MathWorks
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Development of a Real-Time Thermal System Model for Electric Class 8 Trucks

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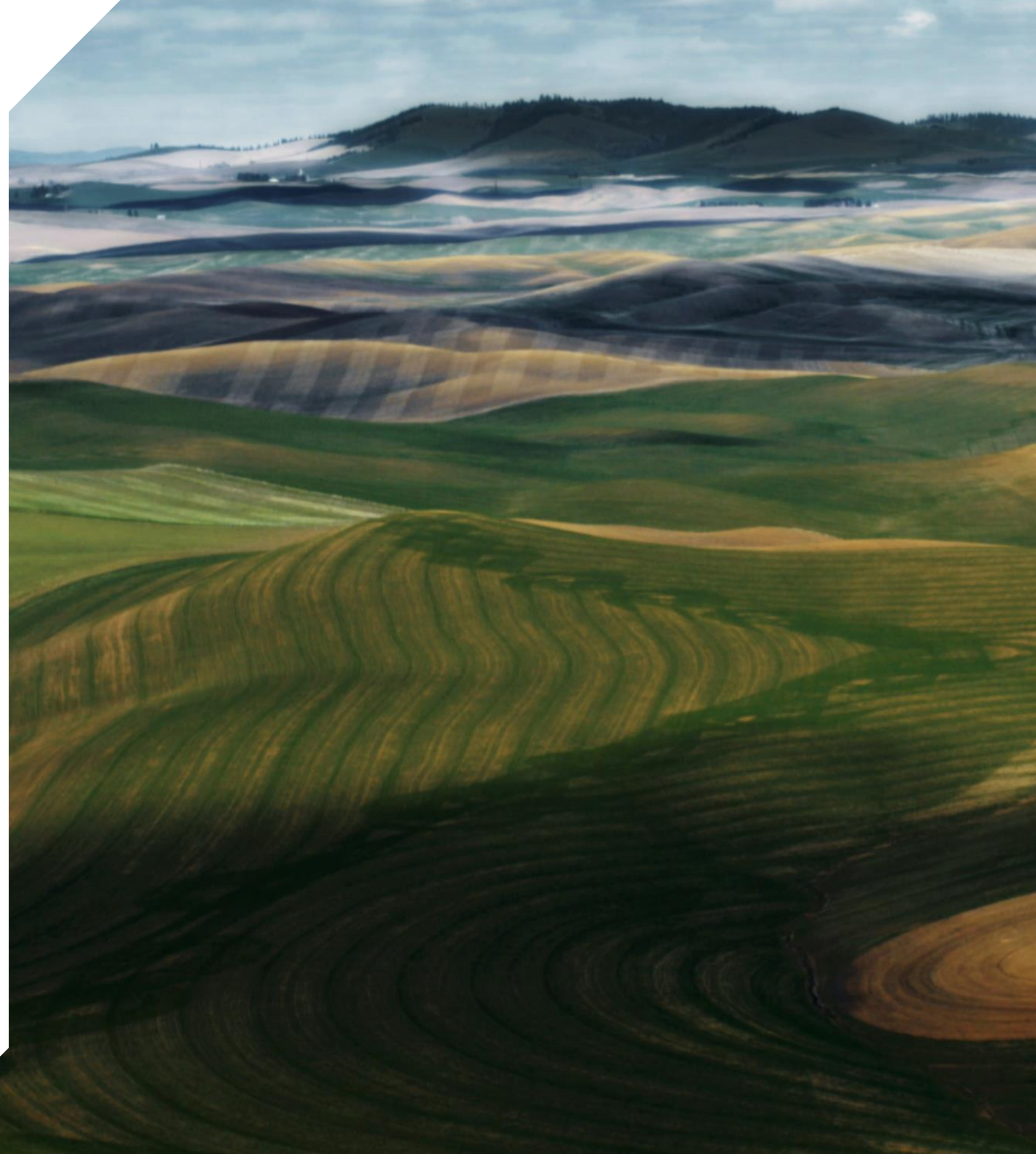

01

Section
Introduction

Problem Statement

- Development of closed loop thermal model for HIL
- Closed loop model should be able execute with turnaround time of 1 millisecond
- Detailed model for component design may not by capable to run on HiL
- Lumped parameter modeling is essential to make model RT compliant
- Refrigeration loop provide stiff challenge for Real-Time execution on HiL
- A procedure for Real-Time implementation of the refrigerant models is discussed

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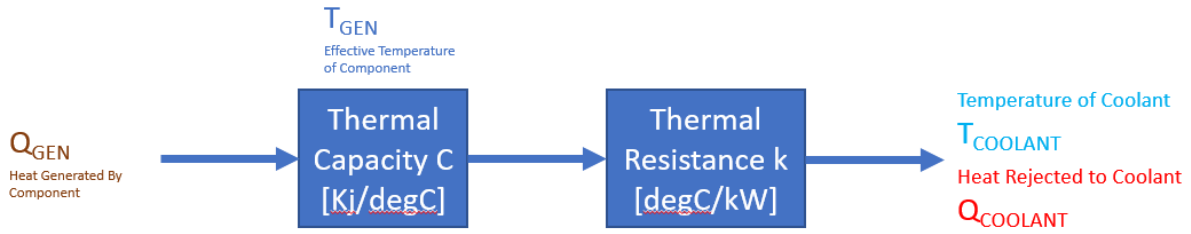
Section **Modeling overview**

Thermal Modeling – Simscape Model v2022b

- Model compatible with fixed time step of 1ms and executes on single core of dSpace SCALEXIO HIL System
- Model includes battery loop chiller with two phase flow physics
- Coolant hydraulic model is physics based and correlated with GT-SUITE model used for cooling system sizing and design
- Thermal interface for electric motor, DCDC converter, inverter and battery cell implemented in the model is described in the adjacent figure
- Operating Mode Data for Model Initialization is used to initialize Simscape model at -25degC, 25degC and 45degC

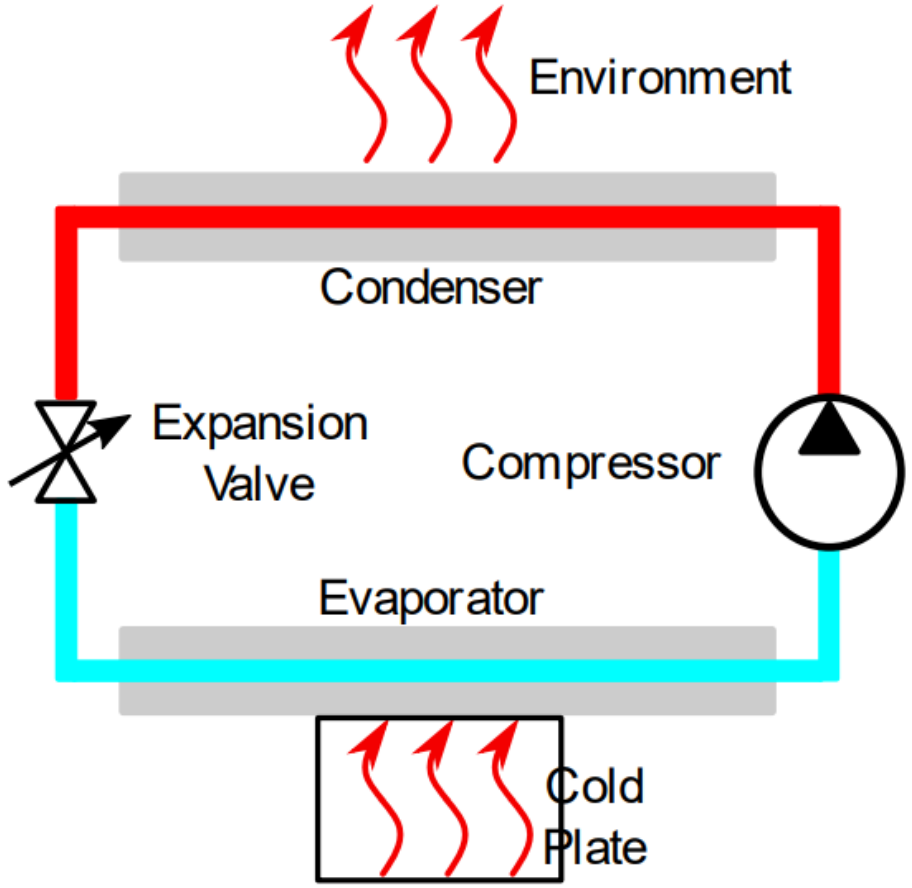


$$T_{GEN}^{t+\Delta t} = T_{GEN}^{t} + \frac{Q_{GEN}^{t} \times \Delta t}{C} - \frac{Q_{COOLANT}^{t} \times \Delta t}{C}$$

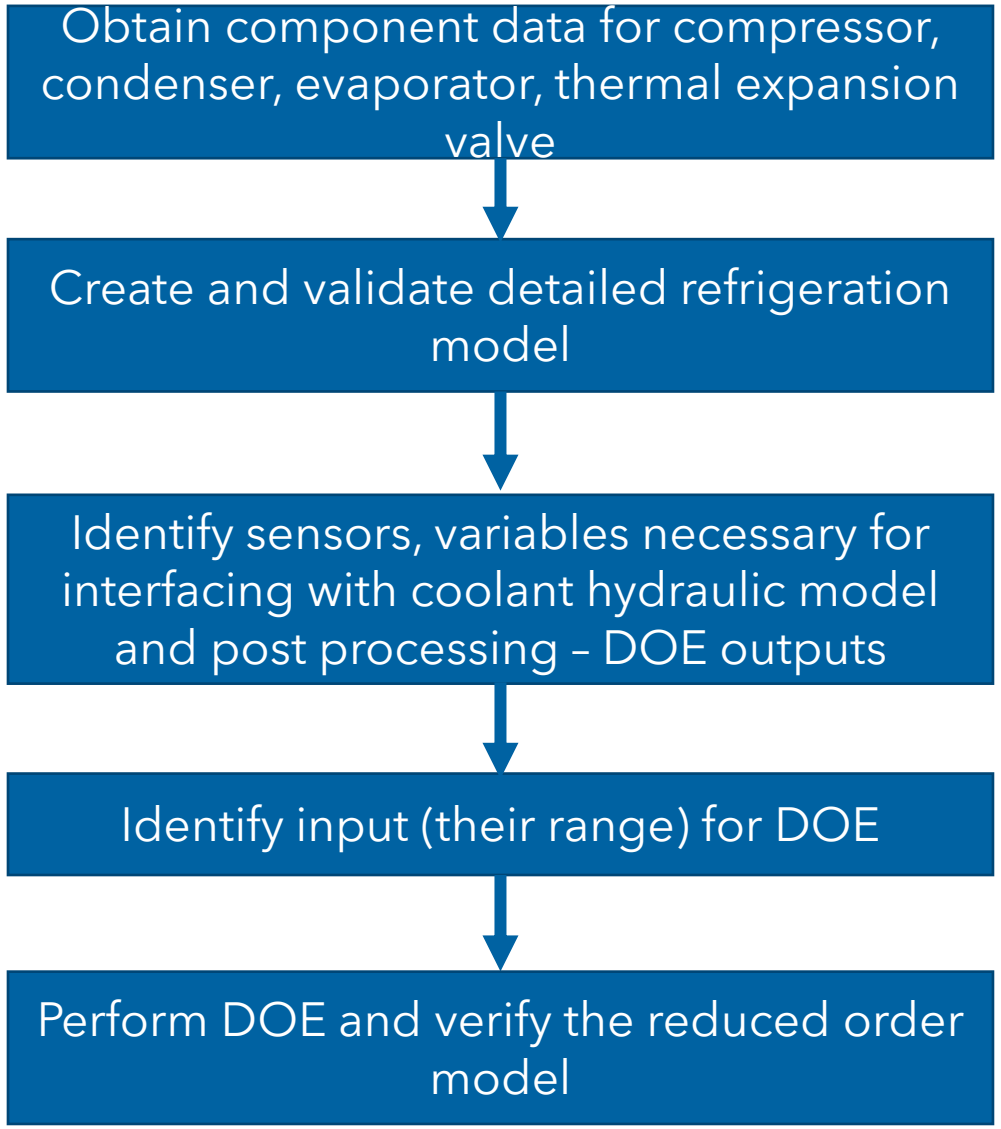
$$Q_{COOLANT}^{t+\Delta t} = k(T_{GEN}^{t} - T_{COOLANT}^{t})$$

Refrigeration model overview – Battery Cooling

- The battery cold plate which is heated externally in thermal contact with refrigeration loop
- Refrigeration loop expels its heat to the environment
- The refrigeration loop contains four main components, an evaporator, a condenser, a compressor and an expansion valve
- Condenser for battery cooling is an indirect condenser with cooling medium as coolant
- Evaporator (Chiller) is also a refrigerant to coolar heat exchanger



Procedure for refrigeration system modeling for HiL

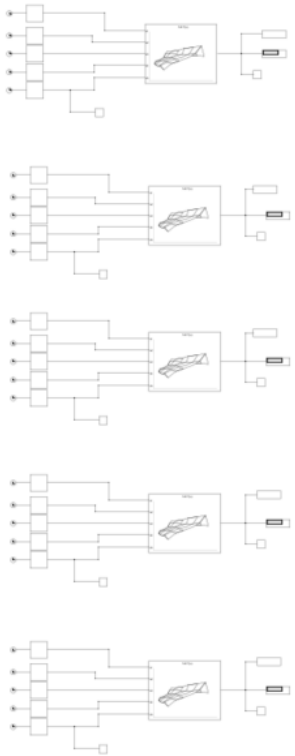


Definition of DOE – Battery Cooling

DOE Inputs	DOE Outputs
Condenser coolant inlet temperature	Compressor inlet pressure
Condenser coolant flow rate	Compressor outlet pressure
Evaporator coolant inlet temperature	Compressor inlet temperature
Evaporator coolant flow rate	Compressor outlet temperature
Compressor speed	Heat transfer to coolant in evaporator
	Heat transfer to coolant in indirect condenser
	Compressor power

- To make the refrigeration model RT compliant DOE is defined to perform batch simulation with detailed refrigeration model and generate look-up tables for the DOE outputs as defined above
- Range of coolant flow and temperature for DOE inputs is obtained from detailed GT-SUITE model

HiL Execution – Chiller Refrigerant loop model



Periodic Task 1/Task Call Counter	n-D Lookup\nTable1/Out1
900843	19.8245813555656
	n-D Lookup\nTable3/Out1
	92.5567573160062
Periodic Task 1/Task Turnaround Time	n-D Lookup\nTable5/Out1
	2.03253213749029
1.0234179914077E-05	n-D Lookup\nTable7/Out1
	2.80523084789126
	n-D Lookup\nTable9/Out1
	12.1235271657316
Periodic Task 1/Overrun Count	n-D Lookup\nTable11/Out1
0	7.46813773886685

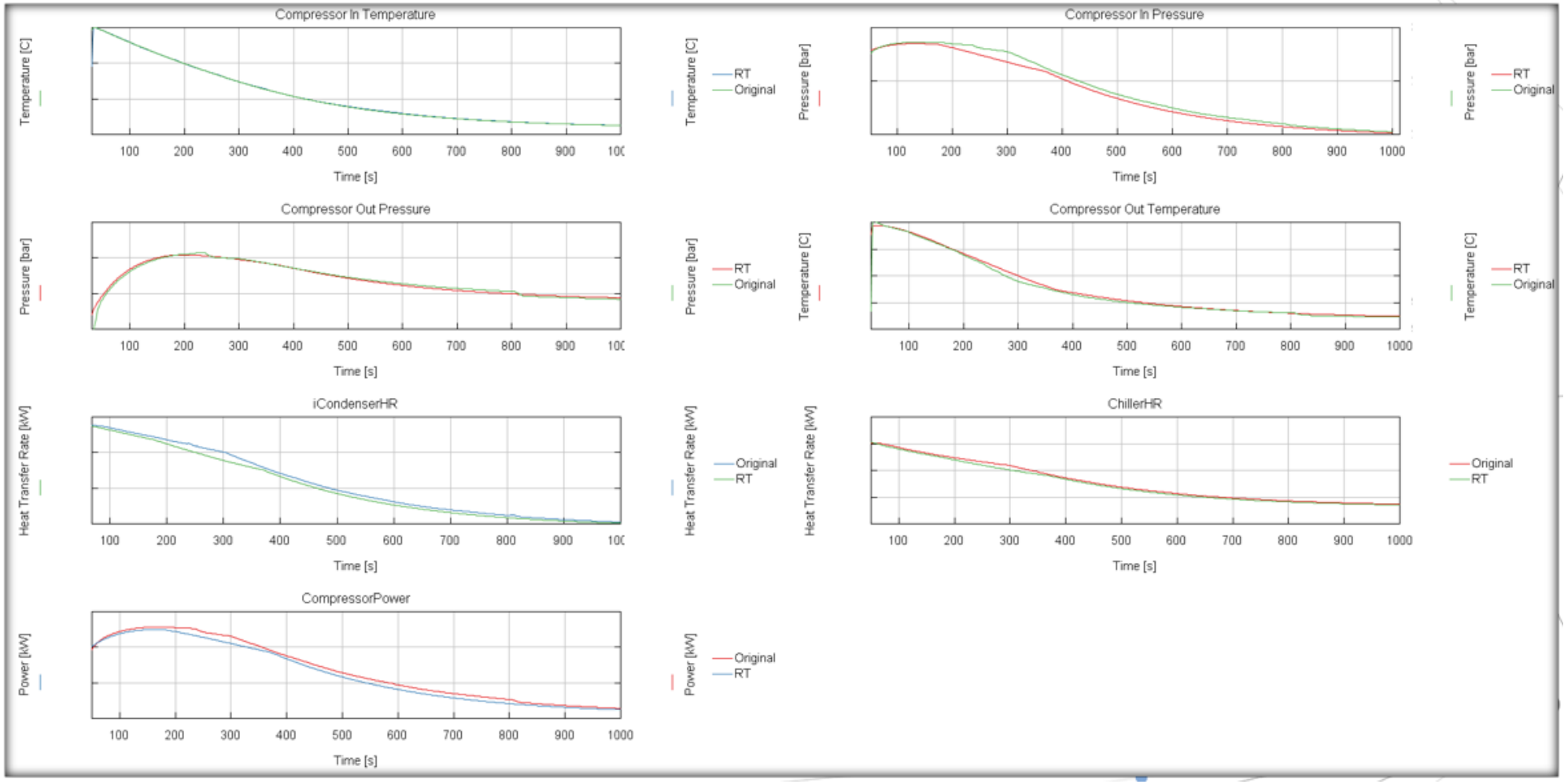
- Turnover time is 10 microsecond for Real-Time compatible RESS refrigerant loop
- Implementation of refrigerant model is as a 5-D lookup table within Simulink
- **For a steady state simulation, the CPU time of original model is 157.08s; RT model can perform same simulation within 1s for 35s simulation time**

03

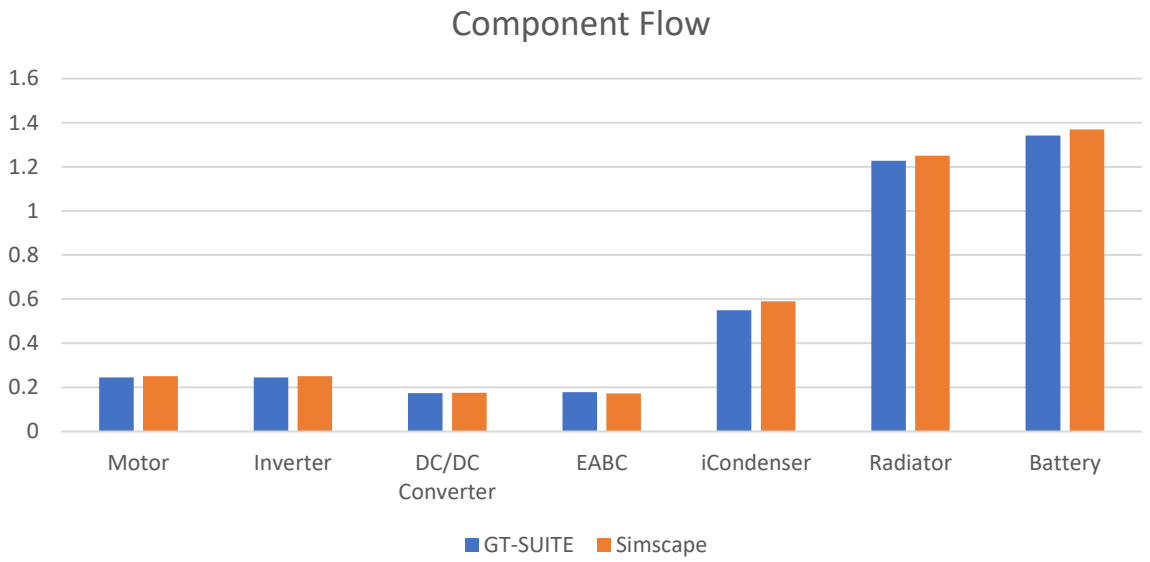
Section

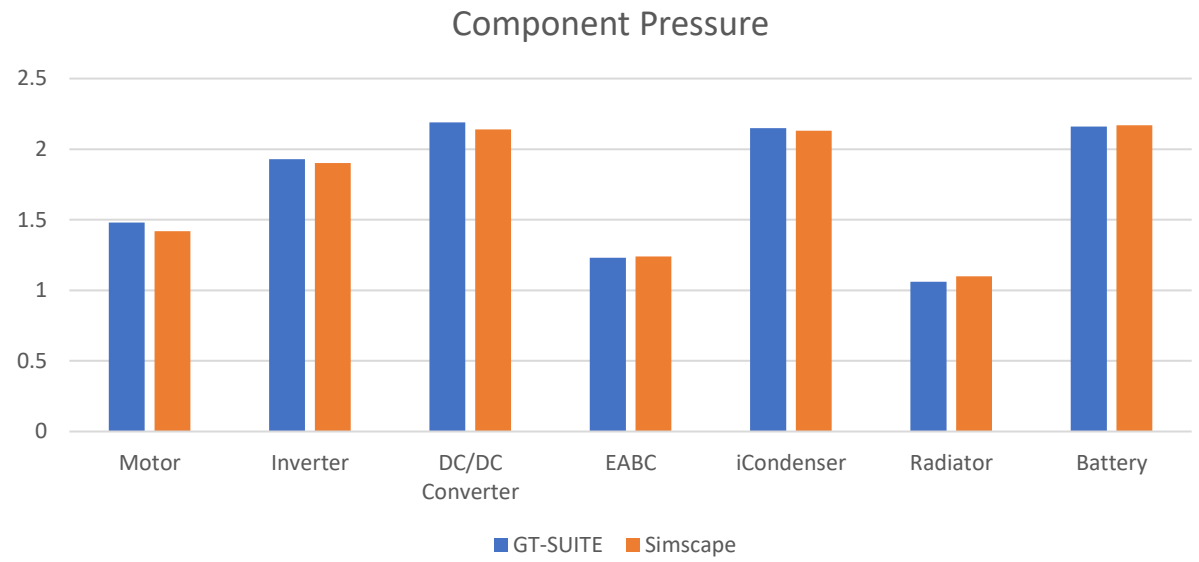
Model correlation & HIL

Correlation– Real-Time model Vs Original model



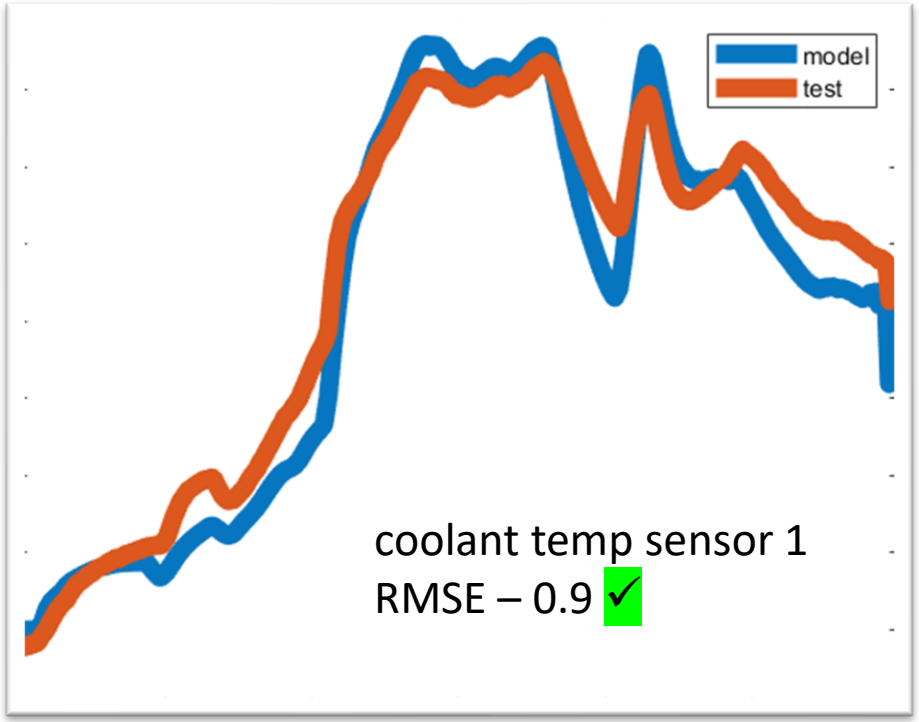
Comparison of GT Suite detailed and Simscape RT



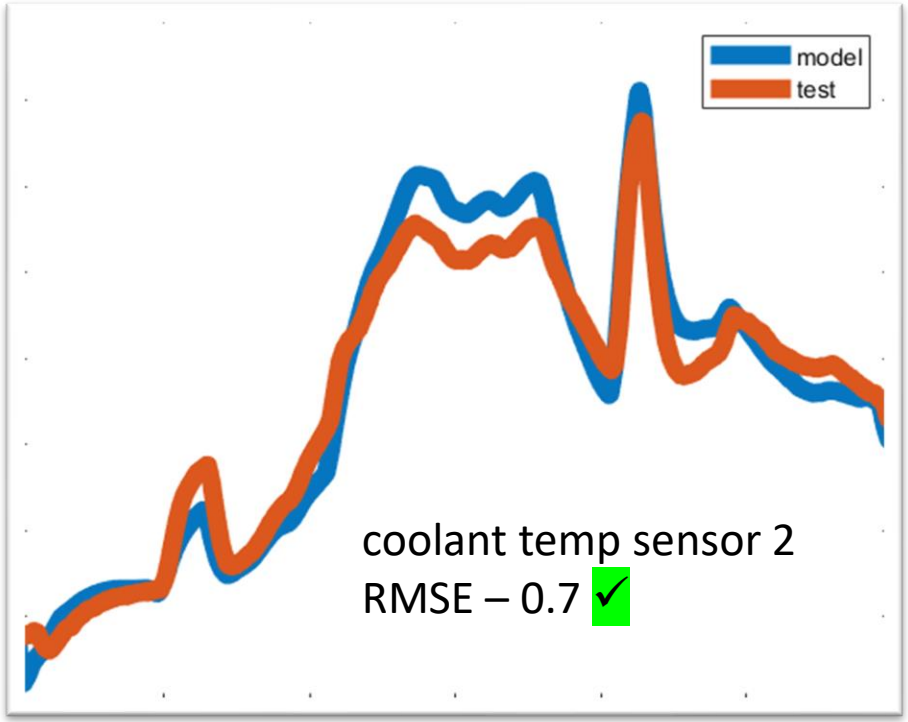


- Overall, there is a good agreement for component coolant flow and pressure between Simscape and GT-SUITE model
- GT-SUITE model is correlated with flow rig test data

Vehicle Correlation

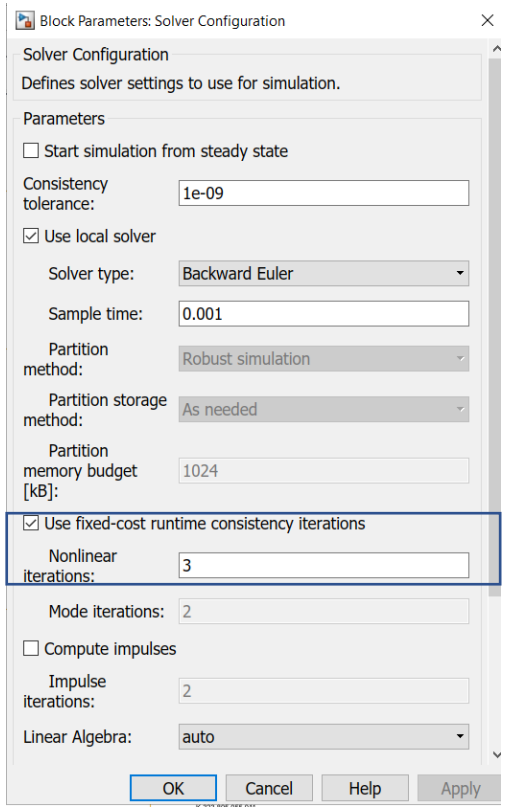


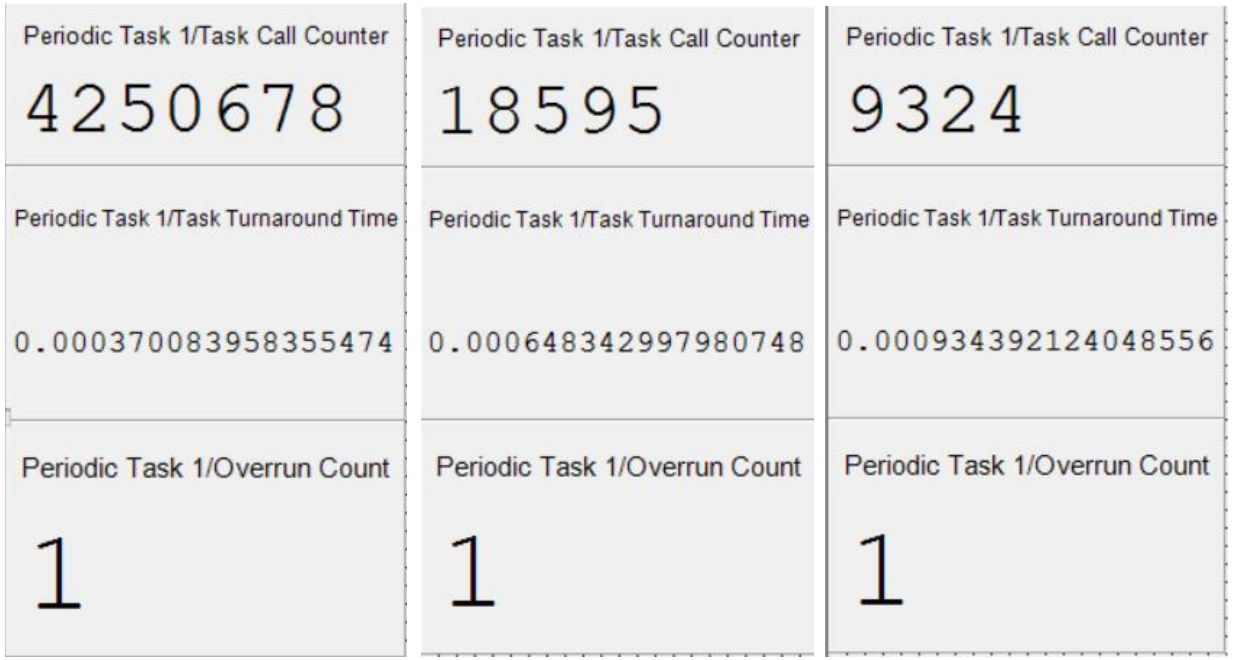
coolant temp sensor 1
RMSE – 0.9 ✓



coolant temp sensor 2
RMSE – 0.7 ✓

HIL Execution – Complete Thermal Model





Fixed cost 1 Fixed cost 2 Fixed cost 3

- Periodic task should be within 1ms to prevent task overrun
- Fixed cost factor of 2 provides an optimum task performance for this simulation
- Turnaround time is for complete thermal model on one core of muti-core HIL

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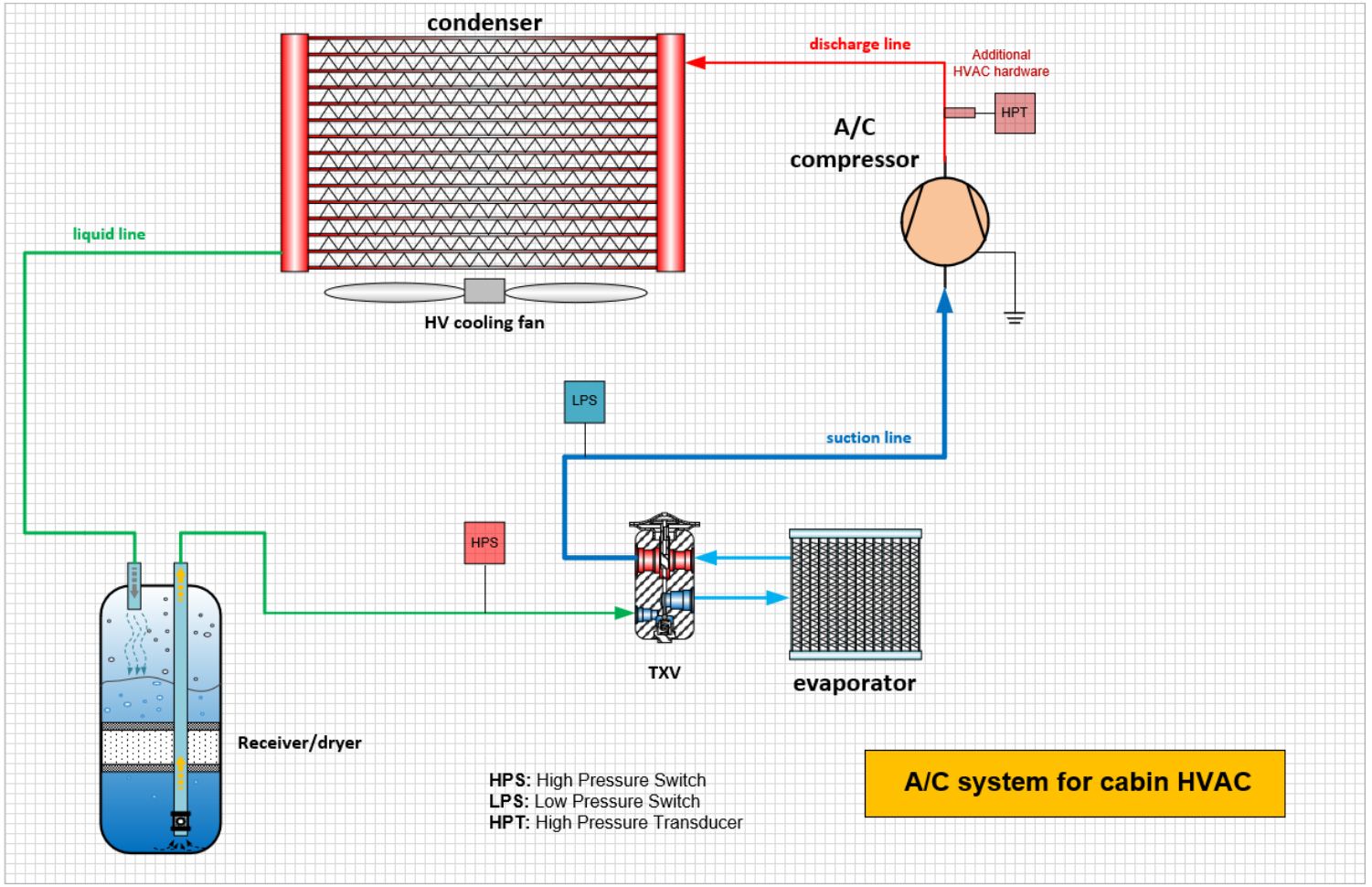
Section

Cabin HVAC model in Simscape

Refrigeration model overview – Cabin Cooling

- The cabin is in thermal contact with refrigeration loop
- Refrigeration loop expels its heat to the environment
- The refrigeration loop contains four main components, an evaporator, a condenser, a compressor and an expansion valve
- Evaporator and condenser are both refrigerant to air heat exchanger



Cabin HVAC Model Overview - Simscape v2022b

1. Fluid
- R134a
- Moist Air

2. Evaporator
- Test Harness
- Parameter script

3. Compressor Model
- Test Harness
- Compressor map post processing

4. Condenser
- Test Harness
- Parameter script

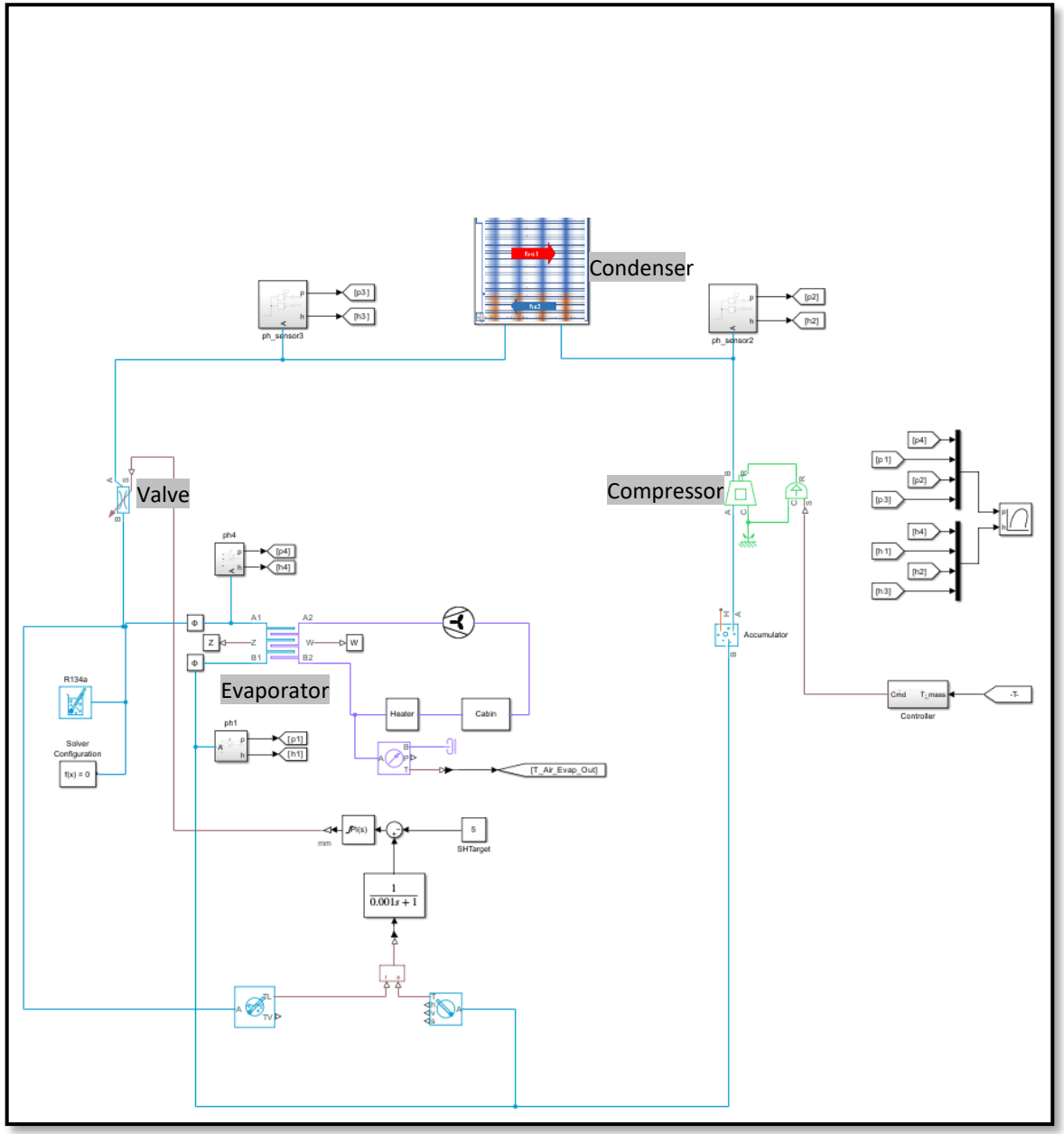
5. Close Loop
- Energy cycle validation

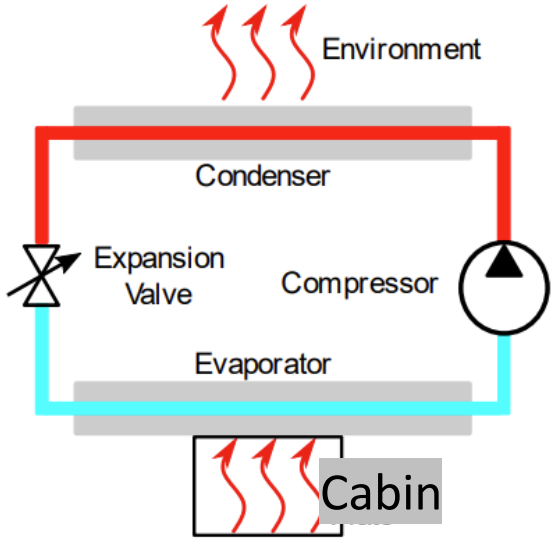
6. Expansion valve
- Test Harness

7. Charging the System
- Compute charge mass
- Initialization

8. Cabin
- Parameter script

9. Close loop control
- Expansion Valve control
- Compressor control;





Definition of DOE – Cabin HVAC model

DOE Inputs	DOE Outputs
Ambient temperature	Compressor inlet pressure
Condenser air flow	Compressor outlet pressure
Evaporator air inlet temperature	Compressor inlet temperature
Evaporator blower flow rate	Compressor outlet temperature
Compressor speed	Compressor power

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Section
Conclusion

Conclusion/Remarks

- A workflow for implementing Simscape model to run in Real-Time Hardware-In-Loop platform of dSpace SCALEXIO is discussed
- Simscape Fluids supports execution of complete thermal system model on Hardware-In-Loop test bench
- Turnaround time of the complete thermal system model including real time compatible refrigerant loop model is within 1 millisecond which is necessary to prevent task overrun
- Workflow supports execution of complex EV thermal system model on HiL and development of powertrain and energy management controller upfront in vehicle development

Thank You

NAVISTAR