Integrated Electrical-Thermal-Structural Analysis in High-Frequency AC Systems Using LS-DYNA

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Mercedes-Benz

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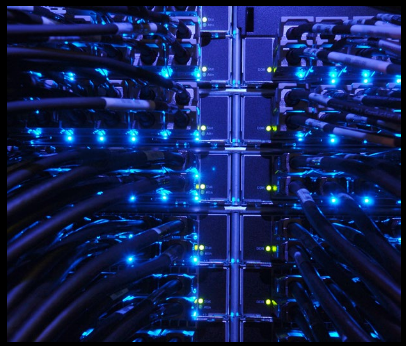


Data centers

Electric vehicles

Challenge

High voltage/current flow → Leads to resistive heating → Impacts thermal & structural integrity

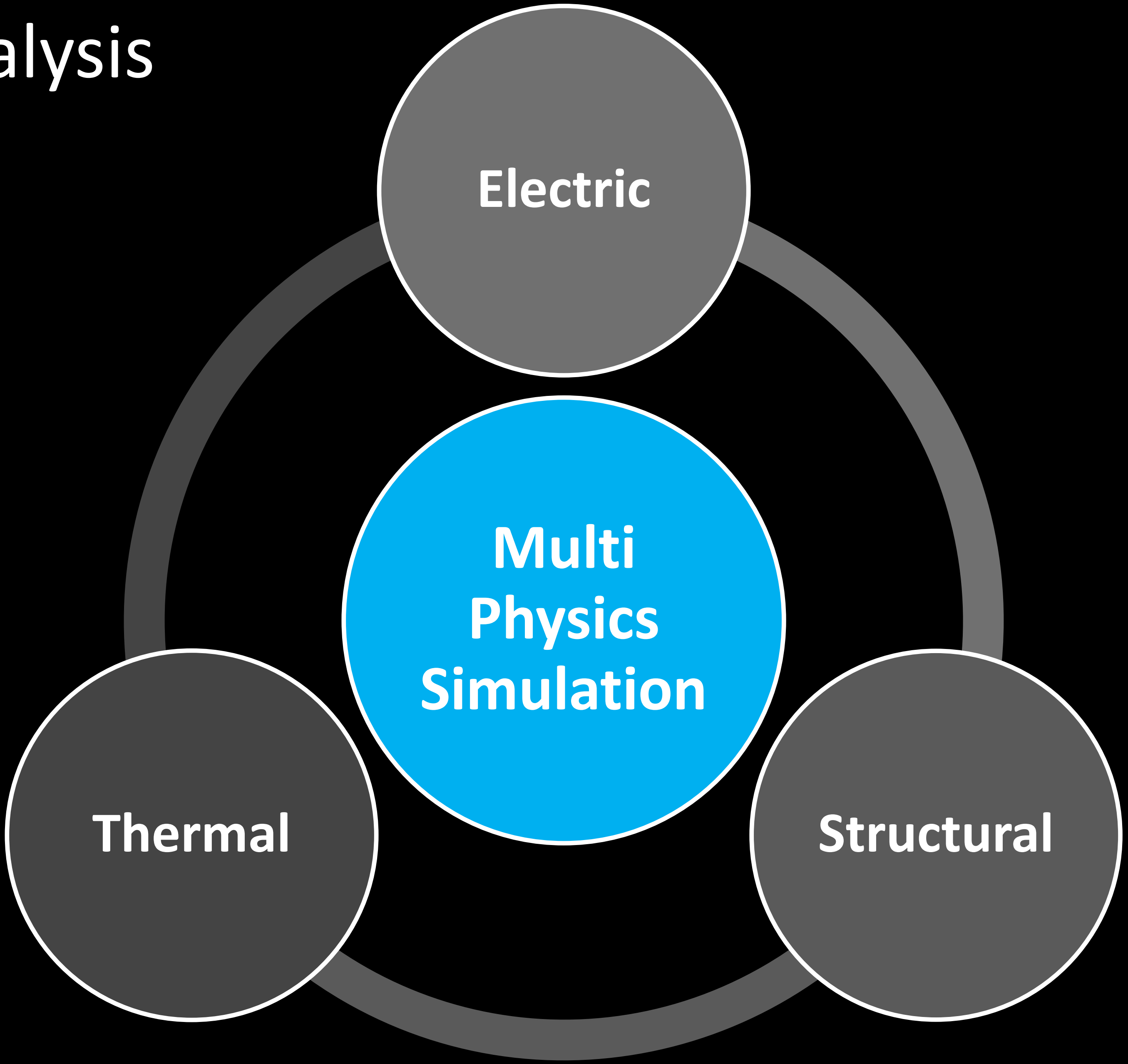
Coupled multi physics analysis

Multi Physics analysis - Advantages

- Interdependency of multiple physics
- Enhanced accuracy
- Better design insights
- Efficient integrated workflow

Conventional methods

- Separate independent analyses
- Multi physics interaction with 3 phase AC not captured.

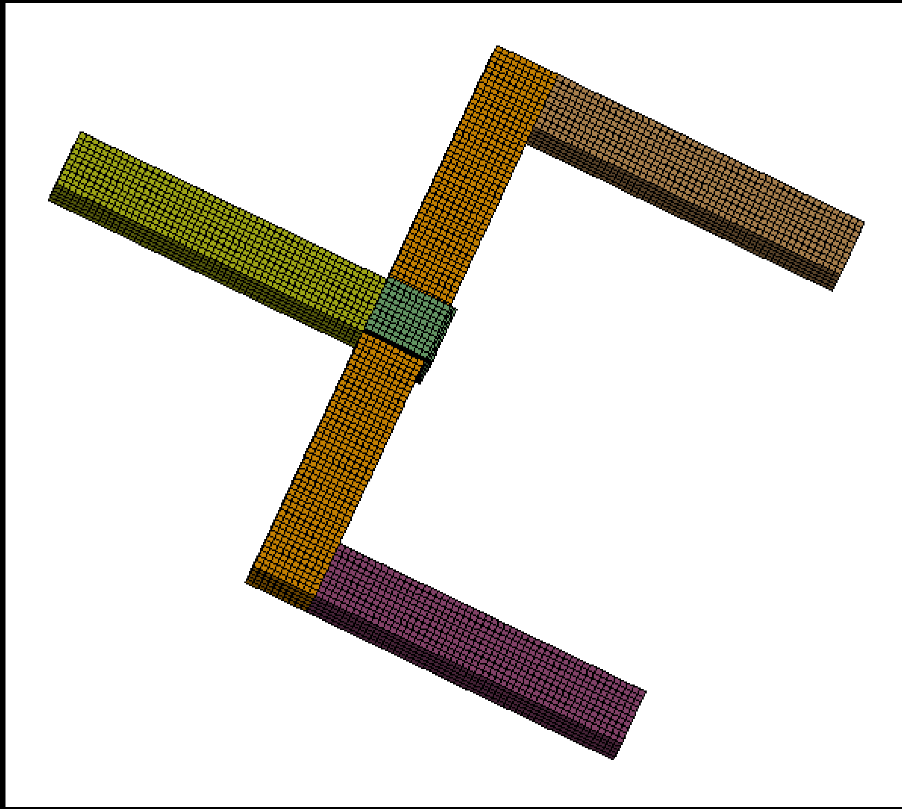


Generic case study

- A simplified 3-wire configuration, with each wire carrying one phase of a 3-phase AC current and converging at a common junction.

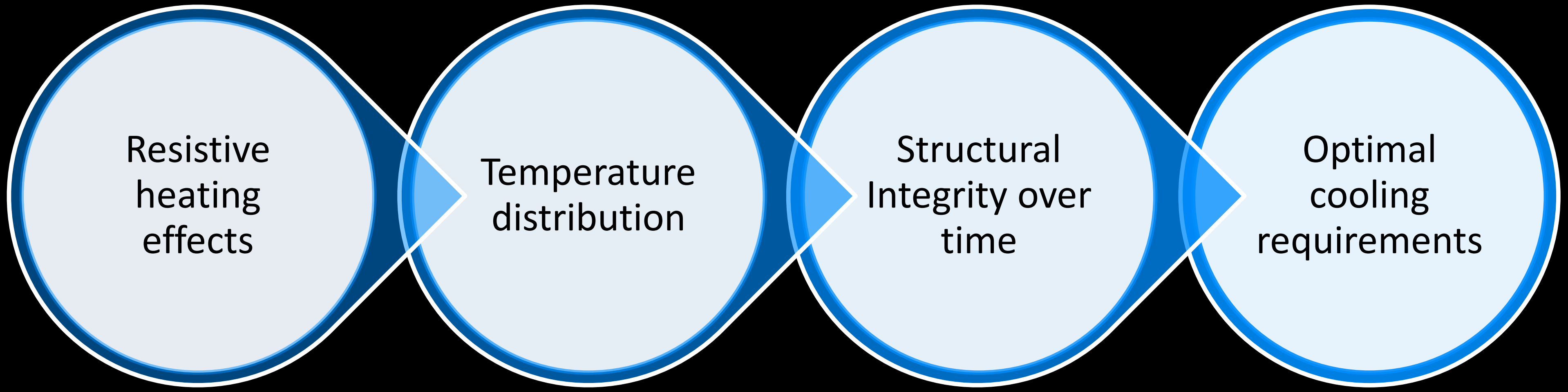
- Demonstrate effectiveness of the simulation methodology
  - Identifying potential hotspots.
  - Evaluating the risk of thermal-induced mechanical failure.
  - Optimizing thermal management strategies.

- Applicable to more complex 3 phase AC systems.



Objectives

- Analyze the coupled electrical, thermal, and structural dynamics in high-frequency 3-phase AC systems.
- High current flow leads to resistive heating increasing the temperature and thereby impacting the structural integrity. This is minimized by optimizing the cooling requirements.



Simulation setup

Assumptions

- Homogeneous and isotropic material
- Radiation is not considered in the thermal model
- Skin effects are not included in the electrical model.

Electrical Analysis

- Current density and resistive losses

Thermal Analysis

- Heat generation by resistance heating
- Conduction and Convection

Structural Analysis

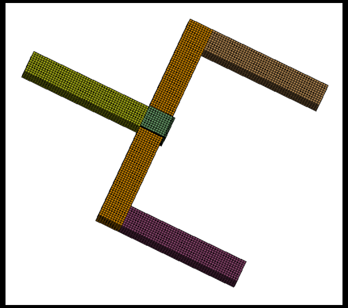
- Thermal expansion
- Stresses and Strain

Coupled multi physics Approach

- Coupling of the electrical, thermal, and structural analyses within LS-DYNA

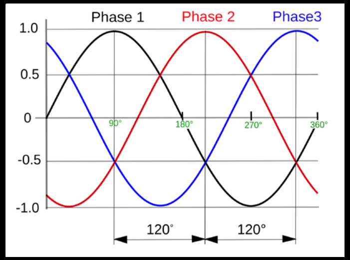
Simulation setup – LS DYNA

Meshed model

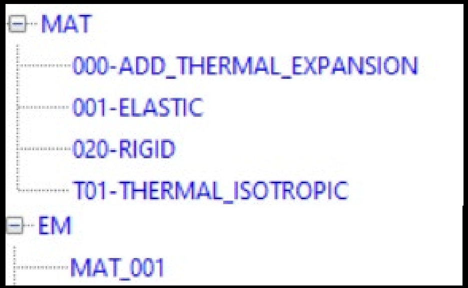


Hex Mesh
14330 elements

Electric current input (3 AC)



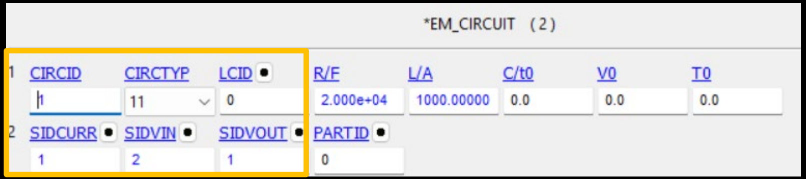
Material models

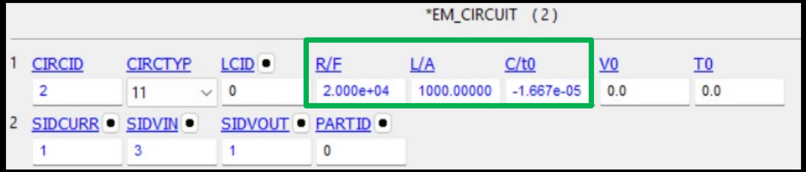


Thermal Convection Boundary Condition (BC)

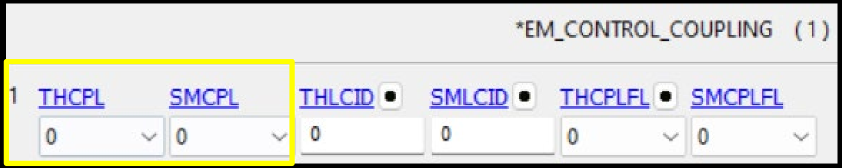
Structural BC provided by rigid body at the junction

Electric Circuit – (Modified Resistive heating model)



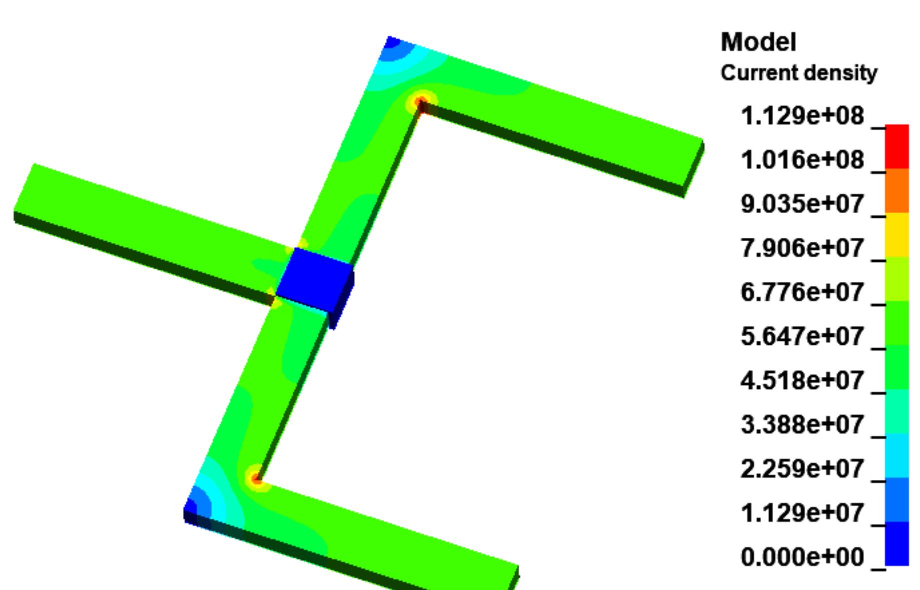


Multi physics coupling

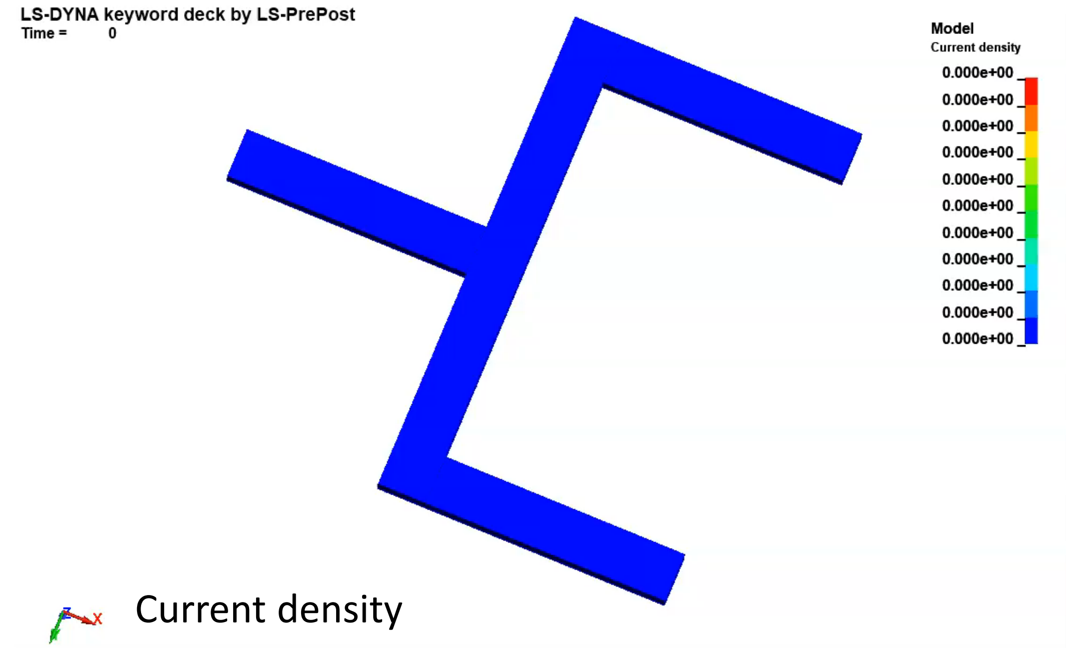


Results – current density

- Current density affects the resistive heating and thermal distribution.
- Uniform current density observed across each wire's cross-section, consistent with the exclusion of skin and proximity effects.
- Contours change over time due to the 3-phase AC current.



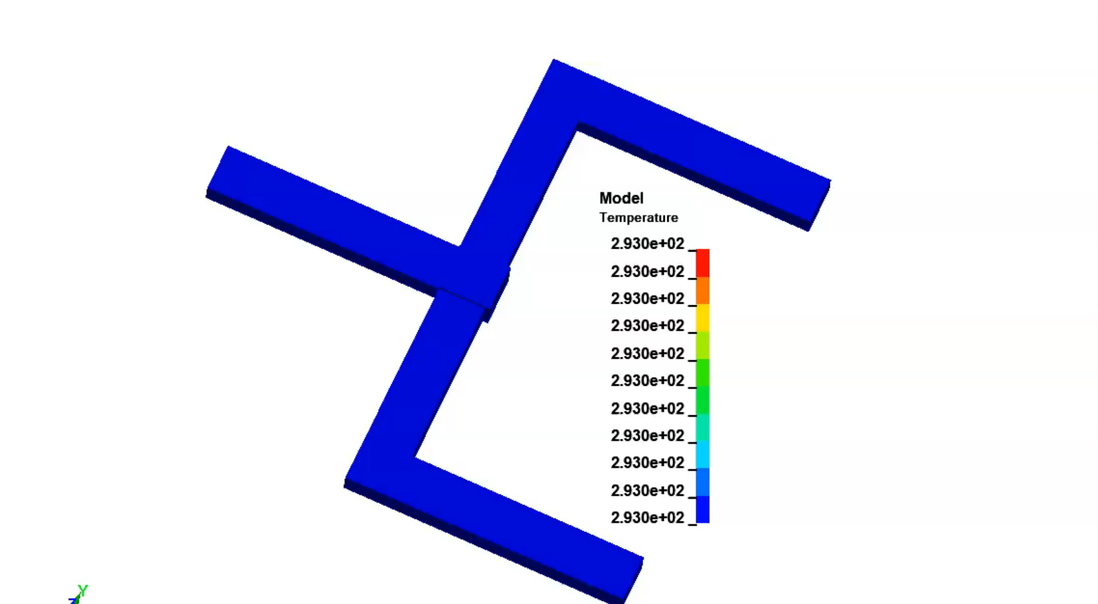
Avg. Current density



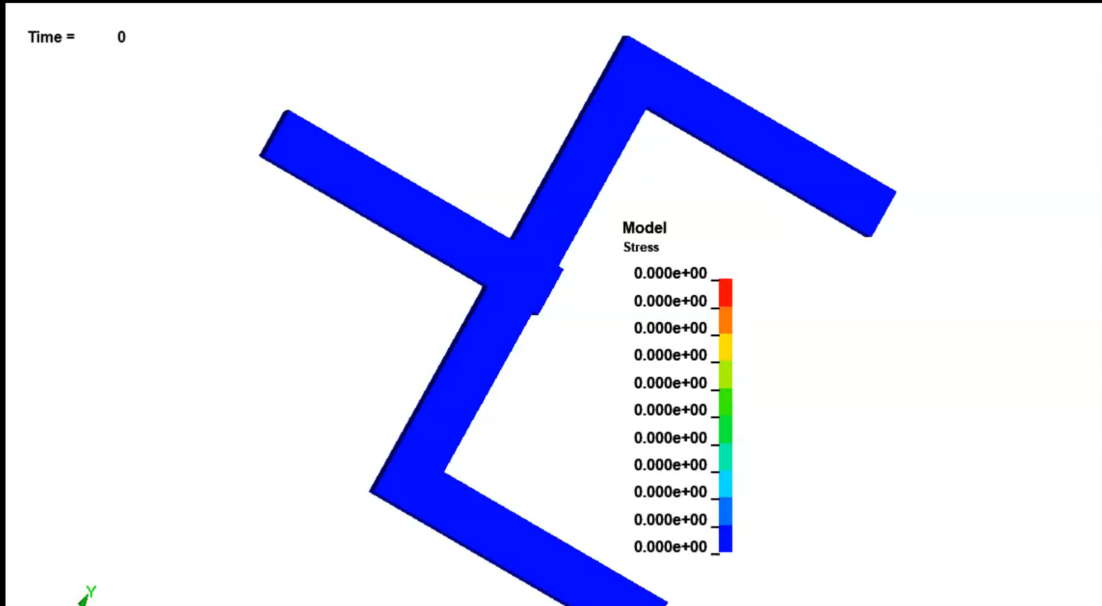
Current density

Results – thermal & structural analysis

- Temperature rise corresponds to areas of higher current density.
- Hotspots indicate potential thermal stress and material degradation, requiring targeted thermal management.
- Transient simulation captures the dynamic interplay between thermal expansion and stress concentrations.



Temperature profile



Stress development

Summary

- Demonstrated effective transient simulation integrating electrical, thermal, and structural analyses using LS-DYNA for high frequency 3-phase AC systems.
- Effective in predicting temperature evolution and mechanical stress development during current flow.
- Generic case study shows applicability to complex systems.
- Insights valuable for thermal management and structural optimization strategies.

Future work

1.Enhanced Physical Models: Incorporating more complex physical phenomena:

- The skin effect at high frequency current are computationally expensive
- The impact of electromagnetic forces (and corresponding eddy current and hysteresis losses).

2.Advanced Validation Techniques:

- Implementing advanced validation techniques using experimental data, especially for transient behavior.

3.Optimization Algorithms:

- Automate the design optimization, focusing on improving thermal dissipation and reducing mechanical stresses.

THANK YOU!