Journal of Engineering, Electrical and Informatics

E-ISSN: 2809-8706
P-ISSN: 2810-0557

Research Article

Design of Single-Phase-to-Three-Phase System Reconfiguration to Improve Voltage and Increase kWh Sales Potential on the BF05K2039 Low-Voltage Overhead Distribution Network, Feeder C, ULP Sei Duri

M. Fajri Nugroho[1]*, Dedi Nugroho[2]

[1-2] Department of Electrical Engineering, Concentration in Electric Power Engineering, Faculty of Industrial Technology, Universitas Islam Sultan Agung, Semarang, Indonesia
* Corresponding Author: ajijuan0@gmail.com

Abstract. Voltage quality in a low-voltage distribution network determines both the quality of electricity received by customers and distribution efficiency. At the BF05K2039 Distribution Transformer, Feeder C, ULP Sei Duri, far-end customers experienced low voltage because the existing network still used a single-phase configuration with NFA2X-T 2×10 mm² conductors. This study evaluates the before-and-after performance of reconfiguring the network into a three-phase system and uprating the main conductor to NFA2X-T 3×70+1×70 mm², focusing on the voltage profile, voltage drop, and calculated power losses. A quantitative case-study approach was employed, consisting of field measurements at 20 customer points, calculation of the initial condition, implementation of the reconfiguration design, and post-work remeasurement. Customer voltages increased from 210–226 V to 233–238 V, while the far-end voltage difference from the source decreased from approximately 26 V (11%) to about 4 V (2.2%). Using the study's simplified calculation method, estimated power losses decreased from 1,755.30 W to 152.46 W, a difference of 1,602.84 W. Under the analytical assumptions of 720 operating hours per month and IDR 750/kWh, this difference corresponds to an estimated 1,154.045 kWh per month and an indicative monetary equivalent of approximately IDR 865,534 per month. These kWh and monetary figures are engineering estimates derived from the calculated loss difference, not direct measurements of additional billed energy, realized revenue, or investment return.

Keywords: Estimated kWh Gain; Low-Voltage Distribution Network; Network Reconfiguration; Power Losses; Voltage Drop.

Received: January 10, 2026;
Revised: March 12, 2026;
Accepted: April 15, 2026;
Published: June 30, 2026;
Curr. Ver.: June 30, 2026.

1. Introduction

Electrical energy in a low-voltage distribution network must be delivered to customer connection points with an adequate voltage profile and controlled technical losses. In radial networks, voltage variation and energy losses become increasingly important as distribution distance increases, phase currents become unbalanced, and conductor impedance rises. Studies based on low-voltage network data show that phase imbalance can create additional energy losses and that rearranging phase connections can be used as a corrective measure when network data are limited (Fang & Ma, 2020). Therefore, voltage-quality assessment is related not only to service quality

but also to the efficiency of the energy actually delivered to the point of use.

Voltage drop occurs when load current flows through conductor impedance. In low-voltage networks, the resistive component is relatively dominant; therefore, line length, current, conductor cross-sectional area, and load imbalance are key parameters. Several studies have shown that interphase load balancing and phase reconfiguration can improve voltage conditions while reducing power losses (Grigoraş et al., 2020; Grigoraş, Neagu, et al., 2021; Grigoraş, Noroc, et al., 2021). These findings are reinforced by research on three-phase load management, which identifies phase-balancing optimization as an approach for reducing voltage imbalance in distribution networks (Pati & Mistry, 2023).

The study object is Feeder C of the BF05K2039 Distribution Transformer at ULP Sei Duri. A number of customers are supplied through a line that functions as a shared distribution network but, under the initial condition, still used NFA2X-T 2×10 mm² conductors in a single-phase configuration. The network length is approximately 344 m. Initial measurements at 20 customers showed voltages of 210–226 V, while the source voltage was approximately 236 V. At the far-end customer, the voltage difference reached about 26 V or 11%. These data indicate that the distribution configuration and conductor size need to be evaluated against the actual loading pattern.

Network improvement can be carried out through phase arrangement, topology reconfiguration, and appropriate conductor sizing. Recent reviews of distribution network reconfiguration emphasize that common objectives include loss reduction and voltage-profile improvement (Lotfi et al., 2024), while conductor-sizing optimization demonstrates a direct relationship among conductor selection, network losses, and voltage performance (Montoya et al., 2025). Developments in 2025–2026 also include dynamic reconfiguration, phase-load balancing, and simultaneous optimization of feeder routing and conductor sizing (Bodolică et al., 2025; Cortés-Caicedo et al., 2026; Ivanov et al., 2025; Mogaka et al., 2026; Pilatasig-Gualoto & Muñoz-Pilco, 2026). However, most of these studies focus on optimization algorithms, test models, or planning; therefore, field evidence obtained before and after physical implementation on an actual low-voltage overhead distribution network remains valuable for practical verification.

Field studies and technical assessments also show that low-voltage network evaluation needs to consider actual measurement data. LVAC planning for rural networks, technical-loss estimation, and economic analysis of phase balancing indicate that the benefits of corrective actions depend on load conditions, network length, system configuration, and conductor parameters (Eam et al., 2023; Neagu et al., 2024; Soltani et al., 2025). Therefore, this study does not rely solely on theoretical relationships, but compares conditions before and after the work to assess the changes actually achieved at the study site.

Based on these problems, this study aims to evaluate the before-and-after performance of reconfiguring Feeder C of the BF05K2039 Distribution Transformer from a single-phase to a three-phase system and uprating the conductor from NFA2X-T 2×10 mm² to NFA2X-T 3×70+1×70 mm², with customer voltage, voltage drop, and calculated power losses as the main outcomes. The calculated reduction in power losses is subsequently converted into an estimated recoverable-energy equivalent in kWh and an indicative monetary equivalent. These conversions are analytical estimates based on the study assumptions and are not treated as measured additional sales, realized revenue, or an official customer tariff projection. The study contributes direct before-and-after measurements at 20 customer points under the conditions observed on the studied feeder.

The scope of the study is limited to the low-voltage network of BF05K2039 Feeder C, with voltage, current, conductor resistance, voltage drop, and power losses as the main parameters. Extreme ambient temperature, harmonics, long-term load variation, and a full investment analysis are not examined in detail. These limitations maintain the focus on the effects of phase-configuration changes and conductor uprating. Within this scope, the results may be used as an initial technical reference for other networks showing indications of low voltage and high technical losses, although any application still requires verification of local load characteristics and network conditions.

2. Literature Review and State of the Art

State of the Art of Reconfiguration, Phase Balancing, and Conductor Selection

The phase-balancing literature shows that load imbalance in low-voltage networks can increase energy losses, whereas transferring or rearranging customer phase connections can reduce such imbalance (Fang & Ma, 2020; Liu et al., 2021). The approaches have evolved from statistical estimation for data-scarce networks and smart-meter-based algorithms to sensitivity methods and coordinated control. This research direction indicates that interphase load distribution is an operational variable that can be controlled to improve network efficiency.

On the other hand, studies on distribution planning and reconfiguration emphasize loss reduction, voltage-profile improvement, and conductor-size selection as key objectives (Eam et al., 2023; Lotfi et al., 2024; Montoya et al., 2025; Soltani et al., 2025). More recent studies integrate phase balancing, reconfiguration, and conductor sizing using increasingly advanced optimization techniques (Bodolică et al., 2025; Cortés-Caicedo et al., 2026; Ivanov et al., 2025; Mogaka et al., 2026; Pilatasig-Gualoto & Muñoz-Pilco, 2026). Table 1 summarizes several representative studies to clarify the position of the present research relative to the state of the art.

Table 1. Summary of Previous Studies and the Position of The Present Research.

Reference	Focus	Findings/Relevance
Grigoraş et al. (2020)	Smart-meter-based phase load balancing	Shows that phase balancing can reduce imbalance and improve LV-network operation.
Liu et al. (2021)	Sensitivity-based phase reconfiguration	Provides an efficient strategy for balancing loads through phase reconfiguration.
Pati & Mistry (2023)	Three-phase load optimization	Links phase balancing with reduced voltage imbalance in distribution networks.
Soltani et al. (2025)	Phase balancing and economic analysis	Evaluates reliability improvement and the economic consequences of phase balancing.
Bodolică et al. (2025); Ivanov et al. (2025)	Phase-load-balancing algorithms (2025)	Develops optimization methods for load placement/transfer under unbalanced LV-network conditions.
Montoya et al. (2025); Cortés-Caicedo et al. (2026)	Conductor sizing in distribution networks	Treat conductor size as an optimization variable affecting losses, voltage performance, and network planning.

Table 1 shows that previous research has generally focused on algorithm development, simulation, smart-meter data, or planning optimization. This study takes a different position by evaluating physical implementation on an actual low-voltage overhead distribution network: the single-phase system is reconfigured into a three-phase system, the NFA2X-T 2×10 mm² conductor is uprated to NFA2X-T 3×70+1×70 mm², and voltage and power losses are compared before and after the work. Thus, the practical novelty lies in measured field validation that links voltage improvement, loss reduction, and estimated kWh sales on an actual customer feeder.

2.2. Power Distribution System and Low-Voltage Network

The distribution system is the part of the electric power system that transfers energy from transformation points to end users. In low-voltage networks, radial characteristics, distances between load points, current magnitude, and interphase imbalance affect the voltage profile and technical losses. Recent low-voltage-network literature identifies phase balancing as an operational measure for reducing imbalance, while LV-network planning studies highlight the importance of combining topology, conductor size, and loading patterns (Eam et al., 2023; Grigoraş et al., 2020; Pati & Mistry, 2023).

Low-voltage distribution networks generally use a three-phase four-wire system with a radial configuration and insulated overhead conductors. In this configuration, impedance accumulates along the feeder, making customers farther from the source more sensitive to voltage variation. Phase balancing reduces current concentration on one phase, while a larger conductor cross-section reduces resistance per unit length. These two principles form the technical basis of the reconfiguration evaluated at BF05K2039 (Grigoraş, Neagu, et al., 2021; Grigoraş, Noroc, et al., 2021; Lotfi et al., 2024). The general secondary-distribution configuration used as the conceptual reference is shown in Figure 1.

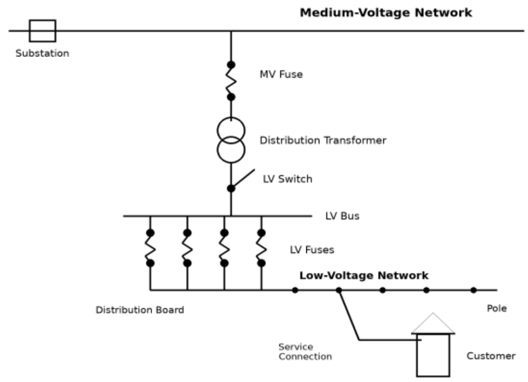

Figure 1. Single-line diagram of the secondary distribution network used as the basis for the low-voltage network configuration.

Figure 1 illustrates the power-delivery path from the distribution transformer to the low-voltage network and customer service connection. In this study, the low-voltage section is the focus because the phase configuration and conductor cross-section are modified on the side that directly supplies customers on Feeder C.

Voltage Drop and Power Losses

When load current flows through a conductor, the series impedance of the line causes a difference between the sending-end and receiving-end voltages. For a balanced three-phase short line, the voltage-drop approximation is expressed in Equation (1), where I is the load current, R and X are the resistance and reactance per unit length, L is the line length, and cos φ is the power factor. This approach is consistent with technical analyses of low-voltage networks that relate losses and voltage profiles to impedance and loading (Lotfi et al., 2024; Neagu et al., 2024).

$$\Delta V = \sqrt{3}\, I\, L\, (R \cos\varphi + X \sin\varphi)$$

For a relatively short low-voltage network, the short-line model is used because the effect of capacitance can be neglected for the purpose of this analysis. The relationship $R = \varrho L/A$ in Equation (2) shows that resistance decreases when the cross-sectional area A is increased for the same material and length. Therefore, conductor sizing is an important component of distribution-network optimization (Cortés-Caicedo et al., 2026; Montoya et al., 2025).

$$R = \varrho L / A$$

Resistive technical losses in conductors are primarily Joule-heating losses and follow the I^2R relationship shown in Equation (3). The quadratic dependence on current means that reducing current in each phase can potentially produce a significant reduction in losses. Low-voltage network loss-estimation methods also show that current data and conductor parameters are key components in calculating technical losses (Fang & Ma, 2020; Neagu et al., 2024).

$$P\_loss = I^2 R$$

In addition to the basic conductor resistance, network losses are affected by current imbalance, power factor, connection quality, and the suitability of the conductor cross-section for the load. Requirements for the selection and installation of wiring systems in low-voltage installations are specified in IEC 60364-5-52 and its adoption as SNI 0225-5-52:2020 (Badan Standardisasi Nasional, 2020; International Electrotechnical Commission, 2024). Accordingly, reconfiguration evaluation should combine field data with appropriate conductor-selection principles.

Conductor Characteristics and Reconfiguration Basis

NFA2X-T is an insulated overhead cable with aluminum conductors and XLPE insulation used in low-voltage networks. In this study, the existing 2×10 mm² conductor is compared with an NFA2X-T 3×70+1×70 mm² conductor. The principles for determining cable ampacity and losses refer to IEC 60287-1-1:2023 (International Electrotechnical Commission, 2023), while the general characteristics of extruded-insulation low-voltage cables refer to IEC 60502-1:2021 (International Electrotechnical Commission, 2021). A comparison of the conductor parameters used as the basis of the analysis is presented in Table 2.

Table 2. Comparison of Conductor Characteristics Used in the Analysis.

Parameter	NFA2X-T 2×10 mm²	NFA2X-T 3×70+1×70 mm²
Resistance	±3.08 Ω/km	±0.443 Ω/km
Maximum temperature	90 °C	90 °C
Theoretical ampacity	50–60 A	200–240 A
Empirical ampacity (30 °C)	57–60 A	230–240 A

The difference in resistance shown in Table 2 provides the technical basis for conductor uprating.

With a larger cross-sectional area, resistance per unit length decreases, thereby reducing voltage drop and conductor heating. In addition, converting a single-phase system into a three-phase system enables a more balanced distribution of loads. The theoretical hypothesis of this study is that the combination of increased conductor cross-sectional area and three-phase load allocation will reduce effective resistance and current in each phase, resulting in measurable reductions in voltage drop and power losses on Feeder C of the BF05K2039 Distribution Transformer. This direction is consistent with conductor-sizing studies showing that cross-sectional selection is an important technical decision for balancing losses, voltage performance, and network requirements (Cortés-Caicedo et al., 2026; Montoya et al., 2025).

Structurally, NFA2X-T uses aluminum as the conductor material and XLPE as the primary insulation. Aluminum has a lower mass and is relatively economical, although its resistivity is higher than that of copper. In bundled cables, the conductor arrangement supports overhead-line installation and may include a neutral conductor or messenger. The existing 2×10 mm² conductor is suitable for smaller loads; however, when it is used as a main line for a group of customers over a long route, resistance per unit length becomes increasingly significant. In contrast, the 70 mm² conductor provides greater ampacity and thermal margin, resulting in a lower loading percentage relative to cable capacity.

The selection of the reconfiguration action in this study is not based solely on conductor ampacity. Field evaluation is still required to determine whether conductor resistance is the dominant cause, how strongly phase imbalance affects current, and whether network length is associated with customer points having the lowest voltages. This principle is important because increasing the conductor cross-section in a network actually limited by other problems, such as low source voltage or poor-quality connections, may not provide the same benefits. Therefore, the BF05K2039 design is consistently compared with actual voltage and current data measured before and after the work.

3. Proposed Method

This study uses a quantitative approach through a technical case study on Feeder C of the BF05K2039 low-voltage network at ULP Sei Duri. The main variables are voltage, current, conductor length, resistance, voltage drop, and power losses. The evaluation design uses a before-and-after comparison: the single-phase condition with NFA2X-T 2×10 mm² conductors is first calculated and measured, and the results are then compared with the condition after three-phase reconfiguration using NFA2X-T 3×70+1×70 mm² conductors. This field-based approach complements phase-reconfiguration and conductor-sizing studies that are generally optimization- or simulation-based (Lotfi et al., 2024; Montoya et al., 2025).

Primary data were obtained through direct voltage and current measurements and observation of network conditions. Secondary data include customer information, connected load, MCB ratings, service-line lengths, and conductor technical information. Conductor ampacity and cable-loss calculations refer to the principles of IEC 60287-1-1:2023 (International Electrotechnical Commission, 2023), while the selection and installation of wiring systems are checked against IEC 60364-5-52 and SNI 0225-5-52:2020 (Badan Standardisasi Nasional, 2020; International Electrotechnical Commission, 2024). The geographical condition and existing network configuration are visualized in Figure 2 so that the position of the study network can be clearly understood.

The customer list in the source manuscript is divided into two network-tap groups representing the load distribution on Feeder C of the BF05K2039 Distribution Transformer.

The first group consists of 12 customers with a total connected load of 10,300 W and a total MCB rating of 46 A, whereas the second group consists of 8 customers with a total connected load of 9,800 W and a total MCB rating of 44 A. Thus, the study includes 20 observation units distributed across two network branches with different conductor lengths and positions relative to the source. The connected load, MCB capacity, and service-line length of each customer are used to map load distribution and identify points that are more likely to experience larger voltage drops. Dividing the customers into two groups also supports the analysis because voltage conditions are influenced not only by load magnitude but also by distribution distance and accumulated impedance along each network section.

Each customer is retained as an observation unit so that network performance can be evaluated more comprehensively. With this approach, voltage changes before and after reconfiguration are not assessed only at the farthest customer but can also be observed at customers located near the beginning, middle, and end of the network. This is important for determining whether voltage-quality improvement occurs consistently along the distribution line or is concentrated only at specific points. In addition, using all customers as analysis units allows power-loss calculations to be performed in greater detail at each service point and then aggregated to obtain an overall picture of network losses. These observations are subsequently used to assess the effectiveness of changing the configuration from a single-phase to a three-phase system and using a larger conductor cross-section to improve the voltage profile, reduce technical losses, and increase the efficiency of electricity delivery to customers.

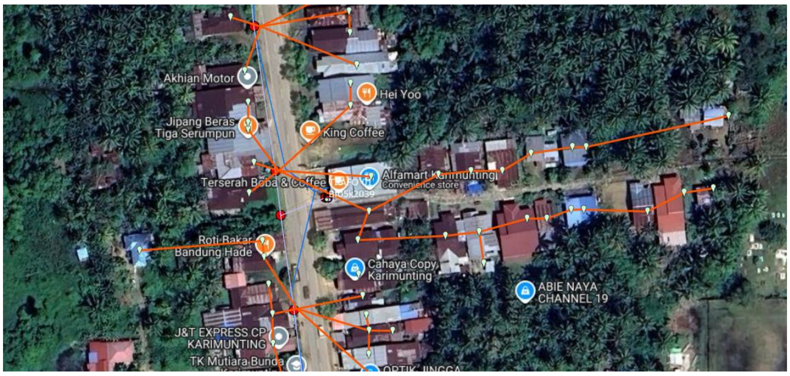

Figure 2. Existing Network Condition of BF05K2039 Feeder C on the Network Map.

Figure 2 places the study network in its actual location context so that the physical condition and position of the study object can be understood before the technical analysis is conducted. Based on this condition, the study begins with an inventory of the existing network configuration, identification of conductor type and size, route length, number of customers, and loading pattern on Feeder C of the BF05K2039 Distribution Transformer. The next stage includes voltage measurements at the feeder origin and customer points to obtain the actual voltage profile along the network. These field data are then used as the basis for calculating voltage drop and estimating power losses under the initial condition. Thus, the existing condition is assessed not from a single parameter but from the relationships among network configuration, loading, conductor length, customer voltage, and the magnitude of technical losses.

After the initial network characteristics are identified, the study proceeds to develop a reconfiguration design by converting the single-phase system into a three-phase system. At this stage, customers are allocated among phases R, S, and T to obtain a more balanced load distribution, while conductor uprating is also planned to increase distribution capacity and reduce network resistance. The design is not limited to structural configuration changes but is also intended to improve electrical conditions at customer points that previously experienced voltage reduction. Therefore, the design process considers the actual load condition, customer positions, conductor characteristics, and the need to reduce voltage drop and power losses simultaneously.

The overall research procedure is summarized in Figure 3. The study is implemented sequentially through seven stages: identification of the existing condition, collection of field technical data, calculation of the initial voltage drop and power losses, preparation of the reconfiguration proposal, three-phase load allocation, field implementation, and post-improvement measurement and evaluation. These stages are arranged so that every technical decision can be compared directly between the conditions before and after reconfiguration. With this approach, the effectiveness of the improvement is evaluated not only from the successful physical implementation of the network but also from measurable changes in performance parameters, particularly voltage-profile improvement and network-loss reduction. This principle is consistent with studies emphasizing that distribution network reconfiguration should be evaluated according to its effects on voltage quality, load balance, and technical-loss minimization (Lotfi et al., 2024; Pilatasig-Gualoto & Muñoz-Pilco, 2026).

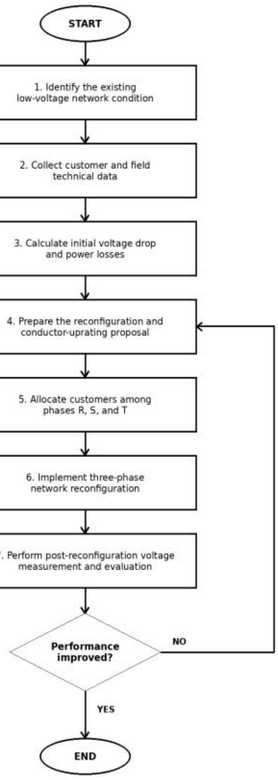

Figure 3. Flowchart of the Research Stages and Network-Reconfiguration Evaluation.

Figure 3 shows that remeasurement is the main verification stage after implementation. Power-loss evaluation follows the approach used in the research data, namely comparing estimated losses for each customer before and after the work and then aggregating them for all 20 customers. Because this approach is simpler than loss estimation based on a complete load profile, the results are treated as technical estimates and discussed with due consideration of the method's limitations (Neagu et al., 2024).

$$E\_gain = (\Delta P\_loss \ / \ 1000) \times 720 \quad (4)$$

The recovered energy is then converted using Equation (4), assuming 720 operating hours per month. The monetary potential is calculated using the analytical assumption of IDR 750/kWh contained in the research data. This value is retained to maintain consistency in the internal comparison and is not presented as an official customer tariff. Accordingly, the economic discussion only illustrates the potential energy value resulting from loss reduction and does not constitute an investment-feasibility analysis or a revenue projection based on the prevailing tariff.

4. Results and Discussion

Network Condition Before Reconfiguration

Under the initial condition, Feeder C of the BF05K2039 Distribution Transformer still used a single-phase configuration with NFA2X-T 2×10 mm² conductors. The network had a total length of approximately 344 m and supplied 20 customers divided into two branch groups. Stepwise calculations showed an increasing voltage reduction toward the far end. The section-by-section voltage summary before reconfiguration is presented in Table 3 as a basis for comparison with field measurements.

Table 3. Summary of Section-By-Section Voltage Calculations Before Reconfiguration.

Position	Section length	Section current	Section voltage drop	Node voltage
Starting point	–	30 A	–	229.00 V
40 m	40 m	30 A	6.77 V	222.23 V
80 m	40 m	20 A	4.51 V	217.72 V
120 m	40 m	5 A	2.26 V	215.46 V
340 m	220 m	0 A	6.20 V	209.26 V
Total	340 m	–	19.74 V	≈209.3 V

Table 3 shows that the accumulated voltage drop increases along the line until the calculated far-end voltage approaches 209.3 V. The 229 V value in the starting-point row is the tap-point voltage used in the theoretical calculation, whereas approximately 236 V represents the distribution-transformer/source voltage in the field measurement. Direct customer measurements show the same trend, with voltages ranging from 210 to 226 V. The customer with the lowest voltage receives approximately 210 V. The agreement in trend between the calculation and measurement supports the indication that line length, single-phase current concentration, and conductor resistance are important factors under the initial condition.

Under the initial condition, the manuscript estimates power loss for each customer by relating the measured voltage difference to the assumed current derived from the MCB rating. The individual values are then aggregated across the 20 observed customers, resulting in a total estimated power loss of 1,755.30 W. This value represents the calculated technical loss under the pre-reconfiguration condition and is used to characterize the initial performance of Feeder C before any network modification is implemented. When converted into energy using an assumed operating duration of 720 hours per month, the estimated loss corresponds to approximately 1,263.8 kWh per month. Using the analytical energy value of IDR 750/kWh adopted in the study, the corresponding monetary equivalent is approximately IDR 947,430 per month.

This initial estimate serves as the baseline for evaluating the effectiveness of the subsequent reconfiguration. By comparing it with the post-reconfiguration loss estimate, the study can quantify the reduction in calculated power losses and estimate the amount of energy that may potentially be preserved after the network is converted from a single-phase to a three-phase configuration and the conductor size is increased. However, these values should be interpreted as engineering estimates rather than direct measurements of actual energy losses, because the calculation uses current assumptions based on MCB ratings rather than continuous measurements of customer load current. Therefore, the baseline is primarily intended to support a consistent before-and-after technical comparison within the scope of this study.

Reconfiguration Design and Prediction

The improvement is designed by converting Feeder C into a three-phase network and increasing the conductor to NFA2X-T 3×70+1×70 mm². This strategy combines two principles that are consistent with the literature: phase reconfiguration to distribute current among phases (Bodolică et al., 2025; Grigoraş et al., 2020; Grigoraş, Neagu, et al., 2021; Ivanov et al., 2025; Liu et al., 2021) and conductor sizing to reduce line resistance (Cortés-Caicedo et al., 2026; Montoya et al., 2025). The physical reconfiguration design is shown in Figure 4.

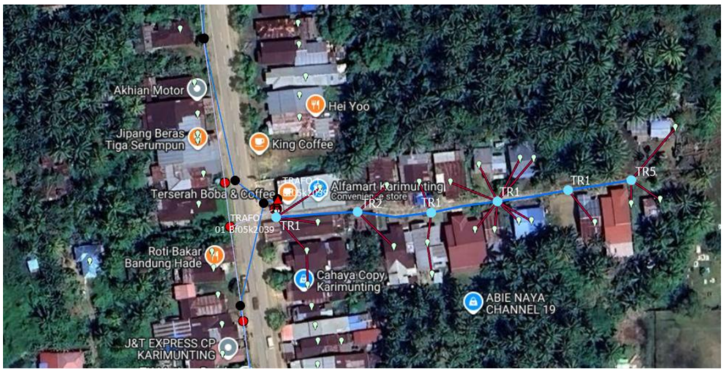

Figure 4. Reconfiguration Design of BF05K2039 Feeder C as a Three-Phase Network.

Figure 4 shows the changes in the power-delivery route and phase-allocation points after reconfiguration. Customers are then distributed among phases R, S, and T at each pole to reduce load concentration on a single phase. The allocation plan covers six pole groups, as summarized in Table 4. This arrangement is intended to achieve a more proportional current distribution among phases without changing the individual customers' power requirements.

Table 4. Customer Allocation by Phase In The Reconfiguration Design.

Pole no.	Phase R	Phase S	Phase T
1	1	2	1
2	1	0	1
3	1	1	0
4	2	3	3
5	1	2	2
6	1	1	1

Table 4 shows that customers are no longer concentrated on one phase but are distributed among phases R, S, and T across six pole groups. This allocation provides the operational basis for reducing current imbalance before the post-improvement voltage evaluation is performed.

Voltage Evaluation After Reconfiguration

The reconfiguration work was carried out on August 7, 2026, and post-improvement measurements were performed on August 9, 2026, during the peak-load period so that network performance after the changes could be evaluated under relatively high loading. The measurements show that the phase-to-neutral voltage at the origin of Feeder C was 236.6 V on phase R, 237.2 V on phase S, and 235.5 V on phase T. The measured currents were 9.98 A, 11.73 A, and 7.97 A, respectively, with a neutral current of approximately 2.71 A. These values indicate that the total load was distributed among three phases and was no longer concentrated on a single phase conductor as under the pre-reconfiguration condition. Although the phase currents were not completely equal, the post-work loading pattern showed a more proportional distribution that supported improved network performance.

The improvement is also evident in the customer voltage profile. After reconfiguration, the voltages measured at the 20 customers ranged from 233 to 238 V, while the far-end customer, which previously received only about 210 V, increased to approximately 233 V. Relative to the source voltage, the voltage difference at the far-end point decreased from about 26 V or 11% to approximately 4 V or 2.2%.

This reduction shows that three-phase reconfiguration combined with increased conductor capacity can substantially reduce voltage drop along the service line. Distributing the load among three phases prevents current from being concentrated in a single conductor, while the larger conductor cross-section helps reduce network resistance and improve power-delivery capability. The effect is observed not only at the feeder origin but also at customers in the middle and at the end of the network, where the largest voltage reductions had previously occurred. In addition to improving the voltage profile, this condition supports a more balanced current distribution and can reduce network power losses. These changes indicate that the reconfiguration design provides a more uniform technical improvement in customer service quality. To clarify the performance changes, the conditions before and after reconfiguration are summarized in Table 5, allowing direct comparison of voltage profiles, current distribution, and voltage-drop levels.

Table 5. Summary of Network-Performance Changes Before and After Reconfiguration.

Indicator	Before	After	Change
Customer voltage range	210–226 V	233–238 V	Increased
Far-end customer voltage drop	26 V (≈11%)	≈4 V (≈2.2%)	Reduced by ≈22 V
Total estimated losses	1,755.30 W	152.46 W	Reduced by 1,602.84 W
Estimated loss-equivalent energy/month	≈1,263.82 kWh	≈109.77 kWh	Estimated avoided-loss energy: 1,154.045 kWh
Indicative monetary equivalent/month	–	–	IDR 865,534 (estimate)
Indicative monetary equivalent/year	–	–	IDR 10,386,403 (estimate)

Table 5 shows that the voltage increase occurs together with a decrease in estimated power losses. The voltage-profile improvement results from two mechanisms operating simultaneously. First, the larger conductor cross-section reduces resistance per unit length. Second, distributing the load among three phases reduces current concentration in a single conductor. This direction of change is consistent with the results of phase balancing and phase reconfiguration in low-voltage networks (Bodolică et al., 2025; Grigoraş et al., 2020; Ivanov et al., 2025; Liu et al., 2021; Pati & Mistry, 2023; Soltani et al., 2025).

Compared with previous studies, the BF05K2039 findings are consistent in direction but differ in their validation context. Algorithmic studies report that balancing and reconfiguration can reduce imbalance, losses, and voltage deviation (Bodolică et al., 2025; Grigoraş et al., 2020; Grigoraş, Neagu, et al., 2021; Grigoraş, Noroc, et al., 2021; Ivanov et al., 2025; Liu et al., 2021; Pilatasig-Gualoto & Muñoz-Pilco, 2026; Wang & Zhang, 2025), while conductor-sizing studies show that an appropriate cross-section can reduce losses while supporting the voltage profile (Cortés-Caicedo et al., 2026; Montoya et al., 2025). In the present study, these benefits are verified through physical work and post-improvement measurements, providing implementation evidence from an actual low-voltage overhead distribution network.

Evaluation of Losses and Estimated kWh/Monetary Gain

The aggregate estimated losses for the 20 customers decreased from 1,755.30 W to 152.46 W. Thus, the calculated difference was 1,602.84 W, or approximately 1.60 kW. Because the study uses a simplified loss-estimation method, this result should be interpreted as a scenario-based engineering estimate rather than a continuously measured feeder-loss value. The direction of the result is consistent with technical-loss-estimation and phase-imbalance literature, which identifies current and conductor resistance as important loss drivers (Fang & Ma, 2020; Neagu et al., 2024).

The 1,602.84 W difference is converted using 720 hours per month, producing an estimated recovered energy of approximately 1,154.045 kWh per month. If assumed to persist throughout the year, the energy potential reaches 13,848.538 kWh per year. At an energy value of IDR 750/kWh, the economic potential is approximately IDR 865,534 per month or IDR 10,386,403 per year. These values are not intended to represent net profit or an investment-feasibility analysis, but rather the value of energy that can technically be delivered more effectively after network losses are reduced.

It should be noted that the loss evaluation in this study uses a simplified approach based on voltage differences and currents assumed from MCB capacities. Because the actual customer current may vary over time and is not always equal to the MCB rating, the energy and monetary results should be interpreted as estimates under the research scenario. More precise energy-loss values would require actual current and power records over a longer period, power-factor measurements, and separation of losses in the main conductor and customer service connections.

The current distribution after reconfiguration also provides additional information regarding the success of load allocation. The currents in phases R, S, and T were approximately 9.98 A, 11.73 A, and 7.97 A, respectively. Although not completely identical, these values are far more representative of three-phase loading than the initial condition, in which the load was concentrated on a single phase. A neutral current of 2.71 A indicates that some imbalance remains, but its magnitude is relatively low compared with the phase currents. This condition strengthens the explanation that the voltage improvement is attributable not only to the larger conductor cross-section but also to a more even current distribution along the conductor route.

Agreement between the predicted and measured results is an important part of evaluating the design. The initial prediction placed customer voltages in the range of approximately 231.4–234.5 V, while the actual measurements produced a range of 233–238 V. The slightly higher measured values can be explained by the feeder-origin voltage during testing, which was approximately 236–237 V, and by load conditions that were not always identical to the calculation assumptions. Despite the numerical difference, both approaches show the same pattern: the far-end voltage drop is reduced to only a few volts. Thus, the simplified calculation model remains useful as an initial planning tool as long as its results are verified in the field.

Nevertheless, the direction of change is consistent between the voltage measurements and the loss estimates. Customer voltages improved throughout the network, the far-end voltage drop decreased, and the estimated network losses were reduced. These results reinforce literature findings that reconfiguration and conductor selection can be used complementarily to improve distribution-network operation (Cortés-Caicedo et al., 2026; Lotfi et al., 2024; Mogaka et al., 2026; Montoya et al., 2025; Pilatasig-Gualoto & Muñoz-Pilco, 2026). In this study, the calculated loss reduction is also converted into an indicative recoverable-energy equivalent (kWh) and monetary equivalent for the studied feeder; these values do not represent directly measured additional billing or realized revenue.

5. Conclusions

Within the BF05K2039 Feeder C case study, post-work measurements after the single-phase-to-three-phase reconfiguration and conductor uprating to NFA2X-T 3×70+1×70 mm² showed customer voltages of 233–238 V compared with 210–226 V before the work, while the far-end voltage difference from the source decreased from approximately 26 V (11%) to about 4 V (2.2%). This direction is consistent with phase-balancing, reconfiguration, and conductor-sizing literature (Liu et al., 2021; Lotfi et al., 2024; Montoya et al., 2025; Pati & Mistry, 2023). The study's simplified loss calculation produced an estimated decrease from 1,755.30 W to 152.46 W, a difference of 1,602.84 W. Using the study assumptions of 720 operating hours per month and IDR 750/kWh, this difference corresponds to an estimated 1,154.045 kWh per month (13,848.538 kWh per year) and an indicative monetary equivalent of approximately IDR 865,534 per month (IDR 10,386,403 per year). These figures are engineering estimates derived from the calculated loss difference; they are not direct measurements of additional billed kWh, realized revenue, or investment return. Because phase configuration and conductor size were changed simultaneously, this before-and-after design cannot isolate the independent contribution of each intervention.

The findings are limited to one low-voltage feeder, a relatively short before-and-after measurement window, and a loss-estimation method that does not use a complete time-series load profile or continuously measured customer currents. Accordingly, the results should be interpreted as evidence for the measured BF05K2039 Feeder C conditions rather than as a general performance guarantee for other feeders. Future work should integrate smart-meter or time-series load data, long-term phase-balance measurements, conductor thermal validation, and investment analysis. These directions are consistent with recent research on network data, reconfiguration optimization, and conductor sizing (Bodolică et al., 2025; Cortés-Caicedo et al., 2026; Ivanov et al., 2025; Mogaka et al., 2026; Pilatasig-Gualoto & Muñoz-Pilco, 2026).

Author Contributions: Conceptualization, M.F.N. and D.N.; methodology, M.F.N.; investigation, M.F.N.; data curation, M.F.N.; formal analysis, M.F.N.; validation and supervision, D.N.; writing original draft preparation, M.F.N.; writing—review and editing, D.N. All authors have read and agreed to the submitted version of the manuscript.

Funding: Funding information was not reported in the source manuscript.

Data Availability Statement: The data supporting the results of this study were obtained from field measurements and technical documents for BF05K2039 Feeder C at ULP Sei Duri. Access to operational data by external parties is subject to permission from the authorized unit/institution.

Conflicts of Interest: A conflict-of-interest declaration was not reported in the source manuscript.

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