Safety Risk Analysis of Public Electric Vehicle Charging Station (SPKLU) Infrastructure in DKI Jakarta : A Comparative Study of Standard Requirements versus Actual Field Conditions

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Abstract— The expansion of public electric vehicle charging stations (SPKLU) requires field-based safety evaluation because regulatory compliance does not guarantee uniform implementation. This study assesses safety compliance and risk priorities at 20 PLN-associated SPKLU units in DKI Jakarta. A 52-item checklist based on Minister of Energy and Mineral Resources Regulation No. 1 of 2023, IEC 61851, IEC 62196, SNI IEC 61851-1:2017, and Jakarta Governor Regulation No. 31 of 2022 was applied. Compliance scoring, gap analysis, Pareto analysis, Spearman correlation, and HIRARC were integrated. Mean compliance was 64.48%. Electrical safety had the highest compliance at 83.33%, followed by location and accessibility at 70.33%, user health at 68.00%, and fire safety at 36.25%. Fire safety therefore had the largest gap, 63.75%. The three dominant fire-safety deficiencies each occurred at 20 locations and contributed 39.2% of non-compliance. HIRARC identified 25 risks: 10 extreme, 4 high, 8 medium, and 3 low. HIRARC identified 14 high-to-extreme risks, demonstrating that relatively high aggregate compliance can coexist with low-frequency but high-consequence safety deficiencies. The findings support risk-prioritized improvement of fire protection, emergency preparedness, and engineering controls at SPKLU.

Keywords— Charging station; Electrical safety; Electric vehicle; Fire safety; Gap analysis; HIRARC; Safety compliance

I. Introduction

The transition toward battery electric vehicles has increased the need for reliable public charging infrastructure. Public charging stations operate at the intersection of electrical systems, public access, vehicle movement, emergency response, and user interaction. Unlike controlled industrial electrical installations, SPKLU facilities are often located in public or semi-public environments such as shopping centers, office complexes, parking facilities, public facilities, and transportation areas. This operating context creates a multidimensional safety profile that cannot be assessed only from the technical performance of the charger.

Electrical hazards remain fundamental because charging systems involve high electrical energy and require effective grounding, residual-current protection, overcurrent protection, insulation, connector integrity, and emergency shutdown functions. Wang et al. identified electrical safety considerations in large-scale electric vehicle charging stations and emphasized the need to manage facility degradation, energy-system risks, and other hazards within the charging environment [1]. Kivelä et al. also demonstrated the importance of functional safety requirements, including protection against overcurrent, leakage current, and failures in charging control [2]. These findings support the need to verify whether technical protection requirements remain effective during actual operation.

Fire safety represents another critical concern. Charging facilities can experience overheating, electrical faults, connector problems, or failures associated with energy storage systems. Feng et al. proposed a whole-process fire safety framework covering pre-incident, incident, and post-incident phases and identified weaknesses related to early detection, warning systems, and emergency response integration [3]. The relevance of these issues increases in public charging environments because users may not understand electrical and fire hazards and may depend on the availability of visible instructions and emergency facilities.

The health dimension also requires attention. Dong and Lu evaluated electromagnetic exposure from DC charging stations through numerical dosimetry and reported exposure levels below the applicable ICNIRP limits under the simulated operating conditions [4]. Field evidence from the UCLA Fielding School of Public

Health has also raised attention to particulate matter around fast-charging facilities [5]. These studies demonstrate that user safety extends beyond direct electrical and fire hazards to environmental conditions around charging equipment.

Indonesia has established a regulatory framework for charging infrastructure. Minister of Energy and Mineral Resources Regulation No. 1 of 2023 establishes requirements for charging infrastructure, including electrical safety, product certification, technical personnel , supporting electrical service requirements, and operating certification [6]. IEC 61851 specifies requirements for conductive charging systems, while IEC 62196 addresses plugs, socket-outlets, vehicle connectors, and vehicle inlets [7], [8]. SNI IEC 61851-1:2017 and related SNI standards provide national references for charging system requirements. Jakarta Governor Regulation No. 31 of 2022 provides a spatial planning reference that is relevant to location and accessibility assessment [9]. The existence of standards, however, does not guarantee uniform implementation at every operating location.

Previous studies in Indonesia have mainly addressed infrastructure development, home charging, functional safety, battery swapping stations, or integrated charging safety models. Dharmawan et al. mapped the development of charging infrastructure in Indonesia but did not verify the physical safety condition of existing SPKLU through direct inspection [10]. Mangunkusumo et al. evaluated home charging safety through qualitative risk assessment, design evaluation, and installation evaluation, but the object differed from public charging stations [11]. Herzasha assessed risk in public battery-swapping stations using interviews and document-based approaches rather than direct physical inspection of SPKLU [12]. Sun et al. developed an integrated safety assessment model based on operational monitoring data, but the model did not directly compare actual conditions with a defined regulatory checklist [13]. Linja-aho reviewed EV charging safety, best practices, and regulatory aspects, while Wang et al. focused on electrical safety [1], [14]. These studies provide important foundations but leave a practical gap in direct, multidimensional verification of existing public charging infrastructure.

A further methodological opportunity comes from comparative safety auditing. Mulyono et al. applied a standard-deviation audit approach to compare ideal infrastructure conditions with field conditions and then prioritize hazardous deficiencies [15]. A similar logic is appropriate for SPKLU because the safety gap can be expressed as the difference between regulatory requirements and observed conditions. The present study extends this logic by integrating four dimensions of safety and applying HIRARC to the identified gaps.

The research objective is to quantify safety compliance, identify dominant gaps, assess risk levels, and formulate risk-prioritized control measures for SPKLU infrastructure. Unlike previous studies that primarily evaluate EV charging safety through simulation, operational monitoring, specific electrical hazards, or qualitative risk analysis, this study introduces a field-based regulatory compliance and risk-prioritization framework integrating direct inspection, multidimensional compliance scoring, Pareto analysis, and HIRARC across operating public charging stations. Twenty SPKLU sites were selected using stratified purposive sampling to represent the five administrative cities of Jakarta and variations in charger type, power rating, installation environment, and site function It contributes methodologically by integrating compliance scoring, Pareto analysis, correlation analysis, and HIRARC in a single assessment sequence. The resulting framework connects the condition of infrastructure with the urgency of corrective action.

II. Research Methodology

A. Research Design and Study Area

A cross-sectional field-based safety audit and comparative risk assessment study was conducted The quantitative component measured compliance with predefined safety requirements, while the qualitative component interpreted field conditions, hazards, and the adequacy of existing controls. The study was conducted on 20 PLN-associated SPKLU units in DKI Jakarta. The sample covered five administrative areas: South Jakarta, Central Jakarta, East Jakarta, West Jakarta, and North Jakarta. The selected units represented different charging capacities, charger technologies, and installation environments. The variation included office areas, shopping centers, public facilities, sports areas, religious facilities, and public parking environments.

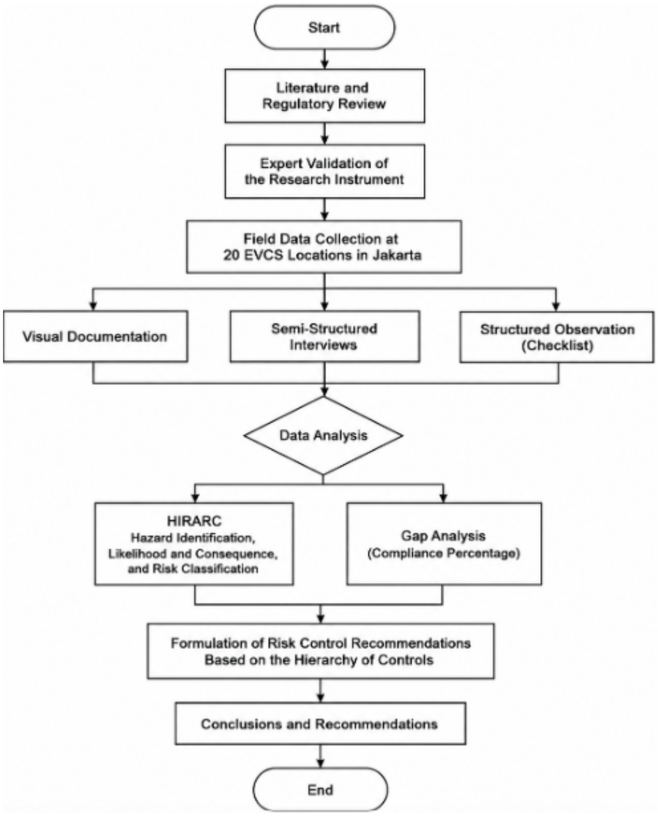

Figure 1. Research Metodhology Flowchart

B. *Safety Assessment Instrument*

The inspection instrument contained 52 items grouped into four dimensions: electrical safety, fire safety, location and accessibility, and user health. The checklist was derived from Minister of Energy and Mineral Resources Regulation No. 1 of 2023, IEC 61851, IEC 62196, SNI IEC 61851-1:2017, and Jakarta Governor Regulation No. 31 of 2022. The instrument included technical conditions such as grounding, RCD/ELCB, electrical panels, cables, emergency stop, SLO, warning labels, connectors, and electrical inspection records. The fire dimension included fire extinguishers, detectors, emergency procedures, evacuation signs, separation distances, and flammable materials. Location and accessibility covered access, physical obstacles, safety signs, directional signs, waiting areas, and vehicle circulation. User health covered ventilation, dust, cleanliness, connector condition, waiting-area separation, heat exposure, emergency contacts, air quality, and housekeeping.

Each checklist item received a binary score. A score of 1 indicated that the requirement was fulfilled, while a score of 0 indicated non-compliance. The compliance percentage was calculated as:

$$= \frac{Number\ of\ Compliant\ items}{Number\ of\ assessed\ item}\ x\ 100 \qquad (1)$$

The gap was calculated as 100% minus the compliance percentage. The study also adopted four deviation categories from the comparative safety audit approach: ≥85% = High compliance, 70–84.99% = Moderate-high compliance, 50–69.99% = Moderate compliance, and <50% = Low compliance [15].

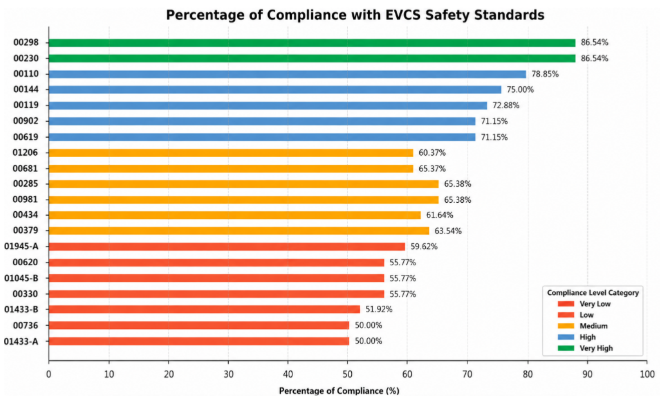

Figure 2. Percentage of compliance with EV charging station safety standards

C. *Data Analysis*

Descriptive statistics were used to obtain the mean, standard deviation, minimum, maximum, and average gap for each safety dimension. The distribution of compliance scores across locations was also examined. Because the Shapiro-Wilk test indicated that not all dimensions met the normality assumption, Spearman rank correlation was used to examine associations among the four dimensions. Correlation results were interpreted as statistical association and not as evidence of causality.

Pareto analysis was used to identify the checklist requirements that contributed most to non-compliance. The analysis ranked non-compliant requirements by frequency and calculated cumulative contribution. The purpose was to identify practical improvement priorities rather than to assume that every frequent deficiency had the highest risk.

D. HIRARC Assessment

Each significant gap was converted into a hazard and risk statement using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method. Likelihood and consequence were scored from 1 to 5. Risk was calculated as:

$$\text{Risk} = \text{Likelihood} \times \text{Consequence} \quad (2)$$

The 5 × 5 matrix classified risk scores of 1–4 as Low, 5–9 as Medium, 10–16 as High, and 17–25 as Extreme. This classification follows the matrix used in the research instrument and is consistent with the risk management references applied in the study [16], [17]. Control recommendations followed the hierarchy of controls, prioritizing elimination and substitution where feasible, followed by engineering controls, administrative controls, and personal protective equipment [18].

Table 1. Likelihood definitions and field evidence used in HIRARC.

Likelihood	Definition	Evidence
1	Rare	No or very limited evidence of occurrence under normal operating conditions; occurrence is exceptional.
2	Unlikely	Occurrence is not expected during routine operation, but credible evidence or conditions exist.
3	Possible	Occurrence can happen during routine operation or under foreseeable abnormal conditions.
4	Likely	Occurrence is expected to happen repeatedly or is supported by recurr field evidence.
5	Almost certain	Occurrence is expected in most operating situations or is supported by frequent/recurrent evidence.

III. Result and Discussion

A. Overall Compliance and Variation Across SPKLU

The field inspection found measurable differences in safety compliance among the 20 SPKLU units. The location-level compliance values reported in the study ranged from 42.31% to 88.46%. The highest location fulfilled 46 of 52 checklist requirements, whereas the lowest fulfilled 22 of 52 requirements. This spread indicates that the existence of a common regulatory framework has not yet produced uniform implementation across all observed units.

Table 2. Descriptive statistics of safety compliance across four dimensions.

Dimension	Mean	SD	Min	Max	Gap	Rank
Electrical safety	83.33%	7.95%	66.67%	100%	16.67%	1
Location & accessibility	70.33%	11.94%	53.33%	100%	29.67%	2
User health	68.00%	20.42%	20%	100%	32.00%	3
Fire safety	36.25%	19.36%	16.67%	75%	63.75%	4

Electrical safety achieved the highest mean compliance at 83.33%, with the lowest standard deviation among the four dimensions. This indicates relatively consistent implementation across locations. Location and accessibility reached 70.33%, while user health reached 68.00%. Fire safety recorded the lowest mean at 36.25% and a gap of 63.75%. The standard deviation of 19.36% also indicates substantial variation between locations.

The results suggest that the main weakness is not the basic charging function itself but the supporting safety system around the charger. Most sites showed relatively better electrical protection, including grounding, RCD/ELCB, electrical panels, and connector condition.

However, the field inspection still identified weaknesses in warning labels, emergency-stop accessibility and function, panel protection, cable arrangement, and maintenance documentation.

B. Electrical Safety

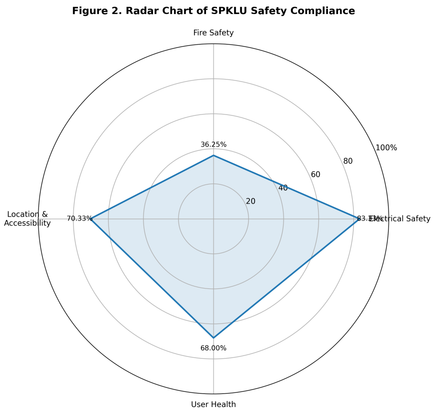

Figure 3. Radar chart of mean compliance across four safety dimensions.

Electrical safety reached 83.33%, the highest of the four dimensions. This result indicates that the core technical elements of the charging installation were generally better implemented than the other safety dimensions. The finding is consistent with the regulatory emphasis on electrical safety in Minister of Energy and Mineral Resources Regulation No. 1 of 2023 and the technical requirements of IEC 61851 and IEC 62196 [6]–[8].

Despite the high mean, the gap analysis identified important deficiencies. The largest electrical gaps involved warning labels that were not sufficiently legible, high-voltage warning labels that were absent or inadequate, and deficiencies around the nearest-point or user-access condition at charging areas. The Pareto analysis reported frequencies of 18 locations for legibility of warning labels, 13 locations for high-voltage warning labels, and 7 locations for the related charging-area requirement. Together, these three groups contributed 76% of the electrical non-compliance.

These findings are important because a high compliance percentage can conceal a small number of high-consequence hazards. The HIRARC assessment demonstrates this point. EL-01, concerning missing or unreadable high-voltage warning labels, received a consequence of 5 and likelihood of 5, producing a risk score of 25. EL-02, concerning an unavailable or non-functioning emergency stop, received consequence 5 and likelihood 2, producing a score of 10.

The EL-02 classification required a methodological correction. The original table classified a score of 10 as medium. However, the research matrix defines 10–16 as high risk. Therefore, EL-02 must be classified as High. This correction is necessary to maintain consistency between the numerical calculation and the risk category. It also illustrates why quality control of the risk matrix is essential before publication.

C. Fire Safety

Fire safety was the weakest dimension, with a mean compliance of 36.25% and an average gap of 63.75%. This result identifies fire safety as the primary improvement area. The field findings indicate that many locations lacked active fire detection, adequate fire emergency procedures, appropriate electrical-fire extinguishers, visible evacuation signs, and supporting emergency facilities.

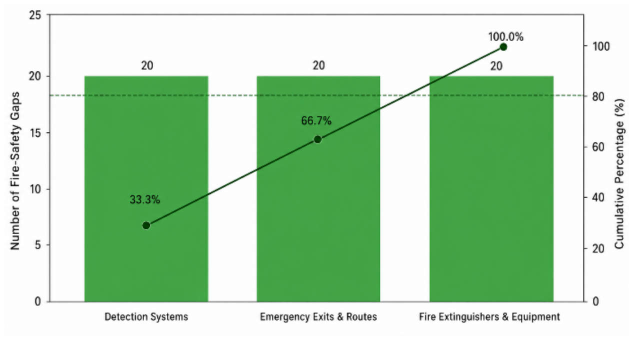

Figure 4. Pareto analysis of dominant fire-safety gaps.

The Pareto analysis identified three dominant requirements. Functional detectors, availability of smoke or heat detectors, and availability of fire emergency response procedures were each non-compliant at 20 locations. These three requirements contributed 39.2% of the total fire-safety non-compliance. The cumulative contribution increased to 79.7% after including visible evacuation signs, valid fire extinguishers, accessible fire extinguishers, and electrical-fire extinguishers.

The result is consistent with the broader safety literature, which identifies early detection and coordinated emergency response as important components of charging-station fire safety [3], [14]. The finding also has operational implications. Fire protection should not be reduced to the presence of an extinguisher. A complete system requires detection, alarm, response procedures, evacuation information, accessible firefighting equipment, and periodic inspection or testing.

D. *Location and Accessibility*

Location and accessibility achieved a mean compliance of 70.33%. The results indicate that vehicle access and general circulation were relatively good at many locations. However, the study identified weaknesses in safety signs, directional signs, waiting areas, and accessibility support.

The Pareto analysis showed that readable safety signs and availability of safety signs each had non-compliance at 18 locations. Waiting-area suitability was non-compliant at 15 locations, while directional information to the SPKLU was non-compliant at 12 locations. These four requirements contributed 70.8% of the location and accessibility gap.

The findings demonstrate that accessibility is part of safety performance. Users need to find the charging unit, understand the hazard information, enter and leave the area safely, and identify an emergency route without relying on operator assistance. This is especially relevant in public environments where users vary in age, familiarity with EV charging, and physical ability.

E. *User Health*

User health had a mean compliance of 68.00% and the highest standard deviation at 20.42%, with values ranging from 20% to 100%. The wide variation indicates that user-oriented facilities and environmental conditions differ substantially between charging locations.

Observed deficiencies included inadequate waiting areas, unclear emergency contact information, insufficient separation between charging areas and waiting areas, and differences in ventilation, cleanliness, and environmental conditions. The result should be interpreted as an infrastructure-level health and safety assessment rather than a clinical assessment of users.

The Spearman analysis found significant positive associations between electrical safety and user health .Spearman ρ + 95% bootstrap CI + adjusted p-value The strongest association occurred between location/accessibility and user health. These associations suggest that safety dimensions tend to coexist at the same site. However, correlation does not establish causality.

F. *Integrated Pareto and HIRARC Findings*

The integrated analysis shows why compliance and risk should be evaluated together. Pareto analysis identifies frequent deficiencies, whereas HIRARC identifies risks based on likelihood and consequence. A deficiency that occurs frequently may not have the highest risk score, while a less frequent deficiency can have a high or extreme consequence.

Table 3. HIRARC distribution before and after EL-02 consistency correction.

Risk category	Before correction	Final
Extreme	10	10
High	3	4
Medium	9	8
Low	3	3
Total	25	25

Extreme: 10 risks. High: 4 risks. Medium: 8 risks. Low: 3 risks. Total: 25 risks. The final HIRARC distribution contains 10 extreme risks, 4 high risks, 8 medium risks, and 3 low risks. Extreme risks include deficiencies involving high-voltage hazard identification, fire detection, emergency response, evacuation, electrical-fire extinguishers, combustible materials, separation between charging units, and several user-access conditions. High risks include the corrected EL-02 emergency-stop deficiency and other hazards with substantial consequence and likelihood combinations.

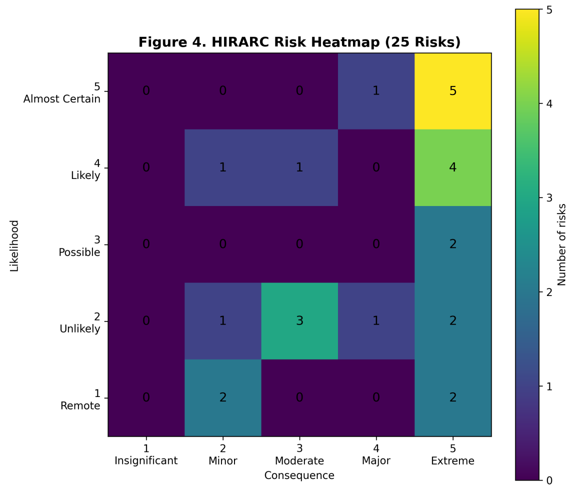

Figure 5. HIRARC heatmap for the 25 identified risks.

The heatmap indicates a concentration of risks at high consequence levels. This pattern is important because several gaps involve consequences that can be severe even when the likelihood is not the highest. The emergency-stop example illustrates the principle clearly: likelihood 2 combined with consequence 5 still produces a high risk score of 10.

The results support a risk-prioritized improvement strategy. First, the operator should address extreme and high risks. Second, the operator should address the dominant Pareto gaps within each dimension. Third, medium and low risks should remain within routine inspection and maintenance programs. This sequence avoids treating every checklist deficiency as equally urgent.

G. *Recommended Risk Controls*

The recommended controls should follow the hierarchy of controls. For electrical hazards, engineering controls should include functional emergency-stop systems, verified grounding, residual-current protection, protected panels, safe cable routing, and periodic functional testing. For fire hazards, engineering measures should prioritize suitable smoke or heat detection, alarm systems where applicable, appropriate electrical-fire extinguishers, safe separation, and control of combustible materials.

Administrative controls should include standardized inspection checklists, documented preventive maintenance, emergency response procedures, emergency contact displays, evacuation information, periodic testing, competency requirements, and documented closure of findings. The study findings indicate that several gaps involve documentation and operational consistency. Therefore, corrective action should not stop after physical installation. Each control should have an inspection frequency, responsible person, evidence of completion, and verification of effectiveness.

For location and user safety, corrective actions should include standardized safety and directional signs, accessible circulation, clear emergency routes, suitable waiting areas, safe separation from charging equipment, and clear emergency contacts. Where feasible, engineering controls such as barriers, physical separation, and controlled vehicle movement should be preferred over signs alone.

The proposed control framework is consistent with the hierarchy of controls and with risk-management principles in ISO 31000 and ISO 45001 [18], [19]. The approach also aligns with the study's central finding that safety performance depends on both infrastructure and the management system used to inspect, maintain, and verify the infrastructure.

H. *Practical and Methodological Implications*

The study has three practical implications. First, SPKLU operators can use the 52-item checklist as a periodic compliance audit tool. Second, the Pareto results provide a basis for allocating improvement resources to dominant gaps. Third, HIRARC provides a mechanism for translating compliance deficiencies into risk priorities.

The integrated sequence can be applied as a continuous safety-management cycle: field inspection, compliance scoring, gap identification, Pareto prioritization, HIRARC assessment, control implementation, and verification. This approach is more informative than reporting a single compliance percentage because it distinguishes between frequency of non-compliance and severity of risk.

The study also provides a basis for standardization across SPKLU locations. The large variation between the best and weakest locations indicates a need for consistent minimum requirements, standardized inspection criteria, documented maintenance, and periodic risk-based audits. The approach can also support future expansion of the assessment to other regions and operators. The main contribution of the study is practical and methodological. Practically, it identifies where the largest safety gaps occur and separates frequent deficiencies from high-consequence risks. Methodologically, it demonstrates how a binary compliance audit can be connected to Pareto prioritization and HIRARC without treating compliance percentage as the sole indicator of safety performance.

This distinction is relevant for operational decision-making because corrective-action budgets and maintenance resources are limited. The framework can be repeated after corrective actions to assess whether compliance improves and whether residual risks move to lower categories. In addition, the framework supports traceability from a checklist finding to a defined risk owner and corrective action. Such traceability is important in multi-site infrastructure because the same technical requirement may be implemented differently depending on site layout, maintenance practices, and local operating conditions. Routine reassessment can therefore be used to determine whether a corrective action has eliminated the hazard, reduced its likelihood, or merely improved documentation. The approach also provides a basis for management review because aggregate compliance scores can be linked to specific risk categories and dominant failure modes rather than being reported as isolated percentages. Future audits can retain the same checklist and scoring logic while adding quantitative measurements, which would improve comparability between inspection periods.

I. Study Limitations

The study has several limitations. The sample covers 20 SPKLU units in DKI Jakarta and therefore does not statistically represent all SPKLU in Indonesia. The checklist uses binary scoring, so the method does not fully capture degrees of partial compliance. The HIRARC likelihood and consequence values depend on field evidence, operator or technician information, and professional judgment, so inter-rater reliability should be examined in future studies. The study also focuses on physical and operational safety dimensions and does not model electrical transient behavior, battery thermal propagation, electromagnetic exposure through direct measurement, or long-term incident frequency.

Future research should expand the sample across Indonesian regions, validate the checklist through expert assessment, test inter-rater reliability, incorporate time-series maintenance data, and combine field inspection with quantitative measurements such as grounding resistance, residual-current protection tests, thermal imaging, air-quality measurements, and electrical power-quality monitoring.

IV. Conclusion

This study evaluated the coordination of the Over Current Relay (OCR) protection system in the 20 kV electrical distribution network supplying PT Garuda Maintenance Facility (GMF) AeroAsia Tbk. under both normal operating conditions and feeder maneuver scenarios. The evaluation was carried out through impedance calculations, short-circuit analysis, relay setting calculations based on the IEC 60255 standard, and protection coordination simulations using ETAP.

The analysis showed that the existing relay settings did not fully satisfy the selective protection coordination principle because the operating sequence between downstream and upstream protection devices was not properly coordinated. Consequently, there was a possibility that upstream protection could operate before the downstream relay during certain fault conditions, reducing the selectivity and reliability of the protection system.

After resetting the OCR parameters, the relay coordination achieved the desired protection hierarchy, where the downstream relay operated as the primary protection while the upstream relay functioned as backup protection. The proposed relay settings improved the selectivity of the protection system, reduced unnecessary feeder interruptions, and ensured that faults were isolated only within the affected section of the network.

Furthermore, the simulation results demonstrated that feeder maneuver operations between Garuda 1 and Garuda 2 did not compromise protection coordination after the proposed relay resetting. The protection system remained properly coordinated under both normal and transfer operating conditions, thereby maintaining the reliability and continuity of electrical power supply for PT GMF AeroAsia Tbk.

The findings of this research provide practical recommendations for optimizing protection relay settings in industrial medium-voltage distribution systems utilizing dual-feeder configurations. Future research may focus on implementing adaptive protection schemes and automatic feeder transfer systems integrated with SCADA to further improve protection system reliability and operational efficiency.

Acknowledgement

The authors would like to express their sincere gratitude to the Master Program in Electrical Engineering, Institut Teknologi PLN, for providing academic guidance and support throughout this research. The authors also acknowledge PT PLN (Persero), particularly the units responsible for the operation and management of Public Electric Vehicle Charging Stations (SPKLU), for granting access to the research sites and facilitating field observations and data collection. Appreciation is extended to all supervisors, lecturers, and respondents whose valuable insights and assistance contributed significantly to the completion of this study.

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