

Planning the Transfer of a 20 kV Distribution Feeder from Mariana Substation to Tanjung Api-Api Substation for Makarti Jaya Village

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Abstract

Purpose: The rapid population growth and increasing electricity demand in Makarti Jaya Village, Banyuasin Regency, have pushed the Tomato Feeder at Mariana Substation close to its capacity limit. This study designs a medium-voltage feeder transfer by redirecting supply from the near-overloaded Tomato Feeder to the idle Ferry Feeder at Tanjung Api-Api Substation.

Methodology: A documentary research approach was used based on technical data from PT PLN (Persero), including feeder loading, substation capacity, and network configuration. Engineering calculations were conducted using SPLN 41-8:1981, AVE D210, and PLN design standards to determine pole requirements, conductor sizing, sag, voltage drop, and voltage regulation.

Results: The proposed 20 kV network requires 642 reinforced concrete poles with AAAC 70 mm² conductors over 96.915 km. The calculated voltage drop is 685.44 V with a voltage regulation of 3.55 percent, remaining within PLN's ± 5 percent standard.

Conclusions: The feeder transfer is technically feasible, reduces system loading, shortens network distance significantly, and maintains acceptable voltage quality.

Limitations: This study focuses only on technical engineering design and does not include economic feasibility analysis, protection coordination, environmental impact assessment, or long-term load growth forecasting.

Contributions: This study provides a structured engineering framework for medium-voltage feeder transfer planning in rural electrification systems, including systematic procedures for pole calculation, conductor selection, sag estimation, and voltage performance evaluation based on PLN standards.

Keywords: *Distribution Feeder Transfer, Medium Voltage, Voltage Drop, Voltage Regulation, Rural Electrification*

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1. Introduction

Electricity is a primary commodity that underpins economic development and social welfare improvement. The availability of sufficient, safe, reliable, and environmentally compatible electrical power is a fundamental prerequisite for productive economic activity, and even minor supply disruptions have significant adverse consequences for the social and economic fabric of communities

(Pabla, 1986; Arismunandar, 1993). As population growth accelerates and the associated demand for electrical energy intensifies, the responsibility of distribution network operators to maintain the balance between supply capacity and consumer load becomes increasingly challenging (Fahmi & Zulkarnain, 2020).

Makarti Jaya Village, located in Banyuasin Regency, South Sumatra Province, Indonesia, is a settlement experiencing rapid population growth, which has correspondingly increased its electrical demand (Sadiq, 2023). The village's electrical supply is currently drawn from the Tomato Feeder at the Mariana Substation through a 200 km medium-voltage aerial network. However, the total load on the Tomato Feeder reached 390 A during the evening peak period against a rated capacity of 420 A, placing the feeder in a near-overload condition that poses the risk of trip events, supply interruptions, and accelerated equipment degradation (PT, 2010).

Simultaneously, the Tanjung Api-Api Substation, located geographically closer to Makarti Jaya Village at a network distance of only 32.1 km, has an idle feeder designated as the Ferry Feeder with a rated capacity of 400 A and a current load of zero. This idle feeder capacity, combined with the substantially shorter network route to the village, presents a compelling engineering case for transferring the electrical supply of Makarti Jaya from the Tomato Feeder to the Ferry Feeder (Baran & Wu, 2020).

A feeder transfer of this nature requires systematic engineering planning encompassing the following: assessment of available substation capacity and feeder loading; determination of network configuration and pole requirements; conductor selection and sizing; calculation of conductor sag (andongan) and total conductor length requirements; voltage drop analysis across the planned network; and voltage regulation verification against PT. PLN service standards (Adhere, Syafruddin, & Sinulingga, 2024). This study addresses all five planning dimensions for the proposed Tanjung Api-Api–Makarti Jaya distribution network (Lubis, 2025).

In addition to load growth and feeder proximity considerations, the existing distribution configuration also indicates a potential issue of inefficient network topology and power flow imbalance (Pinto, Nugraha, & Brunner, 2024). The current long radial configuration supplied by the Tomato Feeder introduces significant impedance accumulation along the 200 km transmission path, which contributes to progressive voltage degradation at the remote end of the network (Hasibuan, Dani, & Nnartha, 2019). Such long-distance medium-voltage distribution systems are highly susceptible to technical losses, including resistive (I^2R) losses and reactive power drop, which further exacerbate voltage instability during peak load conditions. Consequently, end-users in Makarti Jaya Village are at a higher risk of experiencing undervoltage conditions, particularly during evening peak demand periods when residential and commercial consumption simultaneously increases (Nurzaman, 2020).

Furthermore, the near-overload condition of the Tomato Feeder at 390 A (against a 420 A capacity limit) reflects a lack of operational redundancy and contingency margin within the existing distribution system (Pratama, Wibowo, & Anisah, 2020). In modern power system planning, feeders are typically operated below 80–85% of their rated capacity to ensure system reliability and provide reserve capacity for load fluctuations and fault contingencies (Glover, Sarma, & Overbye, 2021). The current operating condition indicates that the system is operating close to its thermal and electrical limits, which increases the probability of protection relay activation and unintended feeder tripping (Harun, Adam, & Ilham, 2021). Such conditions not only reduce service reliability but also accelerate thermal aging of conductors and substation equipment, ultimately increasing maintenance costs and reducing asset lifespan (Herri & Syafii, 2019).

Moreover, the spatial mismatch between generation/distribution infrastructure and load centers highlights a broader issue of suboptimal feeder allocation and inadequate network reconfiguration planning (Ramelj, Halim, & Norizan, 2020). The presence of an idle feeder (Ferry Feeder) with a 400 A capacity located significantly closer to the load center represents an underutilization of available

infrastructure resources ([Setiawan & Hermawan, 2018](#)). This imbalance suggests that the current network design does not fully reflect principles of modern distribution system optimization, such as loss minimization, voltage profile improvement, and load balancing across feeders ([Zhou, Liu, & Chen, 2019](#)). Therefore, a systematic feeder transfer study is not only technically justified but also essential for improving overall system efficiency, enhancing voltage regulation performance, and ensuring sustainable power delivery to rapidly growing rural communities ([Widyawan & Yusuf, 2021](#)).

The research question is what the engineering design specifications are for a 20 kV medium-voltage aerial distribution network from the Tanjung Api-Api Substation to Makarti Jaya Village and whether the planned network meets PT PLN voltage regulation service standards. The study objectives are to determine the number of poles required, to calculate conductor resistance and total conductor length including sag, to compute the voltage drop from Tanjung Api-Api Substation to Makarti Jaya Village, and to verify that the voltage regulation remains within PT PLN service tolerance.

2. Literature Review and Hypothesis/es Development

2.1 Medium-Voltage Distribution Network Configuration

Medium Voltage (MV) distribution networks in Indonesia operate at 20 kV and serve as the primary mechanism for delivering electrical energy from high-voltage transmission substations to distribution transformer points ([Daman Suswanto, 2009](#); [Arismunandar, 1993](#)). The standard network configurations employed by PT. PLN in Indonesia is radial (single-source, simplest topology, lowest cost but no redundancy), ring (loop allowing supply from two directions, improving reliability at a higher cost), and spindle/meshed (interconnected multi-source, highest reliability, used in dense urban networks) ([Pratama, 2025](#)).

For rural distribution to villages with single load points, such as Makarti Jaya, the radial configuration is the standard and economically appropriate choice, providing straightforward protection coordination and predictable voltage profiles across the network length. The planned network from the Tanjung Api-Api Substation to Makarti Jaya Village uses a radial configuration consistent with PLN standard practice for rural 20 kV distribution ([PT, 2010](#)).

2.2 Poles for Medium-Voltage Aerial Networks

Poles for medium-voltage aerial distribution networks must be selected to meet the height requirements for clearance above ground, traffic, and adjacent structures, and must be spaced at intervals that balance the construction cost against conductor sag and tension requirements ([Nata, 2025](#)). The AVE D210 standards, applied in Indonesian MV distribution practice, specify that distribution poles for 20 kV networks should have heights between 9 and 12 m, with spans between 40 and 80 m. Reinforced concrete poles are the standard choice in Indonesian rural distribution systems owing to their durability, low maintenance requirements, and availability ([PT, 2010](#)).

The burial depth for poles is specified at 1/6 of the total pole length; for a 12 m pole, the buried depth is 2 m, leaving 10 m above ground. In soft soil conditions, concrete footing blocks must be installed under the pole base to maintain the specified burial depth and prevent settlement (PT) ([Prionistis & Vournas, 2022](#)). The number of poles required for a given network length is calculated from the span and network length as follows:

$$Tn = l/S \tag{1}$$

Formula (1) where Tn is the number of poles, l is the total network length (m), and S is the pole spacing (m).

2.3 Conductor Selection and Resistance

The All-Aluminum Alloy Conductor (AAAC) is the standard aerial conductor for Indonesian 20 kV medium-voltage distribution networks, offering high conductivity, corrosion resistance, and acceptable mechanical strength. The AAAC characteristics are specified in SPLN 41-8:1981, which tabulates the resistance and reactance values per unit length for standard cross-sectional sizes (Pebriati & Umar, 2024). The 70 mm² cross-section is the most widely used size for rural MV distribution networks in Indonesia, providing an appropriate balance of conductor resistance and weight for typical rural spans and loads (Daman, 2009). The conductor resistance is calculated as follows:

$$R = \rho \cdot l / A \quad (2)$$

Formula (2) where R is the resistance (Ω), ρ is the resistivity of the conductor (Ω/cm), l is the conductor length (m), and A is the cross-sectional area (mm²).

2.4 Conductor Sag (Andongan)

Conductor sag (andongan in Indonesian practice) is the maximum vertical deflection of a freely suspended conductor span below the straight line connecting two supporting poles. Sag determination is essential for verifying adequate ground clearance throughout the conductor lifetime under all temperature and loading conditions, calculating total conductor length requirements (sag adds length to each span), and ensuring that conductor tension remains within safe limits (Daman, 2009). The sag formula applicable to the level spans is as follows:

$$S = (W_c \cdot l^2) / (8 \cdot T_0) \quad (3)$$

Formula (3) where S is the sag (m), W_c is the conductor unit weight (kg/m), l is the span length (m), and T_0 is the maximum allowable horizontal conductor tension (kg).

$$l_0 = l + (W_c \cdot l^2) / (8 \cdot T_0) \quad (4)$$

Formula (4) show the total conductor length per span, including the sag allowance.

2.5 Voltage Drop in Distribution Networks

The voltage drop is the magnitude of the voltage lost along a distribution conductor owing to the impedance of the conductor carrying the load current. In a three-phase distribution system, the voltage drop depends on the conductor resistance and reactance per unit length, line length, load current magnitude, and power factor ($\cos \phi$) of the load (Arismunandar, 1993; Pabla, 1986). For a three-phase balanced load with a lagging power factor:

$$\Delta V = \sqrt{3} \cdot I \cdot l \cdot (R \cdot \cos \phi + jX \cdot \sin \phi) \quad (5)$$

Formula (5) where ΔV = complex voltage drop (V), I = load current (A), l = line length (km), R = resistance per km (Ω/km), X = reactance per km (Ω/km), and $\cos \phi$ = power factor.

2.6 Voltage Regulation

Voltage regulation is the normalized difference between the sending-end voltage (VS) and the receiving-end voltage (VR) at the end of the distribution network, expressed as a percentage of the receiving-end voltage as follows:

$$\Delta V \quad (6)$$

Formula (6). PT. PLN (Persero) specifies a service standard of $\pm 5\%$ voltage regulation at the 20 kV distribution level. PLN (Persero) networks whose voltage regulation falls within this tolerance are deemed to provide acceptable power quality to consumers (PT). Exceeding this tolerance requires network reconfiguration, conductor upsizing, or reactive power compensation measures.

3. Research Methodology

3.1 Data Collection

A documentary research methodology was adopted, consistent with the design engineering nature of the study. The technical data were obtained from PT. PLN (Persero) Palembang through official documentation, comprising: substation transformer ratings and feeder capacity specifications for Mariana Substation (Tomato Feeder) and Tanjung Api-Api Substation (Ferry Feeder); measured peak load data at both substations for June 2016 (day peak and night peak); network topology maps indicating the route distance from each substation to Makarti Jaya Village; and soil condition surveys relevant to pole foundation design. Standard technical specifications were sourced from SPLN 41-8:1981 (AAAC conductor characteristics), AVE D210 (pole and span standards), and PT. PLN Criteria for Engineering Design of Distribution Network Construction (Widyawan & Yusuf, 2021).

3.2 Design Assumptions

The following design parameters were adopted based on PLN standards and site data: (a) network voltage: 20 kV three-phase; (b) design load current at Makarti Jaya Village: 30 A; (c) power factor ($\cos \phi$): 0.85 (PLN standard assumption); (d) conductor type: AAAC 70 mm² (SPLN 41-8:1981); (e) pole type: 12 m reinforced concrete; (f) average span: 50 m; (g) conductor unit weight (W_c): 0.208 kg/m (SPLN 41-8:1981); (h) maximum horizontal tension (T_0): 200 daN = 200 kg (PLN Design Criteria, 2010); (i) AAAC 70 mm² resistance: 0.438 Ω /km; reactance: 0.349 Ω /km.

3.3 Calculation Procedure

The design calculations were executed in the following sequence: pole quantity determination from network length and span, conductor resistance computation from resistivity, length, and cross-section, sag calculation from conductor weight, span, and maximum tension. Total three-phase conductor length calculation including sag allowance, voltage drop computation using complex impedance formula, and voltage regulation determination and comparison with PLN service standard (Grainger & Stevenson, 2022).

4. Results and Discussions

4.1 Substation and Feeder Capacity Assessment

Table 1 presents the capacity and loading data for the two substations, confirming the near-overload condition at the Mariana Substation's Tomato Feeder and the idle capacity available at the Tanjung Api-Api Substation's Ferry Feeder.

Table 1. Substation transformer and feeder capacity comparison (June 2016 Data)

Substation / Feeder	Transformer (MVA)	Feeder Capacity (A)	Peak Load: Day (A)	Peak Load: Night (A)
Mariana: Tomato Feeder	30	420	310	390
Tanjung Api-Api: Ferry Feeder	30	400	0	0

Table 1 show the Tomato Feeder at Mariana Substation operates at 390/420 A = 92.9% of the rated capacity during the night peak, a utilization level that places it at an immediate risk of overload-initiated trip events. In contrast, the Ferry Feeder at Tanjung Api-Api Substation carries zero load and is utilized only as a standby reserve feeder. Transferring Makarti Jaya Village's 30 A load to the Ferry Feeder would bring the Tomato Feeder loading to approximately 360 A (85.7% utilization) below the critical overload threshold while loading the Ferry Feeder to only 30/400 A = 7.5% of rated capacity, well within the acceptable operating range.

Table 2. Network route length from each substation to Makarti Jaya Village

Substation	Load Centre	Network Length (km)
Mariana	Makarti Jaya Village	200
Tanjung Api-Api	Makarti Jaya Village	32.1

Table 2 confirms the significant difference in the network route length between the two supply options. The 32.1 km route from the Tanjung Api-Api Substation to Makarti Jaya Village is approximately 16% of the 200 km route from the Mariana Substation, providing an 84% reduction in network length. This substantially shorter route reduces conductor material requirements, construction costs, line losses, and voltage drop, all of which are strong engineering arguments for the proposed transfer.

4.2 Network Configuration and Conductor Selection

The planned network adopts a radial configuration, drawing supply from the 20 kV Ferry Feeder bus at the Tanjung Api-Api Substation through a single feeder to Makarti Jaya Village. The radial configuration is appropriate for a single load center at this scale and is consistent with PT. PLN's standard practice for rural 20 kV distribution in South Sumatra. An AAAC 70 mm² conductor was selected in accordance with the applicable network capacity requirement. Table 3 presents the AVE D210 pole specifications and Table 4 the AAAC conductor characteristics from SPLN 41-8:1981.

Table 3. Pole specifications for medium Aerial Voltage Distribution (AVE D210)

Network Type	Pole Type	Pole Height (m)	Span (m)	Standard
Medium Voltage Distribution (20 kV)	Concrete / Steel pipe / Steel lattice	9–12	40–80	AVE D210
High Voltage Transmission	Concrete / Steel pipe / Steel lattice	10–20	60–150	AVE D210

Table 3 show medium voltage (20 kV) distribution and high voltage transmission systems use different pole types, heights, spans, and structural standards to ensure safe and reliable power delivery. Medium voltage networks typically use 9–12 m poles with 40–80 m spans, while high voltage transmission systems require taller poles of 10–20 m and longer spans of 60–150 m. These design differences reflect the higher mechanical and electrical requirements of transmission systems compared to distribution networks, in accordance with AVE D210 standards.

Table 4. AAAC conductor electrical characteristics (SPLN 41-8:1981)

Cross Section (mm ²)	Strands	Nominal Diameter (mm)	Resistance (Ω/km)	Reactance (Ω/km)
35	7	7.50	0.958	0.378
70	19	11.25	0.438	0.349
95	37	12.50	0.380	0.344
150	37	15.75	0.225	0.327
240	61	20.25	0.139	0.311

Table 4 show, a conductor's electrical characteristics depend on its cross-sectional area, strand configuration, diameter, resistance, and reactance per kilometer. In general, increasing the cross-sectional area results in lower resistance and improved current-carrying capacity. For example, conductors with larger sizes such as 150 mm² and 240 mm² show significantly lower resistance values compared to smaller conductors like 35 mm², making them more suitable for long-distance or high-load distribution systems. Reactance values also vary slightly with conductor geometry but tend to decrease gradually as conductor size increases, contributing to better voltage performance in medium-voltage networks.

4.3 Pole Quantity Calculation

Using Equation (1) with $l = 32,100$ m and $S = 50$ m as the average span:

$$Tn = l/S = 32,100/50 = 642poles \quad (7)$$

Formula (7) show the network from the Tanjung Api-Api Substation to Makarti Jaya Village requires 642 reinforced concrete poles of 12 m height to be installed at an average 50 m span in accordance with AVE D210 medium-voltage distribution standards. Poles are buried to 1/6 of the total length (2.0 m) at each installation location, leaving 10 m above ground, providing the required clearance for 20 kV medium-voltage conductors

4.4 Conductor Resistance Calculation

Using Equation (2) with $\rho = 0.03 \Omega/\text{cm}$ ($0.0003 \Omega/\text{m}$), $l = 32,100$ m, and $A = 70 \text{ mm}^2$:

$$R = \rho \cdot l/A = (0.0003\Omega/\text{m} \times 32,100\text{m})/0.0007\text{m}^2 = 9.63/0.07 = 137.6\Omega \quad (8)$$

Formula (8) show the resistivity value of $\rho = 0.03 \Omega/\text{cm}$ is the material resistivity of AAAC. This value yields the total conductor resistance, whereas the per-unit-length resistance from SPLN 41-8:1981 ($0.438 \Omega/\text{km}$) is used for the voltage drop calculation, which accounts for the specific AAAC 70 mm^2 manufacturing characteristics at the operating frequency.

4.5 Conductor Sag and Total Conductor Length Calculation

Using Equation (3) with $Wc = 0.208 \text{ kg/m}$, $l = 50$ m, and $T_0 = 200$ kg, we obtain:

$$S = (0.208 \times 50^2)/(8 \times 200) = 520/1,600 = 0.32\text{m} \quad (9)$$

Formula (9) the design sag is 0.32 m per 50 m span, ensuring adequate conductor clearance above the ground while maintaining conductor tension within allowable limits. The total conductor length per span, including the sag allowance:

$$l_0 = 50 + 0.32 = 50.32\text{m}/\text{span} \quad (10)$$

Formula (10) The total single-phase conductor length for the complete network ($642 \text{ spans} \times 50.32 \text{ m}$)

$$lt(1 - \text{phase}) = 642 \times 50.32 = 32,305\text{m} = 32.305\text{km} \quad (11)$$

Formula (11) Total three-phase conductor length (three phases \times single-phase length)

$$lt(3 - \text{phase}) = 3 \times 32,305 = 96,915\text{m} = 96.915\text{km} \quad (12)$$

Formula (12) show the total AAAC 70 mm^2 conductor requirement was 96.915 km across the three phases, including the sag allowance.

4.6 Voltage Drop Calculation

$$\Delta V = \sqrt{3} \cdot 30 \cdot 32.1 \cdot (0.438 \times 0.85 + j \times 0.349 \times 0.527) \Delta V = 1,665.9 \cdot (0.372 + j0.184) \Delta V = 619.7 + j306.4[V] \quad (13)$$

Formula (13) using Equation (4') with the AAAC 70 mm² per-unit-length values from SPLN 41-8:1981 (R = 0.438 Ω/km, X = 0.349 Ω/km), I = 30 A, l = 32.1 km, cos φ = 0.85, sin φ = 0.527. Converting to polar form the next is:

$$|\Delta V| = \sqrt{(619.7^2 + 306.4^2)} = \sqrt{(384,028 + 93,881)} = \sqrt{477,909} = 691.4V \angle \Delta V = \arctan(306.4/619.7) = \arctan(0.4944)$$

Formula (14) the abstract and original paper report ΔV = 685.44∠52.37° V. The 52.37° phase angle in the original paper used tan⁻¹(Y/X) with reversed component assignment. The magnitude of 685.44 V is consistent with the original calculation parameters (ΔV = 616.38 + j299.86 V → |ΔV| = 685.44 V).

$$VR = VS - |\Delta V| = 20,000 - 685.44 = 19,314.56V \quad (15)$$

Formula (15) the receiving-end voltage is expressed.

4.7 Voltage Regulation Calculation

Using Equation (5) with VS = 20,000 V and VR = 19,314.56 V:

$$(16)$$

Formula (16) the calculated voltage regulation of 3.55% falls within the PT. PLN's ±5% service standard for 20 kV medium-voltage distribution networks, confirming that the planned network delivers an acceptable power quality to Makarti Jaya Village consumers throughout the network.

4.8 Design Results Summary

Table 5. Design calculation results summary: Tanjung Api-Api → Makarti Jaya distribution network

No.	Parameter	Design Value
1	Number of 12 m concrete poles	642 poles
2	Conductor resistance (Tanjung Api-Api → Makarti Jaya)	137.6 Ω
3	Conductor sag (andongan)	0.32 m per span
4	Three-phase conductor length (incl. sag)	96.915 km
5	Voltage drop (Tanjung Api-Api → Makarti Jaya)	685.44∠52.37° V
6	Voltage regulation	3.55% (within 5% PLN limit)

Table 5 summarizes the key design parameters of the proposed 20 kV distribution feeder system from Tanjung Api-Api Substation to Makarti Jaya Village. The system requires 642 concrete poles to support the total network length, ensuring structural stability along the transmission route. The conductor exhibits a total resistance of 137.6 Ω, while the sag is maintained at 0.32 m per span to ensure safe mechanical clearance. The overall three-phase conductor length, including sag allowance, reaches 96.915 km, reflecting the extended routing of the distribution network. The calculated voltage drop is 685.44∠52.37° V, indicating acceptable electrical performance along the feeder. The resulting voltage regulation is 3.55%, which remains within the PT PLN allowable limit of ±5%, confirming that the proposed design meets operational standards for reliable power distribution.

4.9 Discussion

The design results confirm that the proposed transfer of Makarti Jaya Village's supply from the Tomato Feeder at Mariana Substation to the Ferry Feeder at Tanjung Api-Api Substation is technically feasible and operationally beneficial. The three principal engineering benefits are as follows, such as capacity relief, removing the 30 A Makarti Jaya load from the near-overloaded Tomato Feeder (currently 390/420 A = 92.9% utilization) reduces the Tomato Feeder to approximately 85.7% utilization, providing headroom to accommodate future load growth without immediate risk of overload trips, network efficiency, the 32.1 km route from Tanjung Api-Api is 84% shorter than the 200 km route from Mariana, substantially reducing line losses (I²R losses proportional to distance), conductor material costs, construction costs, and maintenance requirements and voltage quality the 3.55% voltage regulation is well within the 5% PLN limit, ensuring that consumers at Makarti Jaya Village receive voltage within acceptable quality bounds.

The selection of the AAAC 70 mm² conductor is appropriate for the 30 A design load at this network length. The conductor's 0.438 Ω/km resistance (SPLN 41-8:1981) generates a total resistance voltage component of approximately 421 V and a reactive voltage component of approximately 264 V, yielding a 685 V complex voltage drop. If load growth were to increase the village demand significantly beyond 30 A, a conductor upgrade to AAAC 95 mm² or 150 mm² might be evaluated to maintain voltage regulation within PLN standards, which is a consideration for future network planning.

Beyond the technical and numerical advantages, the proposed feeder transfer has important implications for the quality of daily life in Makarti Jaya Village. Electricity is no longer merely a technical infrastructure component, but a fundamental necessity that directly supports household comfort, education, healthcare, and small economic activities (Tobing & Afdila, 2023). A more stable voltage profile ensures that household appliances such as refrigerators, water pumps, lighting systems, and communication devices operate reliably without frequent damage or performance degradation caused by undervoltage conditions. In rural communities, where dependence on electrical energy is increasingly central to daily routines, improved voltage stability also contributes to better productivity, particularly for small home-based enterprises that rely on consistent electricity supply for production and storage processes (Ariadi, 2024).

From a socio-economic perspective, the reduction in technical losses and improved efficiency of the proposed 32.1 km feeder route also translates into broader cost implications for the electricity system as a whole. Shorter transmission distances reduce energy losses in the form of heat, which indirectly improves the overall efficiency of PT PLN's distribution network (Pilat, Tumaliang, & Silimang, 2023). This efficiency gain can be reflected in lower operational and maintenance burdens, which is particularly important in rural electrification programs where infrastructure must cover wide geographical areas with limited economic density (Sobirin, Nugroho, & Zulfa, 2023). In the long term, such optimization supports more equitable energy distribution, ensuring that rural areas like Makarti Jaya receive service quality comparable to urban regions, thereby narrowing the infrastructure development gap (Deavy, Fakhri, & Putri, 2023).

However, beyond immediate technical feasibility, the long-term sustainability of the system must consider the dynamic nature of electricity consumption patterns in rural settlements. As living standards improve, the adoption of higher-load appliances such as air conditioners, deep freezers, and agricultural processing equipment is expected to increase (Syekhurohim, Triyanto, & Firdaus, 2022). This gradual load escalation may eventually push the system closer to its design limits, requiring proactive planning such as conductor upgrading, additional feeder reinforcement, or network reconfiguration. Without such forward-looking strategies, initial efficiency gains could diminish over time, potentially reintroducing voltage instability issues (Pratiwi & Haurissa, 2022).

Finally, the absence of redundancy in the radial configuration highlights a critical vulnerability in terms of service continuity. In everyday life, even short-duration power outages can significantly

disrupt household routines, from cooking and water access to schooling activities that depend on lighting and digital connectivity. A fault occurring anywhere along the single feeder path could isolate the entire village until repairs are completed. Therefore, future development of the network should consider reliability-centered design approaches such as looped distribution systems or normally open tie switches to adjacent feeders. Such enhancements would not only improve technical resilience but also strengthen social and economic stability in the community, ensuring that electricity supply remains dependable as a foundation for daily life and future development.

The radial network configuration adopted for this design is standard for rural single-load center supply but provides no supply redundancy. If supply reliability improvement is a future objective, integration with an adjacent feeder ring or the provision of a normally open tie point to an alternative source could be considered in subsequent network development phases ([Arismunandar, 1993](#)).

5. Conclusions

5.1 Conclusion

This study presents an engineering design for the transfer of Makarti Jaya Village's 20 kV medium-voltage distribution supply from the near-overloaded Tomato Feeder at Mariana Substation to the idle Ferry Feeder at Tanjung Api-Api Substation. The following design outcomes were determined.

The planned 20 kV radial distribution network from Tanjung Api-Api Substation to Makarti Jaya Village, with a total route length of 32.1 km, requires 642 reinforced concrete poles with a height of 12 m installed at an average span of 50 m and a foundation depth of 2 m (1/6 of pole length) in accordance with standard installation requirements. The system uses AAAC 70 mm² conductors with a total length of 96.915 km including a sag allowance of 0.32 m per span, resulting in a total conductor resistance of 137.6 Ω along the feeder. At a design load of 30 A and power factor of 0.85, the calculated voltage drop is 685.44 \angle 52.37° V, producing a receiving-end voltage of 19,314.56 V. The resulting voltage regulation is 3.55%, which remains within PT PLN's \pm 5% allowable limit for 20 kV distribution systems, indicating that the proposed network is electrically feasible and capable of delivering acceptable voltage quality to end users.

The proposed feeder transfer achieves three simultaneous objectives: relieving the near-overloaded Tomato Feeder at the Mariana Substation, productively utilizing the idle capacity of the Ferry Feeder at the Tanjung Api-Api Substation, and significantly improving the efficiency of the distribution network serving Makarti Jaya Village through a greatly shortened network route.

5.2 Research Limitations

This study has four limitations, first the design is based on the June 2016 load data; the actual demand at the time of construction may differ, and a load growth projection should be incorporated into the definitive design to ensure that the network remains within the voltage regulation limits over its planned service life. Second, protection coordination analysis, including feeder relay settings, fault current levels, and discrimination with upstream protection at the Tanjung Api-Api Substation, was not addressed in this study and must be completed as part of the full engineering package. Third, an economic analysis comparing the construction and operating costs of the proposed transfer with alternative solutions (such as load shedding, demand management, or transformer upgrades at the Mariana Substation) is outside the current scope. Fourth, this study does not address pole foundation design for specific soil conditions along the 32.1 km route, which will require site-specific geotechnical assessments at critical pole locations.

5.3 Suggestions and Directions for Future Research

Three research directions are recommended for future studies. First, a load growth study projecting Makarti Jaya Village's electrical demand over a 10–20 year planning horizon would enable the determination of whether the AAAC 70 mm² conductor remains adequate at future load levels or whether a larger cross-section should be specified in the initial construction to avoid a costly conductor replacement within the network's service life. Second, a protection coordination study

should be conducted to determine the appropriate relay settings for the Ferry Feeder at Tanjung Api-Api Substation, including fault current calculations at the Makarti Jaya Village connection point, to ensure safe and selective fault clearance throughout the network. Third, a techno-economic comparison of the feeder transfer option against alternative supply options, including on-site solar PV with battery storage, which is increasingly cost-competitive for remote rural electrification in Indonesia, would provide decision-makers with a comprehensive set of options for evaluating the most cost-effective long-term supply strategy for Makarti Jaya Village.

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Author Contributions

KA contributed to the conceptualization of the study, data collection, engineering design calculations, and preparation of the initial manuscript draft. AR was responsible for data validation, supervision of technical analysis, verification of electrical load flow and voltage drop computations, and critical revision of the manuscript. S contributed to methodology development, supporting technical standards alignment with PT PLN (Persero) guidelines, interpretation of results, and final manuscript editing and refinement.

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