The third stage of repair was by increasing the tap of transformer by 2.5% and 5% on the secondary side of 32 and 13 distribution transformers. The result, after simulating the lowest voltage value on the medium voltage network is 91.69% and on the low voltage network is 90.47%. So that the voltage value obtained after performing the above repair measures resulted in voltage repair that has met the standard SPLN 1: 1987 which is 5 % and -10% against nominal voltage.

KEYWORDS: voltage drop, tap of transformator, shunt capacitor bank, distribution transformer

1. INTRODUCTION

Power losses can be caused by a decrease in voltage during the distribution of electric power, so that the voltage that reaches the electrical equipment does not match the nominal voltage limit [1]. Voltage drops in the distribution system can cause interference with electrical equipment on the part of the provider and the customer of electric power. The voltage drop that occurs in this electricity provider can cause operating errors in control equipment, such as magnetic switches, automatic valves, auxiliary relays [2, 3]. Meanwhile, on the customer side, a voltage drop will cause electrical equipment to not function optimally, such as a decrease in torque at the time of starting the electric motor (starting torque) and also cause a decrease in the intensity of light in lighting equipment [4].

So far, in related papers, there are efforts to improve voltage that have been carried out by previous researchers. Among them is to configure the network by operating switching, smart meter [7]. Furthermore, it provides compensation by placing a shunt bank capacitor and a distributed generation [8-11], optimizing [11-17], coordination [18], and analizing the economy [12, 19]. Next is the operation of the transformer by changing the tap which can be done on power transformers and distribution transformers [20-26].

The condition of the feeder has made efforts to improve the voltage by placing a capacitor bank but has not provided an improvement in the quality of the voltage according to standardization. This study attempts to increase the voltage by changing the transformer tap and optimizing the placement of the capacitor bank on the line. In addition, repairs with transformers changing taps will minimize the use of capacitor banks. So this can reduce repair costs with capacitor banks. These two efforts were made to minimize the voltage drop on both sides of the voltage on the feeder, both on the medium voltage network side 20 kV and on the low voltage network side 380 V.

2. METHODS

2.1 Research Object

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 [4]. 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% [5].

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 [6]. 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.

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 [4].

2.2 Data Source

This research adapts Quantitative methods. The methode is used secondary data consisting of transformer specification, load, and capacitor bank.

Table 2.1 Power Transfomer Spesification

	HV	LV
Merk	PAUWELS TRAFO	
Type	3011120085	
Rated Power	60 MVA	60 MVA
Rated Voltage	150	20
Rated Current	230.9	1732.1
Cooling	ONAN	
Winding	Ynyn0+D	
Impedance	12.5 %	

Table 2.2 Distributi0n Transfomer Data

Distribution Transformer	V (kV)	Capacity (kVA)	Location
27	20/0.38	50	PDK III, Sei Rokan
28	20/0.38	50	PDK III, Sei Rokan
29	20/0.38	50	PDK III, Sei Rokan
50	20/0.38	50	Jl. Cinta Damai
51	20/0.38	100	Jl. Cinta Damai
52	20/0.38	50	Jl. Cinta Damai
53	20/0.38	100	Jl. Cinta Damai
222	20/0.38	100	Desa Cinta Damai
276	20/0.38	100	Desa Kota Bangun
62	20/0.38	50	Dami Mas Tapung

Table 2.3 Load Data

Distribution Transformer	Load (kVA)	Load (%)	Pf
27	22.4	44.7	0.85
28	15.2	30.4	0.85
29	20.5	41.1	0.85
50	29.5	59.1	0.85
51	77.7	77.7	0.85
52	23.8	47.5	0.85
53	71	71	0.85
222	75.3	75.3	0.85
276	78.5	78.5	0.85
62	13.4	26.8	0.85

Table 2.4. Capasitor Bank Data

Capacitor Capacity (kVA)	Location
1200	GH Nagakti Mill
600	GH Kijang Mill

2.3. Load Flow Simulation Existing Condition

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.

2.4. Voltage Quality Improvement

Repair efforts are carried out in 3 stages which aim to find out the results of the most optimal stress quality improvement from the three stages. The stages include, the first stage with a transformer changing the tap (power transformer), then repairs in stage 2 followed by placing a shunt bank capacitor, and further repairs in the third stage followed by a transformer changing the tap (distribution transformer).

1) First Stage

The Maroko feeder from the Tapung Department is supplied by a Unit 1 Gi Balai Pungut 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.

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.

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.

1.0 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.

3.1 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 Fig. 3.1 and Fig.3.2

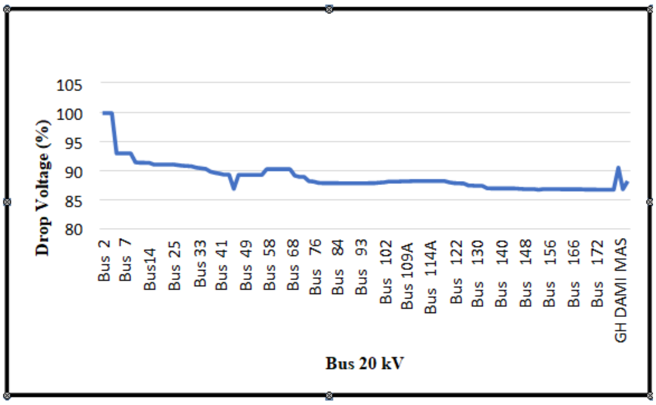

Fig.3.1 The quality of the existing medium voltage (MV)

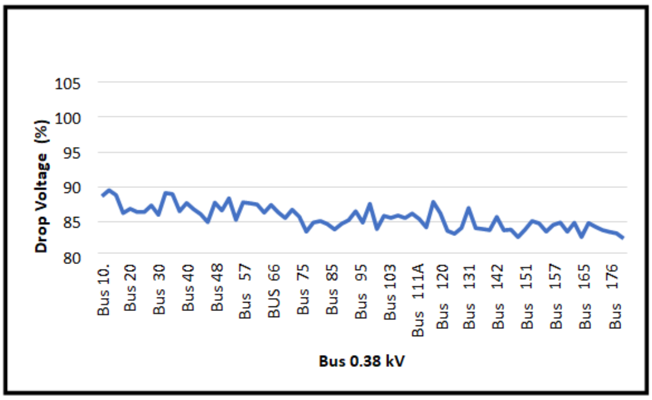

Fig 3.2 The quality of the existing low voltage (LV)

In the Fig.1 above, it can be seen in the MV network the number of buses with a voltage of less than 90% totaling 83 buses. The lowest bus voltage is bus number 175 with a voltage of 86.73%. While in the graph of Fig 2 above, it can be seen in the LV network the number of buses with a voltage of less than 90% totaling 75 buses. The lowest bus voltage is bus number 181 with a voltage of 82.58%.

3.2 Stage 1 Voltage Quality Improvement with Tap Transforamtor 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 Fig. 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.

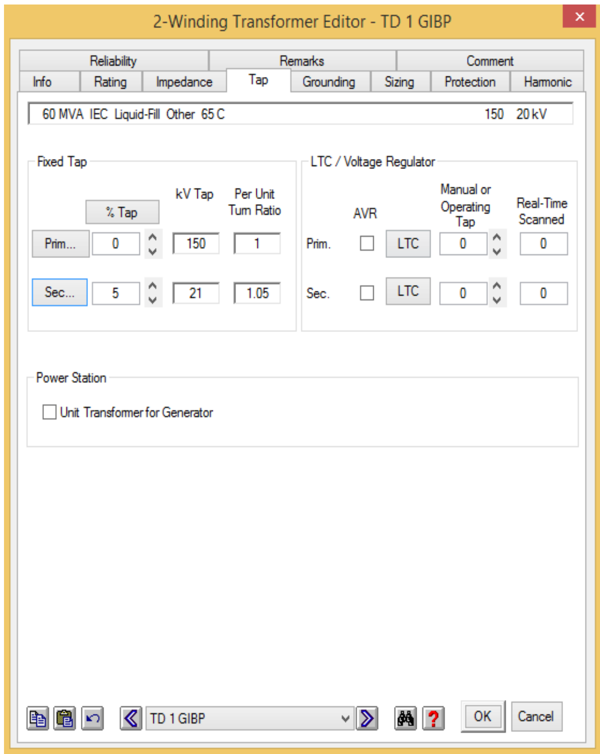

Fig.3.2 Simulation Increase Tap 5% On Power Transformer Unit 1 GI BP

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 3.4 and 3.5.

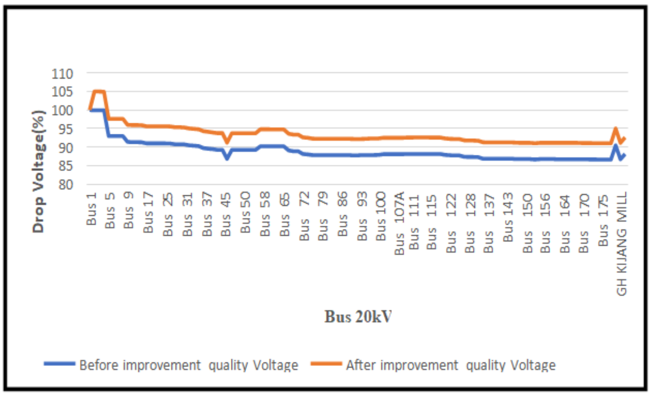

Fig. 3.4 The improvement quality voltage stage 1 with transformator tap changing in medium voltage network

Based on Fig. 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%.

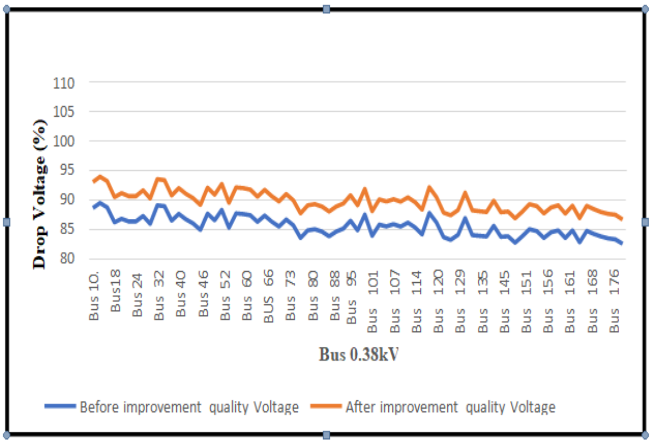

Fig.3.5. The improvement quality voltage stage 1 with transformator tap changing in low voltage network

Based on the Fig. 3.5 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%.

3.3. Stage 2. Voltage Quality Improvement with Optimal Placement Shunt Capasitor 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 choose 5 buses, it can be seen that the bus candidates selected in Table 3.1.

Table. 3.1. Determination of Bus Candidates

Candidate Bus	
ID Bus	**kV**
171A	20
180	20
172	20
175	20
178	20
174	20

Next, to determine the location and optimal capacity of the capacitor. After running using the OPC feature in the ETAP software. The program displays the optimal location and capacity of the capacitor to be installed on the specified bus. The optimal location chosen is bus 172. Next, we can see the results of the report in the form of details of the capacity, location, and total of bank capacitors that must be installed on the Maroko Feeder of the Tapung Department, as shown in table 2.

Table 3.1:Location, Capacity, and Total Capasitor Banks

ID Bus	Banks (kVAR)	Rating Voltage (kV)	Total Banks	Total Banks (kVAR)
Bus 171A	-	-	-	-
Bus 172	400	20	1	400
Bus 174	-	-	-	-
Bus 175	-	-	-	-
Bus 178	-	-	-	-
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 (Ic) 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 ($Ic-I_L$) and reducing the total current flowing to the load. The total current is reduced there by reducing the line load, so that the voltage drop can be minimized. 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 Fig. 3.6 and 3.7.

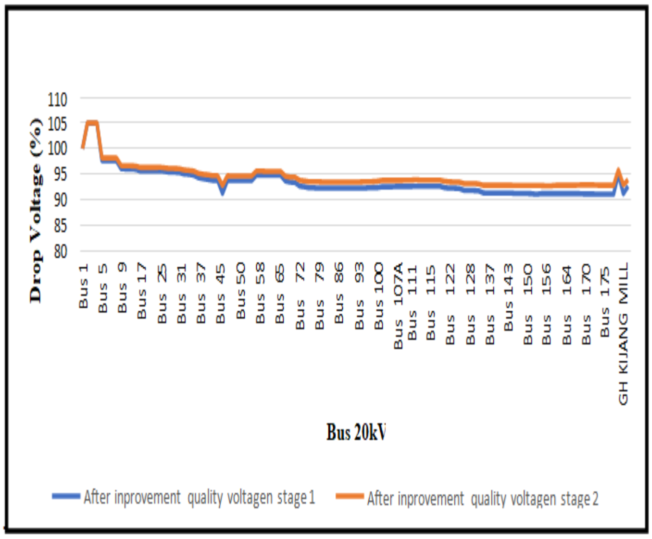

Fig.3.6. The improvement quality voltage comparison stage 1 and stage 2 in medium voltage network

Based on Fig 3.6 above, after making improvements to the quality of the voltage stage 2, there is an increase in the voltage at the MV network compared to after the improvement in stage 1. After improving the quality of the voltage in stage 1, the bus with the lowest voltage (%) is bus number 175 with a voltage of 91.06%. After improving the quality of stage 2 voltage, the bus value with the lowest voltage (%) is bus number 156, namely 92.72%.

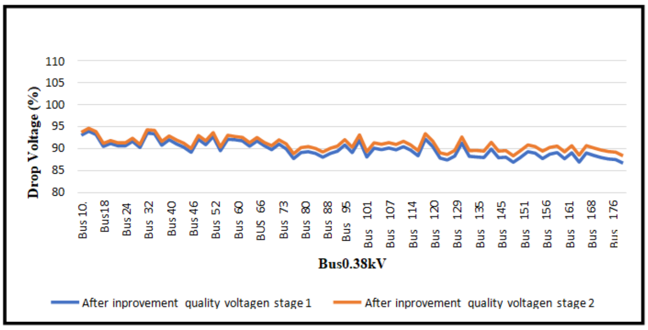

Fig.3.7 The improvement quality voltage comparison stage 1 and stage 2 in low voltage network.

Based on Fig. 3.7 above, after improving the voltage quality of stage 1, there are 42 buses in the LV network with a voltage (%) of less than 90%. After improving the quality of stage 2 voltage, there are 21 buses remaining whose voltage (%) is less than 90%. Meanwhile, after improving the quality of voltage 1, the bus with the lowest voltage (%) is bus number 181 with a voltage of 82.58 %. After improving the quality of the voltage stage 2, the bus value with the lowest voltage (%) is bus number 149, which is 88.37%.

3.4 Stage 3. Voltage Quality Improvement

In the third stage is the improvement of the quality of the voltage by changing the tap transformer (distribution transformer). At this stage the distribution transformer which is tapped once on the secondary side is 2.5% and 5%, totaling 45 transformers. Among them by increasing the tap 2.5% from the initial winding value on 32 including 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 transformer on distribution transformer numbers 200, 175, 128, 121, 119, 120, 174, 132, 126, 250,173, 172, 118, 166.

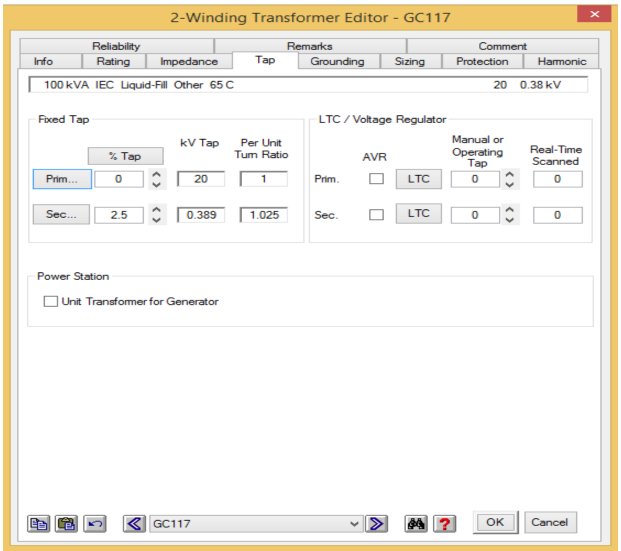

Fig.3.8 Simulation Increase Tap 2,5% On Sekunder Side Distribution Transformer

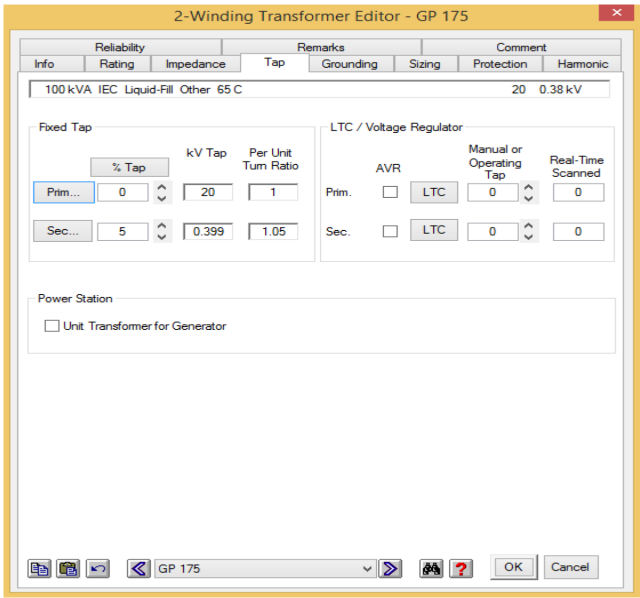

Fig.3.9 Simulation Increase Tap 5% On Sekunder Side Distribution Transformer

After changing the distribution transformer tap settings as shown in Fig. 8 and 9 above, the secondary side voltage is increased by 9 V for the distribution transformer whose winding is increased by 2.5%. While the secondary winding which is added 5% of the initial winding, the voltage increases by 19 V. The increase in voltage occurs due to the addition of the secondary winding, so that the nominal voltage on the secondary side of the power transformer will increase. This increased transformer will cause an increase in the supply voltage on the LV network. While in the MV network there is a slight decrease in the voltage of each bus, because during repairs by increasing the secondary winding. The winding on the primary side automatically decreases down. This causes the bus on the primary side of the transformer to experience a slight voltage drop. Comparison of the voltage between improving the quality of the voltage 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 Fig. 10 and 11.

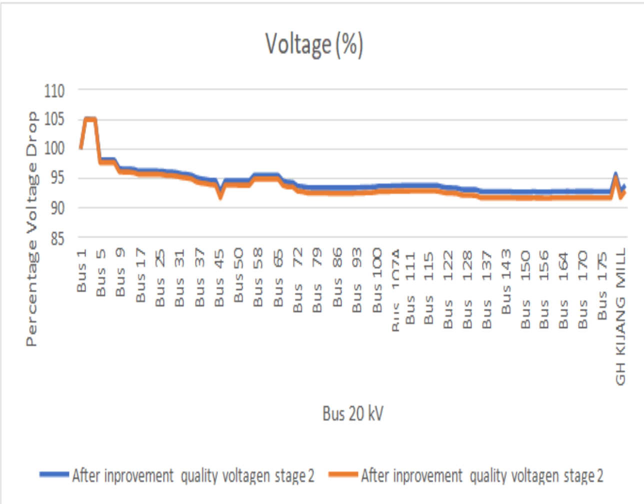

Fig.10 The improvement quality voltage comparison stage 2 and stage 3 in medium voltage network.

Based on the graph in Fig.10 above, after improving the quality of the voltage in stage 3, there was a decrease in the voltage at the MV network compared to after the repair in stage 2. After improving the quality of the voltage in stage 2, the bus with the lowest voltage (%) was bus number 152 with a voltage of 92.72 %. After improving the quality of the voltage stage 3, the bus value with the lowest voltage (%) is bus number 156, which is 91.69%.

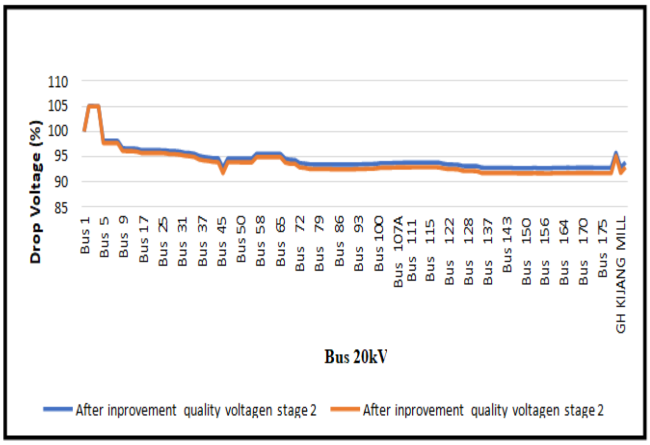

Fig.11 The improvement quality voltage comparison stage 2 and stage 3 in low voltage network.

Based on the graph in Figure 11 above, after improving the quality of stage 2 voltage, there are 21 buses in the LV network with a voltage (%) of less than 90%. After improving the quality of stage 3 voltage, there are no more buses whose voltage (%) is less than 90%. Meanwhile, after improving the quality of voltage 2, the bus with the lowest voltage (%) is bus number 149 with a voltage of 88.37%. After improving the quality of the voltage stage 3, the bus value with the lowest voltage (%) is bus number 145, which is 90.47%.

The improvement in the quality of the voltage at the medium voltaege Moroko Feeder in the Tapung direction was caused by repairs with a transformer changing the tap (power transformer) and placing a shunt bank capacitor. This is because by increasing the tap on the secondary side of the power transformer by 5% it causes the nominal voltage on the secondary side to increase to 21 kV which was previously 20 kV, thereby increasing the voltage. While the installation of a shunt bank capacitor will produce a leading current (Ic) 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 [8, 9, 11]. The total current is reduced thereby reducing the line load, so that the voltage drop can be minimized.

4. CONCLUSION

Prior to improving the quality of the voltage on the Maroko Feeder, Tapung Department, the number of buses with an operating voltage of less than 90% on the MV network was 83 buses. While on the LV network there are 75 buses. Improving the quality of the voltage on the is done by increasing the tap on the secondary side of the power transformer by 5% and placing a 400 kVAR capacitor bank on bus 172. Meanwhile, improving the quality of the voltage on the LV network is done by increasing the tap by 2.5% on the secondary side on 32 distribution transformers and increasing the tap by 5% on the secondary side of the 13 distribution transformer. The lowest voltage before improving the quality of the voltage on the MV network is 86.73%. While on the LV network is 82.58%. After making repairs, the lowest voltage on the MV network is

91.69% and the LV Network is 90.47%. It can be concluded that the voltage after making repairs meets the standard stress limits based on SPLN 1: 1987, namely +5% and -10% of the nominal voltage.

REFERENCES

1. K. Gokbayrak and H. Avci, “A voltage drop limited decentralized electric power distribution network,” *Comput. Oper. Res.*, vol. 118, p. 104907, Jun. 2020, doi: 10.1016/j.cor.2020.104907.
2. M.-H. Chou, C.-L. Su, Y.-C. Lee, H.-M. Chin, G. Parise, and P. Chavdarian, “Voltage-Drop Calculations and Power Cable Designs for Harbor Electrical Distribution Systems With High Voltage Shore Connection,” *IEEE Trans. Ind. Appl.*, vol. 53, no. 3, pp. 1807–1814, May 2017, doi: 10.1109/TIA.2016.2646658.
3. A. Shekhar, L. Ramirez-Elizondo, S. Bandyopadhyay, L. Mackay, and P. Bauera, “Detection of Series Arcs Using Load Side Voltage Drop for Protection of Low Voltage DC Systems,” *IEEE Trans. Smart Grid*, vol. 9, no. 6, pp. 6288–6297, Nov. 2018, doi: 10.1109/TSG.2017.2707438.
4. A. Arief and M. B. Nappu, “Voltage drop simulation at Southern Sulawesi power system considering composite load model,” in *2016 3rd International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE)*, Semarang, Indonesia, 2016, pp. 169–172. doi: 10.1109/ICITACEE.2016.7892432.
5. T. Utomo, R. Nur Hasanah, and M. F. Madjid, “Single-Loop Optimization for Losses Minimization in Medium-Voltage Power Distribution System,” *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 7, no. 4, p. 1347, Aug. 2017, doi: 10.18517/ijaseit.7.4.3135.
6. “6. 53c96-standar-nasional-indonesia-kt-29-04.pdf.”
7. I. Bula, V. Hoxha, M. Shala, and E. Hajrizi, “Minimizing non-technical losses with point-to-point measurement of voltage drop between ‘SMART’ meters,” *IFAC-Pap.*, vol. 49, no. 29, pp. 206–211, 2016, doi: 10.1016/j.ifacol.2016.11.103.
8. T.-H. Jung, G.-H. Gwon, C.-H. Kim, J. Han, Y.-S. Oh, and C.-H. Noh, “Voltage Regulation Method for Voltage Drop Compensation and Unbalance Reduction in Bipolar Low-Voltage DC Distribution System,” *IEEE Trans. Power Deliv.*, vol. 33, no. 1, pp. 141–149, Feb. 2018, doi: 10.1109/TPWRD.2017.2694836.
9. Y. J. Kim *et al.*, “Voltage Drop in a Ferroelectric Single Layer Capacitor by Retarded Domain Nucleation,” *Nano Lett.*, vol. 17, no. 12, pp. 7796–7802, Dec. 2017, doi: 10.1021/acs.nanolett.7b04008.
10. K. Muttaqi, A. Le, M. Negnevitsky, and G. Ledwich, “A Novel Tuning Method for Advanced Line Drop Compensator and its application to Response Coordination of Distributed Generation with Voltage Regulating Devices,” *IEEE Trans. Ind. Appl.*, pp. 1–1, 2015, doi: 10.1109/TIA.2015.2487441.
11. K. Balu and V. Mukherjee, “Siting and Sizing of Distributed Generation and Shunt Capacitor Banks in Radial Distribution System Using Constriction Factor Particle Swarm Optimization,” *Electr. Power Compon. Syst.*, vol. 48, no. 6–7, pp. 697–710, Apr. 2020, doi: 10.1080/15325008.2020.1797935.
12. A. Zeinalzadeh, Y. Mohammadi, and M. H. Moradi, “Optimal multi objective placement and sizing of multiple DGs and shunt capacitor banks simultaneously considering load uncertainty via MOPSO approach,” *Int. J. Electr. Power Energy Syst.*, vol. 67, pp. 336–349, May 2015, doi: 10.1016/j.ijepes.2014.12.010.
13. M. Mosbah, R. D. Mohammedi, S. Arif, and A. Hellal, “Optimal of shunt capacitor placement and size in Algerian distribution network using particle swarm optimization,” in *2016 8th International Conference on Modelling, Identification and Control (ICMIC)*, Algiers, Algeria, Nov. 2016, pp. 192–197. doi: 10.1109/ICMIC.2016.7804297.
14. H. E. Z. Farag and E. F. El-Saadany, “Optimum Shunt Capacitor Placement in Multimicrogrid Systems With Consideration of Islanded Mode of Operation,” *IEEE Trans. Sustain. Energy*, vol. 6, no. 4, pp. 1435–1446, Oct. 2015, doi: 10.1109/TSTE.2015.2442832.
15. L. Chen and H. Li, “Optimized Reactive Power Supports Using Transformer Tap Stagger in Distribution Networks,” *IEEE Trans. Smart Grid*, vol. 8, no. 4, pp. 1987–1996, Jul. 2017, doi: 10.1109/TSG.2016.2539824.
16. R. M. Idris and N. M. Zaid, “Optimal shunt capacitor placement in radial distribution system,” in *2016 IEEE International Conference on Power and Energy (PECon)*, Melaka, Malaysia, Nov. 2016, pp. 18–22. doi: 10.1109/PECON.2016.7951465.
17. M. S. Javadi, A. Esmaeel Nezhad, P. Siano, M. Shafie-khah, and J. P. S. Catalão, “Shunt capacitor placement in radial distribution networks considering switching transients decision making approach,” *Int. J. Electr. Power Energy Syst.*, vol. 92, pp. 167–180, Nov. 2017, doi: 10.1016/j.ijepes.2017.05.001.
18. M. Aryanezhad, “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,” *Int. J. Electr. Power Energy Syst.*, vol. 100, pp. 178–192, Sep. 2018, doi: 10.1016/j.ijepes.2018.02.015.
19. O. Sadeghian, A. Oshnoei, M. Tarafdar-Hagh, and R. Khezri, “A CLUSTERING-BASED TECHNOECONOMIC analysis for wind farm and shunt capacitor allocation in radial distribution systems,” *Int. Trans. Electr.*

Energy Syst., vol. 31, no. 1, Jan. 2021, doi: 10.1002/2050-7038.12708.

20. Z. Li, Q. Li, Z. Wu, J. Yu, and R. Zheng, "A Fault Diagnosis Method for On Load Tap Changer of Aerospace Power Grid Based on the Current Detection," *IEEE Access*, vol. 6, pp. 24148–24156, 2018, doi: 10.1109/ACCESS.2018.2825219.
21. J. Seo, H. Ma, and T. K. Saha, "A Joint Vibration and Arcing Measurement System for Online Condition Monitoring of Onload Tap Changer of the Power Transformer," *IEEE Trans. Power Deliv.*, vol. 32, no. 2, pp. 1031–1038, Apr. 2017, doi: 10.1109/TPWRD.2016.2531186.
22. E. Lei, X. Yin, Z. Zhang, and Y. Chen, "An Improved Transformer Winding Tap Injection DSTATCOM Topology for Medium-Voltage Reactive Power Compensation," *IEEE Trans. Power Electron.*, vol. 33, no. 3, pp. 2113–2126, Mar. 2018, doi: 10.1109/TPEL.2017.2698207.
23. J. de Oliveira Quevedo *et al.*, "Analysis and Design of an Electronic On-Load Tap Changer Distribution Transformer for Automatic Voltage Regulation," *IEEE Trans. Ind. Electron.*, vol. 64, no. 1, pp. 883–894, Jan. 2017, doi: 10.1109/TIE.2016.2592463.
24. T.-T. Ku, C.-H. Lin, C.-S. Chen, and C.-T. Hsu, "Coordination of Transformer On-Load Tap Changer and PV Smart Inverters for Voltage Control of Distribution Feeders," *IEEE Trans. Ind. Appl.*, vol. 55, no. 1, pp. 256–264, Jan. 2019, doi: 10.1109/TIA.2018.2870578.
25. M. Dixit, P. Kundu, and H. R. Jariwala, "Optimal integration of shunt capacitor banks in distribution networks for assessment of techno-economic asset," *Comput. Electr. Eng.*, vol. 71, pp. 331–345, Oct. 2018, doi: 10.1016/j.compeleceng.2018.07.014.
26. R. A. Jabr, I. Dzafic, and S. karaki, "Tracking Transformer Tap Position in Real-Time Distribution Network Power Flow Applications," *IEEE Trans. Smart Grid*, vol. 9, no. 4, pp. 2442–2452, Jul. 2018, doi: 10.1109/TSG.2016.2612177