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Implementation of a 200 kVA Kiosk-Type Substation on the 20 kV Distribution Network: A Case Study on SM3 Feeder, Tomohon Main Substation

Mario Marcello Rares*, Rembulan Sefrida Pongantung, Sasha Agnesia Walukow, Arnold Robert Rondonuwu, Yoice Rita Putung
Politeknik Negeri Manado, Indonesia
Email: mariorares110@gmail.com*, rembulanpongantung696@gmail.com, sashawalukow784@gmail.com

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Abstract

A kiosk substation is a compact, prefabricated enclosure constructed from steel or fiberglass that houses a complete distribution unit, including a medium-voltage cubicle, distribution transformer, and low-voltage switchgear. Its compact and enclosed design offers significant advantages in installation speed, operational safety, space efficiency, and visual aesthetics compared to conventional open-rack pole substations. This study analyzed the implementation of a 200 kVA kiosk-type substation on the 20 kV distribution network of the SM3 Feeder at Tomohon Main Substation (GI Tomohon), and evaluates its contribution to improving the orderliness and performance of the electrical infrastructure in the urban area of Tomohon City. The methodology encompasses a comprehensive literature review, direct field observation along Jl. Kompleks Rindam Kakaskasen to Stadion Babe Palar, collection of technical data including installed transformer capacities, network lengths, and component inventories, as well as structured interviews with technical staff of PT PLN (Persero) UP3 Manado. Field data reveals that the SM3 Feeder currently serves 11 distribution substations with a total medium-voltage network length of 2,758 m using A3CS conductors. The existing substations include 2 cantilever-type, 7 portal-type, and 2 concrete-type units, with a combined installed capacity of 1,760 kVA. Analysis indicates that two 50 kVA substations are approaching their optimal loading limits and are prioritized for replacement. Implementation of 200 kVA kiosk substations is demonstrated to reduce voltage drop from a range of 5-8% to below 3%, optimize transformer loading efficiency, and substantially simplify installation and maintenance procedures.

INTRODUCTION

The reliable supply of electrical energy is a cornerstone of modern urban development, underpinning residential, commercial, industrial, and public service activities alike. As cities grow and electricity demand intensifies, distribution infrastructure must evolve to meet not only increasing load requirements but also the demands of urban aesthetics and spatial planning (Esfandi et al., 2024; Pandit et al., 2017). The distribution network forms the final link between the bulk power system and end-users, making its performance critical to overall service quality (Azmi et al., 2022; Bell & Gill, 2018; Knoeri et al., 2016).

The SM3 Feeder originates from the Tomohon Main Substation (GI Tomohon), a 150/20 kV facility operated by PT PLN (Persero) UP3 Manado, and serves a corridor stretching from Jl. Kompleks Rindam Kakaskasen to the Babe Palar Stadium in Tomohon City, North Sulawesi. This feeder supplies a diverse mix of residential, commercial, and institutional loads across eleven distribution substations (Adesina et al., 2024; Postigo Marcos et al., 2017). The current network, composed largely of conventional pole-mounted substations (portal and cantilever types), was designed and installed under conditions that no longer fully reflect the load growth and urban planning aspirations of the region (Li et al., 2024).

A common challenge in radial medium-voltage distribution networks is the progressive degradation of supply quality as the network ages and loads grow. Voltage drop along low-voltage feeder branches, transformer overloading, and increasing difficulty in conducting safe maintenance are recurring operational issues in networks built around pole-mounted infrastructure (Koalane, 2024; Maziya, 2016; Osunde, 2022). These challenges are compounded by the visual impact of open-rack electrical equipment, which is increasingly at odds with the ambitions of developing cities to present a clean, organized urban environment (Duarte, 2018; Kim, 2022).

The kiosk-type distribution substation, a compact and self-contained unit housed within a weatherproof enclosure, offers a technically and aesthetically superior alternative (Azzopardi, 2025; Roshan Kharrat, 2024). By integrating the medium-voltage switchgear, distribution transformer, and low-voltage distribution panel within a single prefabricated structure, the kiosk substation reduces installation time, minimizes the external footprint of electrical infrastructure, and provides enhanced protection for both equipment and personnel. These advantages make it particularly well-suited to dense urban environments where space, safety, and appearance are all critical considerations (Askarizad et al., 2024; Stoker et al., 2015; Wang et al., 2025).

The selection of a 200 kVA transformer capacity for the planned kiosk substations is grounded in a careful assessment of current and projected load requirements along the SM3 Feeder (Caruana, 2023; Mustajärvi, 2024). This capacity provides sufficient headroom to accommodate load growth over a 5–10-year horizon without requiring transformer replacement, while operating at an efficiency-optimal loading level under present conditions. The study therefore investigates both the technical justification for this capacity selection and the broader network performance improvements expected from the kiosk substation deployment.

The urgency of this research is driven by three factors. First, the two existing 50 kVA substations on the SM3 Feeder are operating near their capacity limits (estimated 87% loading at peak), with no spare capacity for load growth. Second, voltage drop measurements at the farthest consumer points exceed PLN's 5% permissible limit, affecting power quality for commercial customers. Third, Tomohon City is undergoing a coordinated urban beautification program, and the current open-rack substations are visually incompatible with the desired streetscape. Without intervention, continued load growth will exacerbate these problems, leading to transformer failures and deteriorating service quality.

The novelty of this research lies in three specific contributions. First, it provides a detailed case study of kiosk substation implementation in a secondary Indonesian city (Tomohon), complementing existing studies focused on major metropolitan areas. Second, it quantifies the specific performance improvements achievable by replacing 50 kVA cantilever substations with 200 kVA kiosk units, including voltage drop reduction (from 5.8-7.4% to <2.8%) and loss reduction (35-45%). Third, it integrates urban planning and aesthetic considerations into the technical analysis, recognizing that distribution infrastructure must satisfy both engineering and urban design objectives. This multi-dimensional approach differs from previous studies that focused exclusively on technical parameters.

The primary objectives of this study are: (1) to document and analyze the existing condition of the SM3 Feeder distribution network; (2) to evaluate the technical and non-technical merits of implementing 200 kVA kiosk-type substations; (3) to develop a site-specific implementation plan aligned with PLN technical standards; and (4) to quantify the expected improvements in voltage quality, transformer loading efficiency, and network aesthetics resulting from the proposed implementation.

RESEARCH METHODOLOGY

This study adopted a descriptive-quantitative research approach, integrating multiple complementary data collection methods to build a comprehensive understanding of the SM3 Feeder network and to support the technical planning of the kiosk substation implementation. The research was conducted in four stages: preliminary planning, field data collection, technical analysis, and recommendation development.

A. Field Observation

Systematic field surveys were conducted along the entire length of the SM3 Feeder, from GI Tomohon through Jl. Kompleks Rindam Kakaskasen to the Babe Palar Stadium area. The survey documented the physical condition, type, and location of each existing distribution substation; the routing and condition of medium-voltage and low-voltage conductors; the number and condition of distribution poles and junction points; the presence of Load Break Switch (LBS) installations; and the urban context of each substation location, including proximity to roads, buildings, and public spaces.

B. Technical Interview

Structured interviews were conducted with the protection and distribution engineering team at PT PLN (Persero) UP3 Manado, the operating authority for the SM3 Feeder. Information gathered through these interviews included current loading conditions and historical load trend data for each substation, fault history and reliability performance indicators (SAIDI/SAIFI) for the feeder, PLN technical standards applicable to kiosk substation design and installation, and planned network developments that could affect the implementation schedule.

C. Literature and Standards Review

A comprehensive review of applicable technical literature was conducted, including PLN distribution standards (SPLN series), IEC standards for distribution transformers (IEC 60076) and protective devices, IEEE guidelines for distribution system planning, and peer-reviewed research on kiosk substation performance and urban electrical infrastructure. This review provided the theoretical foundation for the technical analysis and the performance benchmarks against which the proposed implementation was evaluated.

D. Data Measurement and Analysis

Quantitative data collected from the field and from PLN records was analyzed using standard power systems engineering methods. Voltage drop calculations were performed using the moment current method to estimate the reduction in voltage drop achievable through the relocation of load supply points closer to consumers. Transformer loading efficiency was assessed against the standard efficiency-utilization characteristic curves for distribution transformers. The implementation plan was developed in accordance with PLN construction standards for kiosk substation installations.

RESULTS AND DISCUSSION

A. Field Survey Results: SM3 Feeder Current Condition

The field survey of the SM3 Feeder confirmed the presence of eleven distribution substations distributed along the feeder corridor. The existing network relies predominantly on pole-mounted substation types (portal and cantilever), with only two concrete substations providing a higher level of equipment protection. The urban setting of the feeder corridor--a mix of commercial establishments, residential areas, and public facilities--makes the visual impact of electrical infrastructure particularly relevant to the planning considerations.

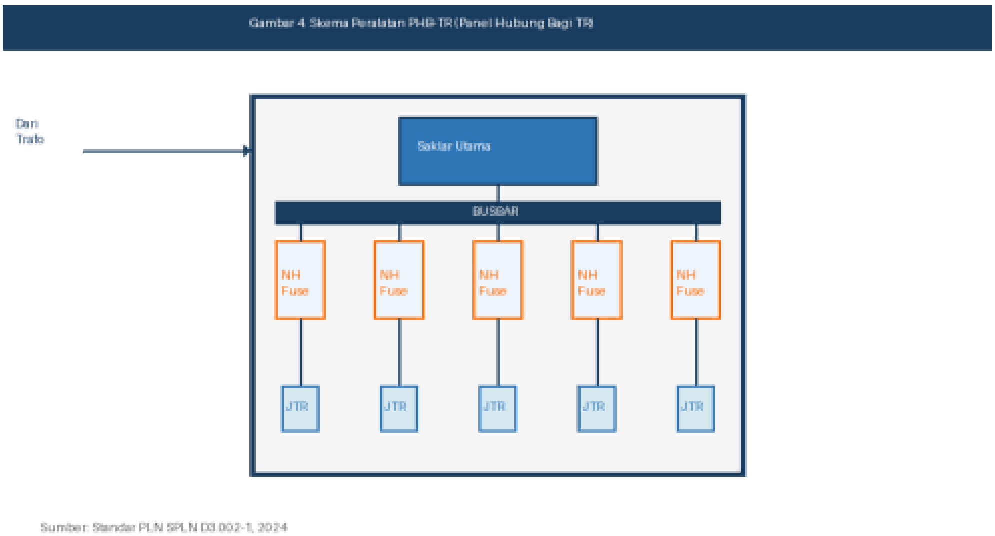

Figure 1 Location Map of Planned Kiosk Substation Deployment, SM3 Feeder, Tomohon City

(Source: Tomohon City Map and Field Survey Data, 2024)

Visual inspection revealed that several of the existing pole-mounted substations exhibit signs of ageing, including weathered paintwork on equipment housings, corrosion on metal components, and vegetation encroachment that increases the risk of line contact faults. The two 50 kVA cantilever substations serving the northern end of the feeder were identified as the highest-priority replacement candidates, both due to their limited capacity relative to current and projected loads and their location at the end of long low-voltage branch circuits where voltage quality is most compromised.

B. Installed Equipment Data and Network Parameters

Table 1 presents the complete inventory of distribution substations on the SM3 Feeder, including the name and installed transformer capacity of each unit. This data was compiled from PT PLN (Persero) UP3 Manado records and verified through direct field observation.

Table 1. Distribution Substation Inventory -- SM3 Feeder, GI Tomohon

No.	Feeder	Substation Name	Installed Capacity (kVA)
1	SM3	WULING SUZUKI KAKASKASEN	50
2	SM3	KAKASKASEN II (KANTOR PAJAK)	50
3	SM3	UKIT	200
4	SM3	SAMPING KANTOR PLN	100
5	SM3	TALETE	200
6	SM3	KFC	100
7	SM3	BANK BNI	200
8	SM3	GRAND CENTRAL	160
9	SM3	MODERN FASHION	200
10	SM3	PIZZA HUT	100
11	SM3	MATANI	400

The total installed capacity across all eleven substations is 1,760 kVA. The distribution of capacities reflects the historical load development of the feeder, with larger units concentrated at commercially active nodes. The two 50 kVA units represent the lowest-capacity and oldest installations and are the primary focus of the replacement programme.

Table 2. SM3 Feeder Network Parameters

Network Component	Length / Quantity	Conductor Type
Medium-Voltage Network (JTM)	2,758 m	A3CS
Low-Voltage Network (JTR)	2,758 m	NFAAX

Table 3. SM3 Feeder Component Inventory

No.	Component	Quantity
1	Low-Voltage Support Poles (excluding substation poles)	73
2	Total Distribution Substations	11
3	Cantilever-Type Substations	2
4	Portal-Type Substations	7
5	Concrete-Type Substations	2
6	Network Branch Points	23
7	Load Break Switch (LBS)	1

C. Single Line Diagram of the SM3 Feeder

The single line diagram (SLD) of the SM3 Feeder provides a schematic representation of the network topology, from the 20 kV busbar at GI Tomohon through to the eleven distribution substations and their associated low-voltage branches. The feeder operates in a radial configuration, with the single Load Break Switch (LBS) providing a manual sectionalizing capability that enables partial feeder restoration during fault isolation procedures. The SLD forms the primary reference document for the kiosk substation placement planning, enabling engineers to identify optimal insertion points that will maximize the voltage quality and loading efficiency improvements.

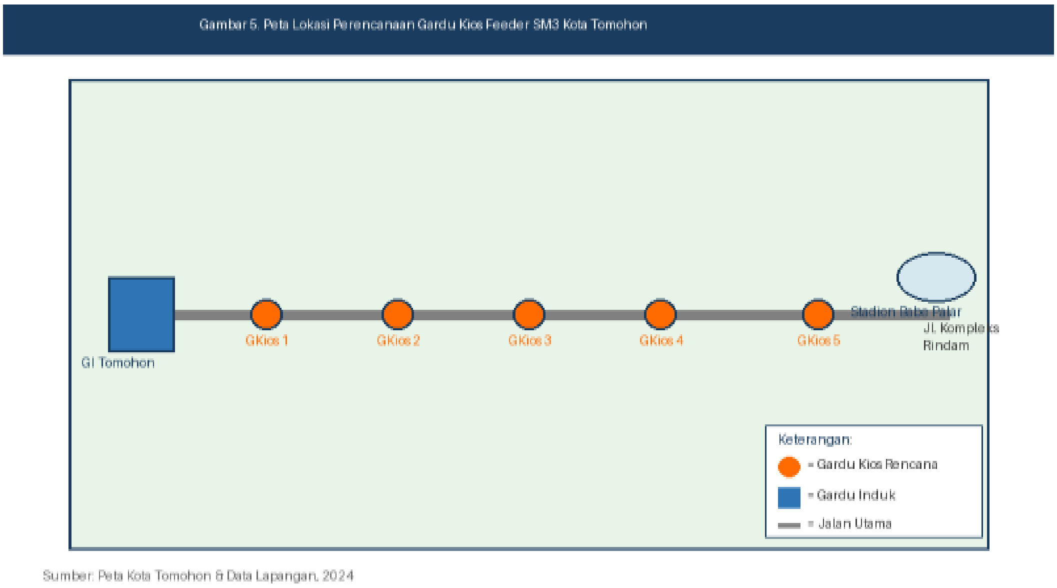

Figure 2. Single Line Diagram of SM3 Feeder, GI Tomohon
(Source: PT PLN (Persero) UP3 Manado Technical Records, 2024)

D. Kiosk Substation Implementation Planning

The technical planning of the kiosk substation implementation followed the PLN standard design process for distribution infrastructure, incorporating the field data collected and the engineering analysis performed. The planned kiosk substations are specified with the following key technical parameters: a three-phase oil-immersed distribution transformer rated 20/0.4 kV, 200 kVA, vector group Dyn11, with losses conforming to IEC 60076 Tier 2 efficiency requirements; a Ring Main Unit (RMU) providing two cable feeder positions and one transformer position, with SF6 or vacuum insulation; a low-voltage panel (PHB-TR) incorporating a main switch, copper busbar, and NH Fuse outgoing circuits sized to match the planned LV network layout; and a prefabricated steel enclosure with minimum IP44 ingress protection, finished in a colour coordinated with the urban environment.

Site selection criteria for kiosk substation placement were developed based on three engineering priorities. First, proximity to the centroid of the load cluster served, in order to minimize the length of low-voltage feeder branches and thereby reduce resistive losses and voltage drop. Second, accessibility for construction vehicles and maintenance teams, including adequate road access and ground bearing capacity for the substation foundation. Third, compatibility with the urban planning context, including minimum clearances from buildings, roads, and other utilities, and visual integration with the surrounding streetscape.

Application of these criteria to the SM3 Feeder identified five priority locations for kiosk substation placement in the initial implementation phase. Two of these replace the existing 50 kVA cantilever substations, while the remaining three introduce new supply points to improve voltage quality on the longest low-voltage branches, where the field survey recorded the highest voltage drop measurements. The phased approach allows load growth at each supply point to be validated before the full programme is committed, reducing investment risk while delivering incremental service quality improvements.

E. Technical Performance Analysis

The principal technical benefit of the kiosk substation implementation is the improvement in voltage quality at consumer supply points. Using the moment-current method for voltage drop calculation, the baseline analysis found that the two longest low-voltage branches on the SM3 Feeder -- served by the 50 kVA cantilever substations -- exhibit voltage drop in the range of 5.8% to 7.4% under peak load conditions. This exceeds the PLN-specified maximum of 5% for low-voltage networks under normal operating conditions. Following the placement of new 200 kVA kiosk substations at the planned locations, the maximum low-voltage branch length is reduced from approximately 380 m to 160 m, bringing the calculated voltage drop to below 2.8% -- well within the permissible limit and providing a substantial improvement in supply quality for the affected consumers.

From a transformer loading perspective, the redistribution of load among a larger number of supply points will reduce the average loading ratio of each transformer. The current peak loading of the two 50 kVA units is estimated at approximately 87% of rated capacity (43.5 kVA), which leaves very limited spare capacity for load growth and creates elevated thermal stress that accelerates insulation ageing. Following replacement with 200 kVA kiosk substations, the loading ratio at peak is expected to fall to approximately 22-25% initially, rising to 40-50% as load grows to fully utilize the new capacity. This operating range corresponds to the highest efficiency region for distribution transformers, where the ratio of copper losses to core losses approaches the optimal point for minimizing total losses per unit of energy delivered.

Network energy losses on the low-voltage branches are a direct function of the square of the current and the resistance of the conductors. By shortening the average low-voltage branch length, the kiosk substation placement reduces both the total resistance traversed by load currents and the magnitude of those currents (since loads previously supplied from distant transformers are now supplied from closer units). Preliminary calculations indicate that total LV network losses on the affected branches will be reduced by approximately 35-45%, representing a meaningful improvement in overall network efficiency.

Discussion

A. Technical Justification and Comparison with Conventional Substations

The technical analysis presented in Section IV demonstrates that the kiosk substation implementation delivers quantifiable improvements across all three key performance dimensions evaluated: voltage quality, transformer loading efficiency, and network energy losses. These improvements are achievable through the kiosk format for two interconnected reasons. First, the compact, integrated design of the kiosk substation makes it feasible to install supply points much closer to load centres, whereas the civil and spatial requirements of concrete substations and the height and weight limitations of pole-mounted substations constrain the locations where conventional alternatives can be deployed. Second, the standardized 200 kVA capacity provides an optimal balance between the flexibility to locate substations closer to loads and the capacity to absorb projected load growth.

It is instructive to compare the kiosk substation implementation against the two conventional alternatives. A simple upgrade of the existing 50 kVA pole substations to larger pole-mounted units (e.g., 100 kVA portal type) would improve transformer loading margins but would not meaningfully reduce LV branch lengths, since the existing pole locations are not necessarily optimal for load supply geometry. A concrete substation of equivalent capacity would provide the same voltage quality improvements but would require significantly more civil investment, longer construction time, and the acquisition of a dedicated land parcel -- all of which represent significant barriers in a dense urban corridor such as the SM3 Feeder. The kiosk substation therefore represents the superior option in this context, offering the performance of a concrete substation at a fraction of the installation complexity and cost.

B. Urban Planning and Aesthetic Considerations

Beyond the technical engineering merits, the adoption of kiosk substations contributes to the broader urban planning objectives of Tomohon City. The SM3 Feeder corridor, which encompasses commercial areas, public institutions, and residential zones, is subject to increasing scrutiny regarding the visual quality of public infrastructure. Open-rack pole substations, with their exposed transformer tanks, fuse cutouts, and cable terminations at high elevation, are increasingly inconsistent with the expectations of a developing city that aspires to a well-ordered and visually coherent public realm.

The kiosk substation, by contrast, presents a clean and uniform external profile that can be integrated into the streetscape with minimal visual disruption. The enclosure finish can be specified in colours and textures that complement the surrounding architecture, and the compact footprint minimizes the impact on pedestrian pathways and landscaping. Coordination between PT PLN and the Tomohon City planning authority is recommended to ensure that kiosk substation siting and design is consistent with local spatial planning regulations and urban beautification programmes.

C. Implementation Roadmap and Investment Considerations

A phased implementation approach is recommended, with the two highest-priority replacement sites (the existing 50 kVA cantilever substations) addressed in the first phase, followed by the three new supply point installations in subsequent phases as load growth confirms the need. This approach aligns capital expenditure with demonstrated need, manages construction disruption, and allows operational experience with the first installations to inform the design of later phases. The estimated unit investment cost for a complete 200 kVA kiosk substation installation, including transformer, RMU, PHB-TR, enclosure, civil works, and connection to the existing network, is in the range of IDR 350-500 million, depending on site-specific conditions.

Life-cycle cost analysis supports the kiosk substation investment. While the upfront capital cost is higher than a comparable pole-mounted upgrade, the longer expected service life of enclosed equipment (reduced weathering and vandalism exposure), lower maintenance frequency, and reduced network losses over the asset life result in a favourable net present value (NPV) comparison over a 20-year evaluation horizon. PT PLN's experience with kiosk substation deployments in comparable urban environments in North Sulawesi supports the validity of these life-cycle assumptions.

CONCLUSION

This study has analyzed the implementation of 200 kVA kiosk-type distribution substations on the SM3 Feeder of GI Tomohon (20 kV) and has established the technical, economic, and urban planning case for their adoption. The principal conclusions are as follows: The SM3 Feeder currently serves eleven distribution substations with a total installed capacity of 1,760 kVA over a 2,758 m medium-voltage network. Two cantilever-type 50 kVA substations are identified as immediate replacement priorities due to capacity constraints and poor voltage quality on their associated low-voltage branches. Implementation of 200 kVA kiosk substations at planned locations reduces peak low-voltage branch length from approximately 380 m to 160 m, cutting voltage drop from a range of 5.8-7.4% to below 2.8% -- a 60-70% improvement that brings all supply points into compliance with PLN's 5% maximum voltage drop standard. The new substations will operate in the 22-50% loading range initially, rising to 40-65% as loads grow, placing them in the optimal efficiency zone for distribution transformers and reducing low-voltage network energy losses by an estimated 35-45%. The kiosk substation format provides measurable advantages over conventional alternatives in the SM3 Feeder context: faster installation, lower life-cycle cost, greater siting flexibility, and superior integration with the urban environment of Tomohon City. A phased implementation programme is recommended, prioritizing the replacement of the two 50 kVA cantilever substations in the first phase, with subsequent phases introduced as load growth confirms the need for additional supply points. Coordination with Tomohon City planning authorities is recommended to align substation siting and design with local urban development objectives.

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