JOURNAL LA MULTIAPP

VOL. 06, ISSUE 06 (1410-1423), 2025
DOI: 10.37899/journallamultiapp.v6i6.2439

Grid System Analysis of the Isolated Unit Load Device Timpah in the De-Dieselization Program

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Article Info

Article history:
Received 12 July 2025
Received in revised form 2 October 2025
Accepted 20 October 2025

Keywords:
Dedieselisasi
Grid System
ULD Timpah
Energy Efficiency
Remote Area Electrificatio

Abstract

The de-dieselisasi program has become a key strategy of PT PLN (Persero) in reducing dependence on diesel power plants in isolated areas, including ULD Timpah, Kapuas Regency, Central Kalimantan. This study aims to analyze the effectiveness of the grid system performance after the implementation of de-dieselisasi, focusing on technical, operational, and financial aspects. The method used is a descriptive quantitative approach with a case study, supported by primary and secondary data, as well as system simulations using the ETAP application. The results show that the electricity distribution voltage remained stable within operational standards, both before and after the project (20.54 kV to 19.17 kV). Operationally, the electricity service hours increased from 16 hours to 24 hours per day, improving the quality of service to customers. Initial financial analysis indicated that the project was not feasible; however, an avoided cost analysis resulted in a positive Net Present Value (NPV) of IDR 162.55 billion, demonstrating significant cost efficiency compared to diesel-based operations. In conclusion, the de-dieselisasi program at ULD Timpah successfully improved the efficiency, reliability, and sustainability of the electricity system in remote areas, providing positive impacts technically, operationally, and financially to support national electrification goals.

Introduction

The geographical energy of Indonesia is inherently connected to its archipelagic nature, as an archipelagic country is made up of a mosaic of more than seventeen thousand islands, which together consist of a living contradiction of abundance and disparity in a land richly endowed with energy. It is blessed with the immense renewable energy potential of hydropower reserves in Sumatra and solar installations in Nusa Tenggara; but energy poverty is still a persistent phenomenon in the peripheral areas of the country. Geography does not just exist as a background in such scattered landscapes, but as a dynamic influence of infrastructural boundaries and accessibility. The percentage of regencies in Eastern Indonesia that continue to be underdeveloped and isolated is over sixty-seven per cent (Herawati et al., 2020), an indicator that illustrates that the process of electrification in the country is rather unevenly distributed. In these terms, electricity is not only about its technical meaning, it is also a symbol of belonging, a factor of opportunity, and a measure of the spatial and social distribution of development (dos Santos & Balestieri, 2018; Stoeglehner et al., 2011; Späth & Rohracher, 2010).

Diesel based power plants (PLTD) have over the decades been the feasible answer to electrification of the most isolated regions of Indonesia (Prayoga & Dalimi, 2020; Manurung

ISSN: 2716-3865 (Print), 2721-1290 (Online)

& Dalimi, 2020; Siregar et al., 2025). They have offered a fast, flexible reaction to the lack of massive grid connectivity, especially where the terrain, distance, and expenses prevent the growth in high-voltage infrastructure. As stated in the electricity supply business plan 20212030 prepared by PLN (RUPTL), over 5,200 diesel generators are still in operation in 2,130 isolated sites around the country (PLN, 2021). Although these units are one of the first stages of rural electrification, their shortcomings have become more apparent. The problem of high fuel consumption, logistical issues, and mechanical susceptibility translates to the great operational costs and poor energy efficiency (Mahendra & Liliana, 2023; Marchi & Zanoni, 2017; Wehner, 2018). What made them deployable previously is the very remoteness that is currently revealing their inefficiency: diesel systems in remote locations waste too many resources to produce only carbon emission, not to mention that they make them dependent on the unstable logistics of volatile fuels to exist. As Bowes et al. (2017) point to, these systems are mired in a loop of technical unsustainability and economic unsustainability, the symptoms of an energy model that is not compatible with the ambitions of a country that aims at sustainable development (Kaygusuz, 2012; Hariram et al., 2023; Bąk et al., 2022).

The de-dieselization program is not just a policy intervention but a renegotiation of what Indonesia is in terms of energy (Suparman et al., 2024). The program, which is initiated by PT PLN (Persero), is a conscious movement of solitary diesel generation to more composite, greener, and efficient grid systems (Susanto & Rasgianti, 2023). In addition to its technical aspirations, de-dieselization assumes a moral and developmental reason that reinvents energy as a connective infrastructure between periphery and the prospect of national development. The plan entails the substitution of diesel generation units with renewable or hybrid sources of energy as well as the incorporation of previously isolated grids into bigger regional grids. However, this integration is not that simple. It requires careful organization of technical criteria, the stability of the network, and the ability to maintain its work, which is usually measured by such indicators as the stability of the voltage, the deviation of the frequency, and such reliability metrics as SAIDI and SAIFI (Eteruddin et al., 2021; Susanto & Prasetyo, 2019). The problem it, thus, becomes is how to take technically feasible solution into a sustainably operational solution- a transformation which must be successful not only in engineering but also in governance.

The interconnected nature as a promise has been well received in practice and scholarship. Dense interconnection of 115 GW was demonstrated by Reyseliani et al. (2024) which may make a major difference in terms of renewable energy penetration and coal reliance by a third relative to remote systems. It helps fill the infrastructural gap between the urban hubs and remote communities, so that the energy flows in and out of the cities, as well as between the social and economic classes (Muhaimin et al., 2022). Nevertheless, as Siregar et al. (2024) and Farghali et al. (2023) stress electrification is not a strictly technical process. It redefines the rhythms of the social life, economic trends, and even cultural activities in newly linked societies. The introduction of 24-hour power supply in a remote location does not only change the comfort level of a household, but also the prospects of education, trade and industry within that locality.

In this respect, energy turns into a condition and a stimulus of evolution a silent revolution restructuring time, productivity, and aspiration.

The changing paradigm is supported by empirical data that is based on a number of case studies performed throughout Indonesia (Erbaugh & Nurrochmat, 2019; Zamili, 2021). According to Manalu et al. (2024), in Pulau Buluh, connected with the PLN Batam grid, diesel generation is forced out, which increases data stability in the system and provides a full 24 ⁻ time of electricity supply. Similarly, Tupalessy et al. (2015) prove that interconnections between the islands by means of submarine cables not only do a better job in correcting voltage but also ensure the reliability of the entire system over a long duration. These

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examples, though geographically separate, are brought together by one theme, and that is; interconnection of remote grids brings with it a level of reliability, cost reduction and service continuity. However, they also show the small limitations of imitation; the topography of each region, the socio-economic situation, and the demand lines set specific challenges that must be modeled with a close attention before being implemented (Ladykova & Vasilieva, 2020). On this note, interconnection is not only a technical novelty but also a place of negotiation in context.

The case of ULD Timpah in Central Kalimantan gains certain analytical importance within the context of the country on the whole. Located around ninety-five kilometres along the Palangkaraya-Buntok main road, ULD Timpah once represented the operational load of diesel-dependent systems: the total generation capacity of 1,200 kW, peak load of 730 kW and daily operations of fourteen hours with a diesel consumption of almost 100,000 litres every month (Huda, 2021). The ULD was connected to the regional grid after the de-dieselization process of PLN, transforming a profile of its operation to be not in isolation, but interconnection. This project not only made provision of electricity up to twenty-four hours in a day, but also made it accessible to more than 1,138 customers in seven neighbouring villages. As a result, an energy enclave was integrated into a larger, active grid ecosystem. This is the dual ambition of de-dieselization to promote efficiency in the system and social inclusion by creating energy accessibility.

It is based on this background that the current study will determine the performance of grid system in ULD Timpah following the de-dieselization process focusing on the efficiency of power distribution, stability of voltage and frequency, and dependability of power supply. The analytical model involves descriptive quantitative analysis and simulation with Electrical Transient Analyzer Program (ETAP) which enables a fine evaluation of the behaviour of the system prior to and after integration. The study will shed light on the contribution of de-dieselization to the engineering optimisation as well as long-term economic viability through correlation of technical information with operational and financial data. In a wider sense, it aims to offer informed opinions on how grid change in remote areas, which takes place due to a policy, can be used as a template to national energy transition policies (Markard, 2018; Poggi et al., 2020).

In the end, this paper finds the ULD Timpah project not merely as a technological experiment, but rather as a micro-scale example of how energy transition in Indonesia spreads across even the furthest areas, and that infrastructural modernization occurs even in the most remote industries.

The empirical evidence of the intersection of interconnection, efficiency, and sustainability in a single design paradigm does not only stand against the local geographical context, but it is also observable by the successful de-dieselization of Timpah. The project, therefore, sheds some light upon the larger developmental story of Indonesia, in which the goal of clean, reliable, and equitable energy is not viewed as a distant ideal, but as a structurally diffusing process, a continual process of change, taking place throughout the archipelago. In line with that, the results of the present study will be used to feed the future policies of PLN and the long-term energy governance of the country to conclude that the course of sustainable electrification includes not only the development of the power networks but also the incorporation of the possibility networks.

Methods

The research design employs a descriptive quantitative approach based on a case study, expanded into a socio-technical–financial framework to evaluate the multidimensional impact of de-dieselization on the grid system in ULD Timpah (Kapuas, Central Kalimantan). This approach not only measures the technical performance of the grid but also links it to energy

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access, affordability, user satisfaction, system resilience, and economic feasibility to ensure the findings are relevant for policy decision-making. The data collection strategy combines primary and secondary sources to ensure evidence triangulation. Primary data include structured interviews with technical and managerial staff at PLN ULP Kuala Kapuas, field observations of distribution infrastructure, and measurements of operational parameters. A household survey was also conducted to capture user perspectives regarding service reliability, electricity bill affordability, and ease of access after grid interconnection. Secondary data were obtained from daily load reports, network disturbance records, operation and maintenance logs, de-dieselization project documents, and the 2021–2030 Electricity Supply Business Plan (RUPTL).

System modeling and simulation were established using ETAP to validate power flow, voltage profiles, and losses, represented through a *single-line diagram* that reflects the actual topology. Sensitivity scenarios were tested to assess performance variations due to load growth, operational changes, and external conditions (such as extreme weather), while anticipating integration challenges from renewable power plants commonly associated with de-dieselization programs. Technical analysis was carried out to assess distribution efficiency, voltage–frequency stability against operational standards, reliability based on SAIDI and SAIFI, and unit operational readiness through EAF. Distribution efficiency was calculated using the formula $\eta = (P_{load} / P_{input}) \times 100\%$, while system stability was assessed based on deviations in voltage and frequency from operational standards (voltage ±5% and frequency 49.5–50.5 Hz). The pre–post comparison was conducted over an equivalent time horizon to minimize seasonal bias, with cross-validation between field measurements and ETAP simulation results.

The socio-technical complement captured service accessibility (spatial coverage and service hours), affordability (ratio of electricity cost to household income), user satisfaction (Likert scale validated for reliability), and system resilience (recovery speed and performance under extreme events). These indicators ensured that the evaluation was not reduced to purely engineering metrics and reflected service value from the user's perspective, including rural and vulnerable communities. Financial feasibility analysis applied investment evaluation practices commonly used in electricity infrastructure projects, including NPV, IRR, *payback period*, and *cost–benefit analysis* (CBA). The cost–benefit components consisted of capital expenditures for the interconnection network, operation and maintenance costs, fuel and lubricant savings, reduction of energy losses, and increased revenue from extended service hours. This framework was enhanced with an *avoided cost* approach to quantify economic efficiency compared to full-day diesel power plant operation.

The technical–economic integration procedure explicitly linked improvements in grid performance to corresponding financial benefits. Reductions in losses and voltage profile improvements were mapped to operating cost savings; SAIDI/SAIFI improvements were linked to decreased outage-related losses (including proxy costs for priority customers); and extended service hours were evaluated for their impact on electricity sales growth. The technical and financial outcomes were then synthesized into a benefit–cost matrix to conclude the project's feasibility. The data analysis procedure consisted of four sequential stages: (1) pre–post comparison based on core technical indicators; (2) simulation-based validation to ensure consistency between field results and modeled outputs; (3) correlational analysis across dimensions (for example, the relationship between reliability, satisfaction, and affordability) using appropriate statistical tools; and (4) financial synthesis integrating technical results into NPV/IRR/CBA and *avoided cost* calculations. Sensitivity testing was performed for key parameters such as load growth and fuel cost assumptions.

Data quality control and instrument validity ensured the strength of inference. Validity and reliability tests were applied to the questionnaires, *data cleaning* was conducted on technical

ISSN: 2716-3865 (Print), 2721-1290 (Online)

logs, and *cross-checks* among disturbance records, operation reports, and simulation outputs reinforced construct validity. Source triangulation (interviews, observations, internal documents) was used to minimize measurement and reporting bias. Ethical and policy considerations ensured compliance with *informed consent*, respondent confidentiality, and protection of operational data. The linkage of findings to policy frameworks was achieved by referencing national electrification targets and energy transition agendas within the RUPTL, ensuring that the methodological outcomes could be operationalized as inputs for planning and decision-making.

Results and Discussion

The implementation of the de-dieselization program at ULD Timpah was carried out through the construction of a 41-kilometer medium-voltage distribution network (MVDN) connected to the BTK 02 feeder from the Buntok Main Substation (GI Buntok).

Figure 1. Construction of Medium Voltage Distribution Network (SUTM) for De-dieselization via BTK02

Based on the results of power flow simulation using the ETAP application, it was found that prior to the project implementation, the voltage at the end of the system (Simpang Pendang) was recorded at 20.54 kV, which is still within the standard operating range of +5% / -10% from the nominal voltage of 20 kV. After the construction of the network and integration into the grid system, the voltage at that point became 19.17 kV, which also remains within the standard tolerance limits. This indicates that, technically, the voltage quality of the system has been maintained after the de-dieselization.

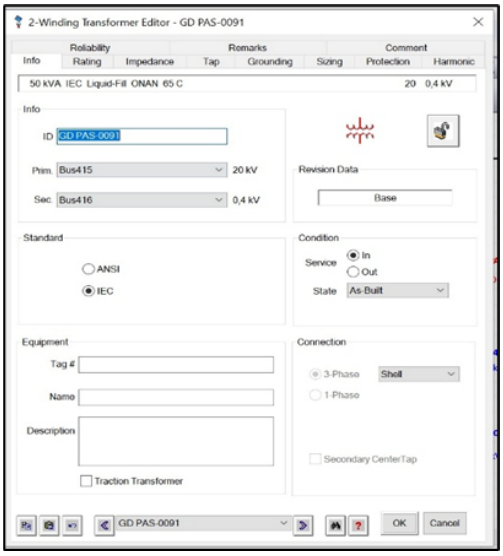

Figure 2. Transformer Input in ETAP Application

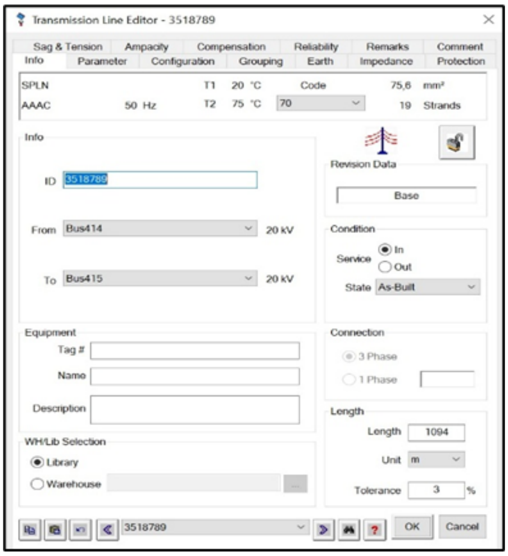

Figure 3. Conductor Input in ETAP Application

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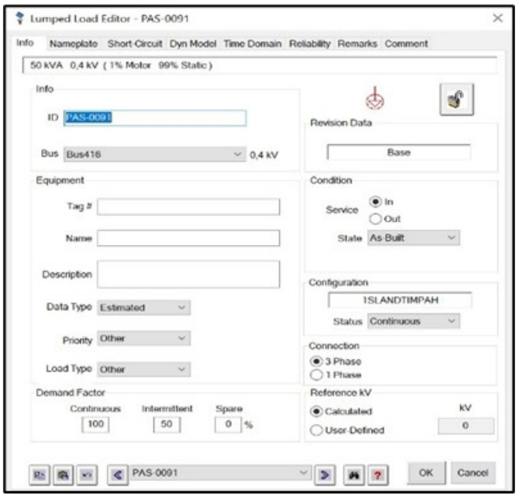

Figure 4. Load Magnitude Input in ETAP Application

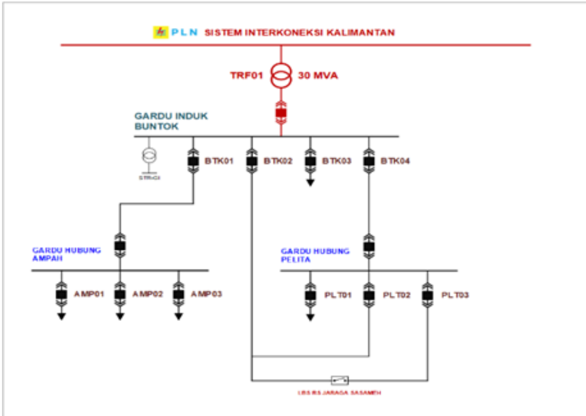

Figure 5. Single Line Diagram of GI Buntok Interconnection System

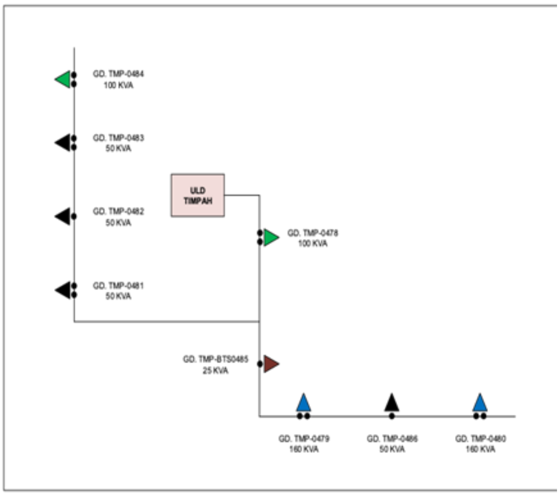

Figure 6. Single Line Diagram of the Isolated System of ULD Timpah

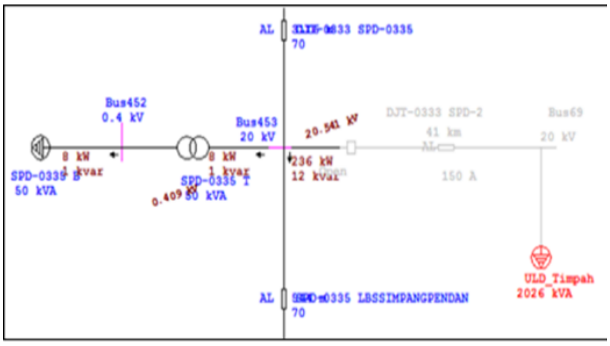

Figure 7. Power Flow Simulation Results in ETAP Application Before the De-dieselization Project

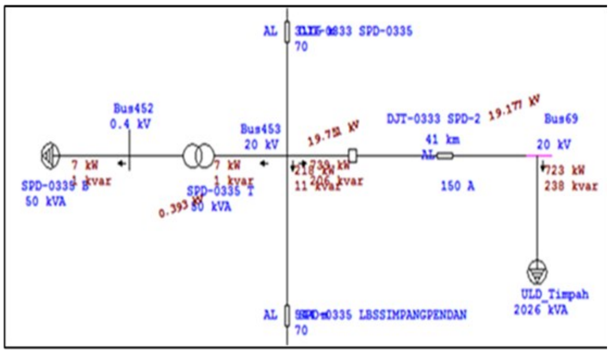

Figure 8. Power Flow Simulation Results in ETAP Application After the De-dieselization Project

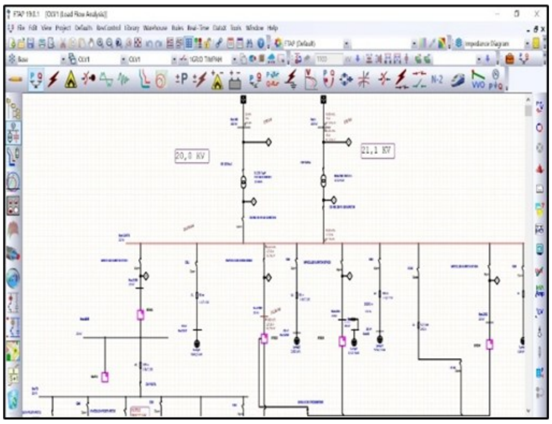

Figure 9. Power Flow Simulation Results in ETAP Application After the Integration of the Timpah System / De-dieselization Project

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Table 1. ULD Timpah Power Plant Report as of December 2024

Power Station Name / Engine Type	Central Code	No. of Units	Installed Capacity (kW)	Maximum Capacity (kW)	Operating Hours	Total kWh	Actual Fuel Consumption (L)	Fuel Loss (L)	Total Fuel (L)	Actual Lubricant Use (L)	Lubricant Loss (L)	Total Lubricant (L)
TIMPAH	2E+10	7	2,378	1,696	—	—	1,766,268	370,956.95	370,956.95	3,927	—	3,927
Deutz / F 5 L-413 FR / 8048168	2E+10	1	40	36	14	—	0.00	0.00	—	—	—	
Deutz / F 6 L-912 / 8681917	2E+10	1	40	35	14	—	0.00	0.00	—	—	—	
D-MWM / TBD 616-V12 / 2205186	2E+10	1	528	315	14	569,554	120,183.05	120,183.05	1,686	—	1,686	
Deutz / TCD 2013 L06 4V / 12021676	2E+10	1	200	180	14	132,452	29,607.50	29,607.50	596	—	596	
Deutz / TCD 2013 L06 4V / 12021658	2E+10	1	250	180	14	31,108	7,108.40	7,108.40	160	—	160	
SCANIA (Mobile Genset) / DC09 072A / 6933336	2E+10	1	264	250	14	142,564	31,453.50	31,453.50	406	—	406	
D-MWM / TBD 616-V12 / 2203515	2E+10	1	528	350	14	720,909	149,283.55	149,283.55	1,079	—	1,079	
Rental / Doosan / PT. Gala	—	1	528	350	14	169,681	33,320.95	33,320.95	—	—	—	

Table 2. Reliability Performance Report of ULD Timpah as of June 2024

UNIT	SAIDI (MINUTES / CUSTOMERS)			SAIFI(TIMES/CUSTOMERS)		
	Target 2024	**Realization sd.**	**%**	**Target 2024**	**Realization sd.**	**%**
ULP BUNTOK	299,64	507,57	59,03	5,41	5,61	96,43
ULP KPS KOTA	455,08	154,23	295,07	5,19	3,72	139,52

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ULP MUARA TEWEH	1098,26	1083,28	101,38	11,3	10,3	109,71
ULP PULANG PISAU	437,48	626,67	69,81	8,12	9,12	89,04
ULP PURUK CAHU	847,27	821,55	103,13	2,47	4,17	59,23
ULP TAMIANG LAYANG	359,64	165,13	217,79	8,84	6,8	130,00
ULD TIMPAH	787,04	1072,02	73,42	8,95	12,68	70,58
ULD PUJON	874,03	884,65	98,80	8,67	11,34	76,46

Table 3. Reliability Performance Report of ULD Timpah as of December 2024

UNIT	SAIDI (MINUTES / CUSTOMERS)			SAIFI(TIMES/CUSTOMERS)		
	Target 2024	Realisasi sd.	%	Target 2024	Realisasi sd.	%
ULP BUNTOK	299,64	402,99	74,35	5,41	5,98	90,47
ULP KPS KOTA	455,08	354,44	128,39	5,19	4,54	114,32
ULP MUARA TEWEH	1098,26	983,13	111,71	11,3	11,13	101,53
ULP PULANG PISAU	437,48	516,34	84,73	8,12	8,92	91,03
ULP PURUK CAHU	847,27	721,11	117,50	2,47	3,45	71,59
ULP TAMIANG LAYANG	359,64	215,22	167,10	8,84	7,24	122,10
ULD TIMPAH	787,04	772,02	101,95	8,95	8,78	101,94
ULD PUJON	874,03	899,65	97,15	8,67	12,76	67,95

As a more detailed overview of the power plant's condition prior to de-dieselization, the operational report for ULD Timpah up to December 2024 shows that there were 9 diesel engine units with a total installed capacity of 2,378 kW and a peak load of 1,340 kW. The recorded energy production was 535,426.85 kWh, with diesel fuel consumption reaching 64,713.95 liters and lubricant usage totaling 3,927 liters (Table 1). This high fuel consumption reflects the characteristic of diesel power plants (PLTD) as energy-inefficient and costly.

In addition to maintaining voltage stability, the de-dieselization program also contributed to improved distribution system reliability at ULD Timpah. Before de-dieselization, ULD Timpah was only able to provide electricity for 16 hours per day. However, after the system was connected to the regional grid, operational hours increased to a full 24 hours. This change is expected not only to improve service to the community but also to directly increase electricity sales revenue. According to PLN data, projected annual revenue increased from IDR 1.83 billion to IDR 2.67 billion following the extension of operational hours and increased energy supply capacity.

Beyond extended electricity service hours, the technical performance of the power plant can also be measured through the Equivalent Availability Factor (EAF), which reflects the plant’s operational availability relative to its maximum capacity. Based on the 2024 EAF realization data for PLTD units in the UID Kalselteng region, including ULD Timpah (within the UP3 Kuala Kapuas jurisdiction), the average monthly EAF ranged between 87% and 94%, with achievement levels reaching between 0.87 and 1.10 times the target. This indicates that, in general, diesel power plants continued to operate reliably, but de-dieselization offers opportunities for further efficiency improvements and reductions in the high operational burden of PLTDs. The EAF value also serves as an important reference for evaluating performance before and after the transition from an isolated to a grid-connected system.

Table 4. Financial Analysis Results

Parameter	Value	Criteria	Result
NPV (Net Present Value)	-30.47	> 0 (Positive)	Not Feasible
IRR (Internal Rate of Return)	#NUM!	> Discount Rate	#NUM!

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BC Ratio (Benefit-Cost)	0.82	> 1	Not Feasible
Payback Period	-39.38	< Asset Lifetime	Not Feasible
Profitability Index	-1.42	> 1	Not Feasible

Table 5. Avoided Cost Financial Analysis

Parameter	Value	Criteria	Result
NPV (Net Present Value)	162.55	> 0 (Positive)	**Feasible**
IRR (Internal Rate of Return)	58.47%	> Discount Rate	**Feasible**
BC Ratio (Benefit-Cost)	1.78	> 1	**Feasible**
Payback Period	1.82	< Asset Lifetime	**Feasible**
Profitability Index	59.23	> 1	**Feasible**

In terms of system efficiency, operational analysis indicates that the construction of the new distribution network has reduced dependency on local diesel power plants, which previously had a very high Basic Production Cost (BPP) of IDR 2,859 per kWh. Following the de-dieselization and integration into the grid system, the targeted BPP was reduced to IDR 1,381 per kWh. This efficiency has contributed to a reduction in annual operating costs, which previously reached IDR 7.3 billion. Although the initial financial analysis deemed the project unfeasible (due to a negative Net Present Value or NPV), the avoided cost analysis conducted to assess whether alternative solutions could result in cost savings showed otherwise. If avoided costs exist, they reflect the efficiency gained from the project. The avoided cost financial analysis compared the 24-hour operation of diesel power plants (PLTD) with the operation of the grid through a 20kV system. As shown in Table 3, when compared to operating the PLTD for 24 hours, the project becomes feasible, as evidenced by a positive NPV of IDR 162.55 billion. Thus, this project proves to be efficient when compared to full-day operation of diesel generators.

Discussion

Technical Aspect

The implementation of the de-dieselization program at ULD Timpah demonstrates improvements in the technical aspects of the electrical system, particularly in maintaining voltage distribution stability. Based on the results of power flow simulation using ETAP 19, the base voltage at the Buntok Substation (GI Buntok) for the BTK 02 feeder was 21.5 kV. Before the project, the voltage at the furthest distribution substation point in Timpah Village dropped to 20.54 kV, and after the grid integration with GI Buntok, it dropped further to 19.17 kV. Both values remained within the operational standard range of ±5% from the nominal voltage of 20 kV. This confirms that despite the system configuration shift from isolated to grid-connected, voltage quality remained controllable. Voltage stability is essential to ensure user comfort, protect consumer electrical equipment, and maintain distribution system efficiency.

Moreover, the power flow analysis revealed that energy distribution through the new network showed good performance in terms of power quality and reliability. No significant short-circuit disturbances or hazardous load imbalances were identified. Evaluation results confirmed that the technical requirements for power flow, system reliability, and electrical power quality were fully met following the new network's implementation. Thus, the de-dieselization through network development successfully met the technical criteria required to enhance the electrical system performance in the ULD Timpah area.

Operational Aspect

The de-dieselization of ULD Timpah not only impacted the technical dimension but also introduced major changes in the operational aspect of the power system. One of the most

ISSN: 2716-3865 (Print), 2721-1290 (Online)

notable improvements was the increase in electricity operating hours. Prior to de-dieselization, the isolated system could only supply electricity for 16 hours per day, whereas after the project, the system was planned to operate continuously for 24 hours.

This extension of operating hours is crucial to improving the quality of life for local communities, expanding economic activities, and enhancing productivity in key sectors such as commerce and education, as supported by research from Farghali et al. (2023).

Furthermore, the number of customers served is expected to increase alongside improved reliability in power supply. With more reliable electricity service, as reflected in the 2024 SAIDI and SAIFI performance data for ULD Timpah, there was a notable reduction in service disruption frequency and duration. The SAIFI performance target was 787.04 interruptions/customer, and the actual performance was 772.02 interruptions/customer. Similarly, the SAIDI performance target was 8.95 hours/customer, and the actual figure was 8.78 hours/customer by December 2025 (Table 3). These figures show a substantial improvement compared to the performance prior to grid connection, where as of June 2024, SAIFI reached only 73.42% of the target and SAIDI achieved just 70.58% (Table 2). The improvement in reliability is expected to increase the electrification ratio in the region in a more sustainable manner. Overall, in terms of operations, the de-dieselization program has led to a significant transformation in improving customer service in Timpah District and its surrounding areas.

Financial Aspect

From a financial perspective, the analysis of the *de-dieselization* project at ULD Timpah reveals both strengths and potential limitations, particularly in how the results are framed. The financial outcomes are summarized in Table 4 (*Financial Analysis Results*) and Table 5 (*Avoided Cost Financial Analysis*), which are placed before this subsection to support interpretation. Based on the initial feasibility assessment using conventional metrics, the project was considered not financially viable because the Net Present Value (NPV) was negative and the payback period was not favorable. However, when the evaluation incorporated *avoided cost* representing the savings achieved by avoiding continuous diesel operation the results shifted dramatically. The recalculated analysis yielded a positive NPV of IDR 162.55 billion, suggesting that the project becomes financially feasible when indirect cost savings are recognized.

In addition to the NPV improvement, the program also resulted in a reduction of the Basic Production Cost (BPP) from IDR 2,859/kWh to IDR 1,381/kWh. This significant decrease reflects improved cost efficiency, reduced fuel dependency, and potential long-term operational benefits. Such outcomes indicate that the project not only enhances the technical reliability of the electricity system but also strengthens PLN's operational profitability and sustainability commitments. Nevertheless, the current analysis presents a simplified financial contrast negative NPV under conventional metrics versus positive NPV with *avoided cost* without fully examining the assumptions behind this difference. The baseline scenario assumes uninterrupted 24-hour PLTD operation, which may not reflect actual field conditions where downtime, load restrictions, and fuel supply constraints frequently occur. This assumption can potentially inflate the perceived savings and make the project appear more financially attractive than it might be under realistic operating circumstances. To enhance credibility, it is recommended to adopt a scenario-based approach that compares results under different operational realities: a) Scenario 0 (S0) : Actual PLTD operation (16 hours/day, with downtime); b) Scenario 1 (S1) : Idealized 24-hour PLTD operation (current *avoided cost* baseline); c) Scenario 2 (S2) : Grid-connected case with conservative demand growth; and d) Scenario 3 (S3) : Stress case with higher O&M costs and slower demand increase.

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Such a framework would better capture the variability of financial outcomes and reduce the risk of overestimation.

Furthermore, the analysis currently lacks a sensitivity evaluation, which is essential to measure how volatile parameters could affect project feasibility. Diesel fuel prices are highly unstable, while demand growth in rural electrification systems can fluctuate significantly. Incorporating sensitivity tests on key parameters such as diesel price, demand growth, CAPEX, O&M cost, and discount rate would strengthen the robustness of the findings and align the study with standard practices in energy economics, where uncertainty is an inherent part of financial decision-making.

The reduction in BPP also holds broader strategic relevance, as lower BPP values support national energy policy goals by contributing to energy subsidy reduction through decreased dependence on costly diesel-based generation, aligning with the 2021–2030 RUPTL targets on efficiency and renewable integration, advancing rural electrification by enabling continuous 24-hour service in underserved areas, and supporting Indonesia's energy transition through greater readiness for renewable energy integration within interconnected grids. These connections between project-level outcomes and policy objectives highlight that the de-dieselization program contributes not only to local operational efficiency but also to Indonesia's long-term sustainability agenda. Nevertheless, several limitations should be acknowledged. The financial model assumes 24-hour PLTD baseline operation, which may overstate avoided cost gains; input volatility such as fuel price, demand, and O&M cost was not examined through sensitivity testing; and the ETAP model focused solely on steady-state power flow without considering contingency or dynamic reliability analyses. Despite these limitations, the findings indicate that the de-dieselization project at ULD Timpah remains financially promising when assessed through a more realistic, scenario-based framework that incorporates operational variability and long-term efficiency improvements.

Conclusion

This study concludes that the implementation of the de-dieselization program through the construction of a new distribution network in ULD Timpah has successfully improved the quality of the electricity system across various aspects. Technically, the distribution voltage remained stable within standard limits, and the power quality met operational criteria. Operationally, electricity service hours increased from 16 hours to 24 hours per day, potentially expanding energy access for the community and driving local economic growth. Financially, although the initial feasibility analysis showed negative results, the avoided cost analysis demonstrated that the project is feasible, yielding significant efficiency gains and a positive NPV. Overall, the de-dieselization program in ULD Timpah is considered effective in enhancing the efficiency, reliability, and sustainability of energy supply in remote areas.

Based on the findings of this study, it is recommended that PT PLN (Persero) accelerate the development of similar de-dieselization projects in other isolated areas, while continuing to prioritize technical and financial analyses based on avoided cost to optimize project efficiency. In addition, regular monitoring of the new grid's performance is necessary to ensure long-term system stability, including the optimization of load management and maintenance programs. Increasing the capacity of human resources in operational areas is also essential to manage more complex and modern grid systems. These efforts are crucial to support the national electrification program and the energy transition toward a more reliable and environmentally friendly power system.

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