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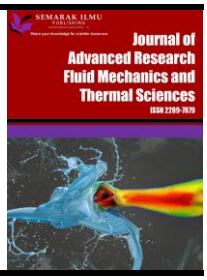


# Thermal Characteristics of Trapezoidal Overhead Conductors Exposed to Galvanic Corrosion

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**ABSTRACT**

The ampacity of overhead conductors is primarily determined by their thermal characteristics. However, current ampacity techniques assume that conductors are in an uncorroded state, a simplification that fails to account for the effects of corrosion. This oversight can lead to elevated operating temperatures in corroded conductors, potentially violating ground clearance requirements, reducing service life, and increasing public safety risks. This study utilizes COMSOL Multiphysics software to model the development of galvanic corrosion on Aluminum Conductor Steel Reinforced (ACSR) conductors with trapezoidal wires, which are commonly used in corrosive environments. Subsequently, the study applies heat transfer modelling to examine the thermal characteristics of these corroded conductors. The findings reveal that galvanic corrosion leads to a loss of conductive area in the aluminum strands, which reduces the overall conductive capacity. Under predefined ampacity conditions, this reduction causes increased temperatures at the core-aluminum interface for ACSR/TW conductors, leading to higher overall conductor temperatures. The reductions in the conductive area for Santee/TW, Martin/TW, and Hawk/TW ACSR are 4%, 8%, and 11%, respectively, resulting in temperature increases of 3°C, 4.4°C, and 5.5°C. These results highlight for the importance of considering corrosion on the ampacity determination.

## 1. Introduction

Overhead conductors are essential for power transmission sector, tasked with carrying large amounts of electrical current over extensive distances. The performance of overhead conductors is heavily influenced by their thermal characteristics, which also determine the maximum safe current-carrying capacity, or ampacity [1]. Standard methods for calculating ampacity typically assume that conductors are free from corrosion. However, in practice, these conductors are exposed to environmental factors that can lead to corrosion, particularly galvanic corrosion that occurs when

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two dissimilar metals are in contact with an electrolyte, leading to accelerated degradation [2]. The galvanic corrosion phenomenon has been found to be problematic particularly for the bimetallic Aluminum Conductor Steel Reinforced (ACSR) conductors, which are commonly used in power grids due to their high strength and excellent conductivity [3]. When corrosion affects these conductors, it can reduce the cross-sectional area of the aluminum strands and cause an increase in the conductor's operating temperature, which in turn affects its ampacity [4]. One significant factor that accelerates the corrosion phenomenon in ACSR conductors is the deterioration of the zinc galvanizing coating on the steel core strands. When this zinc coating is compromised, the exposed steel comes into direct contact with the surrounding aluminum, initiating galvanic corrosion. Corrosion starts when the protective layers on the conductor surface are damaged, and as time passes, the exposed areas expand, eventually penetrating the aluminum layer. Corrosion products in the environment can trigger this process, with factors like chloride concentration, elevated temperatures, and low pH levels accelerating the formation of corrosion [5]. Since aluminum is more anodic compared to steel, it corrodes preferentially, leading to a gradual loss of conductive material. Environmental elements, such as pollutants and moisture, worsen this process by acting as electrolytes at the interface between the aluminum and galvanized steel strands [6]. This corrosion not only compromises the conductor’s structural integrity but also alters its thermal behaviour, resulting in higher operating temperatures and an increased risk of failure [7].

The elevated temperatures due to the corrosion in overhead conductors can also lead to greater sag than originally anticipated. This increased sag can compromise ground clearance requirements, which are crucial for ensuring the safety of people and property beneath the conductors. According to the National Electric Safety Code (NESC), maintaining specific minimum clearances is essential to prevent accidental contact with the conductors [8]. As conductors operate at higher temperatures, they experience thermal expansion, which increases their length and reduces clearance from the ground [9]. Extended exposure to high temperatures can also accelerate the aging of conductors. For instance, elevated temperatures can cause annealing of the aluminum strands in ACSR conductors, diminishing their mechanical strength and making them more brittle [10]. This degradation can lead to premature failures and significantly shorten the conductors' service life [11]. Furthermore, high temperatures can also accelerate the deterioration of insulation materials and other conductor components [12].

While significant efforts have been made in detecting early-stage corrosion, a critical gap remains in the reliable detection of advanced corrosion within conductors. This issue is especially problematic for aging ACSR conductors where the protective zinc coating has severely deteriorated, leading to substantial material loss in both the aluminum strands and the steel core. Existing detection methods review which is done by several studies often focus on surface-level observations or involve costly, labour-intensive techniques that are impractical for large-scale monitoring [13,14]. A major challenge in identifying advanced corrosion is that it frequently occurs internally, at the steel-aluminum interface, which is inaccessible to visual and thermal inspections [15]. By the time corrosion manifests as noticeable performance issues, such as thermal and sag violation, the damage is typically severe, leaving little opportunity for timely intervention. This underscores the need for more effective and scalable methods for detecting and addressing advanced corrosion in conductors.

This study is performed to address the existing gap by employing COMSOL Multiphysics software to simulate the impact of galvanic corrosion on the thermal characteristics of ACSR conductors with trapezoidal wires (TW). By analyzing how corrosion affects thermal behaviour, the study aims to enhance the accuracy of performance predictions for conductors operating in corrosive environments and to refine ampacity models. Specifically, the research will quantify the effect of corrosion on the conductive area of aluminum strands and evaluate the resulting changes in

conductor temperature under set ampacity conditions. The findings will contribute as an initial fundamental step to developing more precise guidelines and standards, ultimately improving the safety and efficiency of overhead conductors in corrosive settings.

## 2. Methodology

The study employed a two-step modelling approach to investigate the thermal characteristics of corroded overhead conductors as shown in Figure 1. The first step involved simulating the galvanic corrosion process on ACSR/TW conductors using COMSOL Multiphysics software. The model considered the interaction between the aluminum strands and the steel in the presence of an electrolyte, which simulates real-world corrosive environments. The next step involved modelling the heat transfer for the corroded conductors.

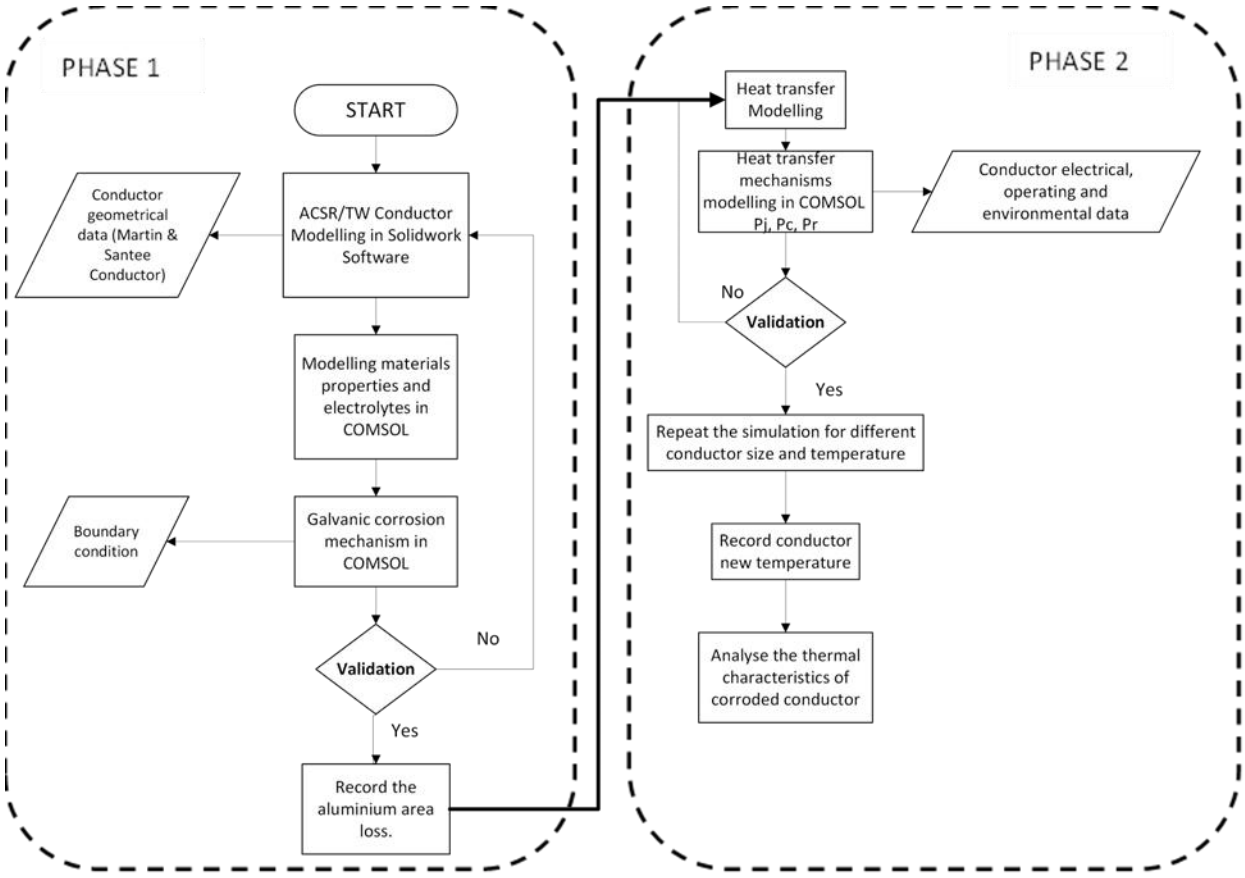


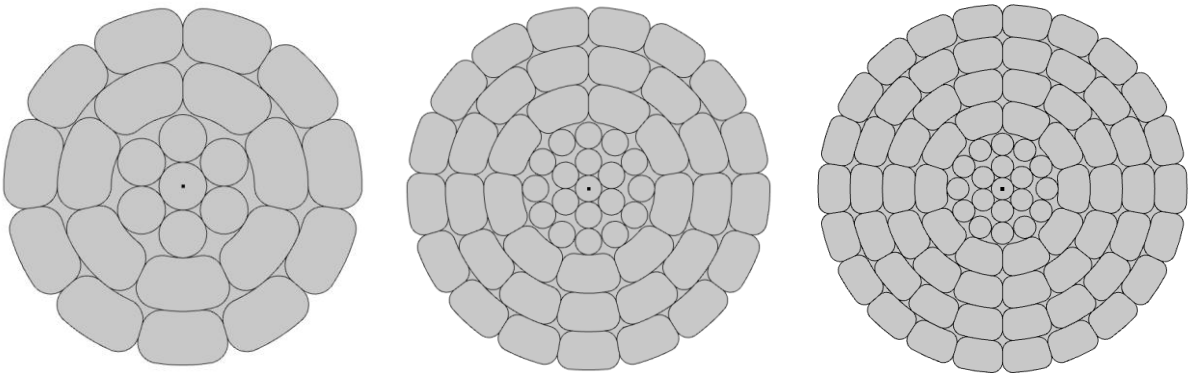

**Fig. 1.** Research framework for thermal characteristics of trapezoidal overhead conductors exposed to galvanic corrosion

The core steel wires are typically protected from corrosion with a zinc galvanization layer. In the modelling of ACSR/TW conductors for this study, several assumptions are made to simplify the analysis and focus on the specific aspects of galvanic corrosion and its impact on the conductor's thermal and mechanical performance. The assumptions are that the zinc coating on the steel core is fully corroded or compromised, and the effect of atmospheric conditions such as wind, rain, and pollution is not considered directly. These assumptions allow the study to concentrate on the internal corrosion mechanisms and their consequences on conductor performance. For this modelling, the inner layer steel wires that acts as a cathode is assumed to be unaffected by the deformation process.

### *2.1 Galvanic Corrosion Modelling*

The study focuses on three commonly used sized ACSR/TW conductors which is Hawk, Martin, and Santee, each with distinct structural configurations and performance characteristics. The trapezoidal wire (TW) of ACSR/TW design optimizes the cross-sectional area of the aluminum strands by minimizing gaps between them, thereby improving the conductor's electrical efficiency without increasing the conductor's diameter [16]. This TW structure is important for high-current transmission systems, as it provides enhanced current-carrying capacity and reduces overall conductor sag. The multilayer strand wires of ACSR/TW are made of high-strength steel and aluminum 1350-H19.

For this investigation, the ACSR/TW conductor with the codename of Hawk, Martin and Santee are used and Figure 2 shows the three conductor models used in the analysis. The round strands at the centre of the conductor model represents the steel core components and they are being surrounded by aluminum strands shaped into a trapezoidal cross-section. The parameters provided in Table 1 are used to model the conductors focusing on the interface between the steel core and the aluminum strands.



Hawk TW 20.07mm  Martin TW 33.02mm  Santee TW 44.074mm

**Fig. 2.** ACSR/TW with codename Hawk, Martin and Santee cross section area

**Table 1**
ACSR/TW Hawk, Martin and Santee conductor data for modelling

| Conductor | Diameter (mm) | Ampacity (A) at 75°C | Max Operating Temperature | Steel Core (No. of Strands) | Aluminum Strands |
|---|---|---|---|---|---|
| Hawk | 20.07 | 667 | 180°C | 7 | 18 |
| Martin | 33.02 | 1260 | 180°C | 19 | 39 |
| Santee | 44.074 | 1885 | 180°C | 20 | 64 |

As shown in Table 2, the aluminum strands, steel cores and electrolytes are modelled using their respective electrochemical properties, including their equilibrium potential ($E_{eq}$), Tafel slope (β), exchange current density ($i_o$) and electrolyte conductivity [17]. In the study of corrosion, current density is commonly used to describe the rate at which electrochemical reactions, such as the oxidation or reduction of metal ions, occur. The Tafel slope is determined by the current densities at the material's interface which is also affected by the anodic and cathodic reactions [18]. The conductors' geometry then was defined to reflect the trapezoidal wire arrangement, and a fine mesh was applied to capture the corrosion effects accurately. The developed model has been validated with experimental studies by Håkansson [19] with about 98% agreement. The area of aluminum loss over time is recorded for simulation of the heat transfer modelling.

**Table 2**
Key parameters for galvanic corrosion modelling of ACSR/TW conductors

| Material | Tafel Slope, A (V) | $E_{eq}$ (V) | $i_o$ (A/m2) |
|---|---|---|---|
| Steel | -0.16 | -0.58 | 0.001 |
| Aluminum | 0.1307 | -0.952 | 0.004232 |

### *2.2 Heat Transfer Modelling*

Following the corrosion modelling, the study proceeded to simulate the heat transfer characteristics of the conductors under predefined ampacity conditions as shown in Table 3. The joule heating effect, which is the heat generated due to electrical resistance, was calculated based on the reduced conductive area resulting from corrosion. Then, the convective and radiative heat losses are modelled using the Conjugate Heat Transfer Laminar Flow physics in COMSOL. The model considered various boundary conditions, including ambient temperature, wind speed, and emissivity, to simulate the operational environment of the conductors [20]. The temperature distribution across the conductor cross-section was analyzed, with particular attention to the interface between the aluminum strands and the core material.

**Table 3**
The parameters for corrosion and ampacity determination

| Parameter | Value |
|---|---|
| Conductor Type | ACSR/TW |
| Conductor Codename (Alu/Steel area) | Hawk (241.7/39.3 $mm^2$)<br>Martin (684.8/86.7 $mm^2$)<br>Santee (1331/105.6 $mm^2$) |
| Crosswind speed | 0.61 m/s |
| Emissivity | 0.5 |
| Absorptivity | 0 |
| Ambient temperature | 30 °C |
| Conductor operating temperature | 75 °C, 100 °C |

## 3. Results

### *3.1 Reduction in Aluminum Area Due to Corrosion*

Based on the galvanic corrosion modelling and evaluation, the loss of aluminum area in Martin ACSR/TW conductor at various exposure durations is presented in Figure 3. It is noteworthy that the pattern of aluminum area loss observed in Martin ACSR/TW conductors is consistent with that seen in other conductor sizes. In all cases, galvanic corrosion predominantly affects only the innermost aluminum layers in which validated by the study conducted by Lequien *et al.,* [15]. The study also noted that the corrosion rate is faster in coastal or industrial area compared to rural areas.

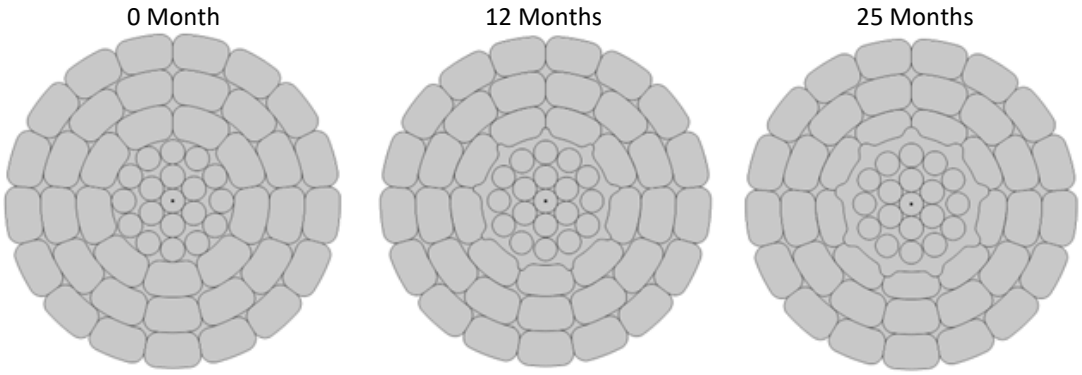



**Fig. 3.** Reduction in aluminum area in Martin ACSR/TW conductor at various continuous corrosive exposure durations

In general, based on Figure 3, the following observations can be made:

**0 Months**: At this baseline stage, the aluminum strands are fully intact, with no signs of corrosion. The cross-sectional view shows a uniform distribution of aluminum around the steel core, representing the conductor's initial, uncorroded condition.

**12 Months**: After one year of exposure, significant thinning of several aluminum strands is evident. The cross-sectional view indicates that strands in direct contact with the steel core have started to corrode. This thinning is attributed to galvanic corrosion, where the more anodic aluminum corrodes preferentially when in contact with the steel core in the presence of an electrolyte.

**25 Months**: After 25 months, corrosion has notably advanced. The cross-sectional view reveals a substantial reduction in both the size and number of aluminum strands. Strands in direct contact with the steel core show severe thinning, with some possibly corroded entirely. This extensive loss of conductive material leads to reduced electrical conductivity and elevated operating temperatures.

### *3.1.1 Reduction in aluminum area on different conductor sizes*

Figure 4 compares the amount of loss aluminum area between three different conductor sizes where the Hawk/TW is the smallest and Santee/TW is the biggest.

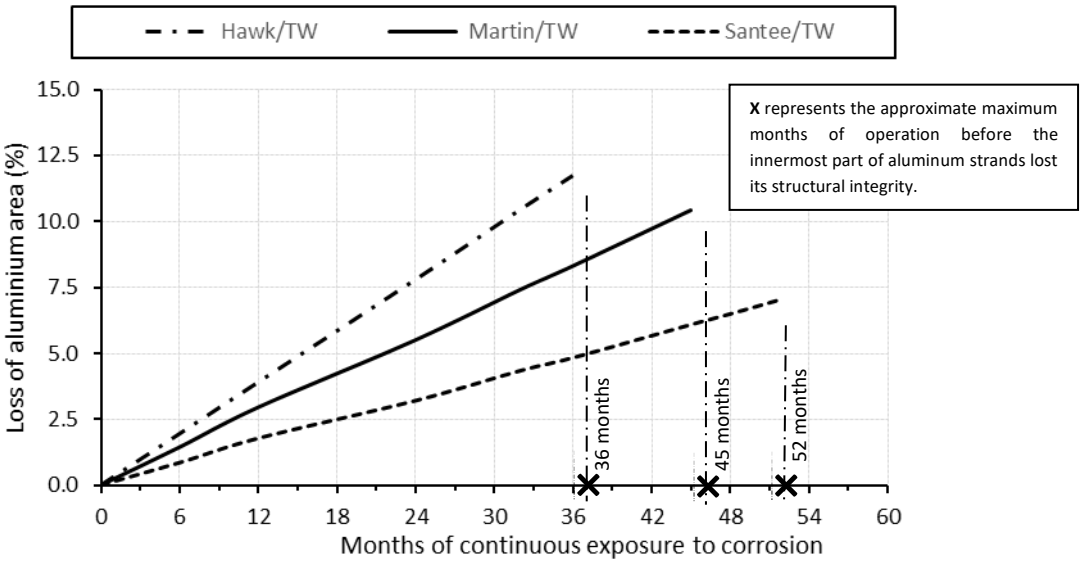



**Fig. 4.** Comparison on loss of aluminum area in different sizes of ACSR/TW conductor up to 60 months of continuous exposure to corrosion

The results indicated that all three conductors show a significant degradation in the loss of aluminum rate as the exposure time increases. This indicates that prolonged exposure to corrosion consistently leads to higher aluminum degradation. However, the smallest Hawk/TW conductor experience largest amount of loss compared to the other conductors. The reason for this is likely due to its smaller size, which makes it more susceptible to corrosive elements.

It is also interesting to note that, the record for the loss of area of the conductors from the simulation process is stopped after certain months of exposure. This is due to the loss of almost 80% of the aluminum at the most inner layer parts as shown in Figure 5. The observations of the findings proved that the occurrence of galvanic corrosion happens internally and hence this situation is expected to be unnoticeable in real-life situation until a localized thermal hot spot is observed through thermal monitoring exercise.

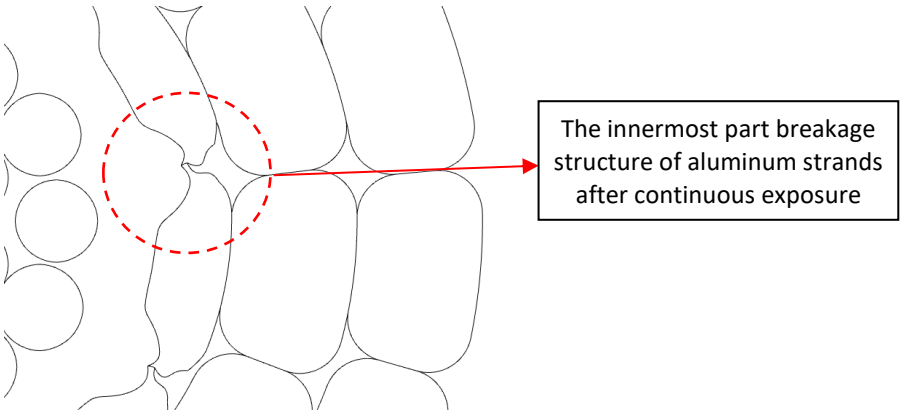



**Fig. 5.** Cross section of Martin/TW after 45 months of exposure

### *3.2 Changes in Conductor Thermal Profile Due to Corrosion*

The corroded conductor is then subjected to electrical current, and its thermal profile is monitored at various exposure durations. Figure 6 presents the thermal observations of the Martin ACSR/TW conductor at two conditions: one representing the conductor in an uncorroded state (zero corrosion) and the other after 24 months of corrosive exposure. The primary focus is on comparing the overall conductor temperature recorded under these two conditions.

The results illustrate the impact of corrosion on the overall conductor temperature when subjected to the same electrical current and environmental conditions. In the absence of corrosion, the conductor operates at a temperature of 101.6°C. However, after 24 months of exposure to corrosive conditions, the temperature rises to 103.4°C. This temperature increase is linked to a loss of 2.85% in the inner aluminum strands. The reduction in aluminum strands leads to higher overall conductor resistance. With the same electrical current, this increased resistance results in greater Joule heating, thereby raising the conductor's temperature. Similar trends are observed in other tested conductors, though the extent of temperature increase varies.

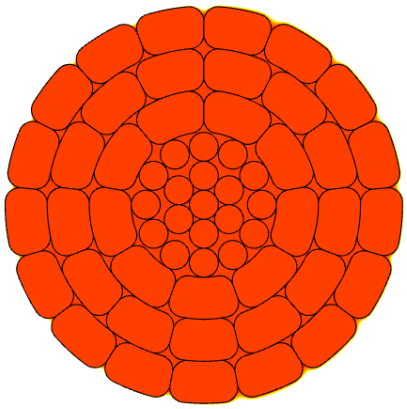
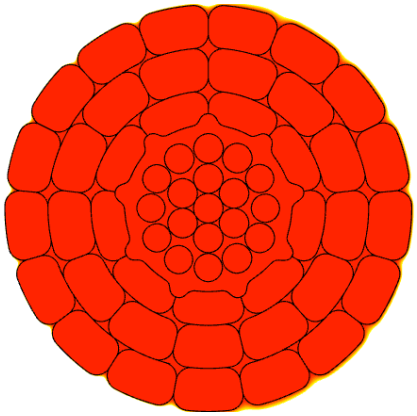
| **Operating and Environmental Conditions** | **Conductor Thermal Profile: Martin ACSR/TW (33.02 mm)** | |
|---|---|---|
| Both conductors are supplied with 1524 A of current.<br>• Cross wind speed: 0.61 m/s.<br>• Ambient Temperature: 30°C. | **Zero exposure to corrosion**<br><br>**Observation:**<br>• No loss of area in the inner aluminum strands layer.<br>• Overall Conductor Temperature: **101.6°C** | **After 24 months of exposure to corrosion**<br><br>**Observation:**<br>• 2.95% loss of area in the inner aluminum strands layer.<br>• Overall Conductor Temperature: **103.4°C** |

**Fig. 6.** Comparison of thermal profile in Martin ACSR/TW conductor: No corrosion vs. 24 months of corrosive exposure

### *3.2.1 Temperature increase on different conductor sizes operating at the temperature*

This section analyses the temperature rise in ACSR/TW conductors of different sizes—Hawk, Martin, and Santee when subjected to the same operating temperature of 75□C.

The goal is to assess how conductor size impacts heat distribution and overall thermal behaviour under typical operational loads. The results of Figure 7 illustrate the impact of corrosion on the overall conductor temperature when subjected to the same electrical current. Overall, the three sizes of conductors show an increasing trend in temperature as the exposure time to corrosion increases. This indicates that prolonged exposure to corrosion leads to higher conductor temperatures. The Hawk/TW conductor shows the steepest increase in temperature, suggesting it is the most affected by corrosion in terms of heat distribution. This implies that Hawk/TW has poorer thermal behaviour under corrosive conditions. The data suggests that Santee/TW is the most effective conductor in terms of minimizing temperature increase due to corrosion, followed by Martin/TW, with Hawk/TW being the least effective. The different temperature increases observed for each conductor type can be attributed to their sizes. Larger conductors generally have better heat dissipation properties, which can result in lower temperature increases under the same conditions. Conversely, smaller conductors may heat up more quickly due to their limited surface area for heat dissipation.

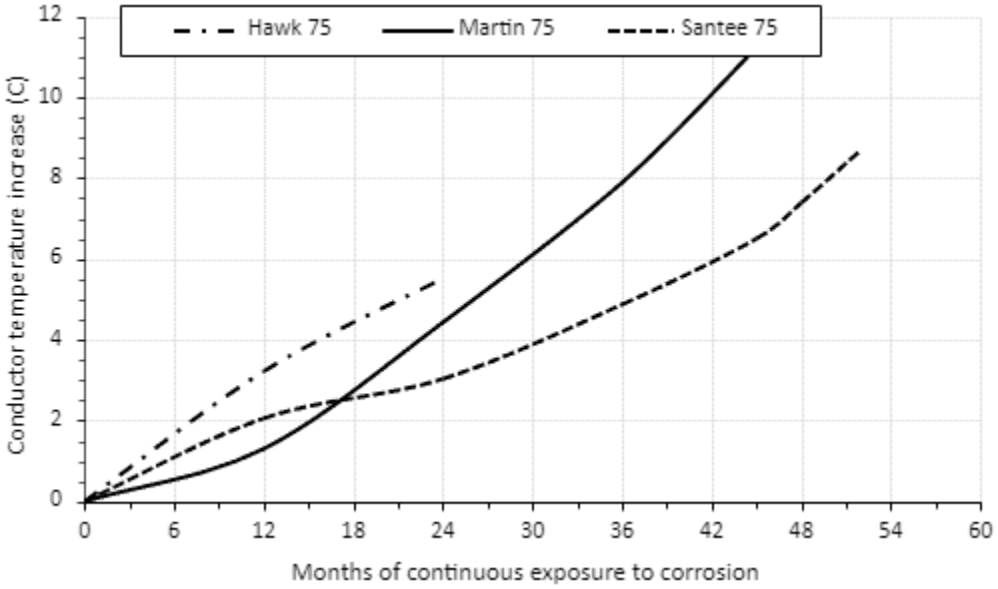



**Fig. 7.** Comparison of temperature increase between different sizes of conductors

### *3.2.2 Comparison of temperature increase on different operating temperature of the same sizes*

For this analysis, the Martin/TW ACSR conductor was evaluated under two different operating temperatures: 100°C and 75°C, to understand the effect of elevated temperatures on its thermal profile. By comparing the conductor's performance at these two distinct temperatures, we can assess heat dissipation behaviour of the conductor, the impact on loss of area of the aluminum strands, and the potential risks of overheating as shown in Figure 8.

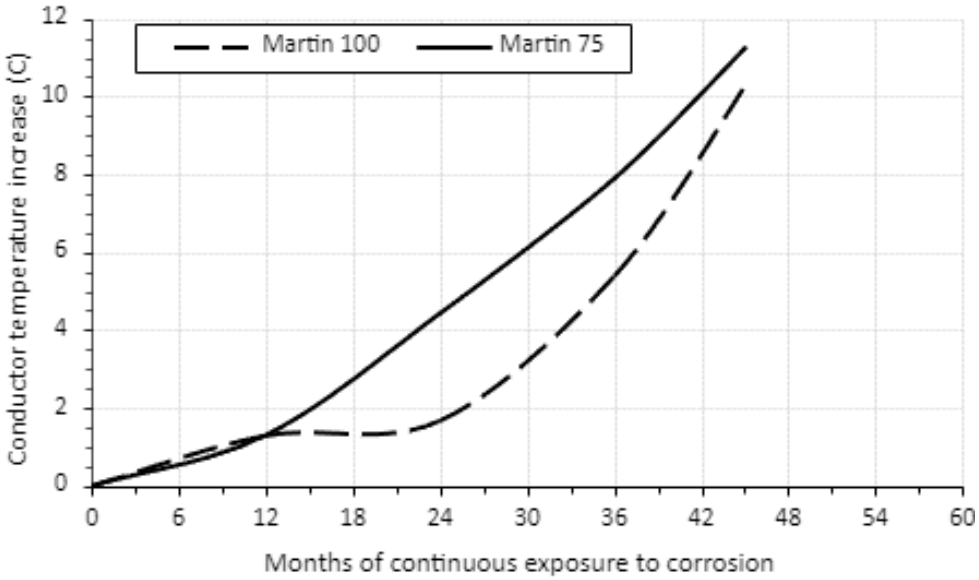



**Fig. 8.** Comparison of temperature increase between different operating temperatures for Martin ACSR/TW conductor

Based on the results, it is indicated that the higher operating temperatures generally lead to greater thermal stress and faster degradation, resulting in higher temperature increases over time. Conversely, lower operating temperatures may result in slower degradation and better thermal performance. Contrary to typical expectations, the Martin/TW conductor operating at 100°C exhibited a lower temperature gradient compared to the same conductor operating at 75°C. This

observation is due to several factors, including the improved heat dissipation at higher temperatures and the reduced thermal resistance at the conductor's surface. The temperature difference between the steel core and the outer aluminum strands is more pronounced at 75°C, which may result in a steeper temperature gradient within the conductor cross-section. The temperature difference between the steel core and the aluminum strands at 100°C is smaller compared to that at 75°C. This results in a lower internal temperature gradient across the conductor. As the conductor approaches thermal equilibrium at 100°C, heat is distributed more evenly throughout the conductor, reducing the steepness of the gradient.

## 4. Conclusions

This study has demonstrated the significant impact of galvanic corrosion on the thermal characteristics of ACSR/TW conductors. Based on the study, it is found that the galvanic corrosion has negative impact on the conductors' thermal characteristics and their ampacity. For the tested ACSR/TW conductors, the corrosion has significantly reduced the conductive area of the aluminum strands, leading to increased electrical resistance and elevated the conductors' operating temperature. For a longer period, this phenomenon can ultimately compromise the safety and reliability of power transmission systems. It should also be highlighted that there is a need to revise the existing standard ampacity calculation technique as to account the effect of galvanic corrosion phenomenon for an accurate ampacity determination. On the other hand, future research should focus on long-term monitoring of corroded conductors in various environmental situations to validate and refine the models developed in this study.

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