DINASTI RESEARCH
Ranah Research
Journal of Multidisciplinary Research and Development
E-ISSN: 2655-0865
082170743613 ranahresearch@gmail.com https://jurnal.ranahresearch.com

DOI: https://doi.org/10.38035/rrj.v7i6

Optimization of Distribution Network Inspection Using Drones to Improve Maintenance Effectiveness

Muhammad Yoga Prima Nanda[1]
[1]Department of Electrical Engineering ITPLN, myoga2310092@itpln.ac.id

Corresponding Author: myoga2310092@itpln.ac.id[1]

Abstract: The maintenance of Medium Voltage Overhead Distribution Lines (SUTM) requires effective inspection methods to ensure the reliability of power supply. Conventional inspection methods have limitations in comprehensively detecting damage and are less efficient in terms of time, cost, and worker safety. The use of drones as an alternative technology offers a faster, more accurate solution capable of reaching difficult areas, thereby improving the effectiveness of distribution network maintenance. This study aims to optimize the use of drones in inspecting SUTM distribution networks by comparing the effectiveness, time efficiency, and operational costs between conventional methods and drone-based inspections. The results of the study indicate that the average inspection time was reduced from 66.45 minutes (conventional) to 21.20 minutes (drone), resulting in a 68.1% improvement in time efficiency. The average operational cost decreased from Rp 648,220 to Rp 298,380, equivalent to a 54% cost saving. Furthermore, the number of faults detected increased from 2.58 to 6.70, representing a 159.7% enhancement in detection effectiveness. Therefore, the implementation of drones in distribution network inspections is a strategic step to support a more reliable and modern maintenance system.

Keyword: *Network Inspection, Drone, Maintenance Effectiveness, Technology.*

INTRODUCTION

The maintenance of medium-voltage distribution networks (SUTM) plays a crucial role in ensuring the reliability of power systems, particularly in an archipelagic country like Indonesia, which faces geographic challenges and a wide distribution of customers. Disruptions in distribution networks can be caused by various factors such as environmental conditions (extreme weather, fallen trees), technical issues (cracked insulators, loose connectors), and external interferences (wild animals or physical accidents). Therefore, routine inspection activities are essential to detect potential disturbances early and prevent outages that could lower service quality (Li et al., 2022).

To date, network inspection practices still rely heavily on conventional methods, namely direct visual observation by field personnel from the ground or by climbing distribution poles. These methods have several limitations, such as prolonged inspection times, high safety risks, subjective assessments, and limited viewing angles (Adhikari et al., 2021). As a result, many minor damages such as fine cracks in insulators or corrosion in connectors often go undetected until they escalate into more serious faults.

In the context of increasing demands for reliable and sustainable electricity systems, network maintenance activities are now required to be more adaptive to technological developments and the dynamic operational environment. As electrical loads grow due to economic development and electrification in remote areas, the pressure on distribution infrastructure increases. Consequently, maintenance approaches must not only repair damage but also prevent potential failures before they occur, through data-driven and condition-based maintenance strategies (Gungor et al., 2013). This approach emphasizes the importance of accuracy and speed in detecting early signs of failure, which highly depends on the quality and completeness of field information. In this regard, digital transformation in the electricity sector becomes key, including the adoption of sensors, artificial intelligence, the Internet of Things (IoT), and the integration of Geographic Information Systems (GIS) to support faster and more accurate decision-making (Pagnano et al., 2019).

On the other hand, the limited human resources and challenging terrain in many regions of Indonesia—particularly inland, mountainous, and island areas—further reinforce the urgency of innovation in inspection methods. Field technicians often have to travel long distances with limited access, face extreme weather, or hazardous natural conditions just to inspect a single network segment. This not only increases operational costs but also delays response time to potential faults (Li et al., 2022). Amid demands for improved operational efficiency and workplace safety, electricity providers such as PLN need to consider adopting technologies that can address geographic challenges and limited resources. Therefore, a more modern, flexible, and smart technology-based maintenance approach is needed to ensure reliable electricity service, especially in regions with unique and complex characteristics.

Aligned with the national policy direction in the 2020–2024 National Medium-Term Development Plan (RPJMN), the Indonesian government emphasizes the importance of infrastructure quality improvement and digitalization of public services, including in the electricity sector (Bappenas, 2020). PLN, as a strategic state-owned enterprise (SOE) in the energy sector, has established a digital transformation roadmap that includes the development of technology-based monitoring and maintenance systems (PLN, 2020). One of the main pillars of this transformation is the implementation of digital intelligent maintenance, which prioritizes the use of real-time data, automation, and advanced technology to enhance operational efficiency, reliability, and safety.

In addition to operational efficiency, modernizing network inspection methods also contributes directly to improved occupational health and safety (OHS) standards. Conventional inspections that require technicians to climb poles or operate near live lines present significant risks of workplace accidents. According to internal PLN data and global reports on electrical industry safety, most incidents during network maintenance occur during manual inspections carried out in poor weather conditions, with limited access, or while technicians are working at height (Adhikari et al., 2021). Therefore, the use of technologies such as drones can significantly reduce direct human exposure to field hazards while strengthening a culture of safe working practices that is a top priority in distribution operations. Moreover, adopting digital inspection technologies supports environmental sustainability by enabling electronic data collection and documentation, thereby reducing the need for repeated physical travel that contributes to carbon emissions from operational vehicles (Gungor et al., 2013).

Considering all these challenges—from geographical conditions and human resource limitations to operational efficiency demands, digital transformation, and safety standards—there is an urgent need to adopt a more adaptive, precise, and future-oriented inspection approach. Emerging technologies that can access high-risk areas without direct human intervention have become increasingly relevant in the context of distribution network maintenance. One of the most prominent technologies in recent years is the drone-based inspection system (Unmanned Aerial Vehicle/UAV), which offers not only long-distance visual capabilities but also the potential for integration with various intelligent analytic tools (Pagnano et al., 2019). This has prompted further studies on the effectiveness of UAV implementation in supporting maintenance tasks that were previously heavily reliant on manual fieldwork.

Recent advancements in drone technology offer innovative solutions to these challenges. Drones enable the collection of high-resolution visual and thermal data from hard-to-reach locations without needing to shut off power or endanger personnel. Equipped with integrated navigation systems, cameras, and advanced sensors, inspection activities can be conducted more quickly, efficiently, and digitally documented (Li et al., 2022). Previous studies have reported that UAVs can reduce inspection time by over 50%, cut operational costs, and increase the effectiveness of fault detection compared to manual methods (Adhikari et al., 2021).

However, quantitative studies comparing the effectiveness of drone-based inspections and conventional methods are still limited, especially in the context of distribution networks in Indonesia. This study aims to conduct a comparative evaluation between conventional and UAV inspection methods on medium-voltage distribution networks, focusing on three main aspects: inspection time efficiency, operational cost efficiency, and effectiveness in detecting potential faults. The study was conducted in the working area of UP3 Palangkaraya and involved 40 field officers experienced in using both inspection methods.

The results show that drone usage reduced average inspection time from 66.45 minutes to 21.20 minutes (a 68.1% efficiency gain), lowered operational costs from Rp648,220 to Rp298,380 (a 54% cost saving), and increased the number of fault findings from 2.58 to 6.70 (a 159.7% improvement in detection effectiveness). These findings confirm that UAV technology offers significant advantages both operationally and technically in distribution network inspection procedures (Adhikari et al., 2021) .

The main contribution of this study is to provide the first empirical dataset comparing two network inspection methods in PLN’s operational context, particularly in the UP3 Palangkaraya area. This study also serves as a technical foundation and policy recommendation for the nationwide implementation of drone-based inspection systems in the power distribution sector, in line with efforts to digitize asset maintenance and improve system reliability. Furthermore, the findings are expected to support the development of strategic policies for designing more effective and adaptive maintenance systems to meet future field challenges.

The structure of this article is organized as follows. Section II reviews the literature on distribution network inspection methods, drone technology developments, and previous relevant studies. Section III describes the research methodology, including the experimental design, data collection techniques, and performance indicators. Section IV presents the data analysis results and discussion. Section V concludes the study and offers recommendations for future implementation and development.

METHOD

This study adopts a quantitative approach using a comparative experimental method to assess the effectiveness of medium-voltage distribution network (SUTM) inspections using drone technology compared to conventional manual techniques. The comparative method was selected to allow direct performance comparison between both approaches under consistent conditions (Kothari, 2004). The aim of this research is to analyze the improvement in inspection time efficiency, fault detection accuracy, and operational cost reduction through the application of drone-based inspections (Cooper & Schindler, 2014).

The research was conducted in the operational area of PLN UP3 Palangkaraya, which is characterized by challenging geographical terrain including forested zones, slopes, and limited road access. This location was intentionally chosen to reflect realistic field conditions where conventional inspections often face operational constraints (Li et al., 2022). A total of 40 PLN technicians were selected using purposive sampling, based on their familiarity and competence with both manual and drone inspection methods. This sampling approach ensures the credibility of data collection by involving participants with relevant technical experience (Creswell, 2012).

The experiment was structured into two stages. The first stage involved conducting conventional inspections manually, where technicians either visually observed from the ground or climbed the poles using ladders and safety equipment. The second stage repeated the same inspection routes but utilized a DJI Mini 4 Pro drone. This structure ensured the validity of comparisons by maintaining equal conditions, such as weather, timing, and location (Adhikari et al., 2021). Efforts were made to maintain consistent external variables to reduce bias in evaluating the inspection performance (Snedecor & Cochran, 1989).

The DJI Mini 4 Pro drone used in this study is equipped with a 48 MP high-resolution camera and 4K HDR video recording capability, along with a 3-axis gimbal stabilizer for steady visual documentation. It also features automatic obstacle avoidance and precise GPS navigation, allowing it to perform detailed inspections of power infrastructure without requiring physical access to dangerous or elevated areas (Li et al., 2022). The drone was flown at altitudes between 15 to 25 meters above ground level, with a maximum flight duration of approximately 25 minutes and an effective inspection range of up to 1.5 km per mission (Adhikari et al., 2021). During operations, the drone captured both photographic and video footage of key distribution components such as insulators, conductors, and joints (Pagnano et al., 2019).

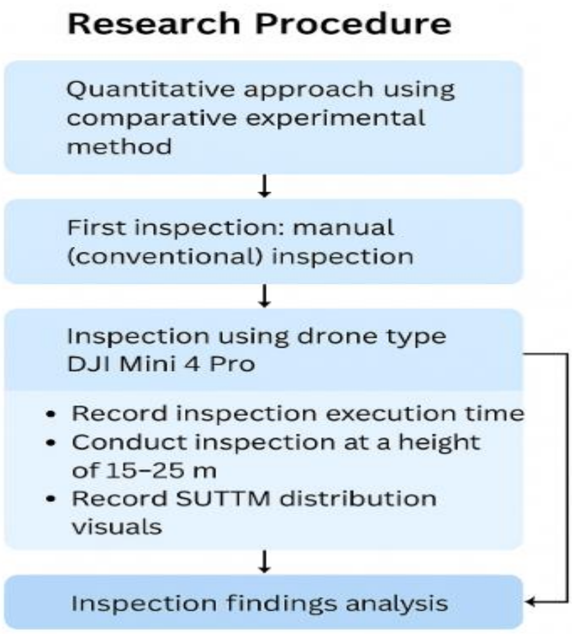

Figure 1. Research Methodology Flowchart

Figure 1 illustrates the structured flow of the research methodology, detailing the sequential steps undertaken from the formulation of the problem to the implementation of both inspection methods, culminating in data analysis and interpretation. During the manual inspection stage, technicians recorded inspection time, detected faults, and operational expenses, which included fuel consumption, manpower, and equipment wear (Gungor et al., 2013). In the drone-based inspection, the operator documented the inspection duration, flight altitude, and GPS-tagged observations. High-resolution visual data was then reviewed by the technical team for further analysis (Norman, 2013).

Data collected in this research comprised quantitative metrics such as inspection duration (in minutes), the number of faults detected, and estimated operational costs. In addition, qualitative data were gathered via a structured questionnaire to capture technicians' perceptions regarding ease of use, physical fatigue, and safety. This questionnaire was validated through a pilot test to ensure reliability, with Cronbach's Alpha values exceeding 0.8, indicating high internal consistency (Hair et al., 2010). All primary data were cross-verified with fault logs obtained from PLN UP3 Palangkaraya's official monitoring systems (PLN, 2020).

The data analysis employed descriptive statistical methods to calculate averages, standard deviations, and data distribution. To examine significant differences between the two inspection methods, a paired sample t-test was conducted using a 5% significance level ($\alpha = 0.05$) (Snedecor & Cochran, 1989). Triangulation was applied to confirm the consistency between field observations, drone findings, and PLN's historical disturbance records (Denzin, 1989). External validation further confirmed the reliability of drone-detected faults by comparing them with actual recorded outages in PLN's system logs (PLN, 2020).

This study was conducted in accordance with established research ethics. All technician participants joined voluntarily after being informed about the research objectives and processes. Data confidentiality was strictly maintained, and the information collected was used solely for academic purposes (Creswell, 2012).

RESULT AND DISUCUSSION

The findings obtained from this study provide strong and measurable evidence of the significant advantages offered by drone-based inspection technology over conventional manual inspection techniques in the context of medium-voltage power distribution networks. Among the most critical aspects observed during the comparative analysis were inspection time efficiency, reduction in operational costs, and improvements in the detection rate of potential faults. Each of these performance metrics showed substantial gains when drones were employed, thereby reinforcing the suitability of unmanned aerial vehicle (UAV) technology for large-scale implementation within the distribution sector.

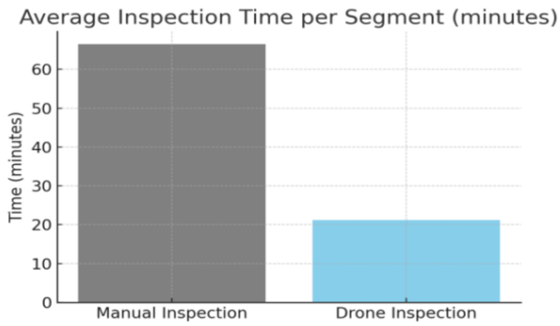

Figure 2. Drone usage significantly reduced average inspection time from 66.45 to 21.20 minutes.

As shown in Figure 2, the drone-based inspection significantly shortened the inspection duration, visually confirming the 68.1% increase in time efficiency. One of the most striking results is related to inspection duration, where drone usage reduced the average time needed for inspecting a segment of the network from 66.45 minutes to just 21.20 minutes. This change reflects a 68.1% improvement in time efficiency, an outcome that is highly relevant in scenarios where inspection teams must cover large geographical areas or respond quickly to early signs of technical failure. The ability of drones to fly over extended segments of overhead lines without the need for ground-based traversal or pole climbing allows them to reach difficult and hazardous locations much faster than human crews. This operational flexibility not only shortens task duration but also frees up resources to be allocated to other critical maintenance activities. The time advantage is consistent with earlier studies, which found that UAV deployment could compress inspection schedules by more than half, especially in rugged terrain (Adhikari et al., 2021). In practical terms, faster inspections can translate into quicker fault identification, earlier response to potential outages, and ultimately better continuity of electrical supply to customers.

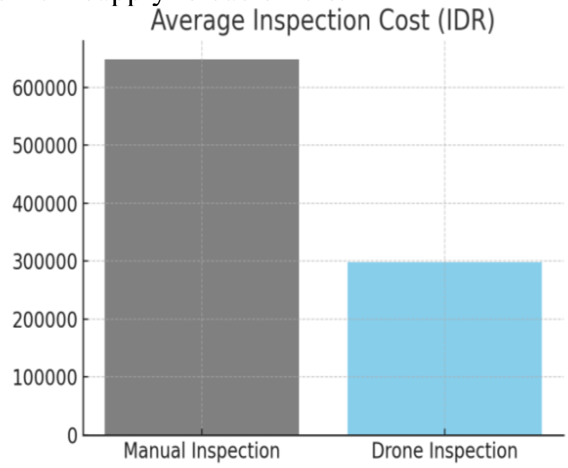

Figure 3. Operational costs reduced by 54% with drone-based inspections.

This is clearly depicted in Figure 3, which shows the comparative reduction in average operational cost, emphasizing the economic advantage of drone-assisted inspections. Another critical dimension of the analysis pertains to financial efficiency. When comparing the costs involved in executing inspections, the drone-based method reduced average expenses from Rp648,220 to Rp298,380, yielding a 54% saving in operational costs. These savings result from multiple contributing factors, including but not limited to the reduction in vehicle fuel consumption, lower dependence on large inspection crews, and decreased usage of personal protective equipment and climbing tools. Drones, when operated by a small team of trained personnel, can inspect the same infrastructure with fewer human and logistical resources. Moreover, by minimizing technician exposure to high-risk environments, the organization can reduce hidden costs associated with injury risks, downtime, and insurance claims. The financial benefit aligns with theoretical frameworks in business research that emphasize the cost-effectiveness of technology-led interventions in operational workflows (Gungor et al., 2013; Cooper & Schindler, 2014). Over the long term, PLN and similar utility providers stand to gain substantial efficiency improvements in their maintenance budgets by embracing drone-assisted inspection programs.

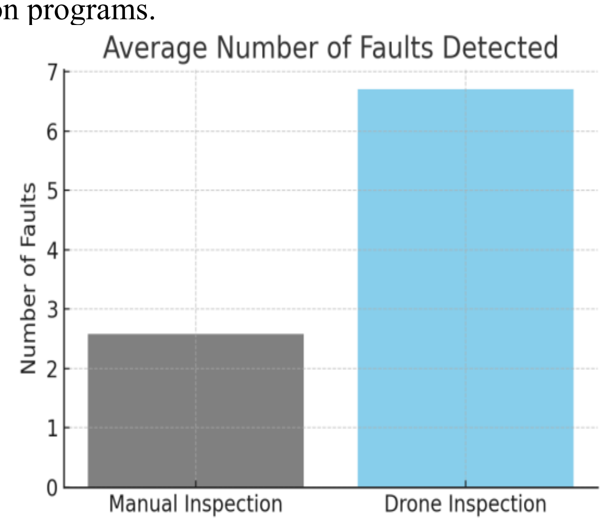

Figure 4. Fault detection improved by 159.7% with drone-based inspections.

Figure 4 illustrates this improvement, highlighting how high-resolution drone imagery facilitated more accurate and comprehensive fault identification. Perhaps the most technologically meaningful outcome of this study is the dramatic increase in fault detection capability. The number of faults or potential issues identified during inspections rose from an average of 2.58 when using manual inspection to 6.70 when drones were used—representing a 159.7% improvement. This result can be attributed to the high-resolution camera mounted on the DJI Mini 4 Pro drone, which allows operators to detect even small anomalies such as micro-cracks in insulators, corrosion on connectors, or signs of vegetation encroachment that may not be visible from ground level. The aerial vantage point offered by drones gives a more complete and accurate picture of the system's condition. These findings confirm the claim that drone systems not only accelerate the inspection process but also enhance its quality by reducing the rate of missed diagnoses (Li et al., 2022; Pagnano et al., 2019). This is particularly important in preventive maintenance regimes, where early detection of small issues can avert major service disruptions or costly equipment failures.

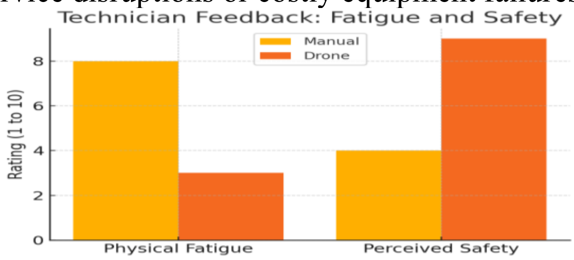

Figure 5. Technicians reported lower fatigue and higher safety using drones.

Figure 5 supports this finding, showing a summary of technician feedback indicating lower physical strain and improved safety perceptions. Beyond quantitative data, this study also considered the perceptions and experiences of field technicians. The majority of respondents reported reduced levels of physical fatigue and a marked increase in their sense of safety during drone operations compared to manual inspections. Traditional inspection often requires workers to climb poles, walk through challenging terrain, or be exposed to outdoor elements for extended periods. In contrast, drone operations are conducted remotely, often with the use of automated flight paths and minimal need for physical exertion. This shift not only improves job satisfaction and worker health but also aligns with international best practices in occupational safety and health (Norman, 2013; Adhikari et al., 2021). Therefore, the human factor becomes another strong argument in favor of adopting UAV-based solutions as part of a sustainable and worker-friendly inspection strategy.

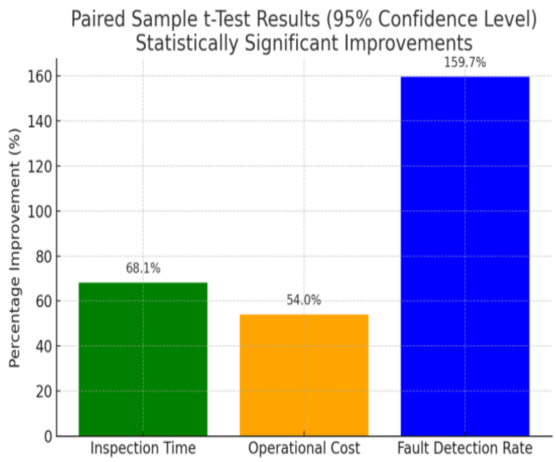

Figure 6. Statistically significant improvements based on paired sample t-tests at 95% confidence level.

Figure 6 presents the outcome of these statistical tests, confirming that the improvements recorded are not only observable but also statistically valid, reinforcing the robustness of the study's conclusions. The statistical analysis of the results supports the significance of these improvements. Using paired sample t-tests at a 95% confidence level, all differences observed between the two inspection methods—whether in time, cost, or detection rate—were found to be statistically significant. This validates the reliability of the measured outcomes and provides robust support for operational decision-making within PLN's maintenance strategy. Moreover, the consistency between quantitative results and technician feedback further strengthens the internal validity of the research and ensures that the proposed innovations are grounded in both technical performance and real-world usability.

Considering these compelling results, drone technology can no longer be viewed as merely a complementary tool; rather, it represents a transformative alternative to conventional inspection methods, especially in areas that are difficult to access or dangerous to personnel. However, to fully implement UAV-based systems, several organizational adjustments must be considered. These include workforce training in drone piloting and data analysis, investment in software for image processing and reporting, and the development of cloud-based systems to manage and archive inspection documentation. Institutionalizing the use of drones also requires the drafting of comprehensive standard operating procedures (SOPs) to guide deployments under various operational scenarios, including emergency response during extreme weather events or natural disasters. Further, integration with Geographic Information Systems (GIS) and artificial intelligence tools could enhance the value of collected data by enabling predictive maintenance scheduling and automated fault recognition (Pagnano et al., 2019; Gungor et al., 2013). In this way, drone technology not only improves current inspection practices but also opens new pathways toward the digital transformation of distribution asset management in Indonesia.

CONCLUSION

This study concludes that the application of drone technology in electrical distribution network inspection delivers significant advantages across multiple operational aspects. First, in terms of time efficiency, drone-based inspections reduced the average inspection time by 68.1%, from 66.45 minutes to 21.20 minutes. This substantial reduction enhances productivity and allows maintenance teams to inspect broader areas in a shorter time frame. Second, regarding operational cost efficiency, the drone method lowered average expenses by 54%, from IDR 648,220 to IDR 298,380. These savings were achieved through reduced fuel consumption, minimized manpower deployment, and lower equipment usage compared to conventional methods. Third, in terms of fault detection effectiveness, the use of drones increased the number of detected anomalies by 159.7%, from an average of 2.58 to 6.70 faults per inspection. The high-resolution imaging and aerial access provided by UAVs enabled the identification of defects that were difficult to observe through manual ground inspections.

In addition to measurable operational improvements, field technicians reported lower levels of physical fatigue and an increased sense of safety during drone operations. This improvement is attributed to the reduced need for physical exertion, such as climbing poles or navigating hazardous terrain. All improvements were statistically validated using paired sample t-tests at a 5% significance level, confirming that the differences in time, cost, and detection performance between the two methods are statistically significant and not due to random variation.

Moreover, the integration of drone-based inspection aligns with PLN's digital transformation roadmap and the objectives of the Indonesian Government's 2020–2024 National Medium-Term Development Plan (RPJMN), which emphasize the digitalization of infrastructure and the enhancement of public service quality. These findings strongly support the nationwide implementation of drone inspections, particularly in geographically challenging regions, such as rural, mountainous, and island areas.

However, the successful large-scale deployment of this technology requires thorough organizational preparedness. This involves establishing specialized training programs to equip drone operators with the necessary technical competencies, allocating investment for advanced visual data analysis and management software, and formulating standardized operating procedures (SOPs) to ensure consistent and safe UAV operations. Furthermore, it is essential to integrate Geographic Information Systems (GIS) and Artificial Intelligence (AI) into the inspection framework to enable predictive maintenance strategies and support data-driven decision-making across the distribution network.

Finally, beyond its operational and technical contributions, drone-based inspection supports environmental sustainability by reducing the need for fuel-based transportation and lowering associated carbon emissions. In conclusion, the implementation of drone technology represents not only an operational innovation but also a strategic and transformative advancement toward a more reliable, efficient, and sustainable electrical distribution system in Indonesia.

REFERENSI

Adhikari, R., Shrestha, A., Gautam, B., & Poudel, R. (2021). "Application of UAV for Power Line Inspection: A Case Study." International Journal of Engineering Research & Technology (IJERT), 10(7), 1–5.

Bappenas. (2020). Rencana Pembangunan Jangka Menengah Nasional (RPJMN) 2020–2024. Jakarta: Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional.

Cooper, D. R., & Schindler, P. S. (2014). Business Research Methods (12th ed.). McGraw-Hill Education.

Creswell, J. W. (2012). Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research (4th ed.). Pearson.

Denzin, N. K. (1989). The Research Act: A Theoretical Introduction to Sociological Methods (3rd ed.). Prentice Hall.

Gungor, V. C., Sahin, D., Kocak, T., et al. (2013). "Smart Grid Technologies: Communication Technologies and Standards." IEEE Transactions on Industrial Informatics, 7(4), 529–539.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate Data Analysis (7th ed.). Pearson.

Kothari, C. R. (2004). Research Methodology: Methods and Techniques (2nd ed.). New Age International.

Li, Y., Zhang, H., & Wang, Z. (2022). "Drone-Based Inspection of Power Distribution Lines: Advances and Challenges." Energies, 15(8), 2957.

Norman, D. A. (2013). The Design of Everyday Things (Revised & Expanded Edition). Basic Books.

Pagnano, A., Maffei, A., & Rauch, E. (2019). "Smart Maintenance: A Literature Review." Procedia Manufacturing, 39, 976–983.

PLN. (2020). Roadmap Transformasi Digital PLN 2020–2024. Jakarta: PT PLN (Persero).

Snedecor, G. W., & Cochran, W. G. (1989). Statistical Methods (8th ed.). Iowa State University Press.