

System Level Simulation Technique for Optimizing Battery Thermal Management System of EV

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01 Uses of 1D Simulation

Explains how 1D simulation is used in automotive industry.

02 Overview of Battery Cooling Circuit

Explains how a generic battery cooling/heating system works.

03 Modeling of Battery Thermal Management System of EV

Explains how a physical system modelling tool Matlab/Simulink/Simscape is used for battery thermal modeling

04 Model Validation

1D model results are compared with test data from vehicle thermal trials and validated

05 Logic Development and Results

Testing of different thermal logics

Uses of 1D Simulation

01

Component Selection

In an early stage of the development cycle, 1D system level simulation can be used for dimensioning or to test different designs.

02

Logic Development

1D models can be used for developing control logics and to improve algorithms

03

Controller Testing

1D system level simulation is used to test controllers connected to the simulated system instead of the real one (HIL testing)

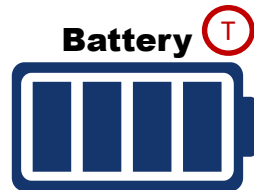
04


System Optimization

1D simulation can be used to quickly evaluate the effect of component change

Generic Battery Cooling/Heating Circuit

GENERIC BATTERY COOLING/HEATING CIRCUIT

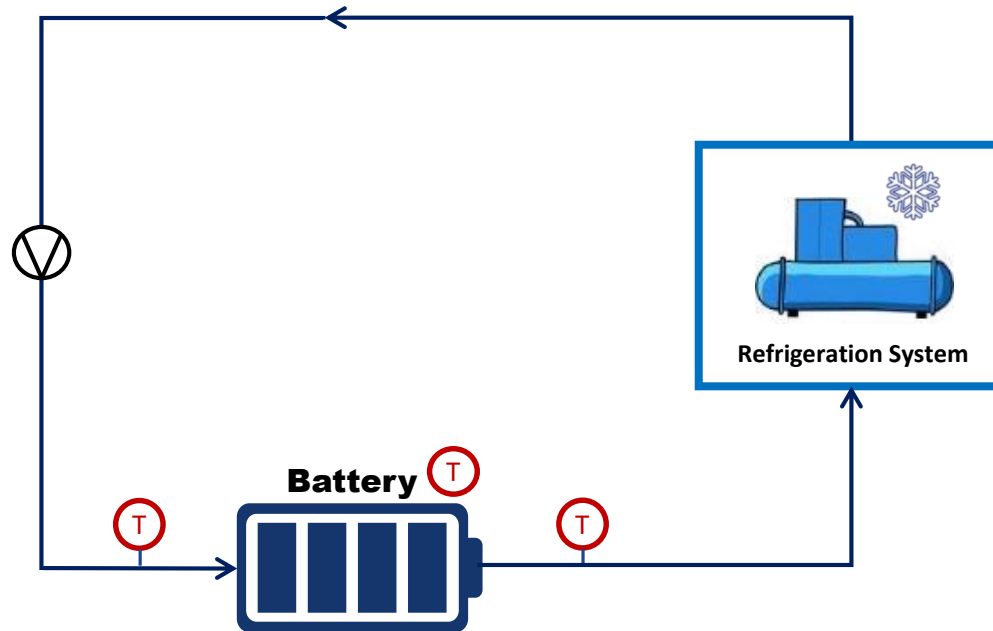


 Temperature Sensor

Battery

- Battery temperature needs to be maintained between 25°C and 45°C.
- I^2r losses will generate heat inside the battery during charging and discharging

GENERIC BATTERY COOLING/HEATING CIRCUIT



Pump

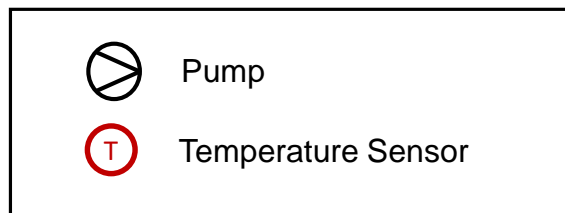
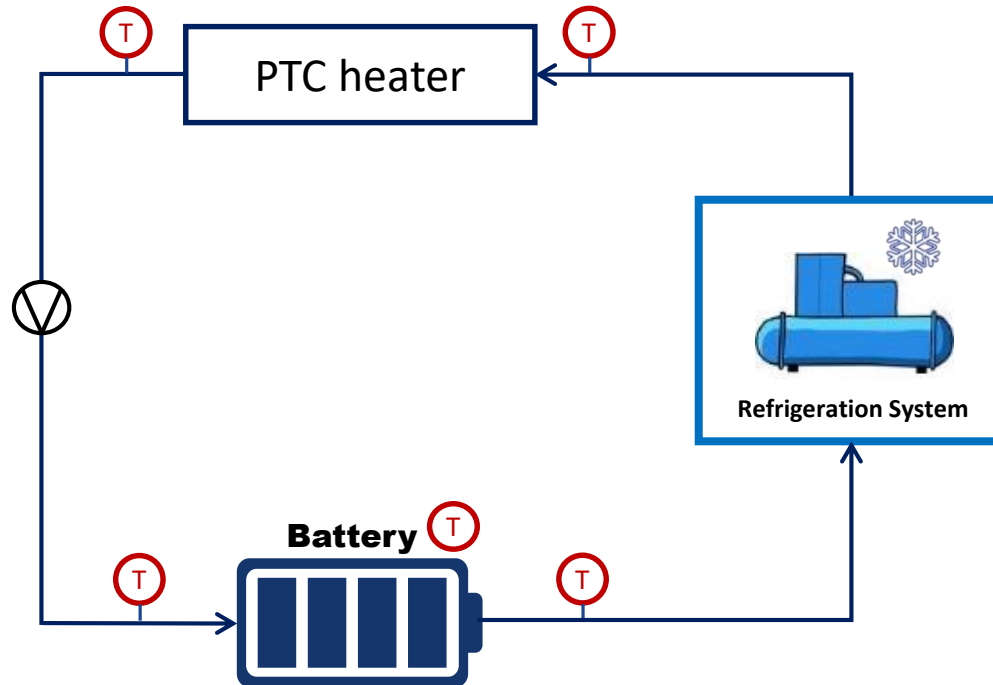


Temperature Sensor

Chiller Circuit

- When the battery temperature crosses 30°C, refrigeration system is turned ON, which will cool down the coolant

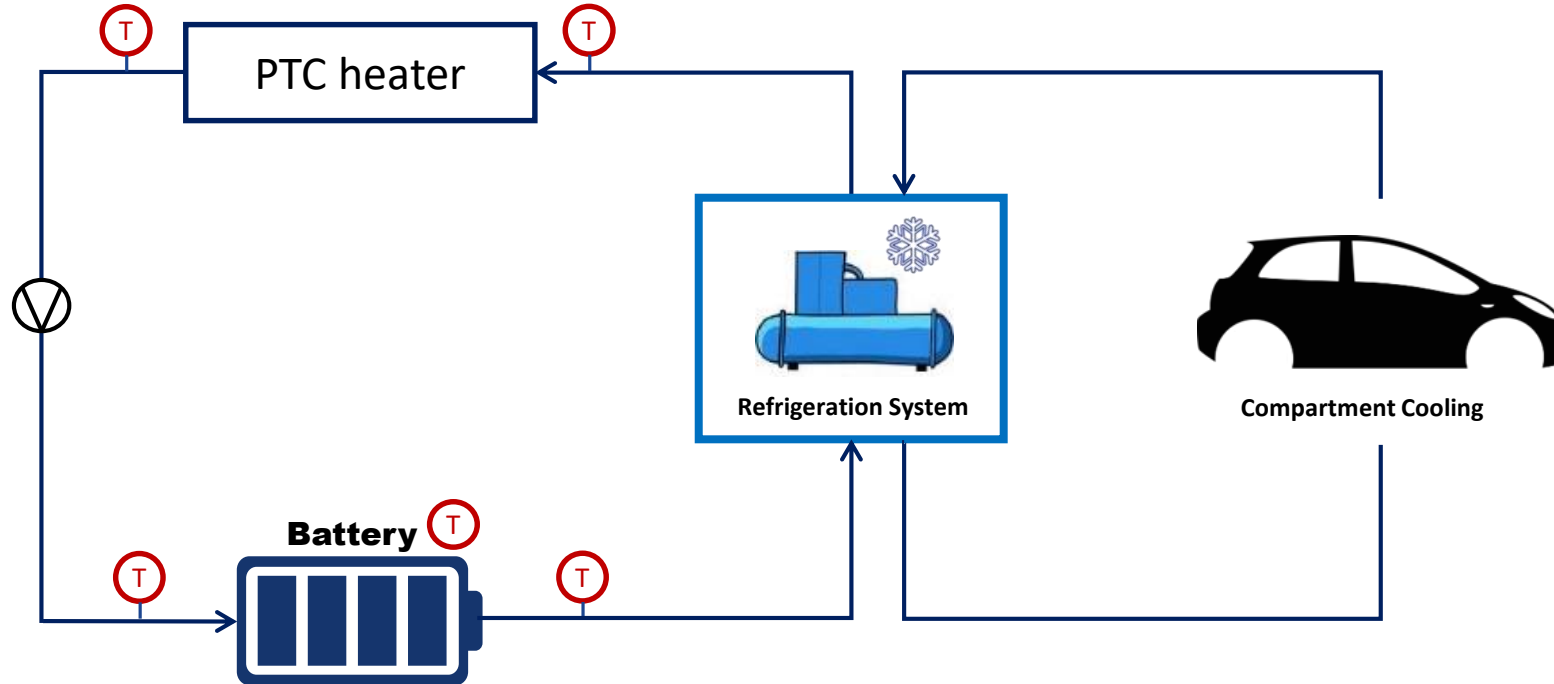
GENERIC BATTERY COOLING/HEATING CIRCUIT



Heater Circuit

- If battery temperature drops below 10°C, heater is used to heat the coolant.

GENERIC BATTERY COOLING/HEATING CIRCUIT



Pump



Temperature Sensor

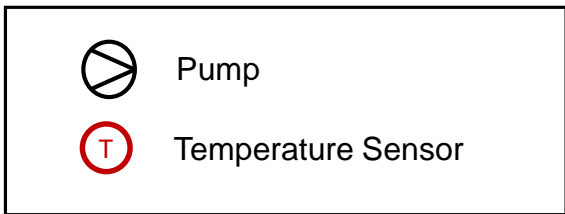
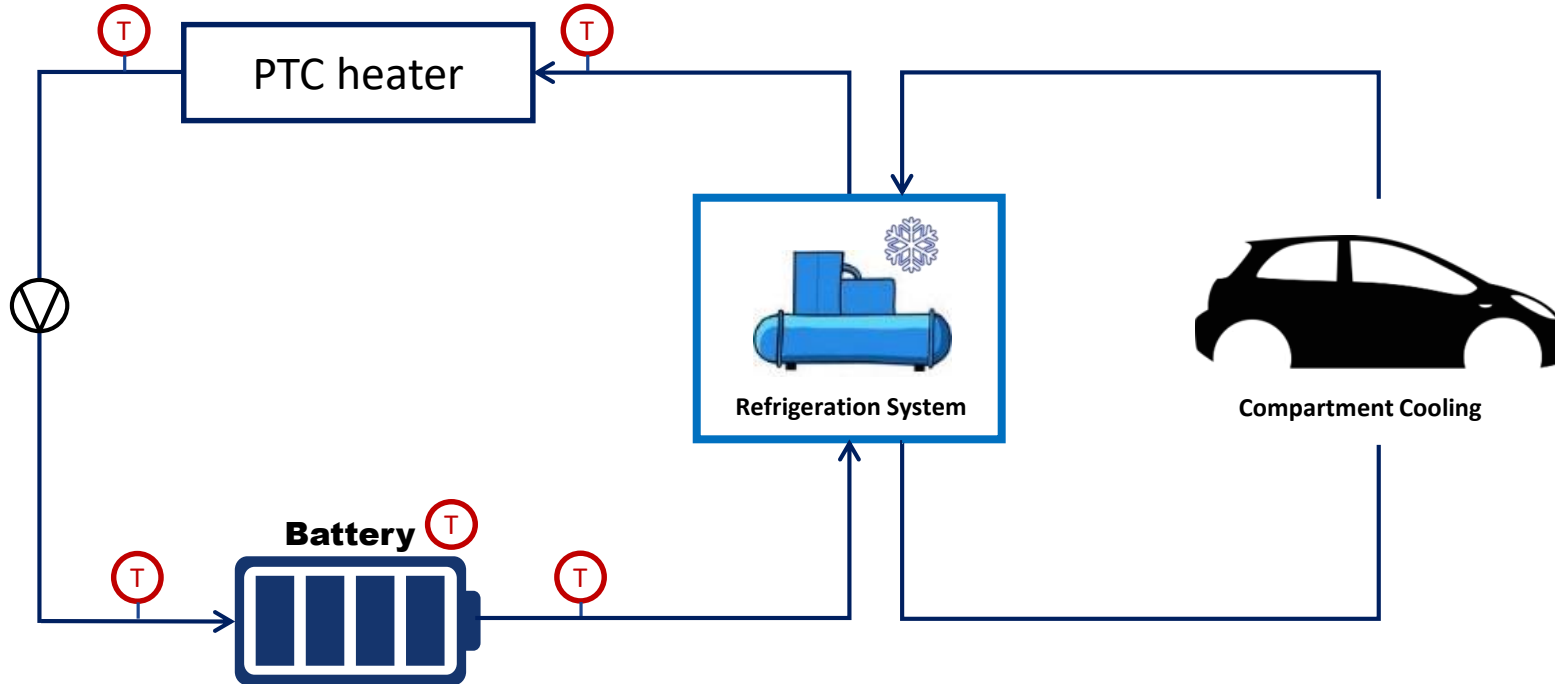
Compartment Cooling

- Refrigerant Circuit is shared by battery as well as HVAC system of the vehicle

GENERIC BATTERY COOLING/HEATING CIRCUIT



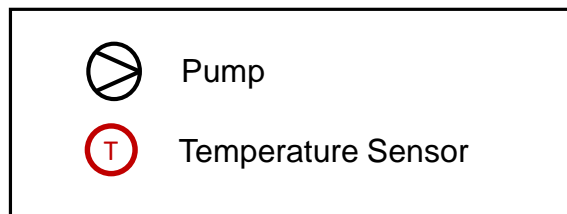
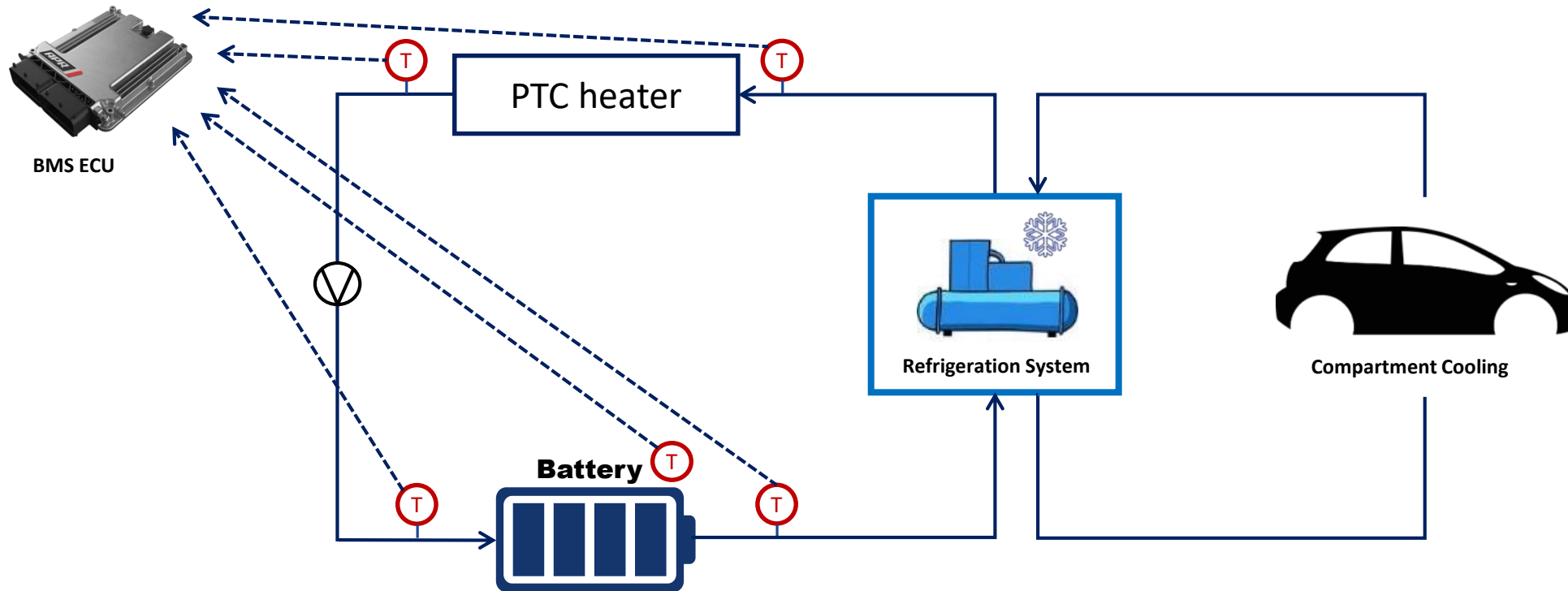
BMS ECU



BMS ECU

- Battery Thermal Management Functions are handled by BMS ECU

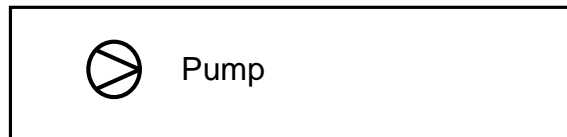
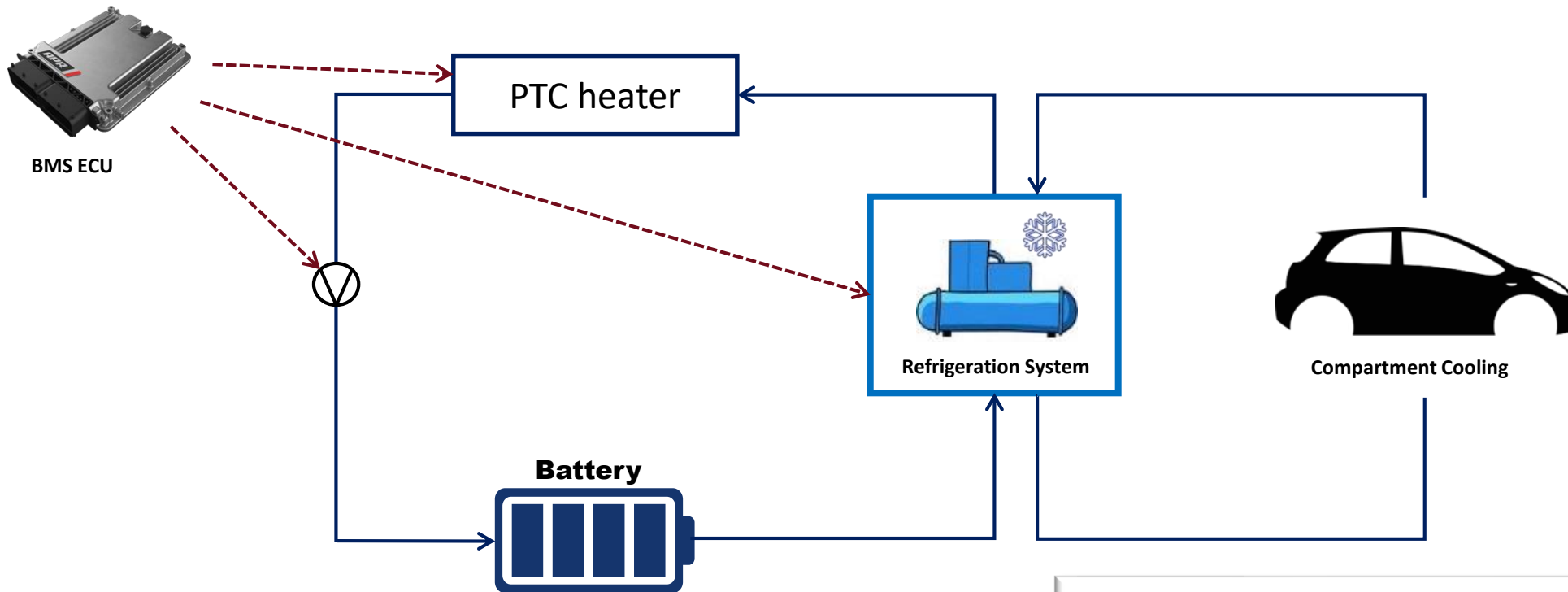
GENERIC BATTERY COOLING/HEATING CIRCUIT



Input to BMS

- Battery temperature sensor values
- Coolant temperature sensor values
- Heater temperature sensor values

GENERIC BATTERY COOLING/HEATING CIRCUIT

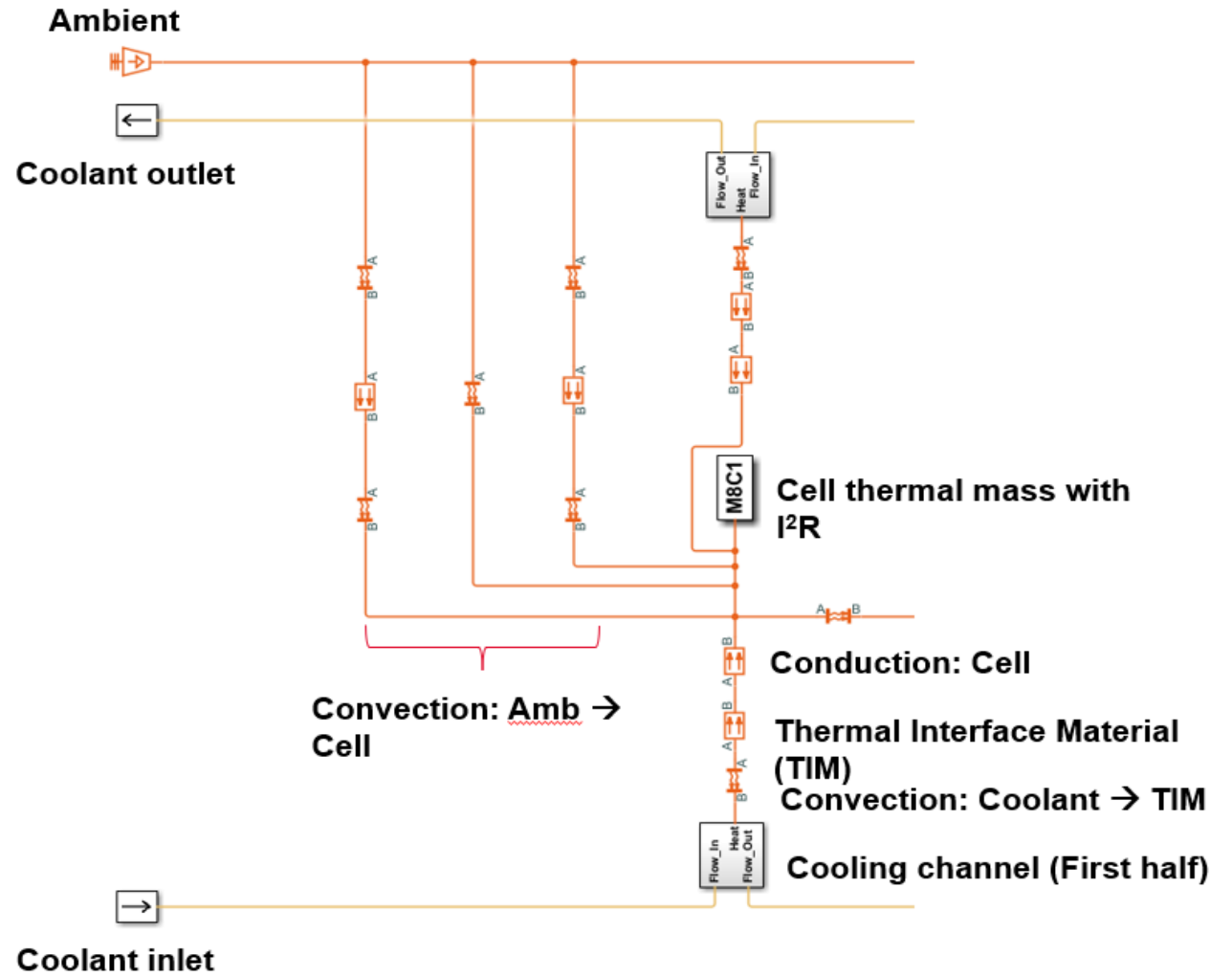
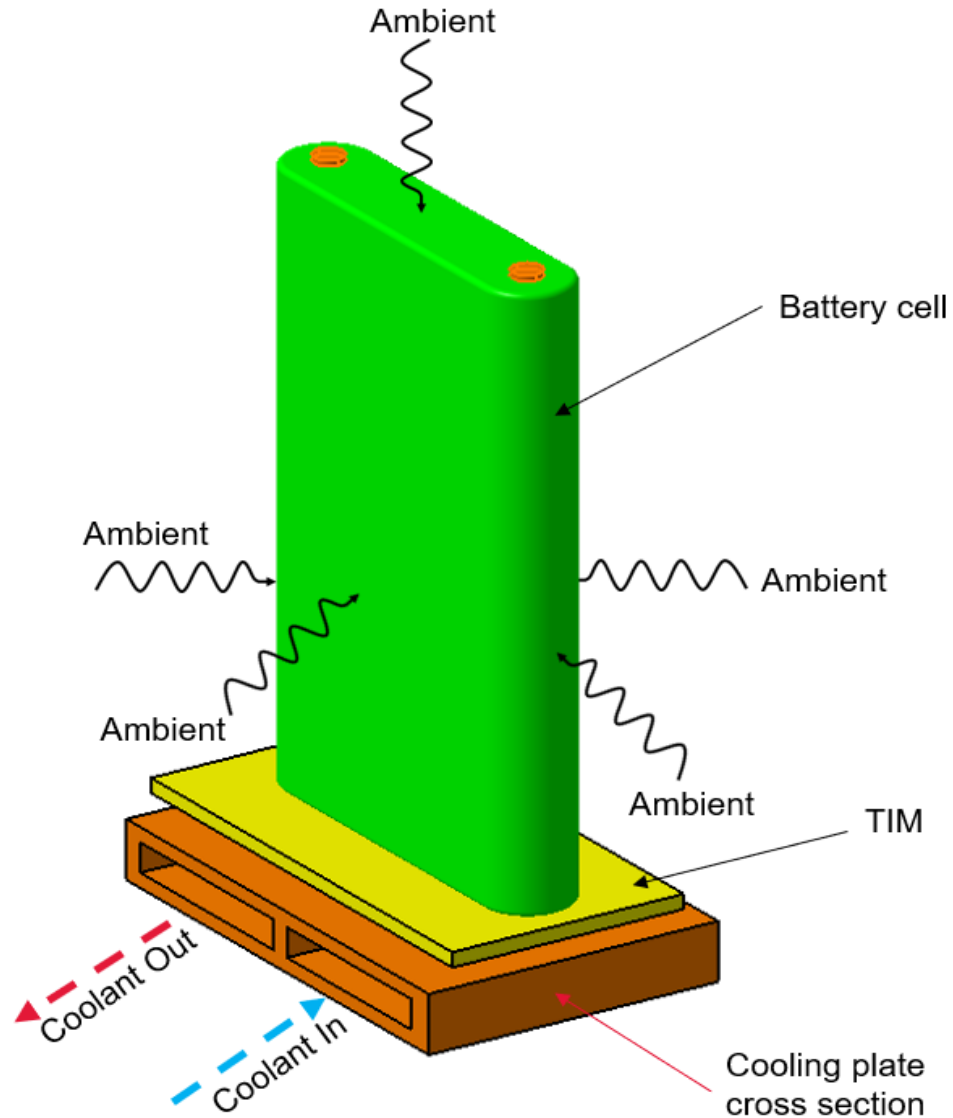


Output from BMS

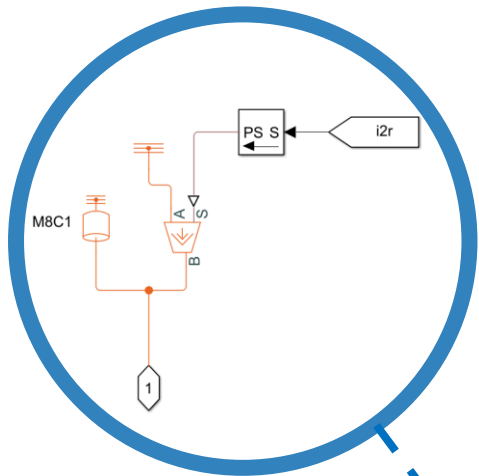
- Coolant Pump Speed
- Heater On/Off request
- Heater power Required (Watts)
- Chiller On/Off Request
- Chiller power required (Watts)

Simulink/Simscape Modelling

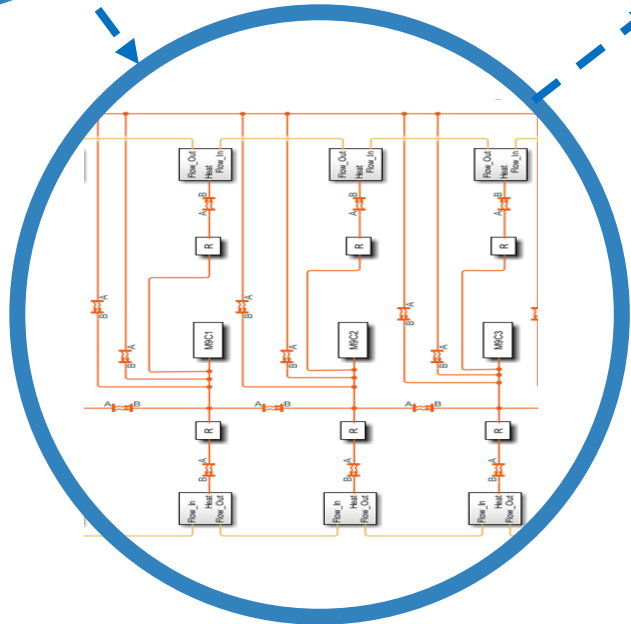
CELL MODELLING



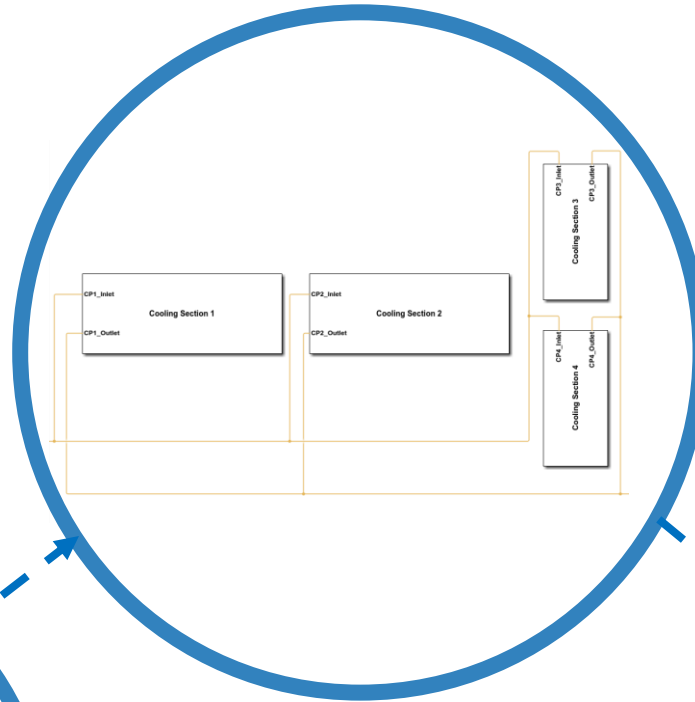
1D BATTERY THERMAL MODELING



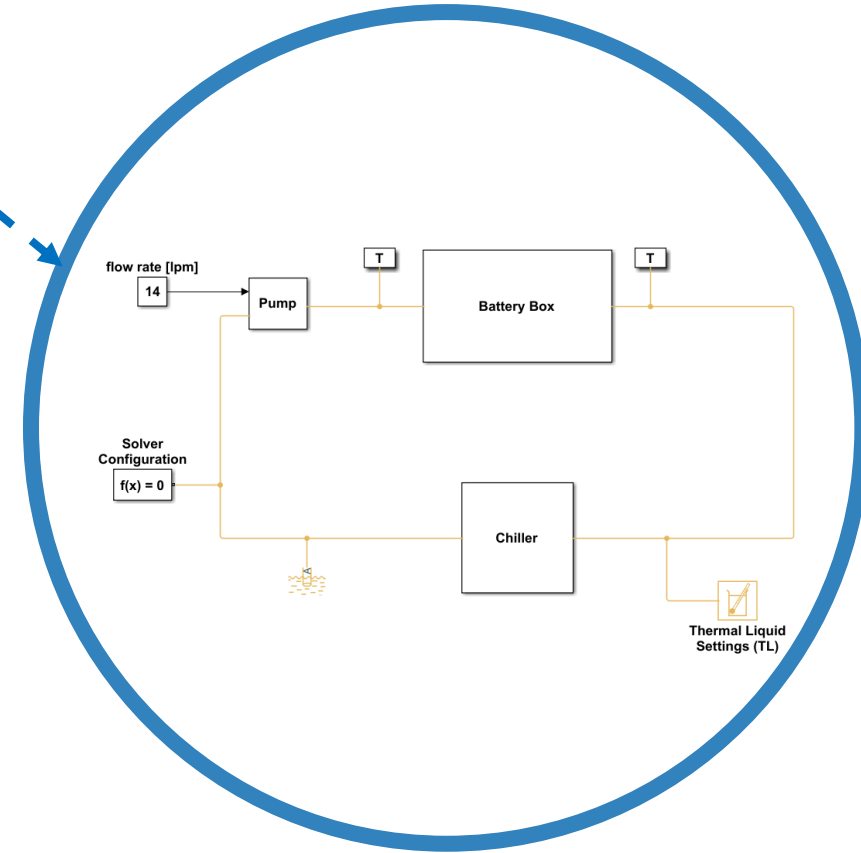
Cell Level



Module Level

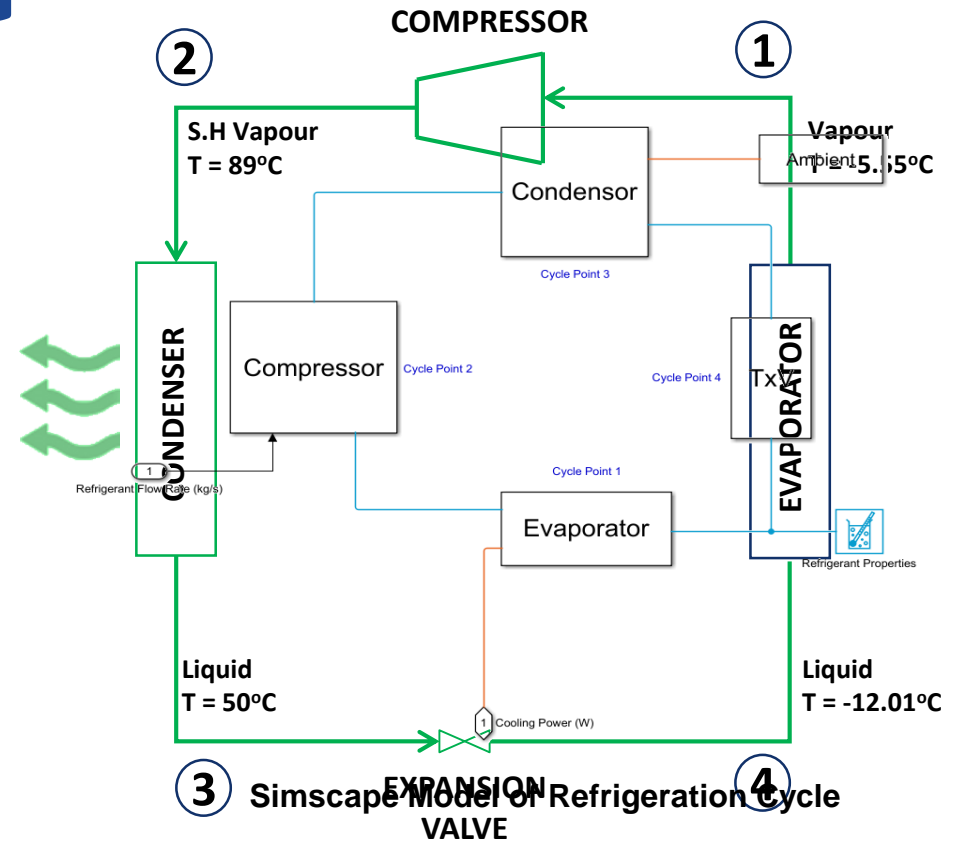
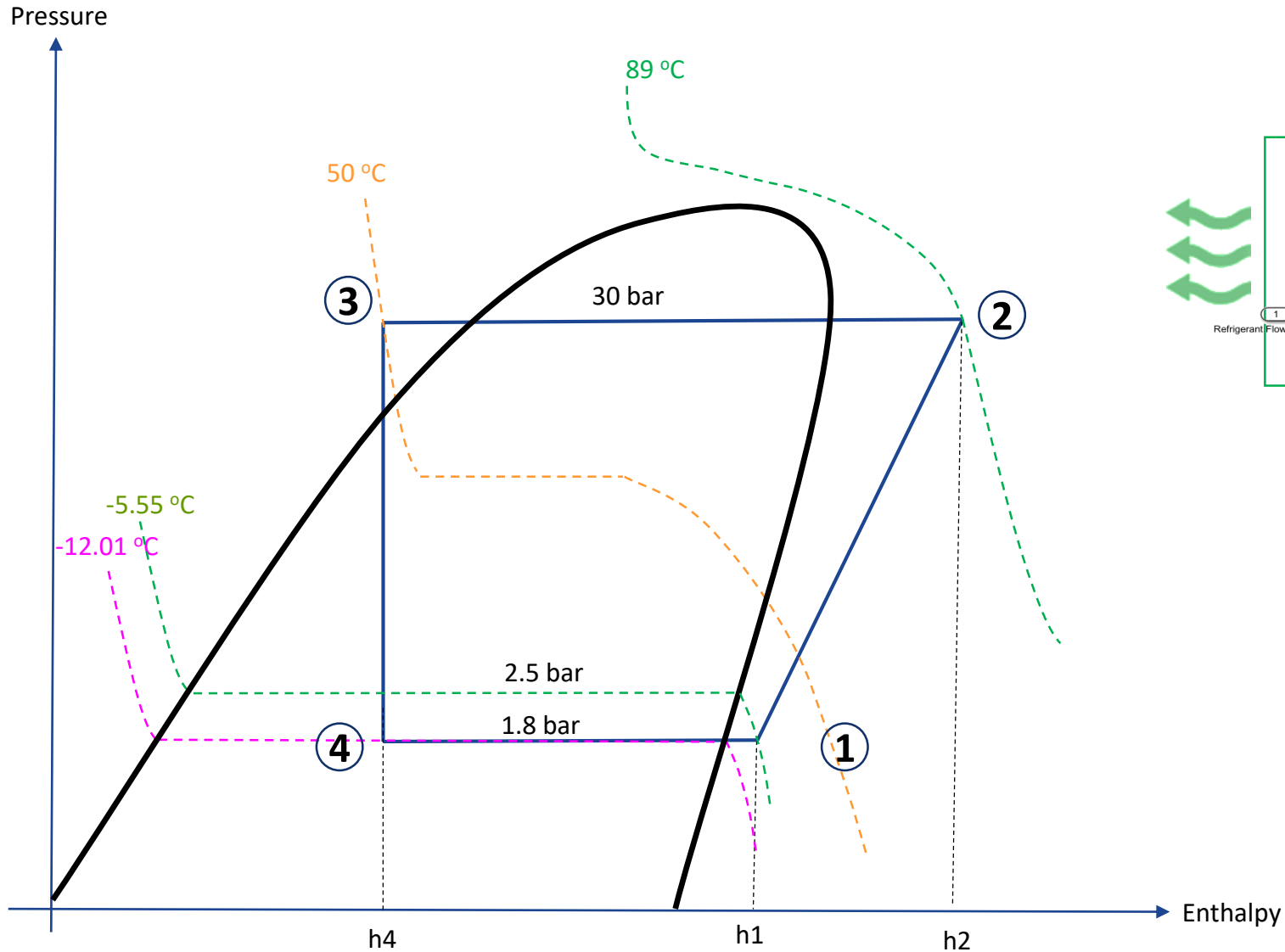


Pack Level



System Level

REFRIGERATION CYCLE MODELING



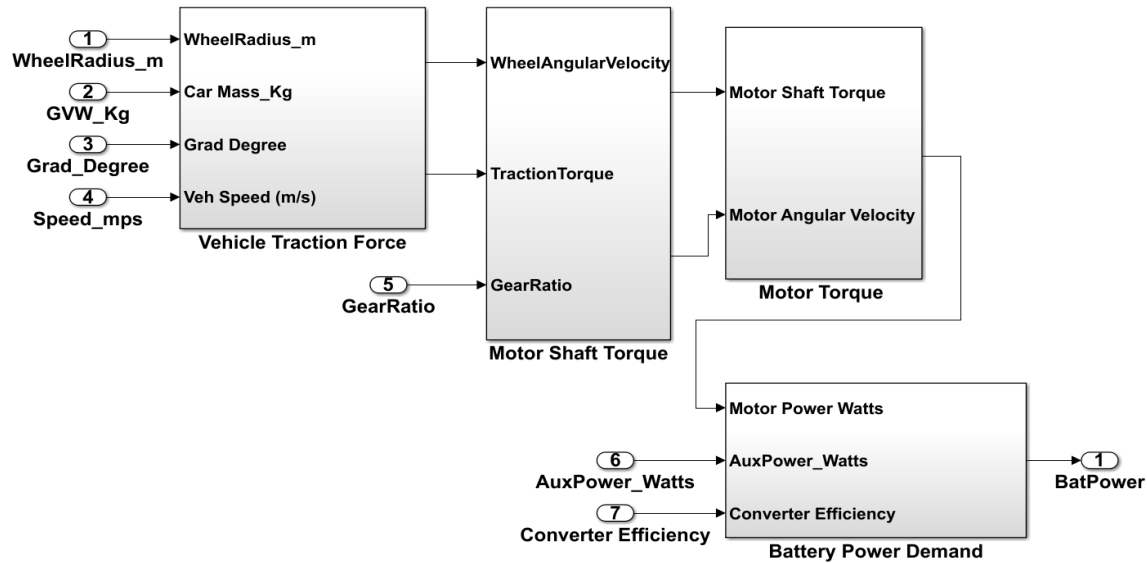
$$\text{Compressor Power} = m(h_2 - h_1)$$

$$\text{Cooling Power} = m(h_1 - h_4)$$

$$\text{COP} = \frac{h_1 - h_4}{h_2 - h_1}$$

m - Refrigerant mass flow rate

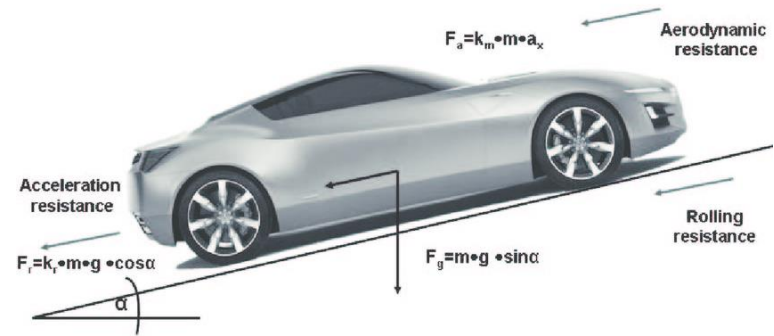
VEHICLE MODELING



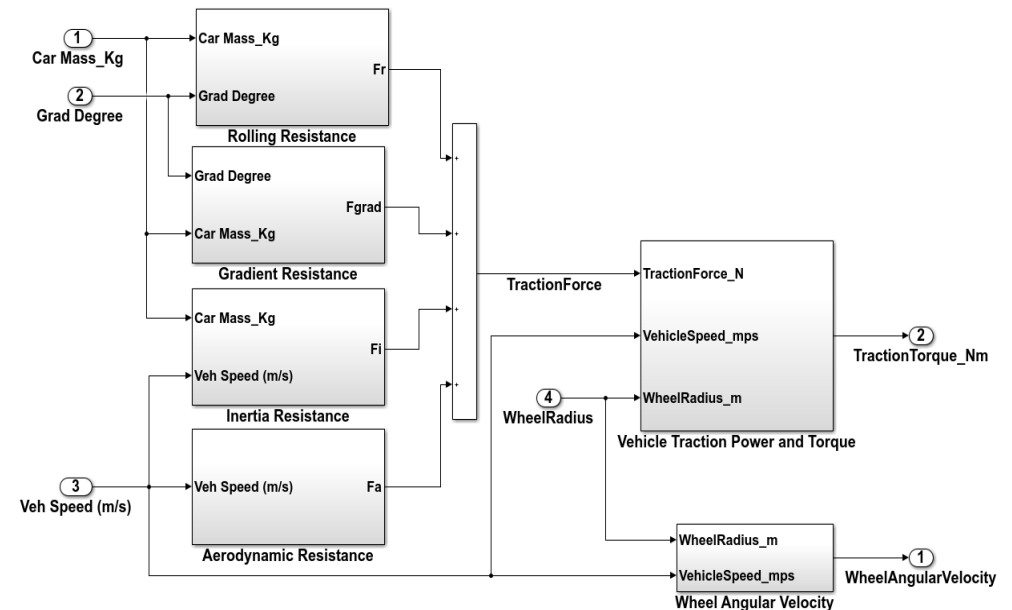
Simulink Vehicle Model

- Vehicle Model will predict the instantaneous power demanded from the battery for different drive cycles.
- Drive cycles under consideration: MIDC, MIDC Part1, NEDC, WLTP
- Traction Force is calculated by considering Rolling resistance, Gradient resistance, Inertia resistance and Aerodynamic resistance.
- Motor shaft torque depends on vehicle torque, gear ratio as well as transmission efficiency.

Resistances on Vehicle

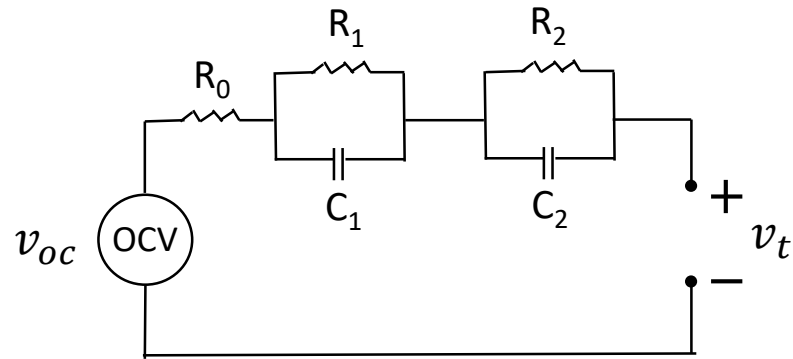


<https://www.researchgate.net/publication/259477397>



Simulink Vehicle Traction Model

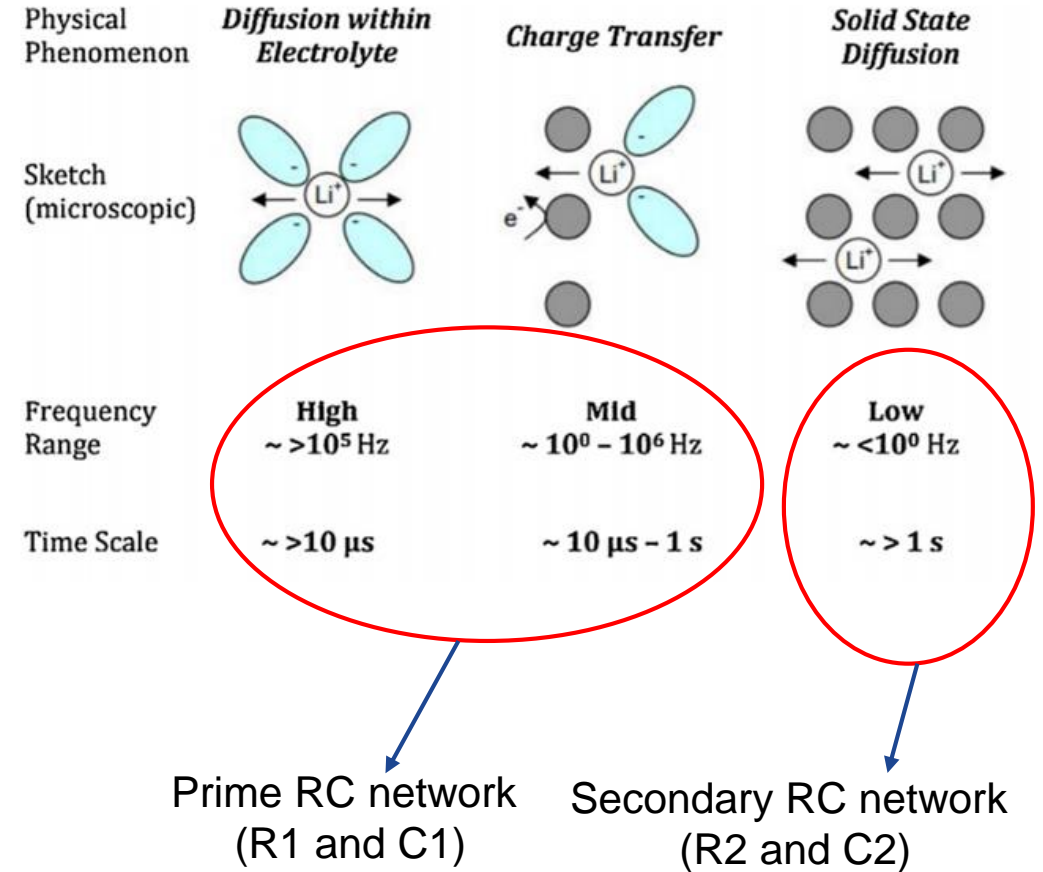
EQUIVALENT CIRCUIT MODELING



Second order equivalent circuit model

- $v_{oc}[k] = v_t[k] + i_t[k] * R_0[k] + v_{c1}[k] + v_{c2}[k] \dots \dots \dots (1)$
- $v_{c1}[k] = v_{c1}[k - 1] * e^{-\frac{\Delta t}{\tau_{1}[k]}} - i_t[k] * R_1[k] * \left(1 - e^{-\frac{\Delta t}{\tau_{1}[k]}}\right) \dots \dots \dots (2)$
- $v_{c2}[k] = v_{c2}[k - 1] * e^{-\frac{\Delta t}{\tau_{2}[k]}} - i_t[k] * R_2[k] * \left(1 - e^{-\frac{\Delta t}{\tau_{2}[k]}}\right) \dots \dots \dots (3)$

Acronym	Meaning
v_t	Terminal voltage
i_t	Battery current
v_{c1}	Voltage across capacitor C1
v_{c2}	Voltage across capacitor C2
k	Time instants

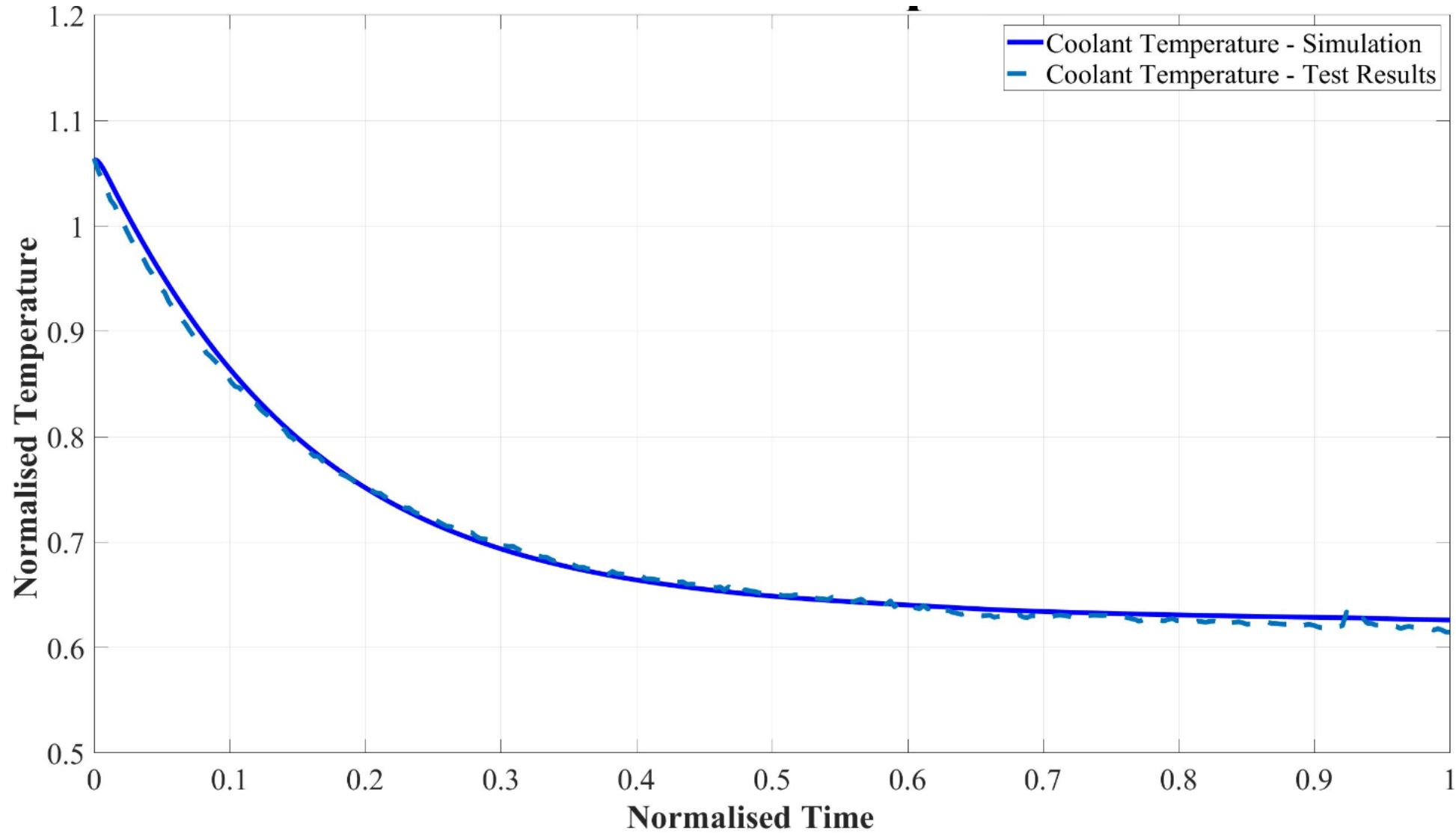


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The ease of parametrization and implementation makes it the most widely employed model for real-time battery management applications.

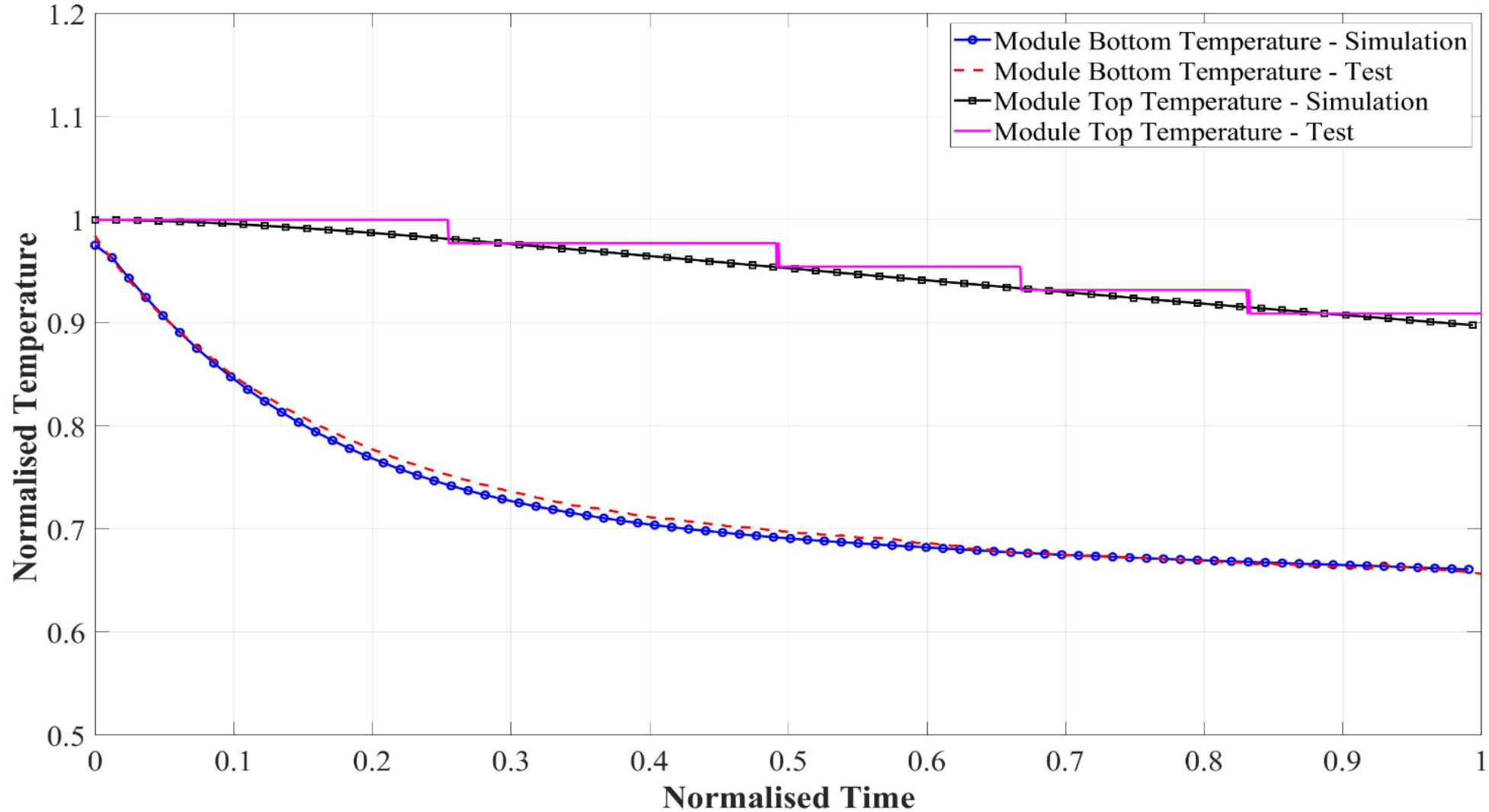
Model Validation

COMPARING TEST AND SIMULATED COOLANT INLET TEMPERATURE



Mean Absolute Percentage
Error = 0.70%

COMPARING TEST AND SIMULATED BATTERY MODULE TEMPERATURE – MODULE NO:13



Mean Absolute Percentage Error

Bottom Temperature = 0.66%
Top Temperature = 0.86%

Logic Development and Results

COMPRESSOR ON-OFF LOGIC

Current Compressor Logic

- Compressor cut off logic in the old algorithm was only based on battery temperature
- When the battery temperature reduces to a set value, compressor will cut off

Proposed Compressor Logic

- New compressor operation logic will consider both battery temperature as well as coolant temperature for compressor ON/OFF.
- Once the coolant temperature drops to the set temperature or the battery temperature drops below the set value, compressor will turn OFF
- It will turn back ON again only if the battery temperature is still above the set value and the coolant temperature rises by 3°C

Simulation Parameters

Sl.No	Parameter	Values
1.	Charging C rate	1C, 0.3C
2.	Ambient Temperature	41°C
3.	Battery Initial Temperature	41°C
4.	Coolant Initial Temperature	41°C

RESULTS & INFERENCE

Simulation Results 0.3C Charging

Old Algorithm	Battery Final Temperature	34.22°C
	Energy Consumed by Compressor	1.321 kWh
New Algorithm	Battery Final Temperature	35.76°C
	Energy Consumed by Compressor	0.832 kWh

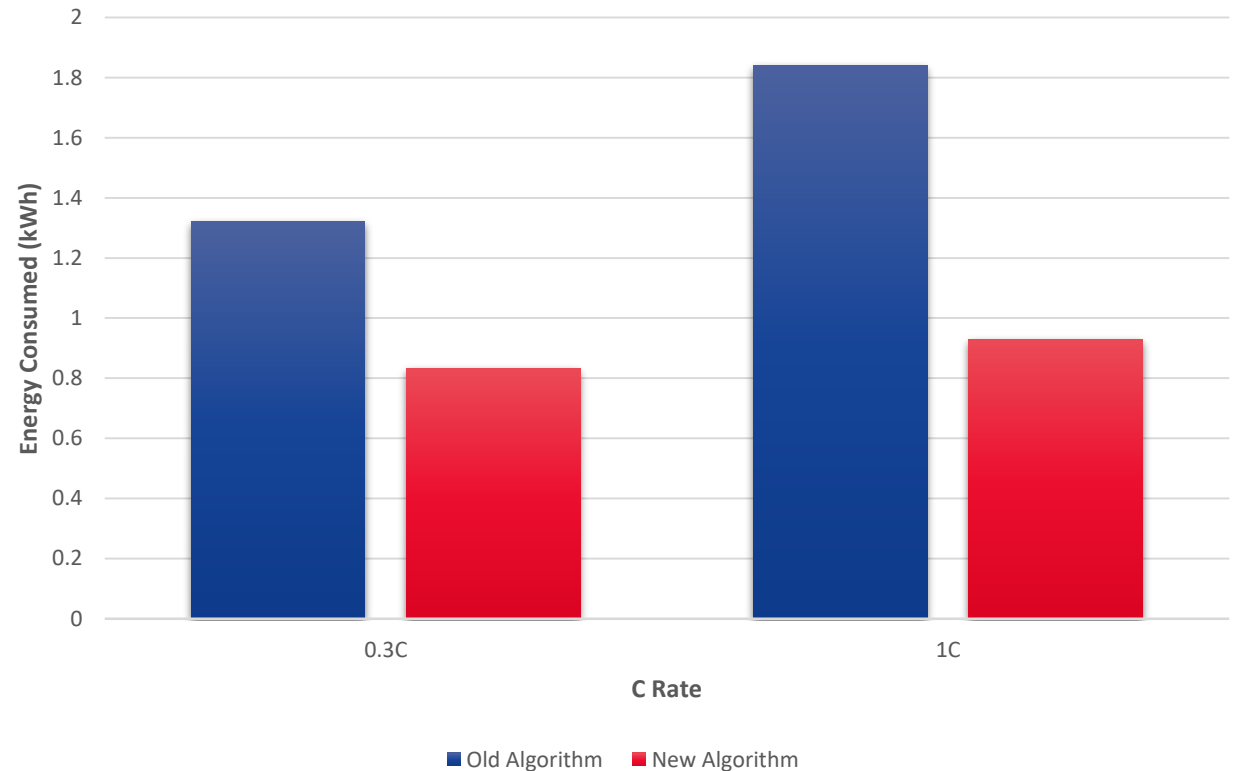
Simulation Results 1C Charging

Old Algorithm	Battery Final Temperature	43.71°C
	Energy Consumed by Compressor	1.84 kWh
New Algorithm	Battery Final Temperature	44.21°C
	Energy Consumed by Compressor	0.928 kWh

Inference

Battery final temperature is slightly more with new algorithm but the energy consumed by compressor reduces. In 0.3C charging, battery final temperature is 1.5°C more with the new algorithm but power consumed by compressor is ~37% less. In 1C charging, battery final temperature is 0.5°C more with the new algorithm, but power consumed is ~50% less.

Simulation Results



Thank You
