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

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Contents

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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

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Generic Battery Cooling/Heating Circuit

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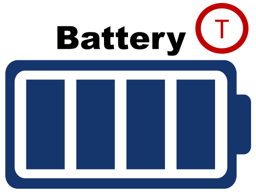
GENERIC BATTERY COOLING/HEATING CIRCUIT

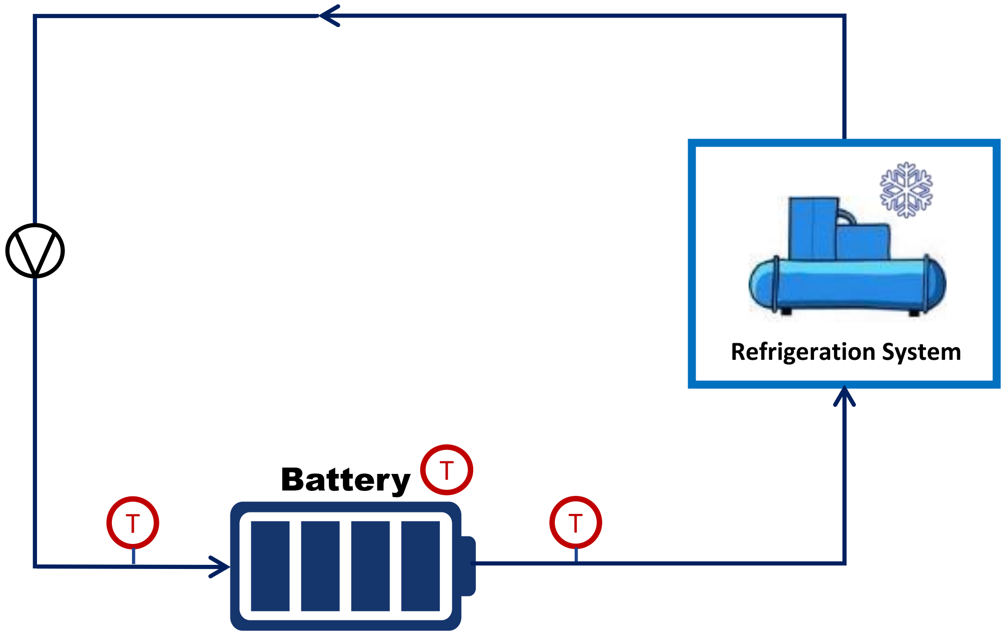


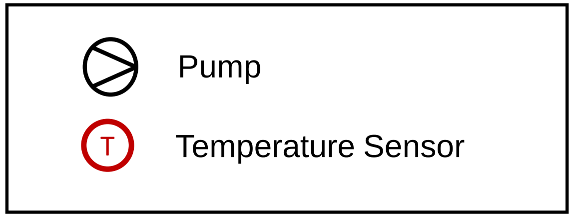
T	Temperature Sensor

Battery

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

GENERIC BATTERY COOLING/HEATING CIRCUIT

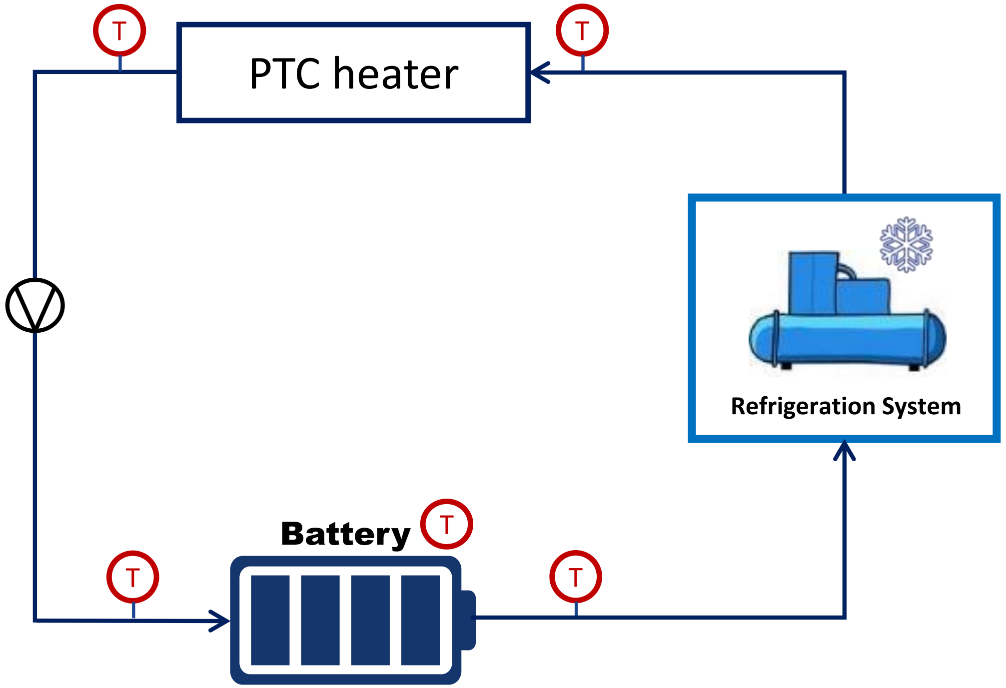


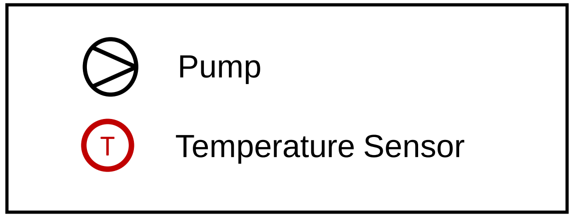


Chiller Circuit

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

GENERIC BATTERY COOLING/HEATING CIRCUIT

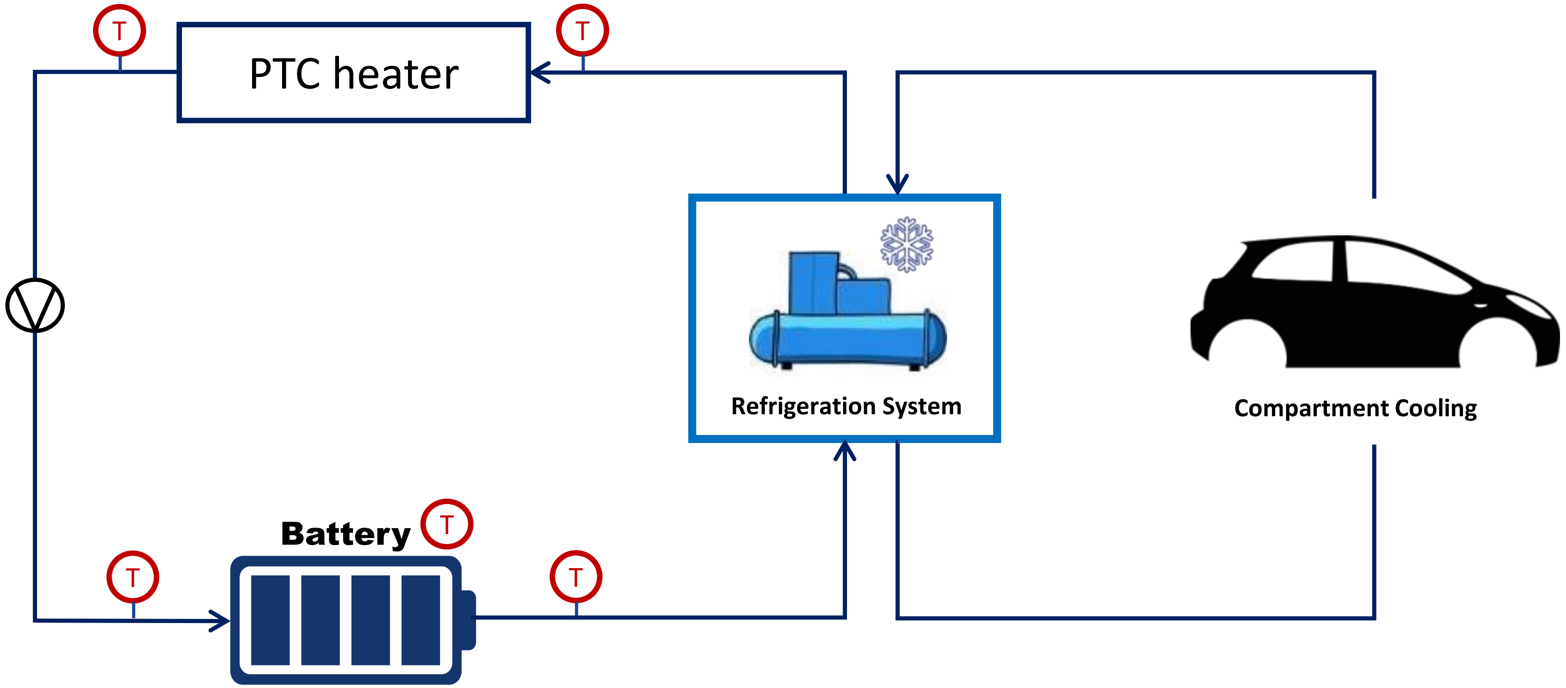


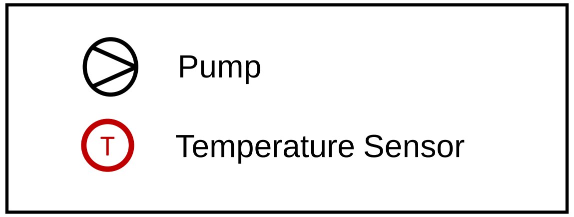


Heater Circuit

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

GENERIC BATTERY COOLING/HEATING CIRCUIT

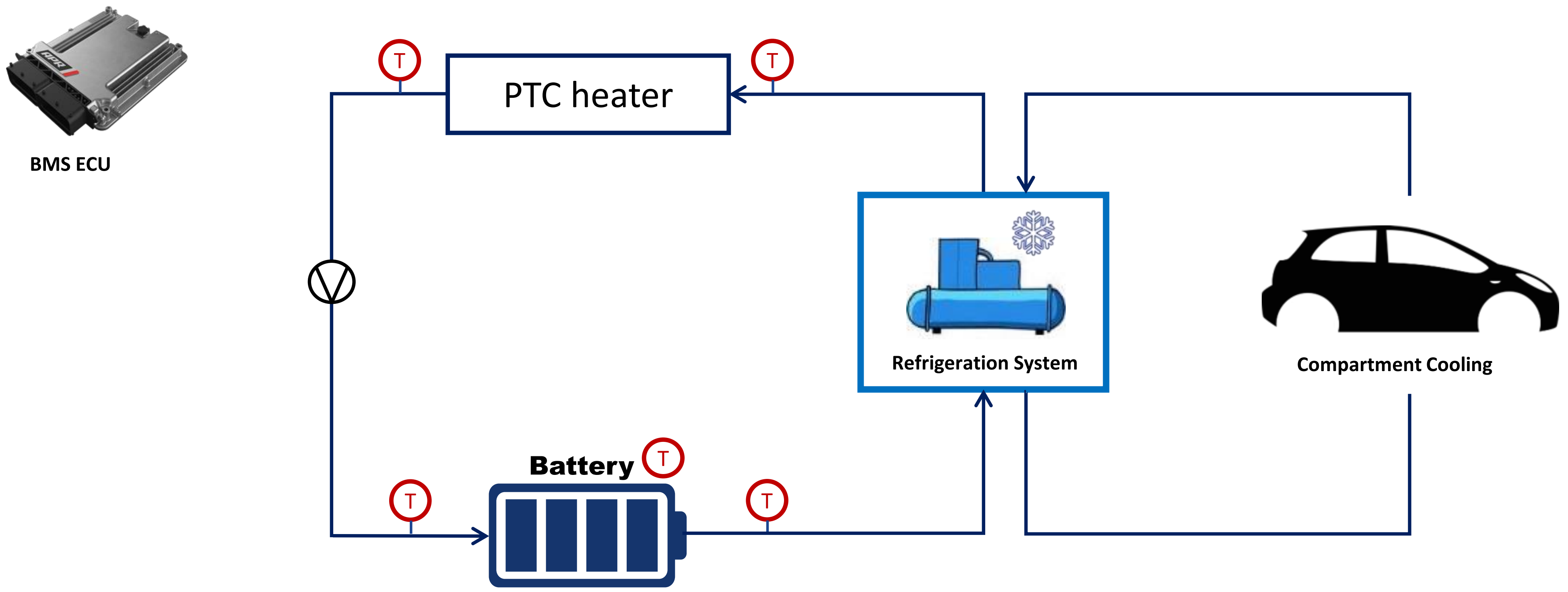


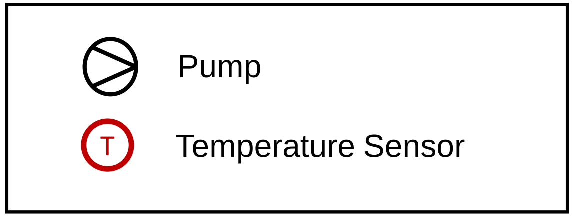


Compartment Cooling

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

GENERIC BATTERY COOLING/HEATING CIRCUIT

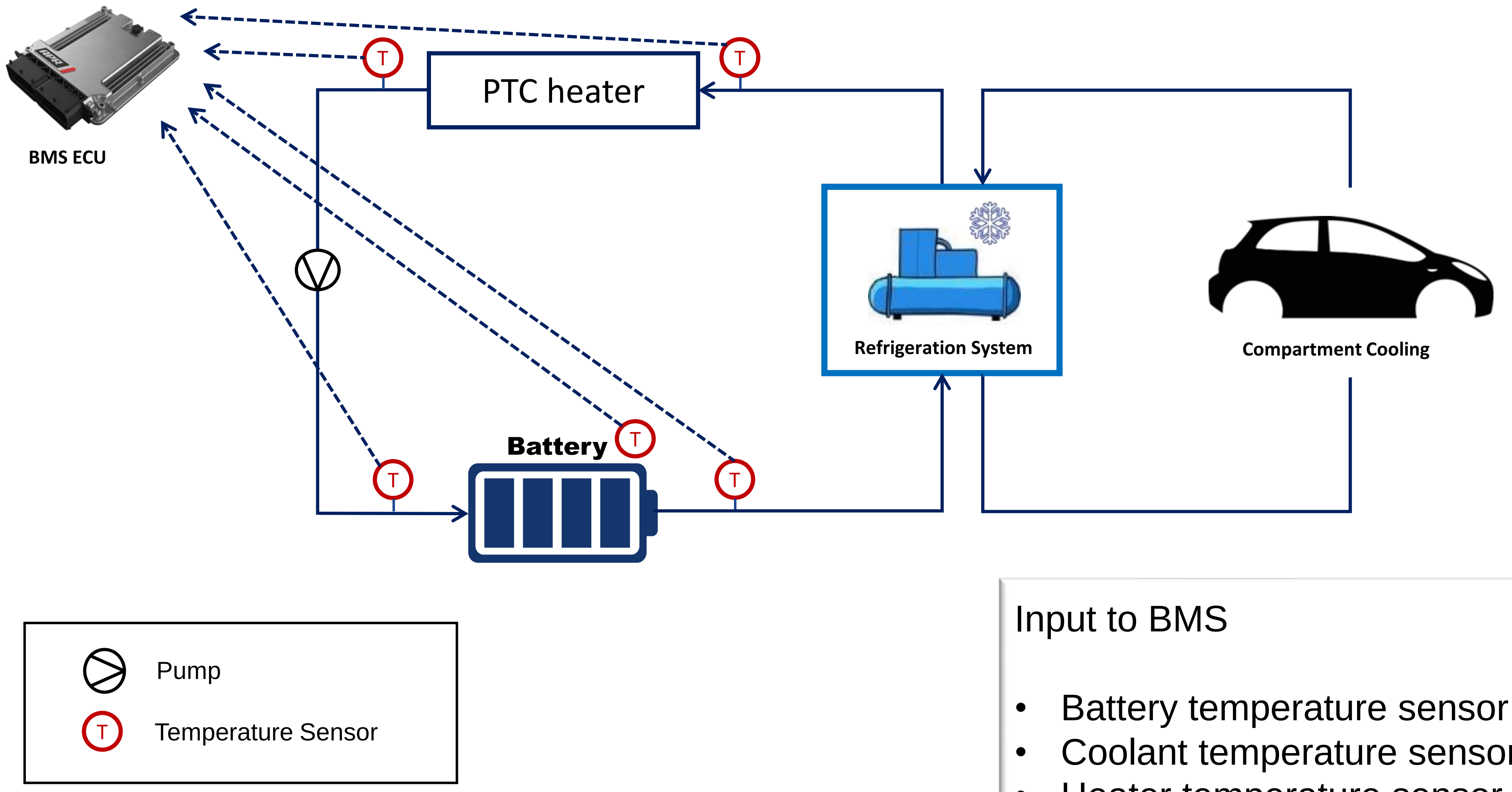




BMS ECU

- Battery Thermal Management Functions are handled by BMS ECU

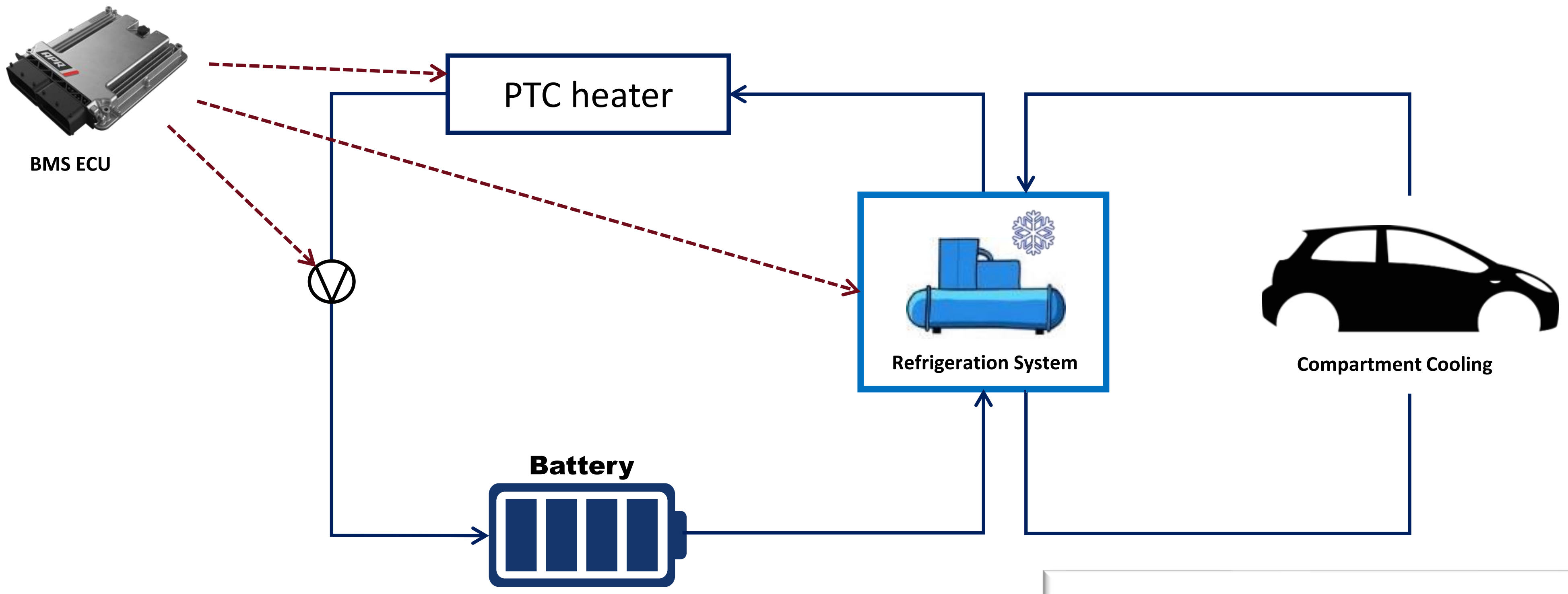
GENERIC BATTERY COOLING/HEATING CIRCUIT

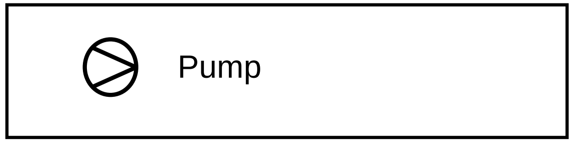


Input to BMS

- 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

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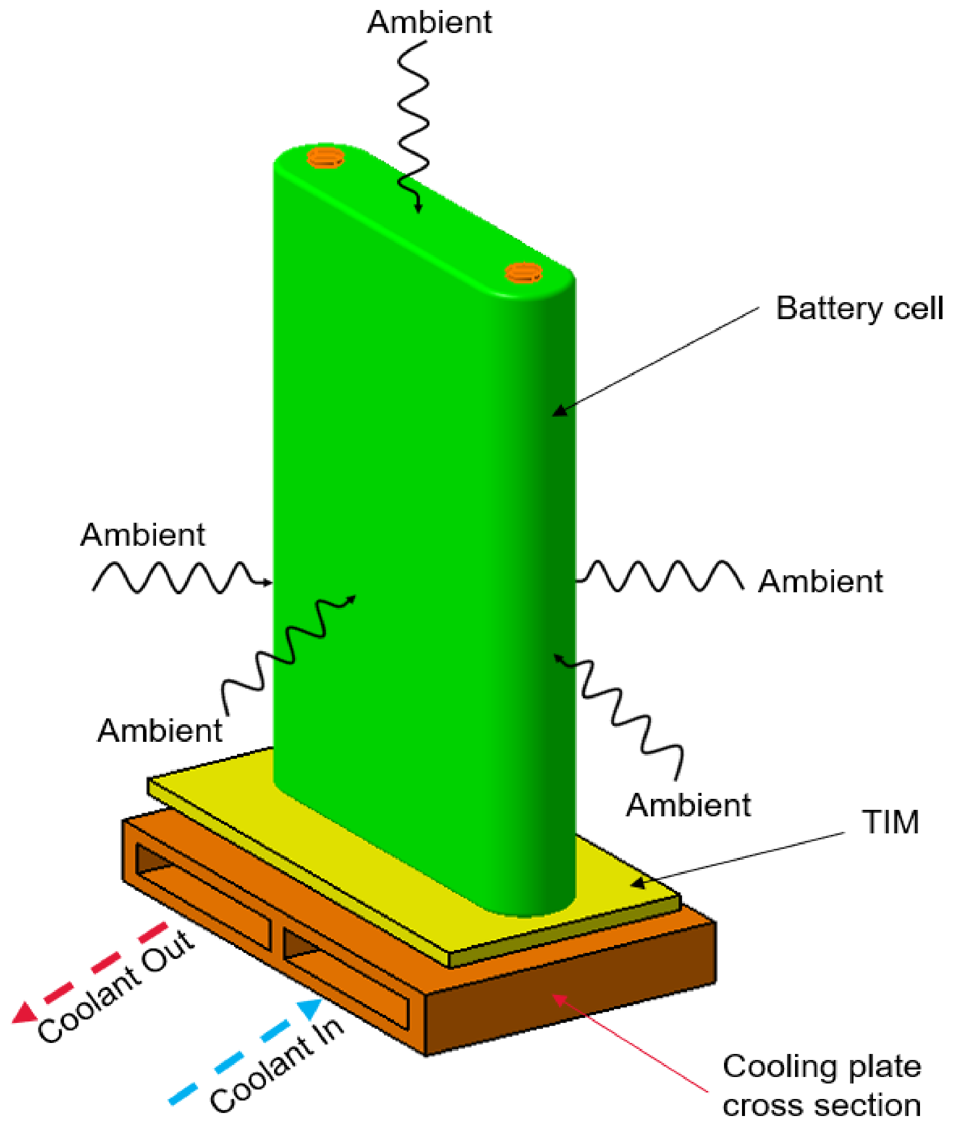
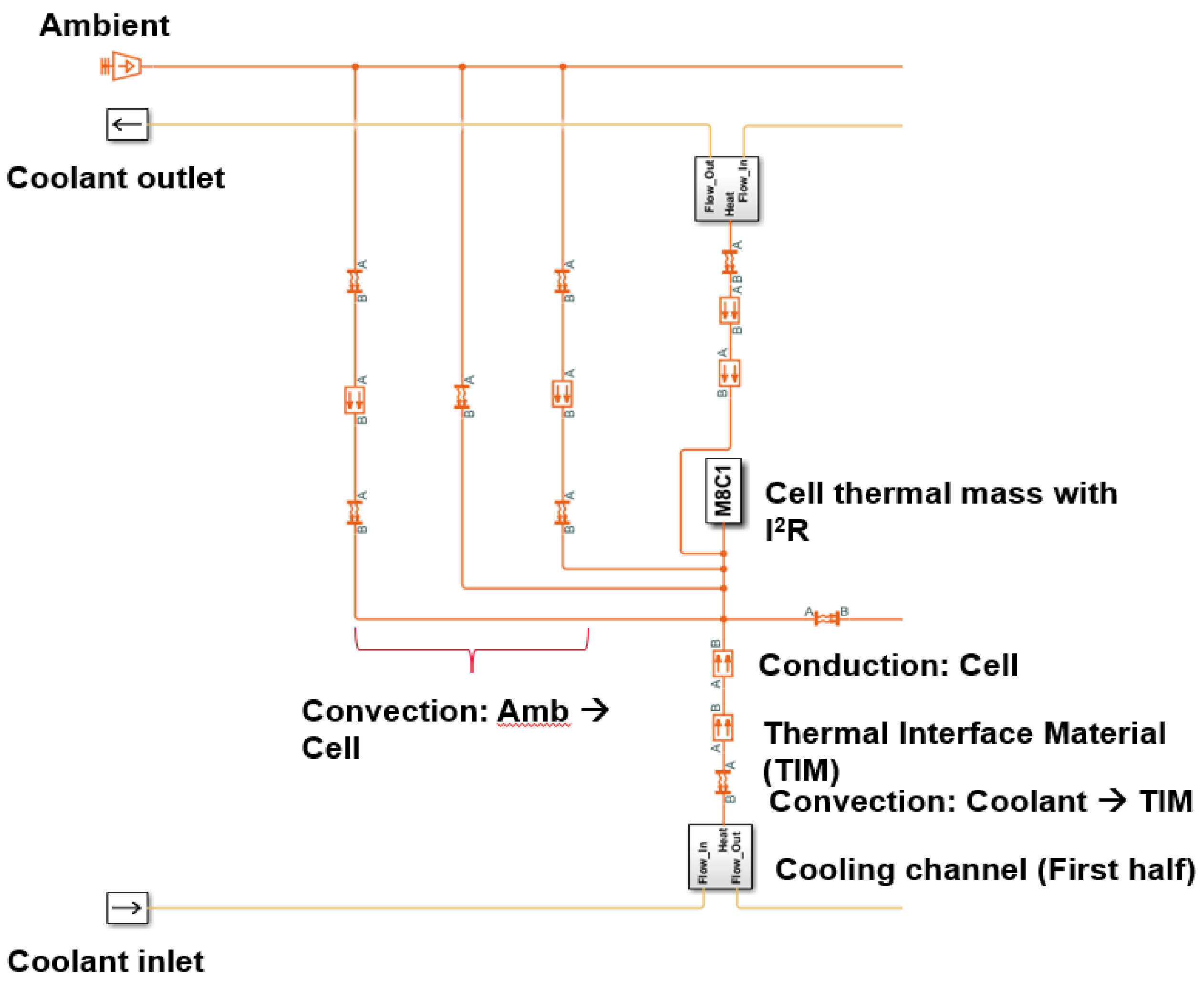
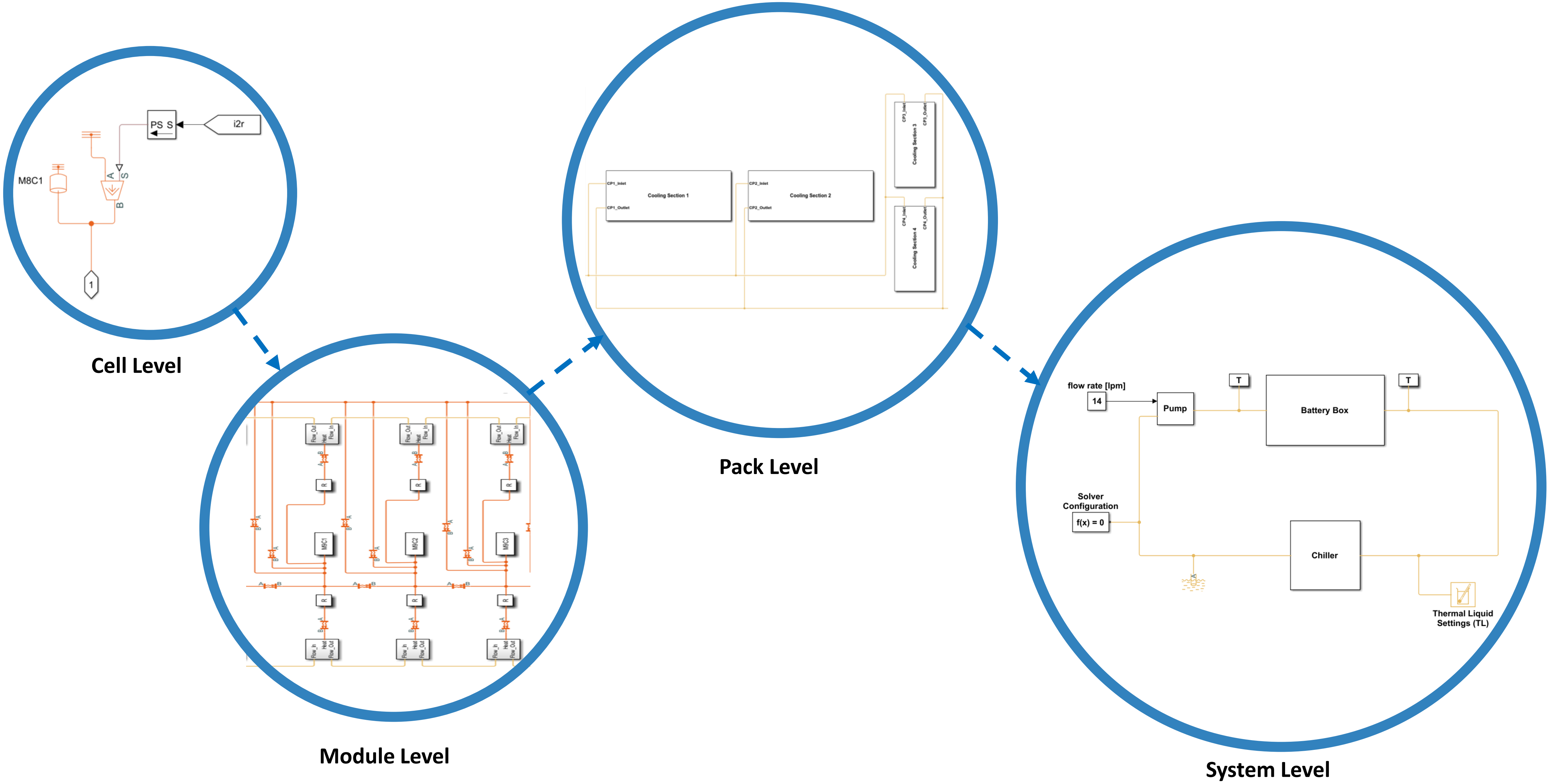
CELL MODELLING

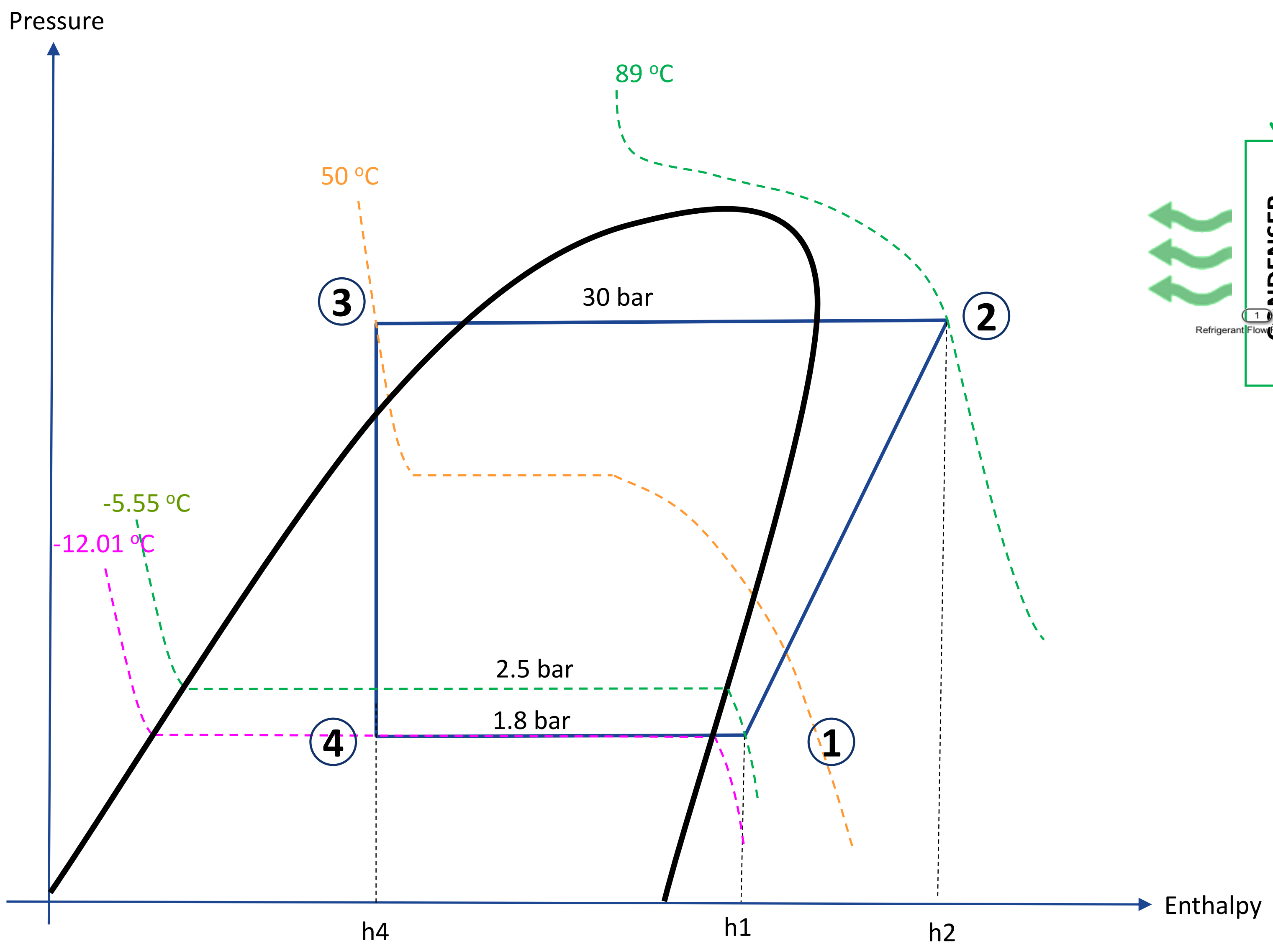


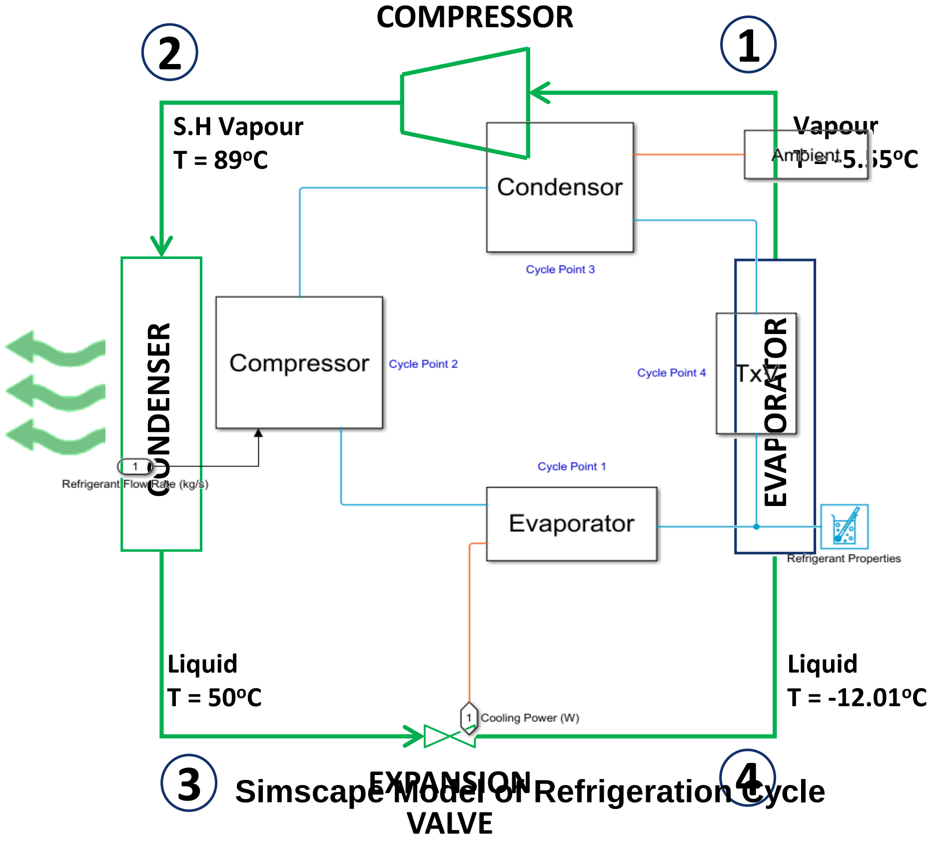


1D BATTERY THERMAL MODELING



REFRIGERATION CYCLE MODELING





Simscape Model of Refrigeration Cycle

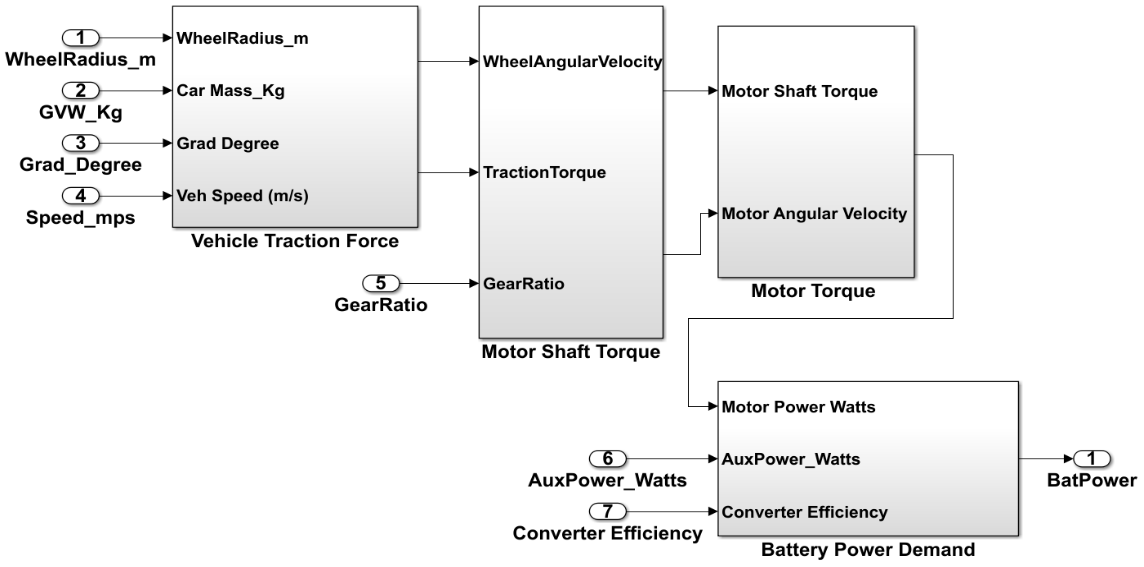
Compressor Power = $m(h_2 - h_1)$

Cooling Power = $m(h_1 - h_4)$

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

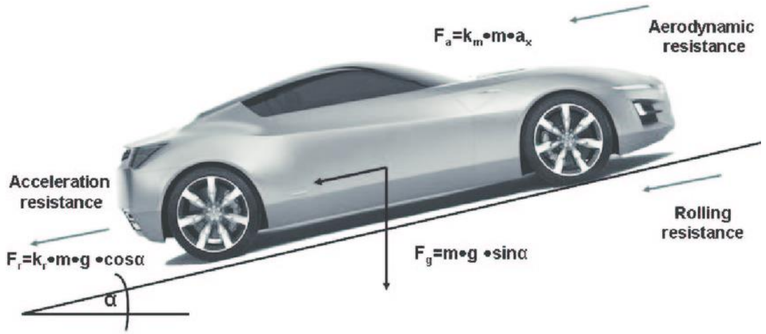
m – Refrigerant mass flow rate

VEHICLE MODELING

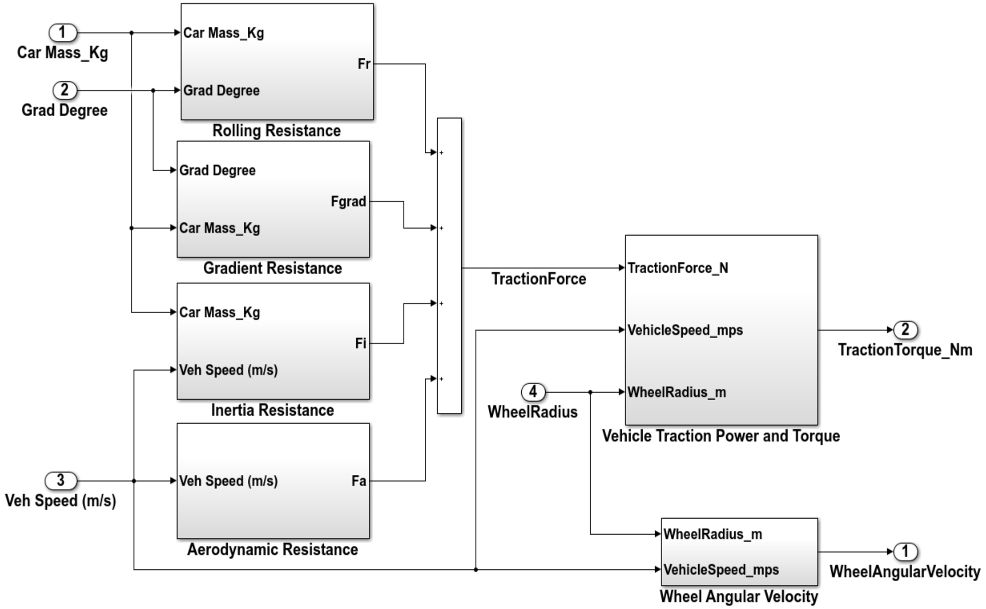


Simulink Vehicle Model

Resistances on Vehicle



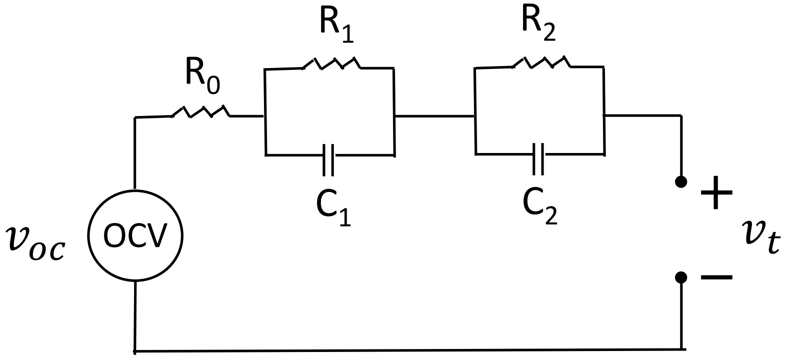
https://www.researchgate.net/publication/259477397



Simulink Vehicle Traction 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.**

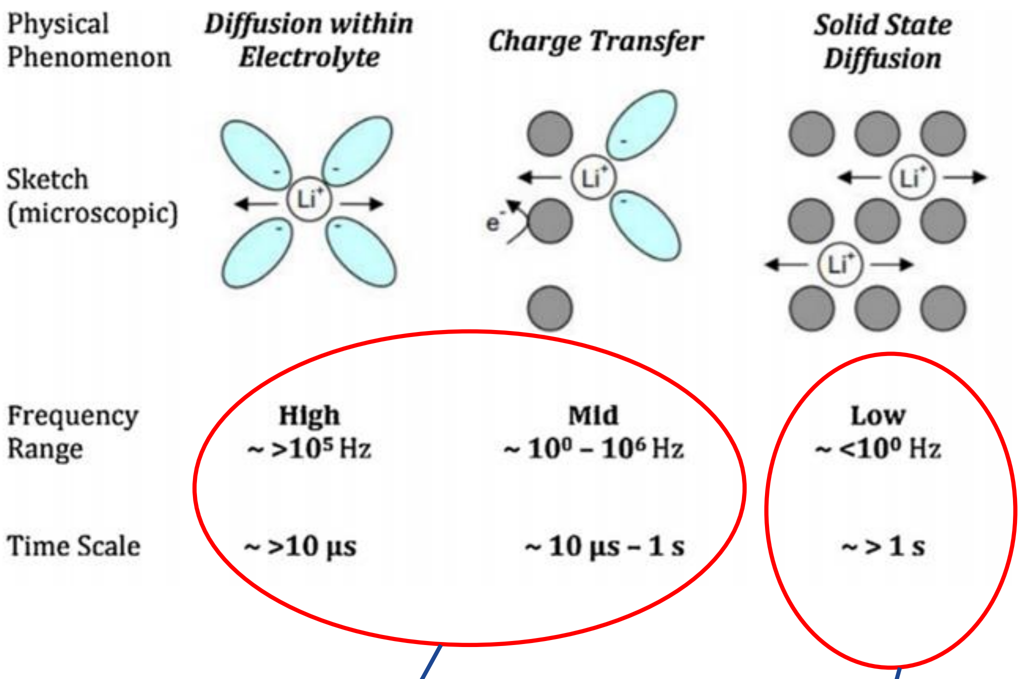
EQUIVALENT CIRCUIT MODELING



Second order equivalent circuit model

- $v_{oc}[k] = v_t[k] + i_t[k] * R_0[k] + v_{c1}[k] + v_{c2}[k]$ ………..(1)
- $v_{c1}[k] = v_{c1}[k-1] * e^{-\frac{\Delta t}{tau_1[k]}} - i_t[k] * R_1[k] * \left(1 - e^{-\frac{\Delta t}{tau_1[k]}}\right)$ …….(2)
- $v_{c2}[k] = v_{c2}[k-1] * e^{-\frac{\Delta t}{tau_2[k]}} - i_t[k] * R_2[k] * \left(1 - e^{-\frac{\Delta t}{tau_2[k]}}\right)$ ……..(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



Prime RC network (R1 and C1)

Secondary RC network (R2 and C2)

Journal of Energy Storage 15 (2018) 23–31

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

Ref: G. L. Plett, Battery Management Systems, Volume II: Equivalent-Circuit Methods, Vol. 2 Artech House power engineering series, 2015.

Model Validation

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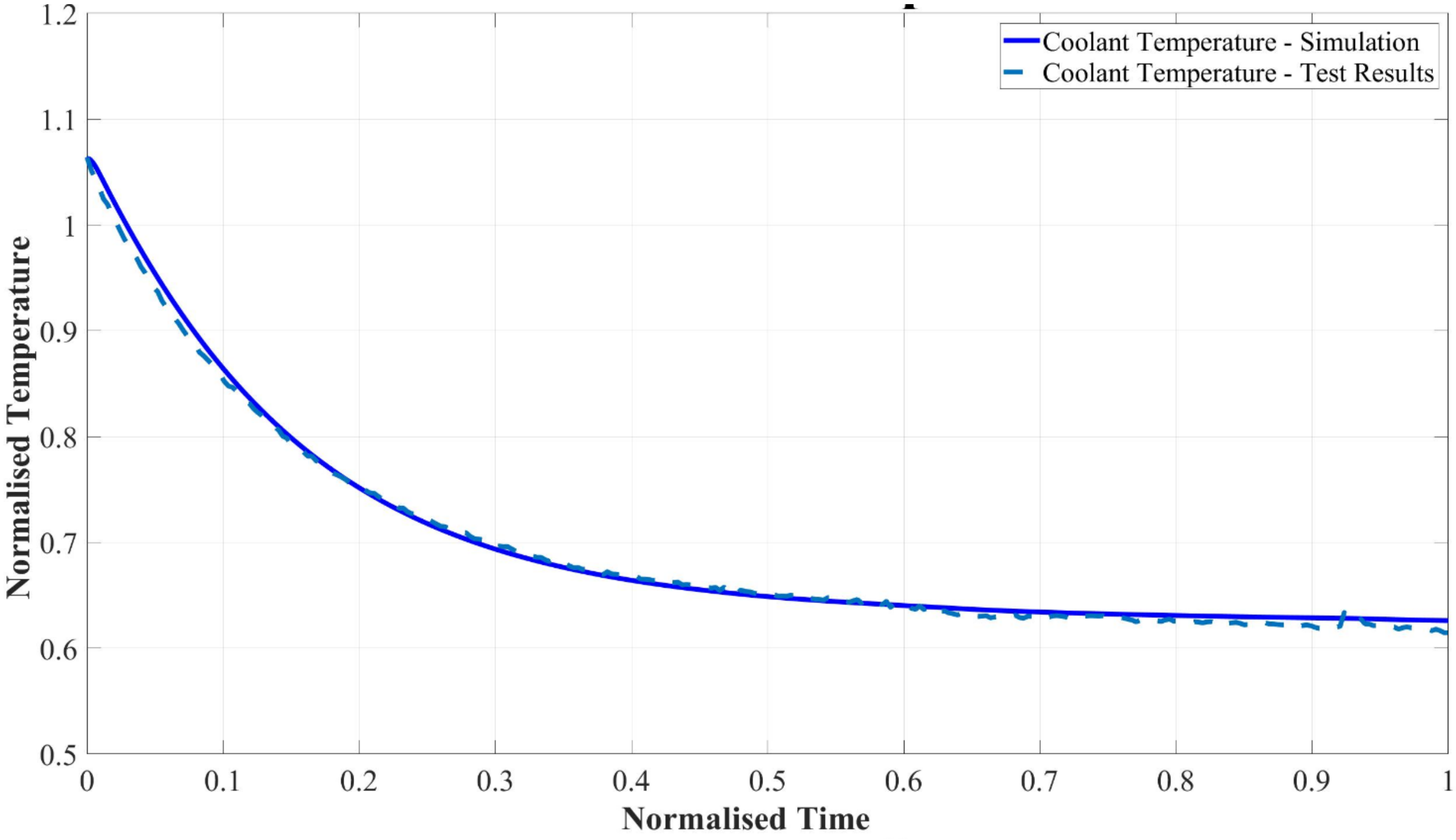
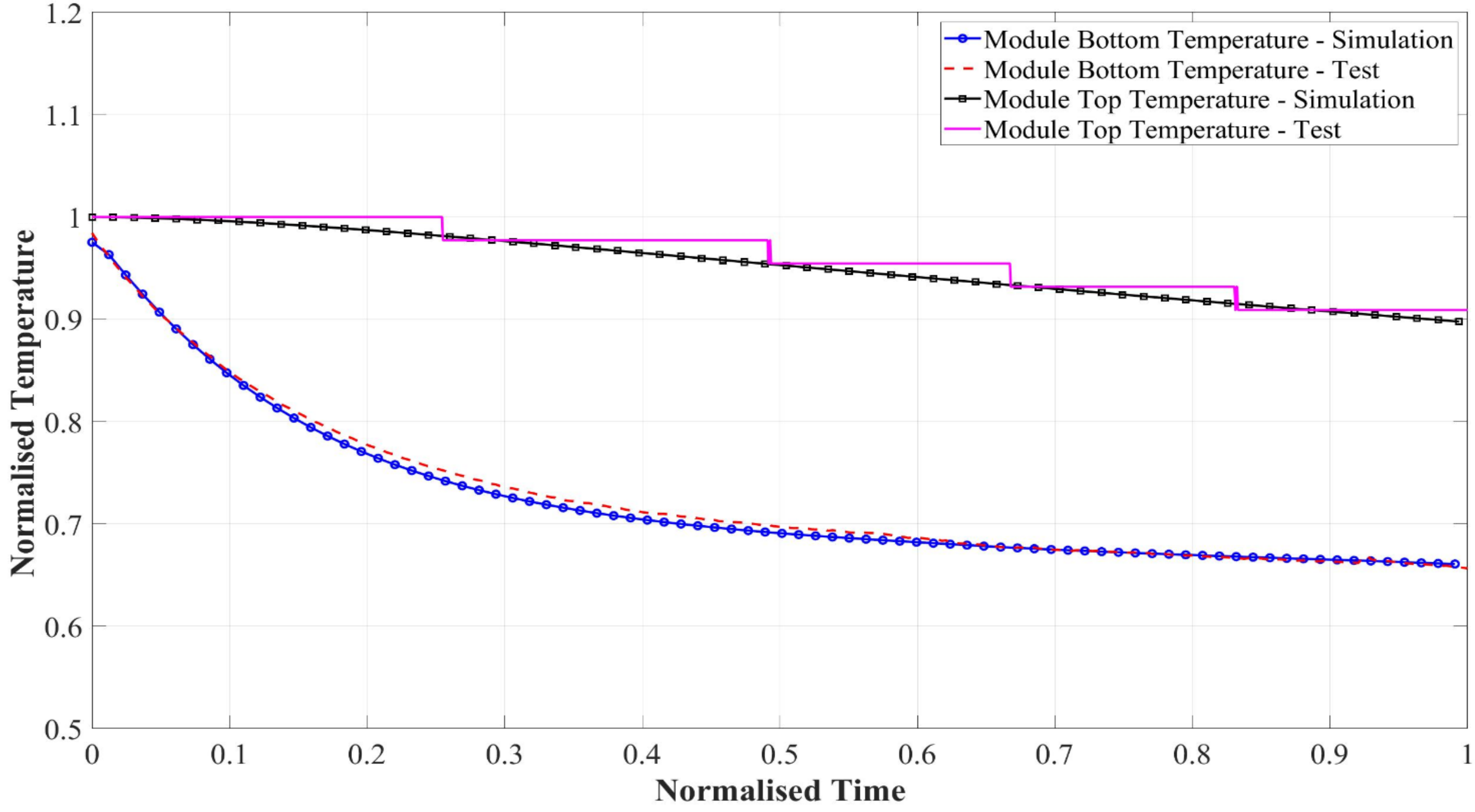
COMPARING TEST AND SIMULATED COOLANT INLET TEMPERATURE



Mean Absolute Percentage Error = 0.70%

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



Mean Absolute Percentage Error

Bottom Temperature = 0.68%
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^oC

Simulation Parameters

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

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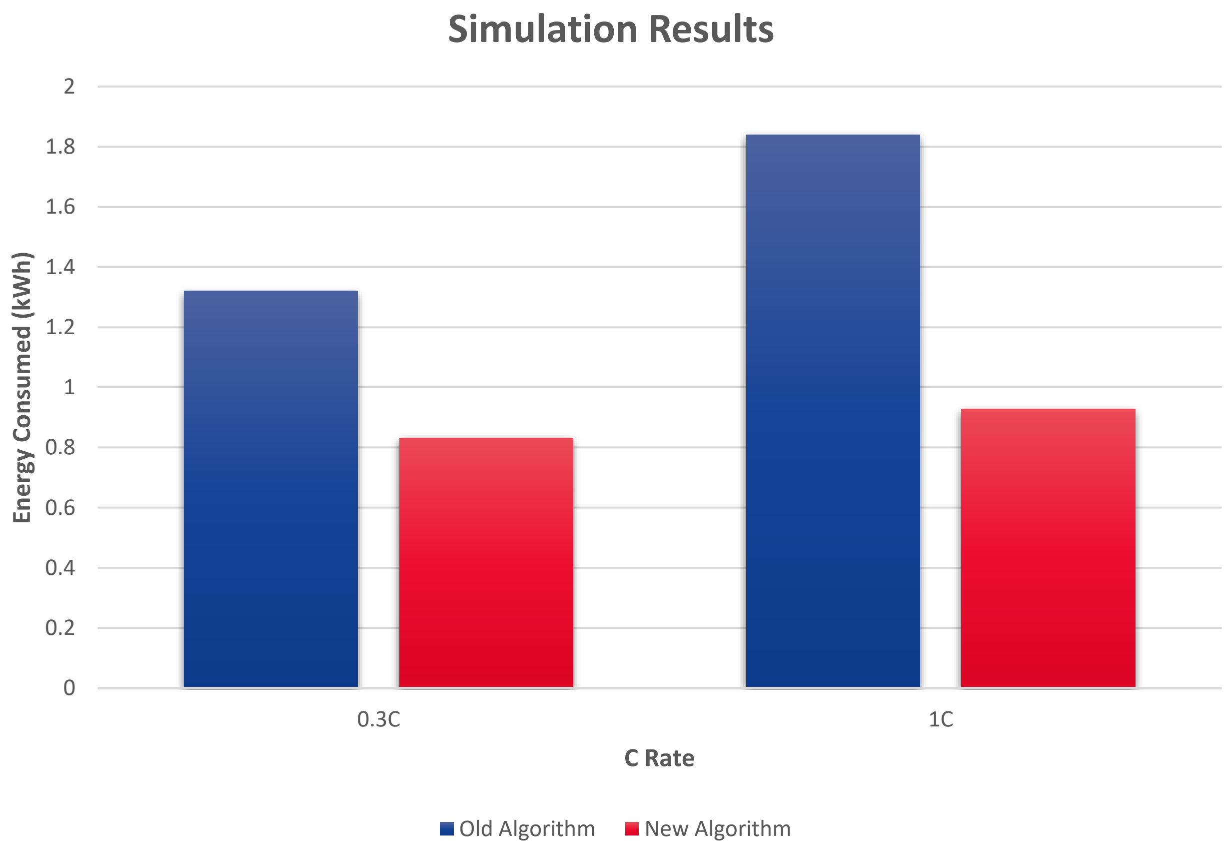
RESULTS & INFERENCE

Simulation Results 0.3C Charging

Old Algorithm	Battery Final Temperature	34.22^{o}C
	Energy Consumed by Compressor	1.321 kWh
New Algorithm	Battery Final Temperature	35.76^{o}C
	Energy Consumed by Compressor	0.832 kWh

Simulation Results 1C Charging

Old Algorithm	Battery Final Temperature	43.71^{o}C
	Energy Consumed by Compressor	1.84 kWh
New Algorithm	Battery Final Temperature	44.21^{o}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^{o}C more with the new algorithm but power consumed by compressor is ~37% less. In 1C charging, battery final temperature is 0.5^{o}C more with the new algorithm, but power consumed is ~50% less.

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Thank You

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