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Investigation of Improvement in Current Carrying Capacity of Various Power Cables Using a Novel Arrangement

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Power cables are essential components of electrical systems, and their ability to carry current depends directly on the size of the conductor. With the rising cost of copper, efficiently utilizing a conductor's current-carrying capacity has become increasingly important. To maximize this capacity, it is crucial to limit the temperature rise, either through effective heat dissipation or by optimizing the cable orientation in a trench. This study introduces new cable arrangements designed to lower the operating temperature of power cables, which in turn increases their current-carrying capacity. Different cable orientations for laying three-phase power cables in both single and double circuit configurations were examined. A high-resolution thermal imager was used to accurately measure the temperature. Two of the proposed orientations led to a significant reduction in operating temperature compared to the cable arrangements specified in BS 7671. These novel orientations can increase the current-carrying capacity by approximately 6% without the need to increase the cable size.

Keywords: Thermal Imaging for Cables, Power Cables Orientations, Relationship between Temperature and Ampacity, Novel cable arrangements, Trench Installation

Introduction:

Electrical power systems use both high and low voltage cables, each with its current-carrying capacity. The capacity of a cable changes depending on environmental and physical factors, such as whether the cable is laid indoors or outdoors, overhead or underground, concealed or exposed, and spaced or compacted. As a result, there are two primary research approaches to improving cable current-carrying capacity and temperature management: the first method aims to reduce the cable's temperature by changing its orientation, while the second method seeks to increase current-carrying capacity by minimizing the magnetic field effect. This research proposes a novel cable arrangement designed to enhance heat dissipation and increase current-carrying capacity compared to traditional configurations. The goal of the study is to identify an arrangement that reduces cable heating and optimizes performance by analyzing different configurations and their thermal behavior. Outdoor cable installations are more effective at heat dissipation compared to underground or conduit-enclosed installations. When cables are bundled together, their current-carrying capacity is reduced because bundling decreases their ability to dissipate heat. Additionally, temperature rise in the environment reduces the current-carrying capacity of cables, as heat dissipation becomes less efficient. The thermal insulation of cables buried underground varies based on factors such as soil moisture content and chemical composition. Overheating of cables, which can impair their performance, can be prevented through proper ventilation in controlled areas. Standards such as IEC 60287, NEC, BS 7671, and IEEE define key criteria for selecting appropriate cables. Understanding the maximum current capacity helps engineers design efficient electrical systems that ensure both safety and performance. Engineers assess conductor properties, insulation, installation orientation methods, and environmental factors to choose cables that meet operational requirements with safety and durability.

Various studies have focused on different factors affecting cable current-carrying capacity. Xiaoming Xu [1] utilized the data from COMSOL Multiphysics pro-programming software to determine the current through cables and the location of the cable relative to the sectional design and configuration of the tunnel. This work also presented procedures that may be useful in the sequencing of tunneling alongside the cabling process. Chuanqiang Che [2] got the models for cable current capacity from COMSOL Multiphysics simulation software, and the program also provides information about cable temperature. In this work, the distribution of temperature due to the position of the cable and convection of heat was also highlighted. However, when there is enough space for the cable, the electrical current can also be controlled well; and, proper measures in heat dissipating and proper control of temperature also exist. Adel El- El-Efaraskoury, [3] has conducted a study on the steady state thermal ampacity of power cables buried in the ground based on the IEC standards. Before this, a new mathematical formula of the IEC ampacity was coded in MATLAB, and a new procedure of data preparation was also prepared and practiced in the laboratory. Installation characteristics like insulation condition, soil thermal resistivity, bonding type, and depth were selected for the study as they affect the cable ampacity.

George Callender [4] analyzed a low-cost flexible model for conductive heat transfer through complex burial conditions using conformal maps instead of commercial software. Two experiments with buried cables placed in soils of different temperatures were used to validate the established model, while using finite element analysis as the benchmark test. The performance of the model results in calculating continuous and short-term cable ratings. Ritthichai Ratchapan, [5] in their study employed the thermal finite element to de _his project focuses on establishing the relationship created by different conduits on low voltage underground cable ampacity. Among the cable conduits, steel conduits have the highest permissible ampacity, while RTRC conduits, then HDPE conduits, and the lowest is PVC conduits. The resistivity of the cable decreases with the depth of the ground and increases with the decrease in the ground temperature. Nishanthi Duraisamy, [6] has done a work on submarine environment ampacity analysis where she used the finite element method (FEM) for determining the elements comprising it. Concerning to the experimental setup for validation of the FEM simulations and the results of the numerical approach, an experimental design was generated. Analyzing convective heat transfer calculations that have been incorporated in the proposed method improved the ampacity calculations as compared to the conventional methods.

William Sundqvist, [7] in his project, focused on the function of electrical and thermal annealing. There was a possibility to minimize installation losses, which affect the ampacity, and the thermal rating was poor as well. Optimization of ampacity should take the direction to deliver heat dissipation on another parameter apart from electric losses. The distribution of cable ampacity and temperature was studied by the investigators since it determines the reliability of the power cables. It also stated that the current capacity is lower by 12.5 percent in the situation where bottom trench laying is undertaken. Ampacity was found to decrease with cables placed randomly as much as the temperature was higher. Other forms of monitoring systems in multiparameter online control networks are the ones that monitor cable temperature, water level, and the density of smoke. Yifang Wang, [8] for this purpose tried to calculate the ampacity values of EV cables using the finite element simulation with the help of Nelder-Mead method. A study shows that each of the three mentioned parameters, which are the ambient temperature, insulation thickness, and insulation layer thermal conductivity, affects the ampacity of the EV cable differently. Abdullah Ahmed, [9] who compared and assessed the factors as follows about the temperature distribution around the burial and the configuration of the cables, and soil's thermal resistivity, and the kind of backfill materials used. The study objectives focused on enhancing the current in power cable concerning several functional parameters. The right choice of thermal backfilling and the right positioning make for lower temperatures on conductors and improved ampacity for an acceptable cost. Yang Bo [10] also developed an instantaneous connection between the allowable power transmission line and system temperature. It also examined actual scenarios of the influence of ampacity and temperature on the power system with the help of algebra and differential equations. Stanislaw Czapp [11] looked at the impact of the solar radiation, wind conditions, and the position of the cable line on the current carrying capacity of the power cable. Highly professional analysis of the computational fluid dynamics or CFD simulations identified the capacity. These factors remain important for choosing power cables meant for free-air installation as they provide additional information to the IEC standard.

B. X. Du, [12] used high thermal. It has also made it possible to improve the ampacity capability of buried HVDC cables that would not be possible if the con- con-conductivity insulation was not in place. The simulation results showed that in associated with thermal conductance properties, the temperature in the core as well as the temperature of the insulation were higher along with a more homogeneous distribution. Ranya Maher [13] analyzed methods for maximizing the maximum current capability that the existing HV cable can achieve when it is located near H and EHV power cables. Hence, the MATLAB program came in handy as it enabled lecturers to predict cable ampacity under different installations and environmental conditions. By using COMSOL FEM, the researchers were able to determine how the heat was distributed within the multiple layers conforming the cables and ground in case these cables were working at maximum capacity. This results in lower critical temperatures, and puts the ability of the cable itself to carry more current without having a bigger cross-sectional area. Jipeng Tang, [14] was aimed at the enhancement of current in power cable comprised the following: Some of the factors that impose variation on the ampacity include; the working temperature and ground temperature, depth of sand backfill and covering and the grounding method, thermal resistivity of the soil, the number of circuits or the number of conductors to be conveyed and the configuration to be used. Brain scadden, [15] used number of contributions under this field which has been titled as Implementation of the IEE standard wiring regulations for cable installation techniques and the authors of the work included: The comparative analysis for the cable installation system that were taken into consideration was perforated as well as unperforated cable tray, vertical perforated trays and cable ladder wire mesh tray.

Objectives:

1. To develop a practical setup to investigate the current carrying capacity of various cables.
2. To develop various cable orientation schemes and investigate them on the practical rig for their current carrying capacity, along with temperature limitations.
3. To compare and report the results with previously available physical and software-based techniques and conclude the best.

Novelty Statement:

This study investigates the impact of various orientation schemes on the performance of 1.5 mm^2, 2.5 mm^2, and 4 mm^2 PVC-insulated copper cables installed in a closed, thermally insulated trench—a setup that closely replicates real-world underground or concealed installations. Departing from conventional approaches that typically depend on theoretical models or simulations, the research adopts an experimental methodology to provide direct evidence of how cable arrangements such as flat, trefoil, and vertical stacking affect heat dissipation and current-carrying capacity. By maintaining a constant current and monitoring temperature variations, the study identifies specific orientations that enhance thermal performance, reducing core temperatures and permitting higher current loads without breaching thermal limits. These findings offer practical guidance for optimizing cable layouts in space-constrained or poorly ventilated environments, contributing to more efficient and cost-effective electrical installations.

Experimental Setup:

The primary goal of this research was to enhance the current-handling capacity of power cables by analyzing several orientation configurations that optimize heat dissipation. Cables with cross-sectional areas of 1.5 mm^2, 2.5 mm^2, and 4 mm^2 were chosen as the sample for the study. A three-foot cable tray was designed and fabricated, featuring integrated thermal insulation.

Insulated foam was used to encase the trench, effectively preventing heat dissipation to the surroundings, simulating real-world conditions where cables are buried underground or concealed within walls. This design ensured that the thermal resistance closely matched that of actual concealed wiring and trench installations, providing accurate analysis of temperature and current-carrying capacity under similar conditions. The design includes a flexible mounting system that allows the cables to be securely fastened in various orientations, as depicted in Figure 1.

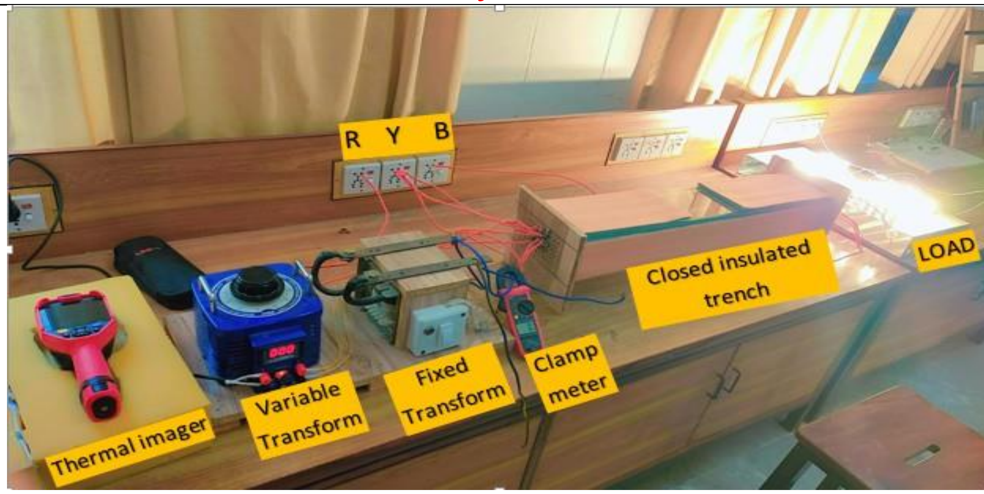


Figure 1. Experimental Setup

We tested all cable samples in various three-phase orientations, one at a time, applying a current of 50A through each phase. A thermal imager was used to measure the temperature of various cables along with different orientation schemes.

For the 2.5 mm² and 4.0 mm² cables, the current was increased from 50A to 100A to accelerate cable heating. The current was kept at a relatively high level to ensure rapid heating. The proposed and existing standard orientation schemes used in the study are shown in Figure 2.

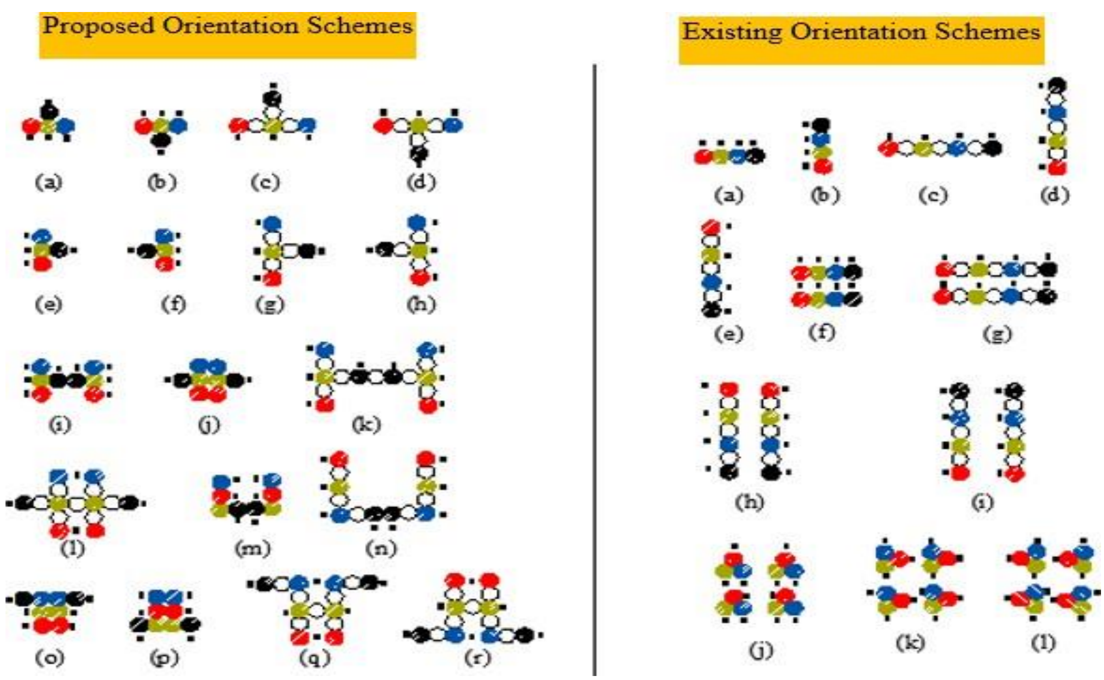


Figure 2. Cable Orientation Schemes

We measured the temperature of the existing orientations under a constant current of 50A and compared the results with those of our proposed orientation schemes. The current is Kept at a relatively high level to accelerate cable heating in a short time. Finally, we analyzed and compared all the findings to determine whether any of the tested orientation schemes resulted in a lower temperature, indicating a corresponding increase in current capacity. The flowchart in Figure 3 provides a clear overview of the methodology used to enhance the current carrying capacity.

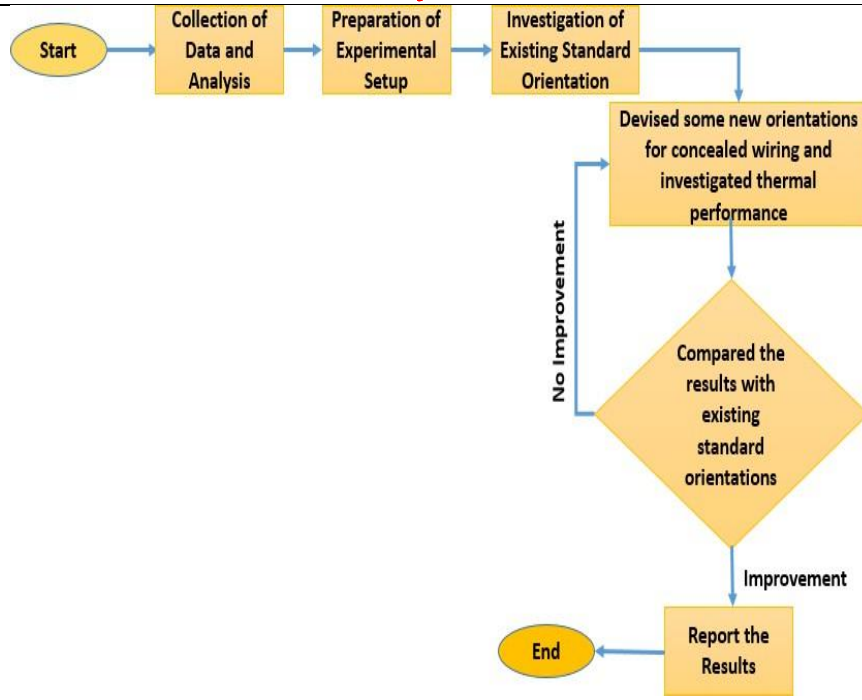
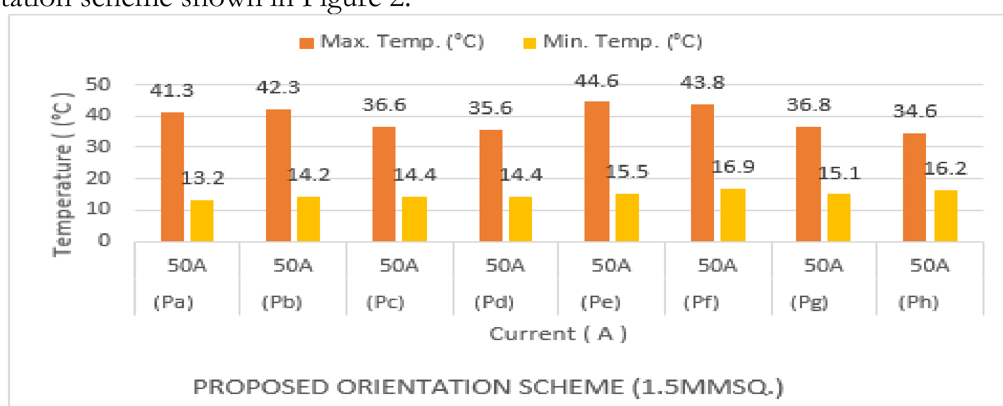


Figure 3. Flow chart

Results:

Orientation Schemes of 1.5mmSq. Cable:

Figure 4 presents the results of the proposed and existing orientation schemes for a 1.5 mm² cable carrying a constant current of 50A under the three-phase single CCTs orientation scheme shown in Figure 2.



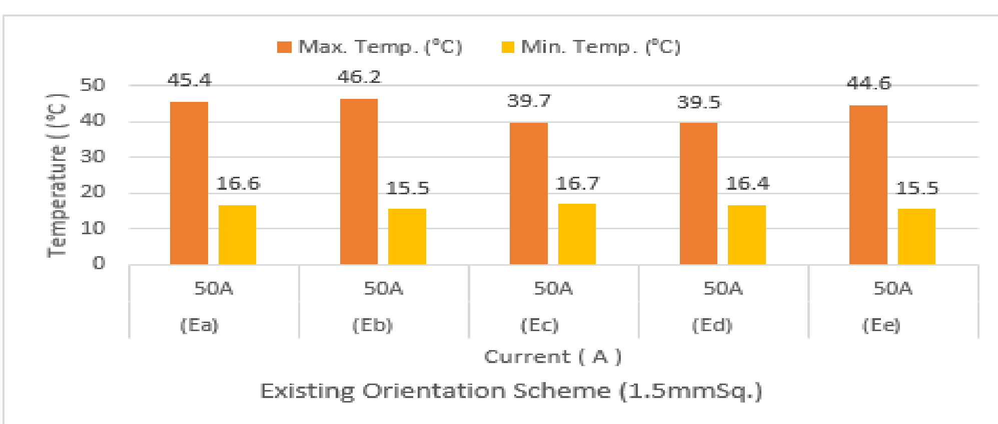


Figure 4. Proposed and Existing Single Circuit Orientation Schemes for 1.5 mm² Cable

In Figure 4, the proposed scheme (P_h) recorded the lowest minimum temperature at 34.6°C, while the existing orientation scheme (E_d) had a minimum temperature of 39.5°C. The lower operating temperature of scheme P_h indicates improved heat dissipation and reduced thermal resistance, making it more effective at managing heat compared to scheme E_d. As a result, scheme P_h is expected to support a higher current while maintaining a lower temperature, making it a better option for enhancing the current-carrying capacity of the cables.

Figure 5 shows that the proposed and existing double circuit orientation scheme, the proposed orientation scheme (P_k) had the lowest minimum temperature at 37.2°C, while the existing orientation scheme (E_h) recorded a minimum temperature of 42.4°C. The lower operating temperature of scheme P_k signifies better heat dissipation and reduced thermal resistance, demonstrating superior thermal performance compared to scheme E_h. This suggests that scheme P_k can carry more current while maintaining a lower temperature, making it a more efficient choice for increasing the current-carrying capacity of the cables.

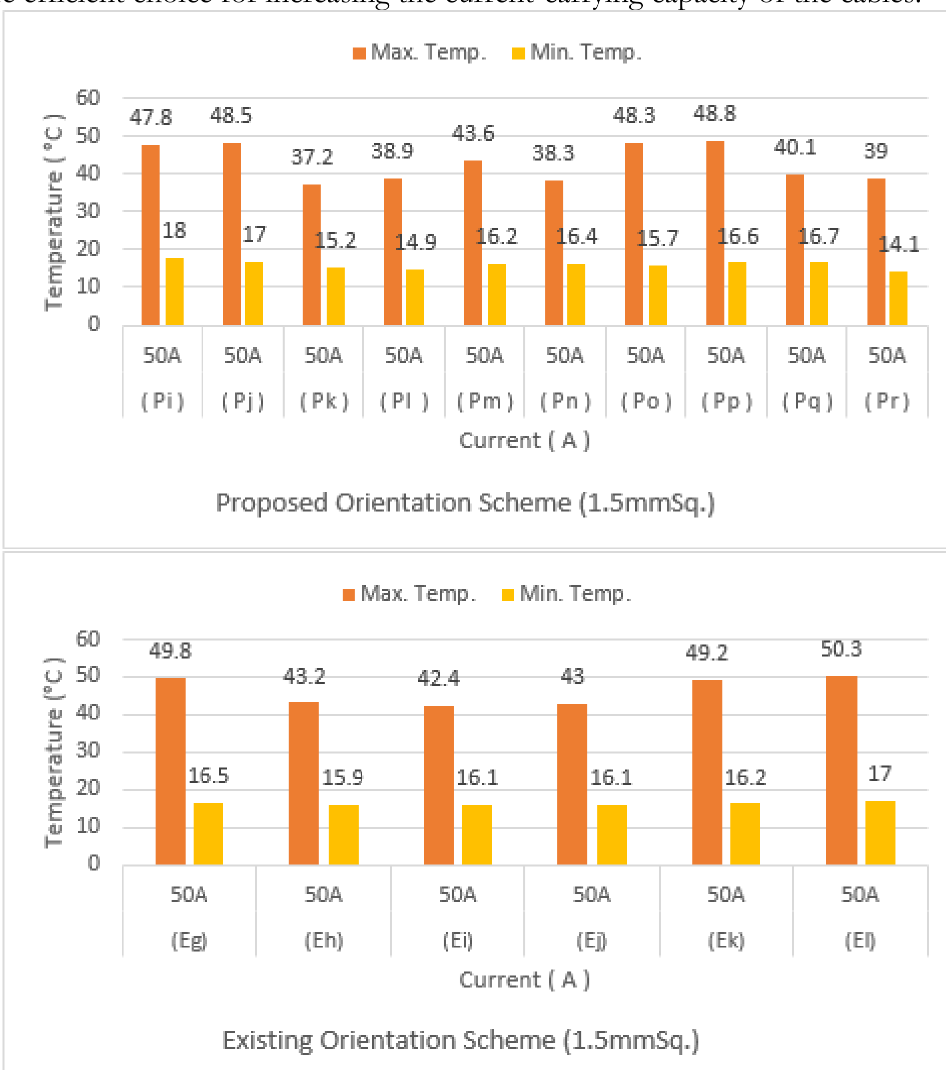


Figure 5. Proposed and Existing Double Circuit Orientation Schemes for 1.5 mm² Cable

Orientation schemes of 2.5mmSq. Cable:

Figure 6 illustrates the results of the proposed and existing single-circuit orientation schemes for a 2.5 mm² cable carrying a constant current of 100A under the three-phase arrangement shown in Figure 2.

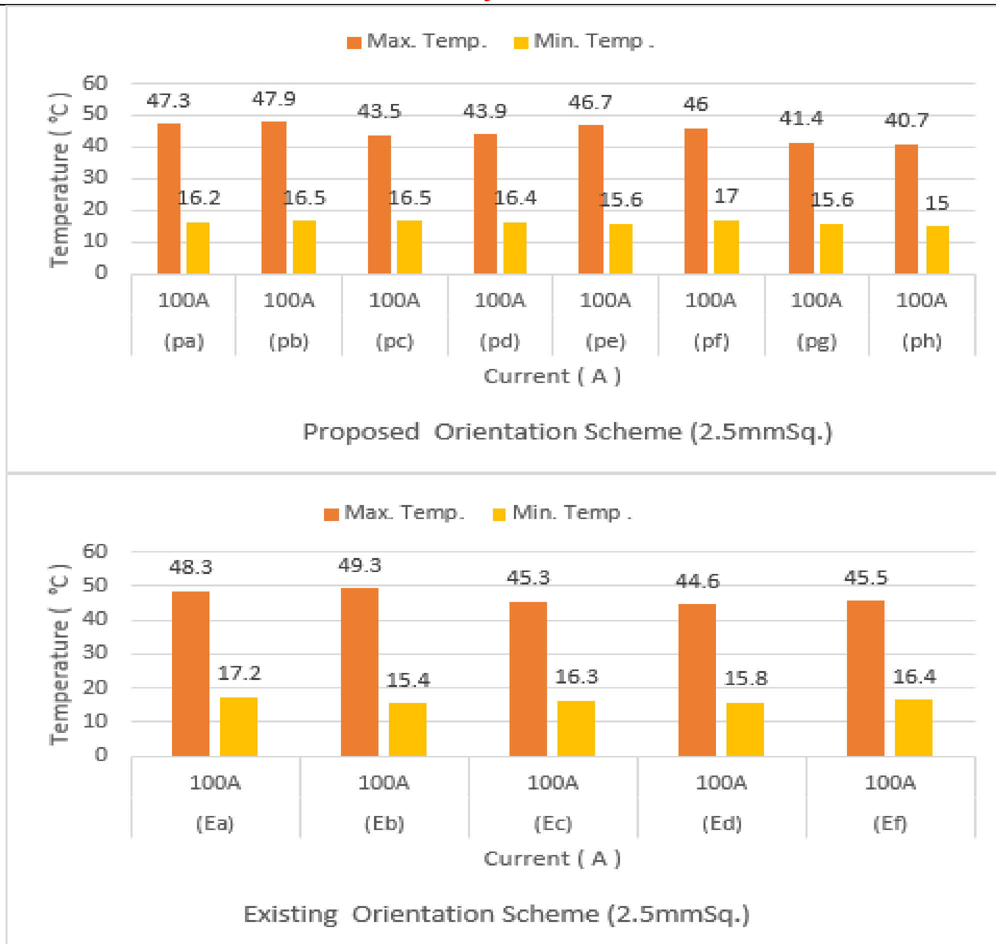


Figure 6. Proposed and Existing Single Circuit Orientation Schemes for 2.5 mm² Cable

From Figure 6, the proposed scheme P_h recorded the lowest minimum temperature at 40.7°C, while the existing orientation scheme E_d had a minimum temperature of 44.1°C under a constant current of 100A. A lower operating temperature indicates better heat dissipation and reduced thermal resistance, which makes scheme P_h more thermally efficient than scheme E_d. This suggests that scheme P_h can carry more current while maintaining a lower temperature, making it a more efficient choice for increasing the current-carrying capacity of the cables.

Figure 7 represents the proposed and existing double circuit schemes; the proposed scheme P_k had the lowest recorded minimum temperature at 45.8°C, whereas the existing orientation scheme E_i had a minimum temperature of 47.0°C under a constant current of 100A. As with Figure 6, a lower operating temperature indicates better heat dissipation and reduced thermal resistance, making scheme P_k more thermally efficient than scheme E_i. This suggests that scheme P_k can carry more current while maintaining a lower temperature, making it a more efficient option for increasing the current-carrying capacity of the cables.

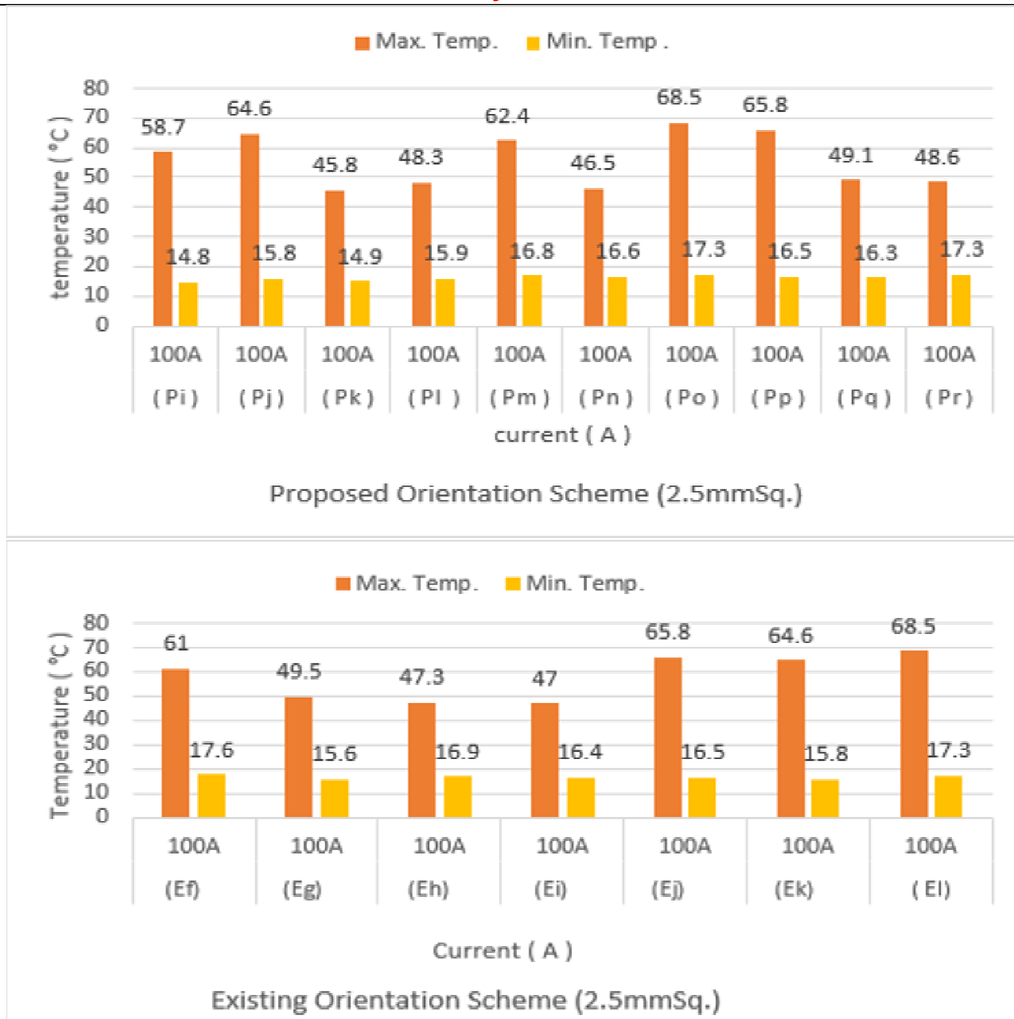


Figure 7. Proposed and Existing Double Circuit Orientation Schemes for 2.5 mm² Cable

Orientation schemes of 4.0mmSq. Cable:

Figure 8 presents a comparison between the proposed and existing single circuit orientation schemes for a 4.0 mm² power cable operating in a three-phase configuration with a constant current of 100 A, as illustrated in Figure 2. The existing scheme, denoted as E_d, follows the conventional cable layout, while the proposed scheme, labeled P_h, introduces a modified arrangement aimed at improving thermal performance. Experimental results show that the proposed orientation achieved a lower minimum temperature of 35.1°C, in contrast to 39.8°C observed in the existing setup, a notable temperature reduction of 4.7°C. This decrease is significant, as it directly enhances the cable's thermal behavior and current-carrying capacity. A lower operating temperature results in reduced electrical resistance, which decreases I^2R losses and mitigates thermal stress on the cable insulation. These improvements contribute to greater energy efficiency, longer service life, and improved safety of the cable system. The enhanced cooling performance observed in the proposed orientation suggests a more optimal physical arrangement of the conductors, likely providing better spacing and airflow for heat dissipation. Therefore, the proposed scheme enables the 4.0 mm² cable to operate more efficiently or handle greater current without exceeding thermal limits, demonstrating its effectiveness in enhancing the performance and reliability of power cable installations.

Figure 8. Proposed and Existing Single Circuit Orientation Schemes for 4.0 mm² Cable

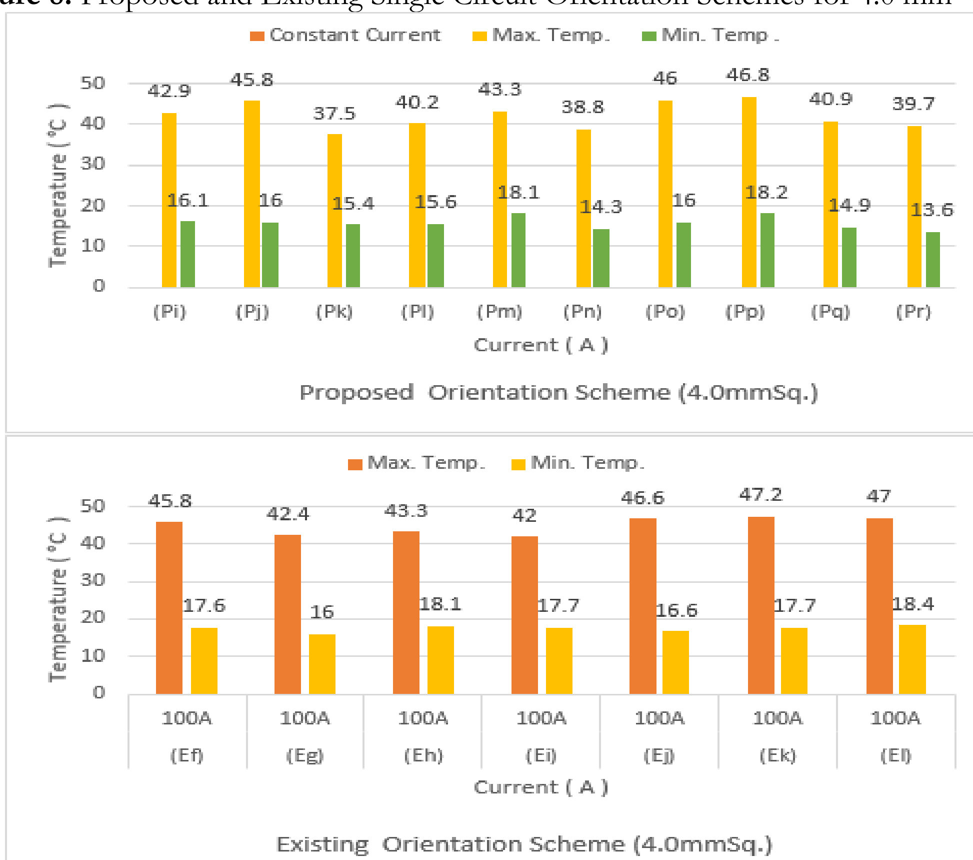


Figure 9. Proposed and Existing Double Circuit Orientation Schemes for 4.0 mm² Cable

Figure 9 presents the results of the proposed double circuit orientation schemes, where the minimum temperature was 37.5°C (scheme Pk) under a constant current of 100A, whereas the existing orientation scheme had a minimum temperature of 42.0°C (scheme Ei). Lower temperatures generally improve the cable's ability to carry more current without exceeding thermal limits. Therefore, the proposed orientation schemes would have led to an increase in the current carrying capacity.

Thermal Imaging Summary:

Figure 10 presents the thermal images of the proposed orientation and existing standard orientation schemes for 1.5 mm², 2.5 mm², and 4.0 mm² cables.

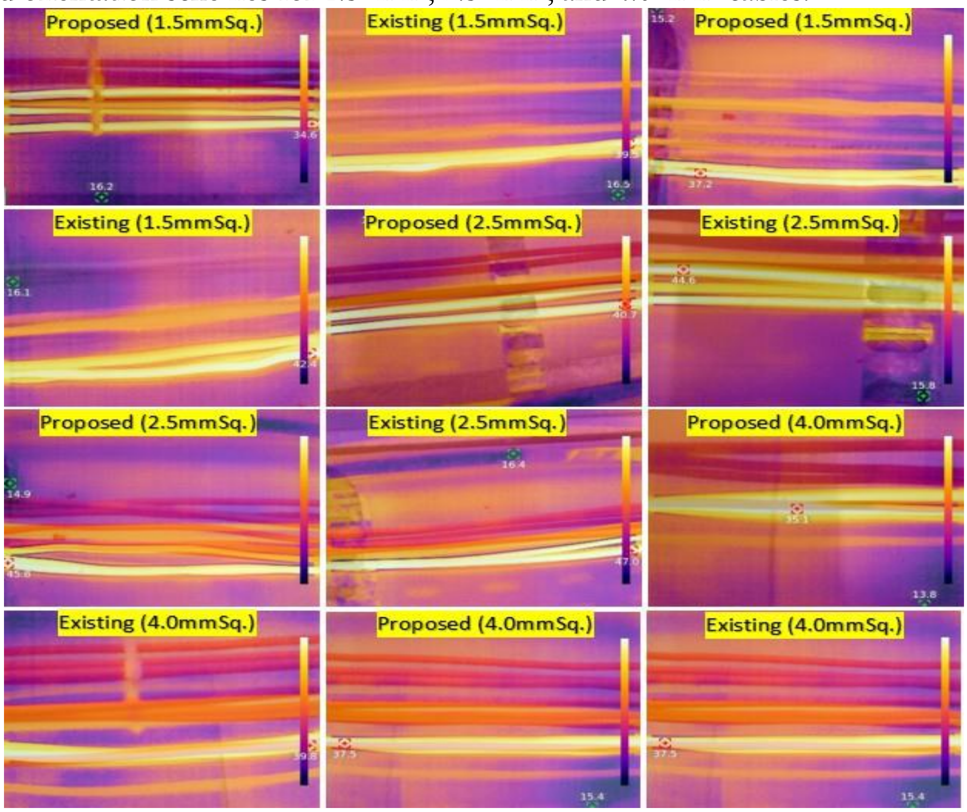


Figure 10. Thermal image of proposed and existing orientation schemes

Discussion:

This research investigated various cable orientation schemes aimed at achieving lower operating temperatures compared to existing standard orientations. All proposed orientations were tested alongside the standard orientations. Two of the proposed cable orientation arrangements were found to be more effective at temperature regulation when a constant current of 50A and 100A was applied to 1.5mm², 2.5mm², and 4.0mm² cables in both three-phase single and double circuit configurations.

The proposed P_h orientation scheme resulted in a temperature reduction of approximately 4.9°C for all three cable sizes tested. Similarly, the proposed P_k orientation scheme led to an approximate 5°C reduction in temperature across all cable sizes. Optimizing cable spacing and layout improved ampacity by reducing thermal resistance.

In addition, the thermal imaging used offered a very effective, non-invasive means of visualizing temperature gradients along cable surfaces. This made it possible to produce reliable verification of each configuration’s performance and to provide visual confirmation of thermal improvements in the newly proposed arrangement. In general, the results suggest that cable orientation is an under-utilized parameter in electrical design, and it may be used to maximize system efficiency and minimize energy losses and life extension of cables in encased or underground installations.

Conclusion:

A 5°C decrease in temperature corresponds to an approximate 6% increase in current-carrying capacity, as supported by existing literature. The findings demonstrate that strategic orientation schemes can enhance cable performance without increasing cable size or trench dimensions, thereby improving system efficiency and reducing operational stress. The improved cable orientations enhance current-carrying capacity by optimizing heat dissipation and reducing thermal resistance. The data from this study shows that adjusting cable layout positions improves performance without altering cable size. These insights contribute to the development of safer and more efficient electrical systems, offering a practical solution for handling increased current levels in confined or insulated spaces.

The use of high-resolution thermal imaging enabled accurate, non-invasive measurement of temperature gradients along the cable surfaces, effectively validating the thermal performance of the proposed orientation schemes. By optimizing cable layout, the study introduces a cost-effective solution to improve electrical system efficiency and safety, especially in environments where spatial limitations or existing infrastructure hinder conventional upgrades. These findings contribute to the advancement of more resilient and energy-efficient electrical distribution systems, highlighting the importance of thermal management in cable installation design.

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The authors hereby confirm that the manuscript has not been published previously, nor is it under consideration for publication elsewhere. All authors contributed equally to the research and preparation of this manuscript and are in full agreement with its content.

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