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21Design and Simulation Study on Busduct System in the Prediction of Temperature Variation Using CFD

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Abstract: Busduct systems are key components in industrial and commercial power distribution, but their thermal performance often limits reliability and safety. Excessive heating in busducts due to high currents, poor ventilation, and suboptimal materials can lead to failures. This paper presents a 3D CFD model to predict temperature variation in busducts under different operating and design scenarios. Variants such as material selection, airflow (forced/free), vent geometry, and insulation are simulated. The study also applies TRIZ (Theory of Inventive Problem Solving) methods to guide design improvements. Results reveal critical hotspots, temperature gradients, and the influence of copper and aluminium busbars under air velocities of 10 m/s and 20 m/s. Forced convection significantly reduces peak temperatures, while copper shows superior thermal performance.The work can help in optimizing busduct design for better energy efficiency, safety, and lifetime.
Keywords: Busduct system; Computational Fluid Dynamics (CFD); Thermal analysis; Forced and natural convection; Heat transfer; Ventilation design; Material optimization; Hotspot prediction; TRIZ methodology; Power distribution reliability.

I. INTRODUCTION

Power distribution in large buildings and industrial plants often uses busduct systems (also called busways or busbar trunking systems) because of their ability to transmit large currents with lower losses compared to cables. However, heating (ohmic loss, eddy current, poor convection) can degrade insulation, cause expansion, mechanical stresses, reduce efficiency, and in worst cases lead to fire risk.

Computational Fluid Dynamics (CFD) has become a powerful tool to simulate airflow and heat transfer in electrical systems (e.g., switchgear, busbars) to locate hotspots and assess thermal performance without the need for extensive physical testing.

This paper aims to:

1) Develop a 3D CFD model for a busduct section, to predict temperature variations under steady and transient loads.
2) Test the effect of design changes: ventilation (free/forced convection), different materials (copper vs aluminium vs perhaps composite/insulated), busduct geometry (duct volume, spacing), insulation, etc.
3) Use TRIZ methodology to systematically generate inventive changes to mitigate thermal issues.

II. LITERATURE REVIEW

1) Thermal Analysis of Heat Distribution in Busbars during Rated Current Flow in Low-Voltage Industrial Switchgear by Łapczyński & Kolimas (2021) uses coupled Maxwell 3D, Transient Thermal, and CFD to determine temperature in low-voltage switchgear busbars under rated loads. They show how airflow, enclosure, and conductor geometry affects thermal rise. MDPI
2) Influence of busbar trunking system design on thermal performance operating with non-sinusoidal currents (Alboyacı et al., 2022/23) investigates the effect of waveform distortion on heating in busducts. Distortion increases losses and hence temperature rise. OUCI
3) A Study on the evaluation of sandwich busduct using temperature rise method (Viswanatha, Vittal, Mohan Babu, CPRI) assesses sandwich busduct thermal profile by physical measurement under load. Provides validation of acceptable temperature rises for different parts. cprijournal.in

These works use experimental and/or simulation methods; most show that clearances, conductor geometry, ventilation, and materials are critical to thermal behavior.

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III. PROBLEM STATEMENT AND OBJECTIVES

A. *Problem Definition*

High temperature rise in busducts under heavy load degrades insulation, reduces efficiency, and decreases system lifespan. Uneven heat dissipation leads to localized hotspots requiring detailed thermal investigation.

B. *Objectives*

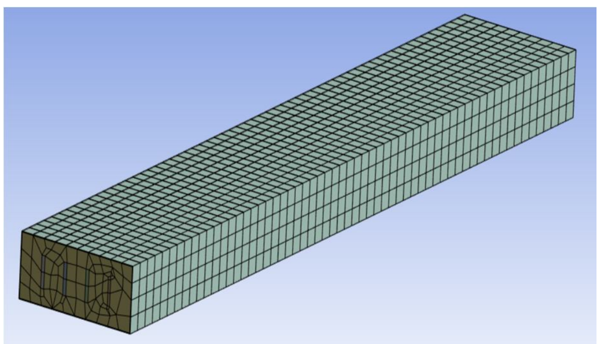
1) Develop a 3D CAD model of a busduct system.
2) Perform CFD analysis to evaluate temperature variation under natural and forced convection.
3) Identify design contradictions using TRIZ methodology.
4) Propose improved ventilation/material concepts to reduce hotspots.

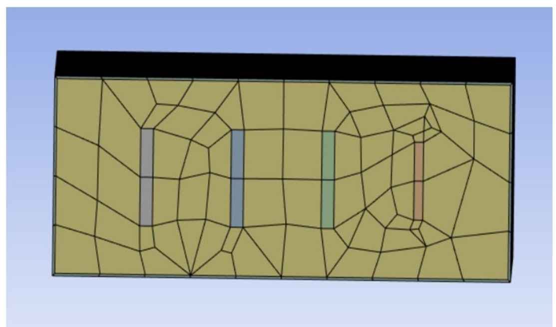
IV. METHODOLOGY

A. *Meshing Strategy*

Mesh generation was performed in ANSYS Fluent Mesher.
Key meshing considerations:

1) Tetrahedral mesh for complex geometry
2) Inflation layers near conductor surfaces for capturing boundary layer
3) Fine mesh in regions of expected hotspots
4) Coarse mesh in free air regions for computational efficiency





Display	
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Defaults	
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Solver Preference	Fluent
Element Order	Linear
Element Size	5.e-002 m
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Quality	
Inflation	
Advanced	
Statistics	
Nodes	10675
Elements	6660

B. Boundary Condition Setup

The following boundary conditions were used:

1) Thermal Inputs

Q=I^2R

The conductor resistances used were taken from department dataset.

2) Convection

Natural convection occur between the ambient air and the busbars

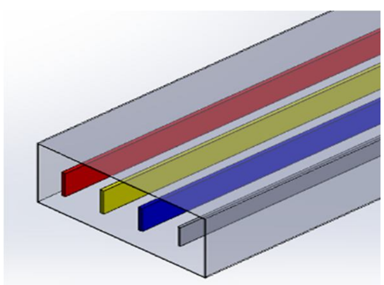
Forced convection inside duct at 10 m/s and 20 m/s

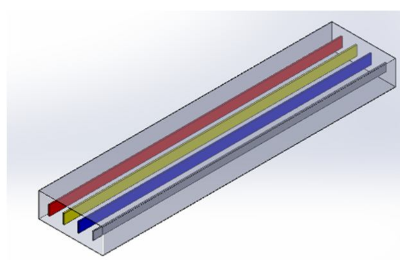
3) Material Properties

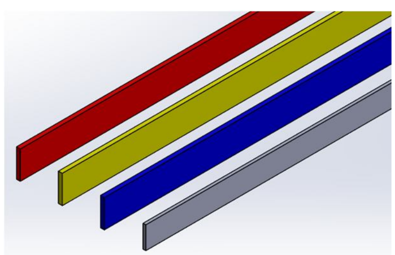
Material	Resistivity (Ω·m)	Density (kg/m³)	Specific Heat (J/kg°C)
Aluminium	2.82×10^{-8}	2707	907
Copper	1.72×10^{-8}	8933	385

C. CFD Model Setup

1. Create a 3D CAD geometry of a typical busduct segment: includes busbars (three-phase, neutral, earth), busduct enclosure walls, vents/openings if any.
2. Material properties: copper or aluminium conductors, insulating supports, enclosure sheet metals. Use temperature-dependent thermal conductivity, density, specific heat.
3. Mesh generation: sufficient resolution near busbar surfaces and ventilation openings; boundary layers to capture convective flows.







D. Boundary Conditions

1. Electrical heat generation: Joule heating from current in busbars. Possibly include eddy losses if relevant.
2. Ambient temperature: e.g. 25°C or other values.
3. Air flow: cases of natural convection (no forced airflow) and forced convection with different airflow velocities.
4. Insulation scenarios: uninsulated vs insulated portions, different insulating materials.

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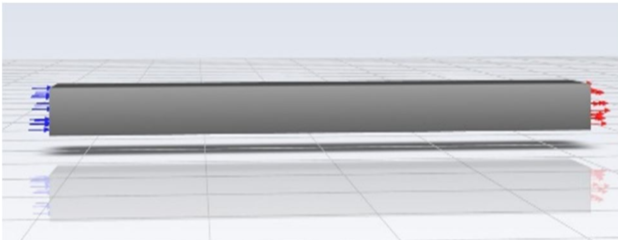
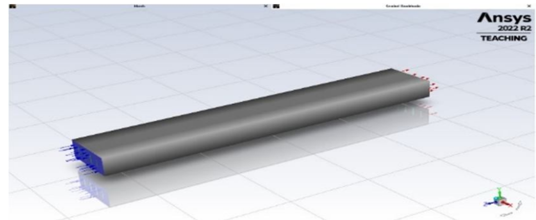




- DUCT INLET – BLUE REGION
- DUCT OUTLET – RED REGION
- DUCT WALL – GREY REGION

E. Simulation Scenarios

Simulate multiple cases,

Case	Material	Airflow	Temperature	Current load level
A	Copper	10 m/s	70 °C	2000A
B	Copper	20 m/s	70 °C	2000A
C	Aluminium	10 m/s	90 °C	2000A
D	Aluminium	20 m/s	90 °C	2000A

Record temperature distribution, steady-state maximum temperature, and transient rise if possible.

V. TRIZ (THEORY OF INVENTIVE PROBLEM SOLVING) INTEGRATION

To systematically generate design improvements, TRIZ tools can be applied:

1) Contradiction analysis: For example, increasing current rating → more conductor cross-section (hence more weight/material cost), but too thin → overheating. Or increasing ventilation improves cooling but may reduce enclosure integrity or increase ingress of dust.

2) 40 TRIZ inventive principles: Identify which principles are applicable. For instance:

a) Segmentation: Separating parts to allow better cooling (segmented busbars/phase separation).

b) "Taking out": Remove parts that hinder cooling (e.g., remove or redesign supports that block airflow).

c) Local quality: Use higher conductivity material (copper, or copper alloys) only at hotspots or junctions rather than whole system.

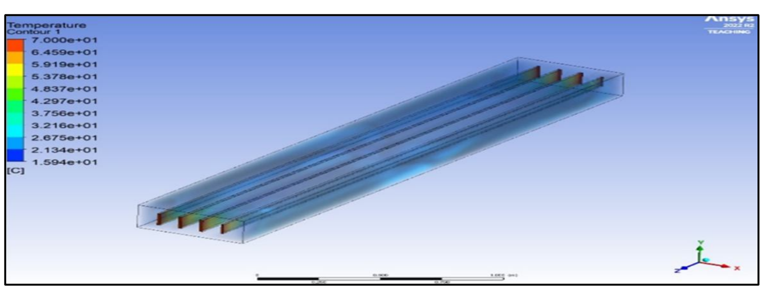
d) Composite materials: Use composite or insulated material in busduct wall or supports to improve thermal insulation where needed.

e) Changing the parameter: Adjust the shape of busbars or cross-section aspect ratio to optimize cooling (e.g. wide but thin strips vs thick compact bars).

Use TRIZ contradiction matrices to match design trade-offs and pick inventive principles to apply to your design iterations.

VI. RESULTS & DISCUSSION

A. Material - Copper at 10 m/s

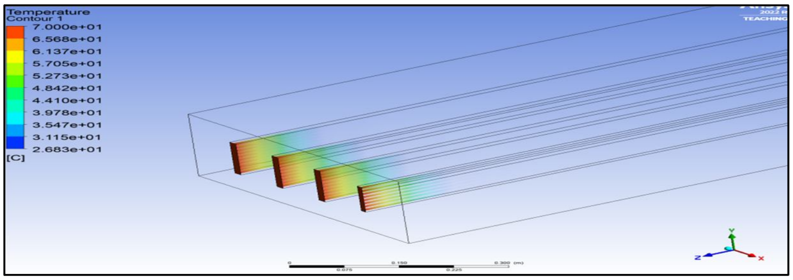


In the case of copper busbars with an air inlet velocity of 10 m/s, the temperature distribution was moderately uniform along the busbar length.

A maximum surface temperature of around 70 °C was observed near the midsection, where airflow circulation was comparatively weaker. The downstream end of the duct showed a gradual temperature drop, indicating effective convective cooling.

The temperature contour demonstrates that the thermal boundary layer was thicker at this lower velocity, which limited heat transfer from the copper surface to the surrounding air.

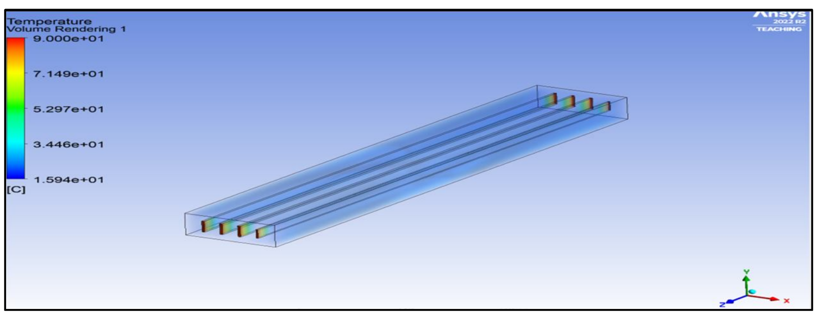
B. Material - Copper at 20 m/s



When the inlet velocity increased to 20 m/s, a significant improvement in cooling performance was observed. The temperature field became more uniform, and the peak temperature reduced by approximately 10–12% compared to the 10 m/s case.

The enhanced air velocity promoted turbulent mixing, resulting in a thinner boundary layer and higher convective heat transfer coefficient. As shown in the contour image, hotspots that previously appeared near the midsection were nearly eliminated, confirming that airflow enhancement is an effective means of controlling temperature rise in copper busducts.

C. Material - Aluminium at 10 m/s

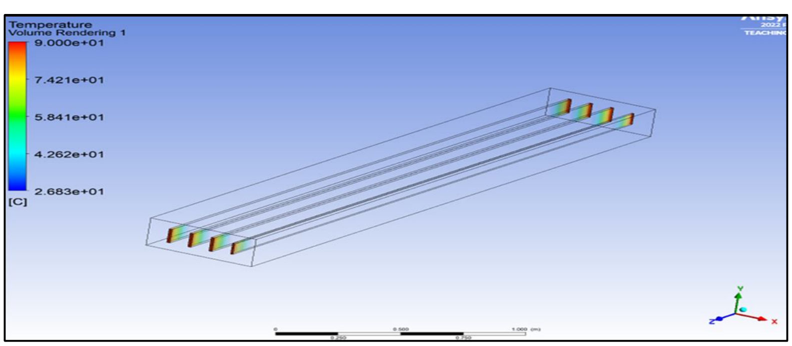


In contrast, the aluminium busbars exhibited higher surface temperatures, with peak values reaching around 90 °C under the same 10 m/s airflow condition. The lower thermal conductivity of aluminium (≈ 237 W/m·K) caused heat accumulation along the busbar length, leading to the formation of pronounced hotspots near the central region.

The contours clearly show non-uniform temperature zones, indicating poor heat dissipation.

This proves that under identical electrical loading, material selection has a significant effect on the overall busduct temperature behaviour.

D. Material - Aluminium at 20 m/s



Upon increasing the airflow velocity to 20 m/s, a noticeable reduction in surface temperature was achieved; however, the overall temperature remained higher than that of copper.
The contours show improved heat removal along the busbar length, yet the thermal gradient between the inlet and outlet regions persisted due to aluminium's limited conductivity.
The high-velocity air minimized the stagnation zones within the duct, reducing thermal accumulation near the contact joints.
These results confirm that airflow enhancement can compensate partially for aluminium's lower thermal conductivity, but not completely eliminate hotspots at high current levels.

VII. CONCLUSIONS

CFD simulation has demonstrated strong effectiveness in predicting temperature variation in busduct systems and identifying thermal hotspots critical to system performance. The analysis shows that design variables such as material selection, ventilation characteristics, conductor geometry, and insulation significantly influence maximum temperature and overall thermal distribution. These insights provide a scientific basis for improving thermal management and enhancing operational reliability. The integration of TRIZ methodology further strengthens the design process by offering a systematic approach to identifying contradictions and generating innovative solutions. Through TRIZ, design enhancements such as segmented busbars, optimized spacing, and selective material use can be conceptualized to effectively address thermal limitations. Overall, combining CFD analysis with TRIZ-driven design innovation yields a more robust, efficient, and thermally optimized busduct system suitable for modern electrical infrastructure demands.

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