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Analytical Study of Temperature Rise in Cable Sealing End (CSE) Clamps

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ABSTRACT

The electric power system relies on high-voltage cable infrastructure in which the Cable Sealing End (CSE) serves as a critical termination component connecting underground cables to high-voltage equipment at substations. A recurring problem observed in this component is overheating at the contact point, threatening system reliability. This study aims to analyse the root cause of temperature rise in the Cable Sealing End Phase "R" at the Extra High Voltage Substation through field-based qualitative analysis using thermographic camera measurements and contact resistance testing, validated against applicable regulatory standards. Field measurements revealed a temperature delta of 30°C at the bushing, exceeding the normal operating limit of 10K, while contact resistance testing yielded 700 µΩ, significantly above the 100 µΩ threshold. Physical inspection confirmed galvanic corrosion between the aluminium conductor and copper terminal, triggered by electrolyte exposure from ambient humidity, which produced a non-conductive oxide layer that increased contact resistance and generated power loss dissipated as excessive thermal energy. Following corrective cleaning of the clamp and conductor, contact resistance was reduced to 60 µΩ within the acceptable limit. It is concluded that galvanic corrosion is the primary cause of elevated contact resistance and temperature rise, which if left unaddressed may progress to arc flash and fire. Regular thermographic inspection and contact resistance testing are strongly recommended as preventive maintenance measures.

1. Introduction
1.1 Research Background

The electric power system serves as the primary backbone for distributing electrical energy from generation sources to consumers, and its reliability and stability must be carefully maintained. The integrity of each component is critically important, as the failure of any single element can lead to the degradation of overall system operational stability [1]. One integral component within the power system is the cable sealing end (CSE), which functions as a termination point for high- and medium-voltage cable connections, and is used to interface with other electrical equipment such as

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transformers, generators, and switchgear or as a transition point between underground cables and high-voltage equipment at switchyards and substations [2,3].

One of the common encountered issues in CSEs is overheating at the contact point, which, if left unaddressed, can escalate into a complete system failure [4]. The cause of this temperature rise is associated with galvanic corrosion in CSE materials [5]. Galvanic corrosion is an electrochemical phenomenon involving two dissimilar metal alloys at a single contact point, triggered by the presence of an electrolyte that initiates an electrochemical reaction [6]. In a CSE, the aluminium cable conductor is connected directly to a copper terminal. The electrolyte present at the metal contact may originate from rainwater, condensation, or ambient humidity. The significant difference in electrode potential between aluminium and copper makes this metal pairing highly susceptible to galvanic corrosion reactions under humid conditions [7].

In this condition, a natural galvanic cell is formed in which the metal with the more negative electrode potential acts as the anode and undergoes oxidation (corrosion), while the metal with the more positive electrode potential acts as the cathode [8]. In a CSE system, aluminium serves as the corroding anode, while copper acts as the relatively protected cathode. The resulting oxidation reaction produces galvanic corrosion that forms a new layer on the material surface with non-conductive properties [9]. This oxide layer — commonly in the form of aluminium oxide or aluminium hydroxide possesses highly insulate characteristics that directly impede the flow of electric current across the CSE contact interface. Consequently, a significant increase in contact resistance occurs at the junction point. As contact resistance rises, power is dissipated in the form of power losses, which are subsequently released as heat energy in accordance with Joule's Law [10]. The greater the current flowing through the high-resistance contact, the greater the heat generated, thereby creating localized hotspot conditions that progressively accelerate material degradation.

The thermal degradation mechanism in high-voltage cable accessories has become a subject of serious concern in power system reliability studies. Prior research indicates that cable accessories such as terminations and joints represent the weakest points in cable systems, with more than 64% of high-voltage cable failure cases occurring at these accessory components [11]. Temperature rise has been demonstrated to correlate directly with the rate of contact resistance increase, leading to uneven temperature distribution and the emergence of localized hotspots at contact points [11]. Power losses in the form of thermal energy generated as a consequence of elevated contact resistance values triggered by galvanic corrosion in the constituent materials — constitute the primary driver of progressive thermal degradation in high-voltage cable accessory components [12]. This condition is further compounded when components do not receive adequate periodic maintenance, as the continuously growing oxide layer will incrementally increase contact resistance over time, ultimately culminating in total component failure [13].

1.2 Literature Review

Several studies addressing temperature rise in high-voltage cable accessories have been discussed comprehensively. As shown in Table 1, relevant research indicates that the termination point of high-voltage cable connections represents the weakest link, with more than 64% of failure cases involving contact resistance and typical defects in the components. Furthermore, temperature rise is directly proportional to the rate of contact resistance increase, resulting in uneven temperature distribution and the formation of localized hotspots at contact points [11]. This is reinforced by the work of Wu *et al*., [14], who developed a 3D electromagnetic-thermal multi-physics simulation model and demonstrated that any increase in contact resistance directly produces a disproportionate temperature surge at the junction point even minor defects can trigger the formation of hotspots capable of permanently damaging cable insulation materials. Contact resistance can generate excessive heat through power losses in the form of thermal energy, arising from resistance value increases triggered by galvanic corrosion in the constituent materials [12,13].

As investigated by Nawawi *et al*., [13], galvanic corrosion at Al-Cu bimetallic joints in overhead line conductors was shown to cause a reduction in the aluminium conductive cross-sectional area of up to 11%, directly resulting in an operating temperature rise of up to 5.5°C — a phenomenon highly relevant to the bimetallic junction conditions present in CSEs. Infrared thermography inspection is a non-contact condition monitoring method that has proven effective in detecting abnormal temperature distributions and identifying hotspots at an early stage in high-voltage substation equipment before failure occurs [15]. More specifically, the application of thermography inspection at 66 kV substations has demonstrated its capability to accurately detect hotspots at bushing connectors and switchgear equipment, establishing it as a highly reliable diagnostic tool within preventive maintenance programs for high-voltage transmission systems [16].

Table 1
Literature review

Title	Research Topic	Key Result
Electromagnetic-Thermal Multi-Physics Coupling Simulation of Cable Joints: Considering Contact Resistance and Typical Defects [11]	Electromagnetic-thermal multi-physics simulation of high-voltage cable joints by considering contact resistance and typical defects, as well as analysing the correlation between contact resistance and temperature distribution.	More than 64% of high-voltage cable failures occur at cable accessories. Cable terminations and joints represent the weakest points in high-voltage cable systems. Temperature rise correlates directly with increases in contact resistance. Defects at the joints cause uneven temperature distribution and form local hotspots.
Analytical Computation of Thermal and Electrical Issues in E-Mobility Cabling Network [12]	Computational analysis of thermal and electrical characteristics in cable networks, including the influence of contact conditions on temperature distribution and power losses.	The conductivity, temperature distribution, and electrical voltage of cables change nonlinearly as contact resistance increases. Poor contact conditions directly trigger a rise in operating temperature.

Title	Research Topic	Key Result
Thermal Characteristics of Trapezoidal Overhead Conductors Exposed to Galvanic Corrosion [13]	The thermal characteristics of trapezoidal aerial conductor (ACSR/TW) resulting from corrosion exposure.	Galvanic corrosion reducing the aluminium cross-sectional area by 11% causes an increase in operating temperature of up to 5.5°C. This phenomenon is highly relevant to the conditions of Cu-Al bimetallic joints.
Electrical Resistance Performance of Cable Accessory Interface Considering Thermal Effects [14]	The electrical interface resistance performance of silicone rubber/XLPE-based cable accessories under long-term thermal exposure.	Long-term thermal degradation cumulatively deteriorates the interface contact quality of cable accessories through three progressive and irreversible stages of resistance change.
A Review of Infrared Thermography for Condition-Based Monitoring in Electrical Energy: Applications and Recommendations [15]	A comprehensive review of infrared thermography (IRT) as a non-contact condition monitoring tool for high-voltage electrical and electronic equipment	IRT is proven effective as a condition diagnostic tool and early hotspot detection in substation equipment. Delta temperature (ΔT) criteria are used to classify normal and defective conditions. IRT is highly applicable to preventive maintenance and online monitoring programmes
Conducting Thermography Inspections in Electrical Substations: A Survey [16]	A survey on thermography inspection implementation in high-voltage substations, covering measurement methodology, environmental factors, and hotspot identification in switchgear and bushing components	Thermography inspection in 66 kV substations successfully detected hotspots at bushing connectors and high-voltage components. Load current and wind speed affect measurement accuracy. Thermography is a reliable diagnostic method for preventive maintenance programmes

Although research on temperature rise in high-voltage cable accessories has continued to advance, studies that specifically analyse the causes of temperature rise in CSE components remain highly limited. The majority of existing research focuses on intermediate cable joints along the cable route, rather than on cable termination components. Furthermore, there remains a notable gap in studies examining galvanic corrosion in conductors and electrochemical-based corrosion modelling, which in practice, constitutes one of the primary contributing factors to temperature rise in CSE systems.

Existing studies have generally examined galvanic corrosion in overhead line conductors such as ACSR and ACCC from a structural standpoint, without directly linking it to the mechanism of temperature rise caused by increased contact resistance in underground cable termination devices such as CSEs. On the other hand, while thermography as a diagnostic tool has been extensively studied for substation equipment in general, it has not been specifically directed toward analyzing the thermal condition of CSEs undergoing degradation due to galvanic corrosion. No research has yet been found that comprehensively integrates the galvanic corrosion chemical reactions at CSE joints with their measurable thermal effects, as quantified through thermography measurement data and direct contact resistance testing conducted in the field.

Based on this identified research gap, the present study aims to address the existing void in the literature by conducting an in-depth examination of the contributing factors to temperature rise in CSE components through qualitative analysis employing a SWOT analysis approach, grounded in field data findings. The methodology encompasses thermography measurements, contact resistance testing, and physical component inspection, all of which are validated against applicable regulatory standards. This research is expected to make a meaningful contribution to the development of more effective condition-based maintenance strategies for CSE components.

2. Methodology

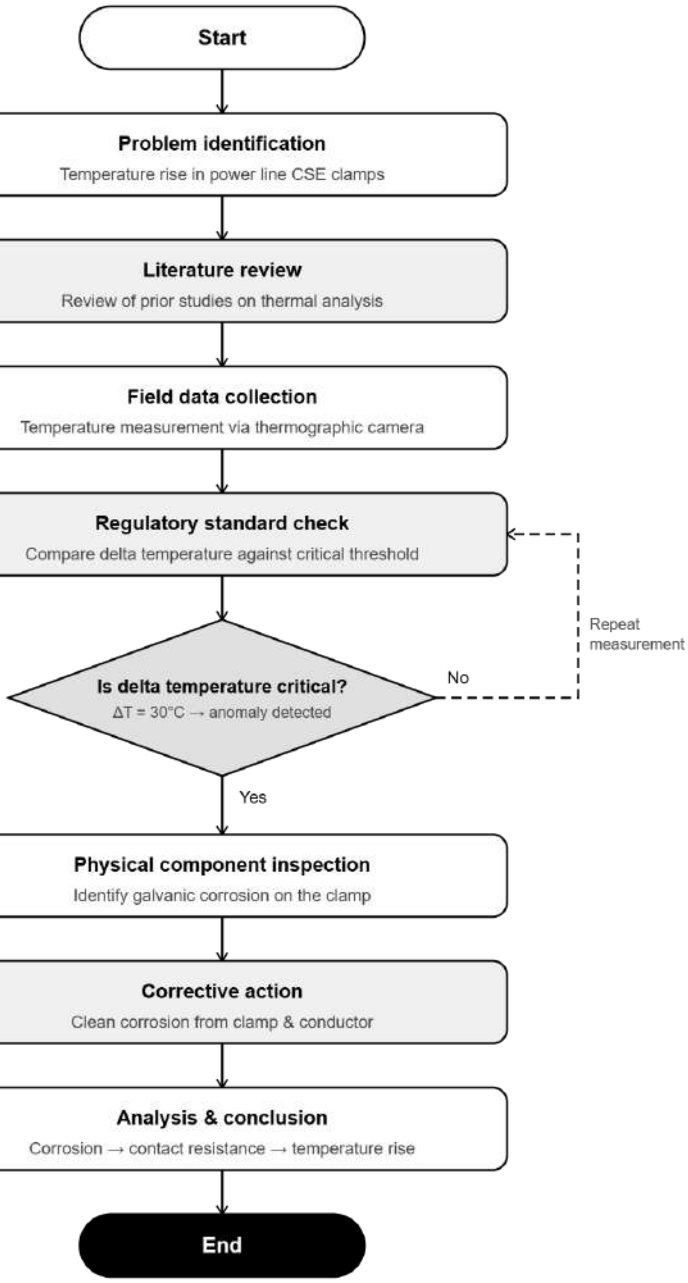

Fig. 1. Flowchart diagram

2.1 Data Collection

In this study, the data used are the results of direct field measurement tests, namely temperature data based on thermography measurements and contact resistance data on CSE clamps. The collected data were then compared against applicable regulatory standards, specifically IEC 62271-1:2017 and PT PLN (Persero) SKDIR No. 0520-2.K/DIR/2014, the details of which can be found in Table 2 [14,17]. The collected data were subsequently subjected to further analysis using the SWOT analysis approach.

Table 2
Regulation standards requirement

Parameter	Normal Value	Critically Value	Regulation
Thermal operation of conductor	≤ 90°C	> 105°C	IEC 62067:2022 / IEC 60840:2020
Delta Temperature	ΔT ≤ 10 K	ΔT > 30 K	IEC 62271-1:2017 and PT PLN (Persero) SKDIR No.0520-2.K/DIR/2014
Contact Resistance	< 100 μΩ	≥ 100 μΩ	PT PLN (Persero) SKDIR No.0520-2.K/DIR/2014

2.2 SWOT Analysis

The analysis process in this study employs the SWOT analysis approach (Strengths, Weaknesses, Opportunities, Threats), which has been widely used to evaluate research findings in a comparative manner. The SWOT analysis approach was selected for its ability to identify issues across four interrelated parameters, namely Strengths, Weaknesses, Opportunities, and Threats [18].

The Strengths parameter refers to internal factors that provide support, such as the existence of applicable standards and regulations to underpin the performance of components in the CSE. The Weaknesses parameter encompasses obstacles or deficiencies within the internal aspects of the system. The Opportunities parameter refers to external factors that can be utilized for further development of the system. Meanwhile, the Threats parameter refers to external factors that have the potential to deteriorate existing conditions, particularly in the long term. Consequently, the SWOT analysis approach can serve as a foundation for formulating recommendations regarding development initiatives and strategies to be adopted, both in the short and long term.

3. Results

Temperature measurement using a thermography camera can be observed in Figure 1 and 2, which indicates a temperature delta of 30°C at the bushing. This delta temperature value falls within the critical condition category in accordance with IEC 62271-1:2017, which stipulates that the normal operating temperature limit should be ΔT ≤ 10 K. Based on the findings from the temperature measurement, contact resistance testing was subsequently conducted, yielding a measured value of 700 μΩ. According to PT PLN (Persero) SE No. 0520-2.K/DIR/2014, the contact resistance for CSE components should be less than 100 μΩ, indicating that the obtained measurement value significantly exceeds the normal operating limit.

Fig. 2. The bushing being observed

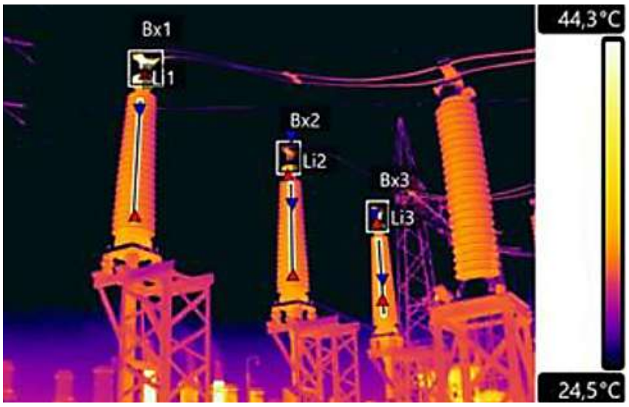

Fig. 3. Thermography measurement

Further investigation was conducted through physical inspection of the component, revealing the presence of corrosion on the CSE clamp. Figure 3 illustrates the corrosion resulting from contact between the clamp and the conductor at the bushing, for which the corrective action taken was cleaning of both the clamp and the conductor at the bushing. It is this corrosion that constitutes the primary cause of the temperature rise observed at the CSE bushing.

Fig. 4. The clamp section that has corrosion

As shown in Figure 4 and 5, the clamp component and conductor at the bushing have been cleaned of corrosion, after which retesting was conducted to verify that the component is operating within acceptable service conditions. Contact resistance was re-measured between the clamp and the conductor at the bushing to confirm a reduction in resistance value, with the expectation that the temperature at the CSE bushing would consequently decrease and the component would function properly. The contact resistance measurement results following cleaning indicated a reduction in resistance value to 60 μΩ, when referenced against PT PLN (Persero) SKDIR No. 0520-2.K/DIR/2014, falls within the acceptable normal operating limit of less than 100 μΩ.

Fig. 5. The clamp that has been cleaned

Fig. 6. The bushing conductor that has been cleaned

The Field investigations on the cable sealing end (CSE) clamp identified galvanic corrosion at the bimetallic contact interface between the aluminium conductor and the copper terminal as the principal factor driving the observed temperature anomaly. This electrochemical process, initiated by the potential difference between the two dissimilar metals in the presence of ambient moisture, causes aluminium to undergo progressive oxidation as the sacrificial anode, producing a non-conductive oxide layer composed primarily of aluminium oxide and aluminium hydroxide. The accumulation of this insulated layer at the contact interface elevates contact resistance over time, leading to disproportionate heat dissipation in accordance with Joule's Law and manifesting as a measurable hotspot condition at the clamp junction. Without intervention, this process becomes self-reinforcing, as rising temperatures further accelerate oxidation and corrosion, progressively compromising the mechanical and electrical integrity of the component and posing a risk of broader system disruption.

Physical remediation through mechanical cleaning of the corroded clamp surface and bushing conductor confirmed that removal of the oxide layer produced a significant reduction in contact resistance, thereby validating the direct relationship between interfacial surface condition and component thermal behaviour. These findings underscore the necessity of implementing a structured and routinely scheduled maintenance programme for CSE components, incorporating thermography surveys, contact resistance testing, and physical inspection to enable early detection of abnormal conditions before they escalate into critical failures. Given the CSE's function as a transitional component between underground cable systems and high-voltage substation equipment, degradation at this point carries implications for overall system reliability. A condition-based maintenance approach, guided by quantitative field data and validated against applicable technical standards, therefore represents the most effective strategy for sustaining the long-term operational performance of the power system.

4. Discussion

Based on the field measurement data obtained, the SWOT analysis regarding the factors contributing to temperature rise in CSE clamps is discussed comprehensively and presented as follows:

4.1 Strengths

The inspection method using a thermography camera and contact resistance measurements revealed abnormal readings against the normal operating standards, with a delta temperature of 30°C and a contact resistance of 700 μΩ. The availability of regulatory standards serves as the primary foundation for identification, evaluation, and follow-up actions. The corrective action of cleaning the clamp and bushing conductor demonstrated good effectiveness, as evidenced by the re-measurement of contact resistance reaching 60 μΩ, well within the acceptable regulatory threshold. Consequently, the component was able to resume operation in a safe condition.

4.2 Weaknesses

The research data utilized is limited to measurement results from a single measurement point, which constrains the generalizability of findings to other component locations, although the method applied was sufficient to identify the existing findings. The absence of quantitative predictive data, such as simulation modelling, means that the rate of decline in contact resistance and temperature caused by galvanic corrosion cannot be estimated. Consequently, this affects the scheduling of more proactive maintenance, which could be made more efficient if measurement data were collected systematically rather than manually.

4.3 Opportunities

Based on the findings of this study, opportunities arise for the development of a continuous early detection system, such as the implementation of a smart (Internet of Things) IoT-based system that enables real-time monitoring of temperature and contact resistance in CSE components. This would eliminate dependence on conventional inspection methods for maintenance execution. Furthermore, alternative analytical approaches can be applied, such as the Finite Element Method (FEM), to examine the corrosion rate behaviour of a material in greater detail, while external factors such as environmental conditions can also be modelled. This in turn enables the development of predictive maintenance estimations.

4.4 Threats

System failures originating from external factors are unavoidable, such as the tropical climate of Indonesia with its significantly high humidity levels. This constitutes an external threat that can progressively degrade system performance over the long term. Under critical conditions, this leads to various issues, one of which is that a significant temperature rise can cause arc flash, which serves as the initial trigger for fire at the contact point. Therefore, a more comprehensive and advanced approach is required to ensure the system can remain operational over an extended period.

5. Conclusions

Evaluation grounded in direct field inspection confirms that infrared thermography measurement and contact resistance testing together constitute a dependable and operationally practical approach for identifying anomalous conditions in CSE components. The measurements obtained from the affected unit recorded a delta temperature of 30°C alongside a contact resistance value of 700 μΩ, both of which surpassed the permissible thresholds stipulated under applicable regulatory standards. These figures are not merely statistical deviations; they represent concrete indicators of active thermal degradation driven by elevated interfacial resistance at the clamp contact point. The combination of both diagnostic methods proved mutually reinforcing, as thermography data provided spatial identification of the hotspot while resistance measurements quantified the underlying electrical cause, together offering a comprehensive picture of component condition.

The Corrective intervention through mechanical cleaning of the CSE clamp surface and the associated bushing conductor yielded a marked improvement in electrical contact quality. Following remediation, contact resistance was re-measured at 60 μΩ, a value that falls within the acceptable range prescribed by the relevant technical standards and represents a reduction of over 90 percent from the pre-intervention reading. This outcome substantiates the conclusion that the thermal anomaly was primarily attributable to the resistive effect of the corrosion-induced oxide layer at the bimetallic interface, and that physical surface restoration is an effective corrective measure when executed thoroughly. The result further affirms that routine inspection and timely intervention can prevent the progression of localised degradation into systemic failure.

The SWOT analysis framework applied in this study usefully illuminates both the strengths of the current diagnostic approach and the areas requiring further development. One substantive limitation lies in the reliance on single-point manual measurement, which constrains the scope of generalisation across multiple contact locations and restricts the capacity for comprehensive condition assessment across all CSE units within a network. To address this, future research should direct attention toward the development of integrated health monitoring systems for CSE components, capable of continuous or semi-continuous condition tracking that reduces dependence on periodic manual intervention. In parallel, the application of finite element simulation methods warrants serious consideration, as such approaches offer considerably greater predictive capability in modelling component behaviour under varying material and environmental conditions, encompassing both external loading factors and internal material properties that govern long-term degradation trajectories.

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