E-TEAM SQUADRA CORSE

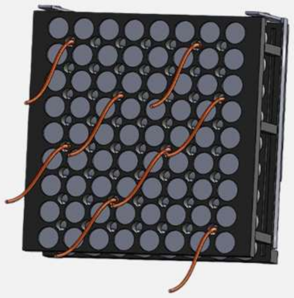
UNIVERSITÀ DI PISA

Powertrain & Electronics

Electric Powertrain

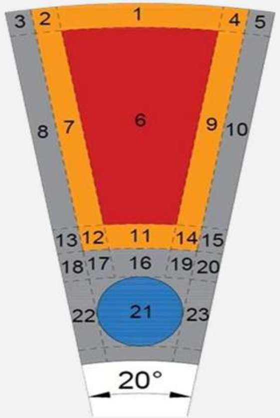
Overview – 2024 problems and limitations

Battery



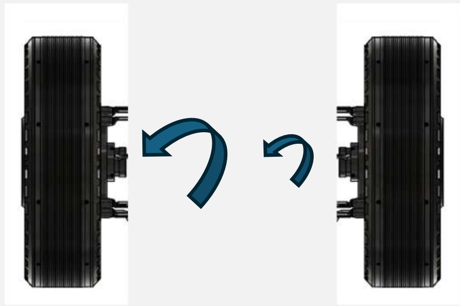
- One module **irreparably damaged**, capacity loss.
- Overheating and **high SOC accelerated wear**.

Powertrain modeling



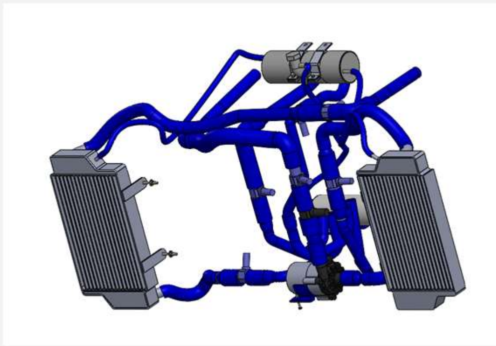
- **Only stator** thermal model used.
- Limited accuracy for race simulations.

Electronic differential



- Two versions tested, inconsistent results.
- **Poor generalization** to all track cases.

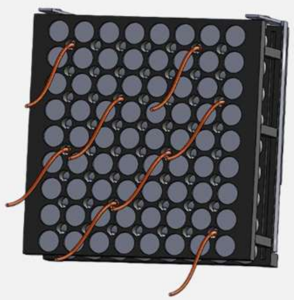
Cooling



- **Complex**, heavy layout.
- Too many sensors, **excess weight.**

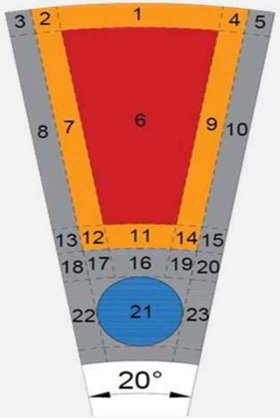
Overview – 2025 targets

Battery



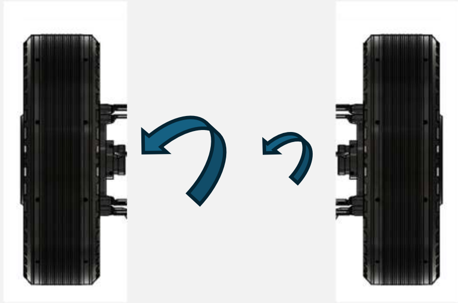
- New battery with weight reduction by **10%**
- Rated energy for Varano Endurance (**64 s median lap**)
- **Flexibility** in maintenance operations and repairs

Powertrain modeling



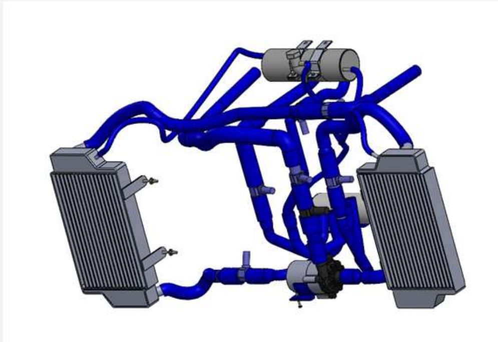
- Modelling the **whole powertrain** (motors, inverters, wires and battery)
- **Validate the battery** model to identify **power management** during endurance.

Electronic differential



- More "**physics based**" control law
- Study on the optimized electronic differential **integrating IMU measurements**

Cooling

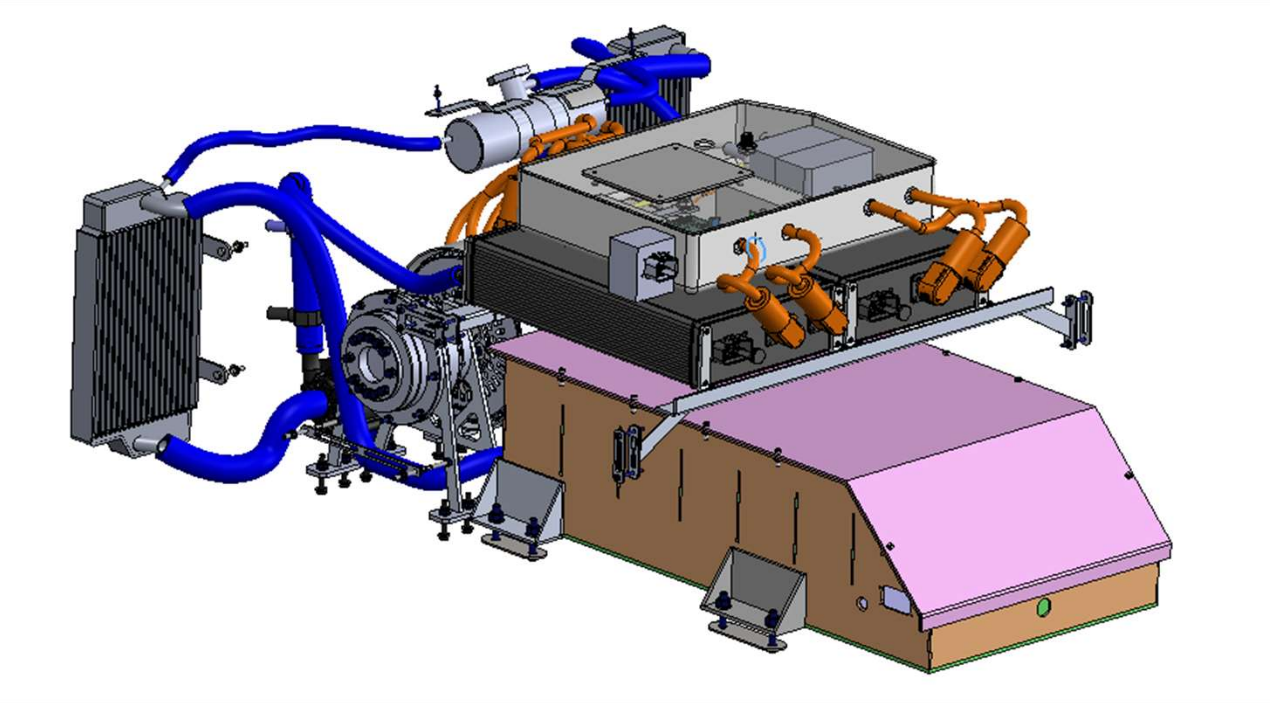


- Weight reduction by **10%**
- **Lower airflow** to enhance aerodynamic effects (**probabilistic sizing**)

Common target: very low budget → cost saving choices

Overview – 2025 electrical powertrain

Rear wheel drive (x2 motors)



- Motors: EMRAX 188 HV *(bought)*
    - Torque: 100 Nm max
    - Speed: 8000 RPM max
    - Power: rated 35 kW, maximum 60 kW
    - Cooling: liquid
    - Weight: 7 kg
- Inverters: DTI HV-500 *(bought)*
    - Weight: 7 kg
    - Switching frequency: 14 kHz
    - Cooling: liquid
- Battery *(built in house)*
    - Energy: 8 kWh
    - Voltage: 600 V max
    - Capacity: 15 Ah

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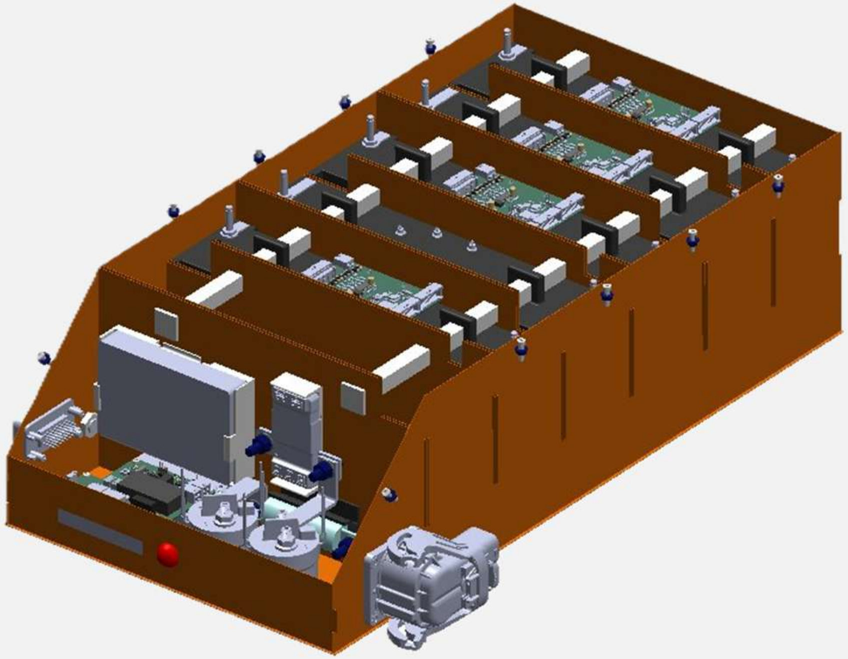
Powertrain & Electronics

HV Battery

Outline

- Objective
- Sizing
- Cells
- SOC estimation
- Module realization
- TSAC
- Comparison with 2024
- Possible improvements



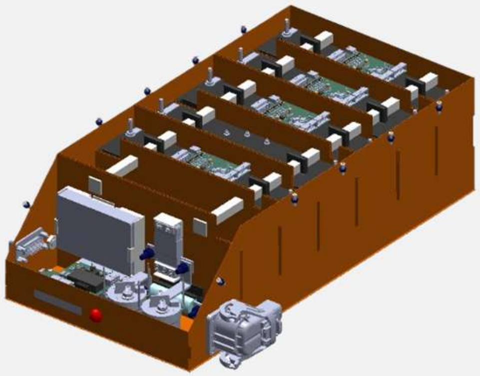
Objective

Main goals:

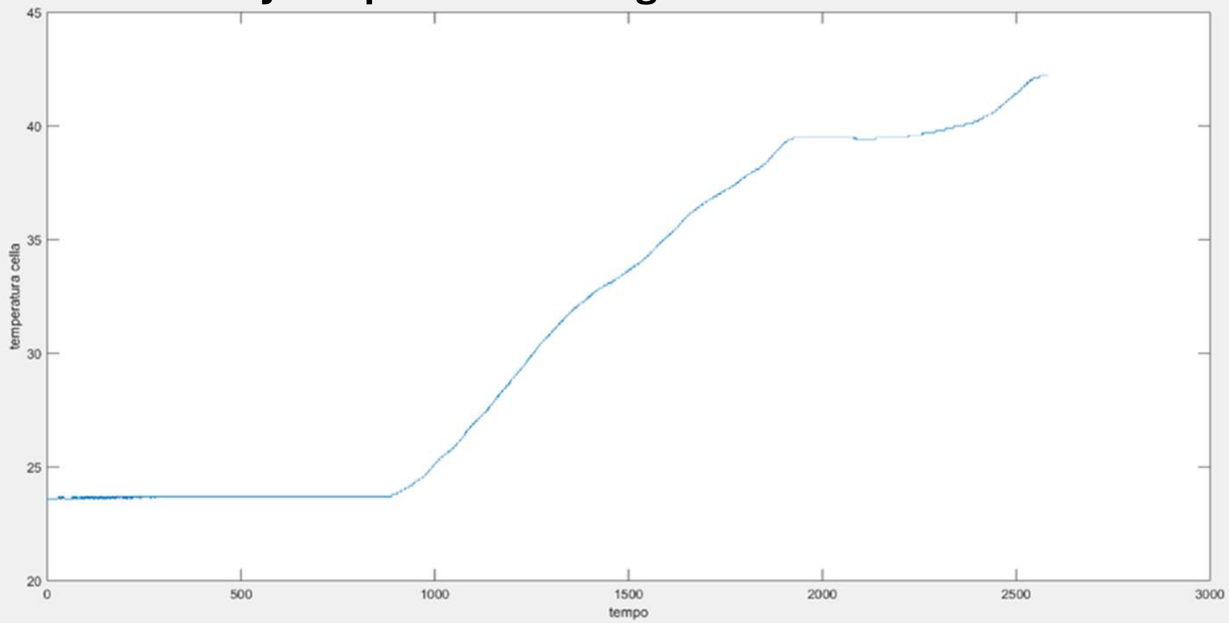
- Center of gravity
- Cooling
- Energy

WHY?

- To improve dynamic of vehicle
- To not limit the potential of the car



Battery temperature during endurance at Varano 2024



5 modules problems: high SOC degradation, high temperatures, car moving slowly to save energy and temperature

Sizing

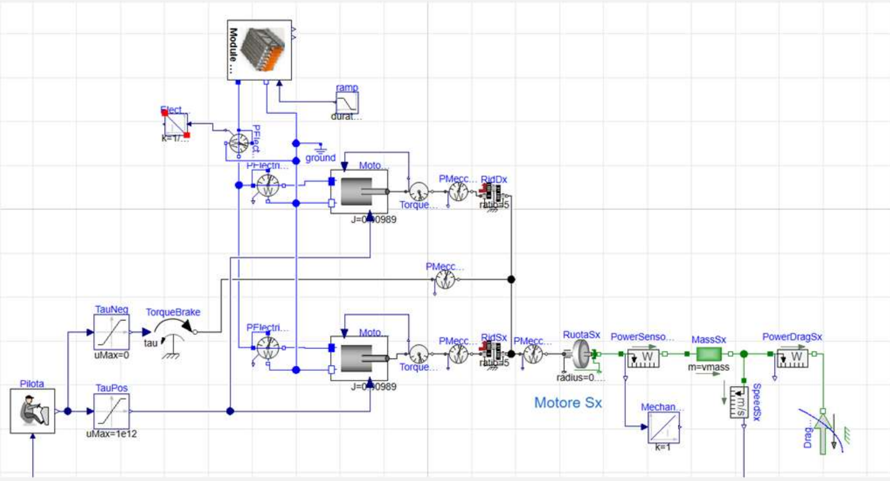
How we estimated the energy:

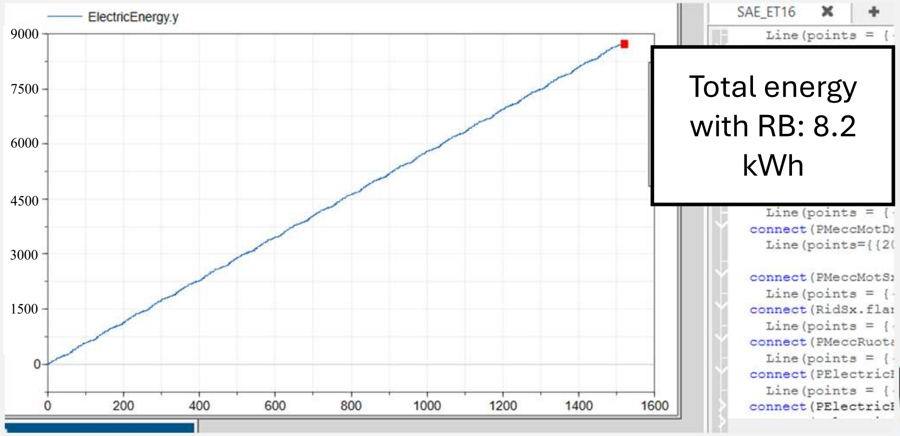
- We started by determining the energy required to complete one **autocross (64 s)** lap at Varano, which serves as our **target** for the 2025 car

- From **total** endurance distance it resulted approximately a battery size of **9 kWh** (no regeneration)

- We simulated the car during the laps, obtaining that **6-10% of the energy** could be regenerated

- Based on these findings, we decided on a target battery capacity of **8 kWh**.





Cells

- We chose **cylindrical cells** for **greater flexibility in dimensions**, **thermal uniformity**, **mechanical robustness**, **modular scalability**

- We analyzed many types of chemistry: LTO, **NMC**, LFP -> NMC have more **power** and **energy** density (NMC 260 Wh/kg vs LFP 120-130 Wh/kg)

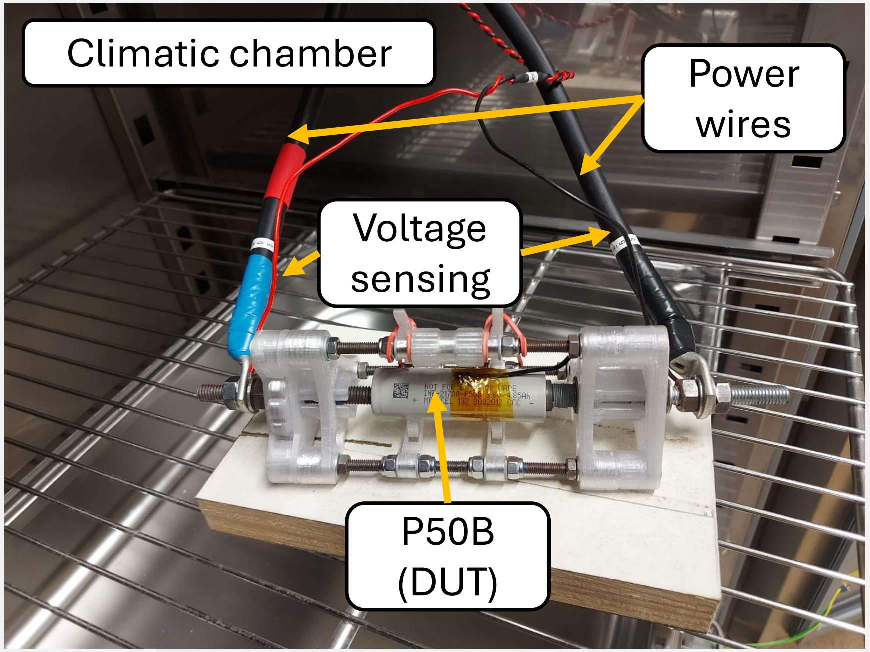
- The better solution for our aim is Molicel-INR-21700 **P50B** with the **144S3P** configuration, to achieve the maximum allowed voltage of **600 V** and lowering dissipations with the **same power delivered**

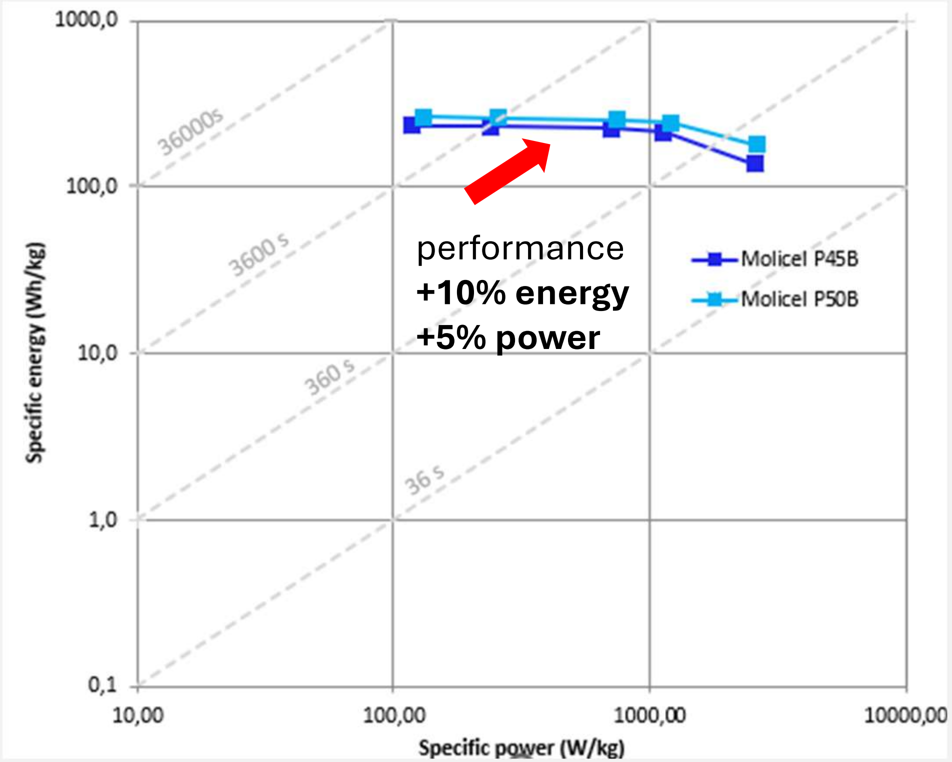
Datasheet cella			Limiti di regolamento		
Vc,max	4,15	v	Pmax	80000	W
Vc,min	2,5	v	Vmax	600	v
Vc,m	3,6	v	Vmin	200	v
Cc,n	5	Ah	Etot	8000	Wh
Ic,max	60	A	#moduli	6	
Peso	71	g			
Calcoli					
Autonomia			Potenza		
ns	144		Imax(quando cella	222,22	A
Cn(corrente per parallelo)	15,43	Ah	Plimitata	64800	W
np_autonomia	3		np_potenza	4	
Etot	7776	Wh	Peso tot celle	30,672	Kg
Etot(con un parallelo in meno)	5184	Wh			
stare attenti a:					
Misure	risultato	margine			
Vmininv>200	ok	160	v		
Vmaxpacco<600	ok	2,4	v		
Vmaxmodulo<120	ok	20,4	v		
Emaxmodulo<6	ok	1,334	MJ		
Peso modulo<12	ok	6,89	Kg		

Cells – test for performance

- **Performance tests** were conducted on multiple cells, enabling **comparisons** to be made between cell **P45B** (2024) and cell **P50B** (2025)

- The results on the **Ragone diagram** confirm that the performance of the adopted Molicel cells has increased

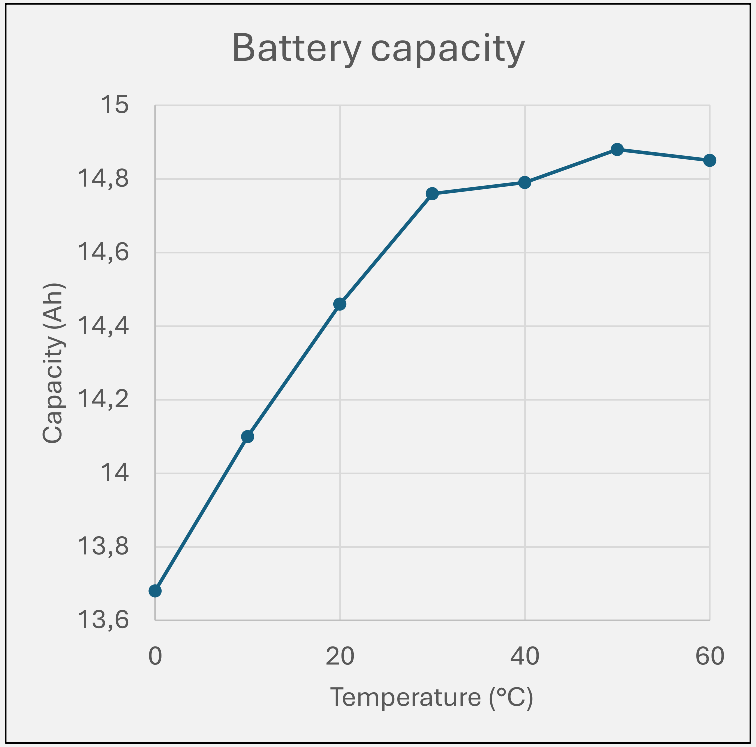


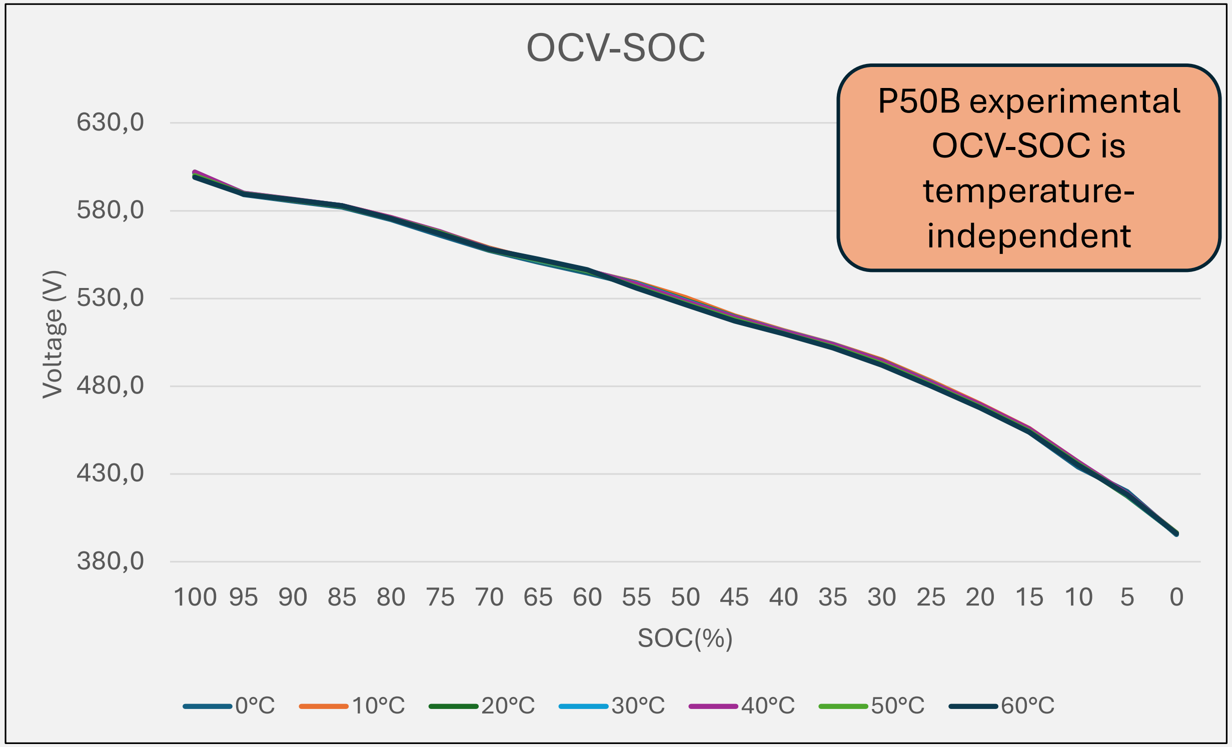


Cells – test for SOC estimation

- **Capacity** tests and **open-circuit voltage** measurements at various temperatures were conducted to calibrate the Battery Management System (**BMS**) accurately, which is developed **entirely in-house**.

- The tests were conducted at cell level and the results were **scaled up** to battery level, considering the 144S3P configuration adopted.





SOC estimation

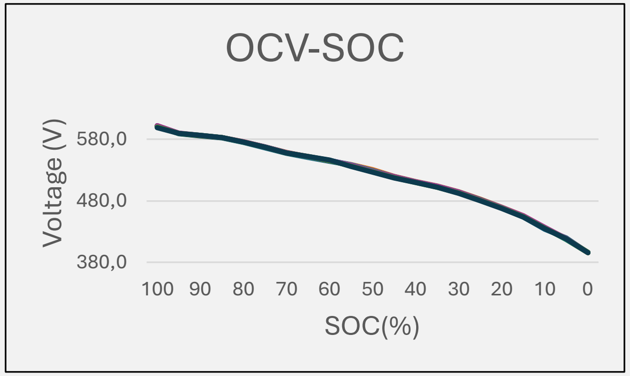
- A **mixed method** has been proposed to approach the problem of the State of Charge (SOC) estimation: **Ah counting** and **OCV-SOC** relationship, due to **simplicity** and **experimental characterization** related
- When the car is turned on and operating in **run mode**, the SOC estimation method is the **Ah counting**
- When the car is in **rest mode**, the **OCV-SOC** curve implemented allow to restore the correct value of $SOC(t_0)$. The rest time needed is at least 45 minutes

Run mode: Ah counting

$$SoC(t) = SOC(t_0) - \frac{1}{C_{nom}(T)} \int_{t_0}^{t} I(t)dt$$

But there is the need to define properly $SOC(t_0)$, due to integral error that add up over time

Rest mode: OCV-SOC



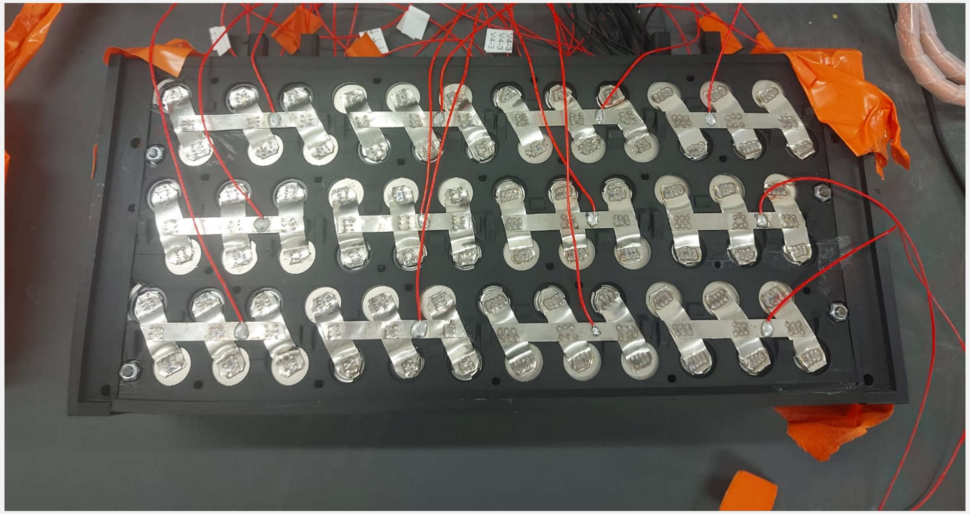
$SOC(t_0)$ adjustment

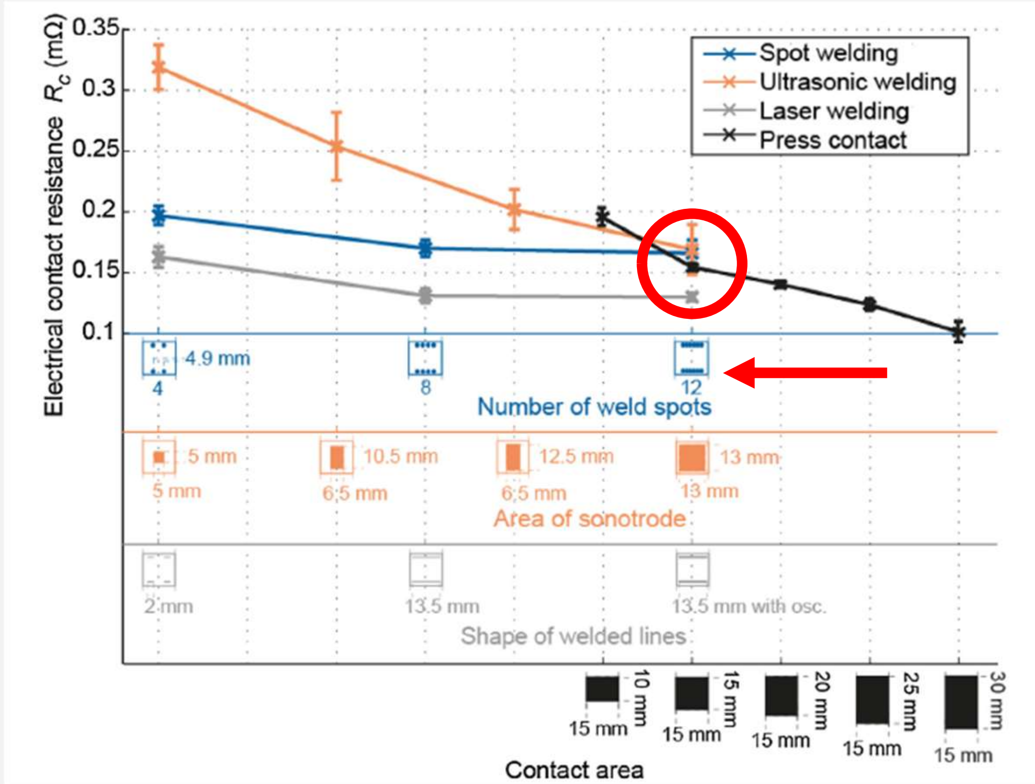
Module realization

- Six modules, each one with **24s3p** cells configuration
- Completely made in house 3D printed with ABS V0
- Structure assembled with **mechanical joints** and **removable parts**

Module realization

- Cells bonding technique: **spot welding**
- The same **total welding resistance** can be achieved using **12** weld spots similarly to other **expensive** welding methods
- Pure nickel strips busbar, **6 mm^2** for each cell power connection (2 x 10 x 0.3 mm)

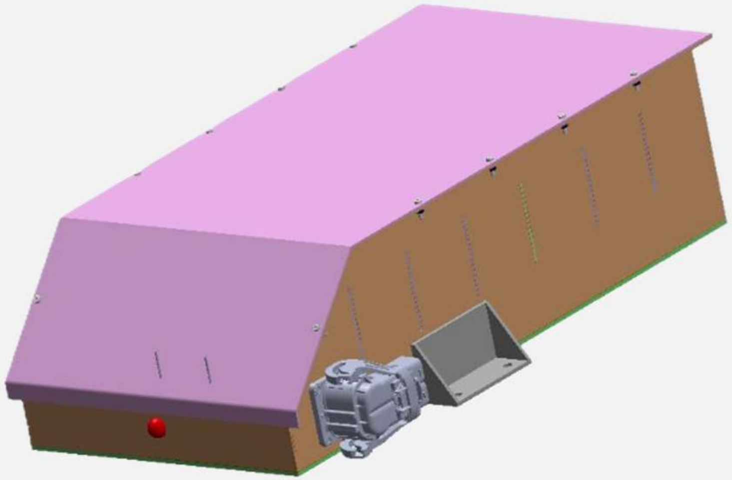




Martin J. Brand et al, Detachable electrical connection of battery cells by press contacts, Journal of Energy Storage, 2016.

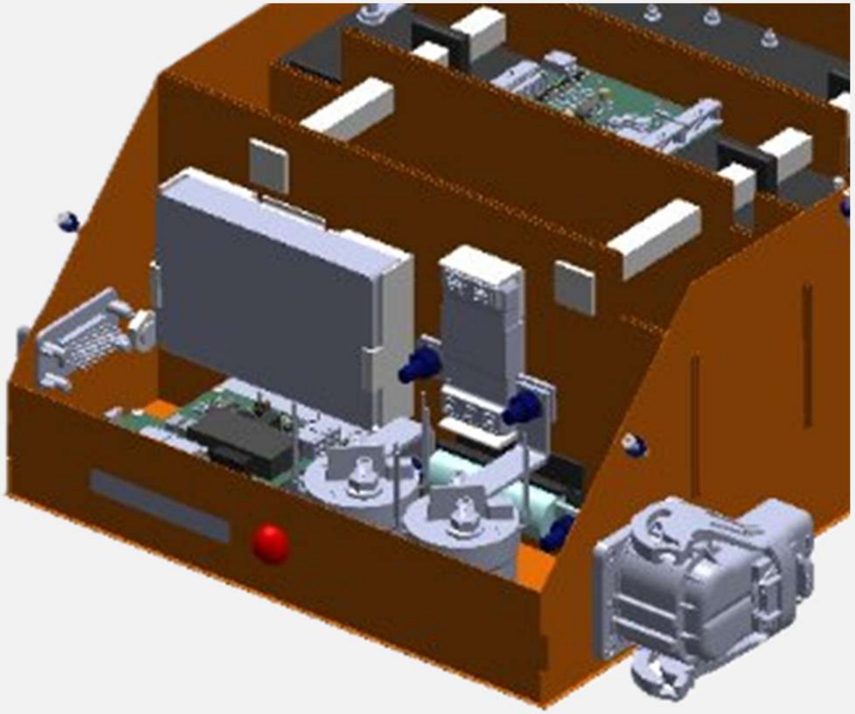
TSAC

- **Compact** electrical layout
- Balanced design with **low center of gravity (~30%)**
- Cooling space **reserved** for future use
- **Easy** to disassemble and structurally compliant



TSAC

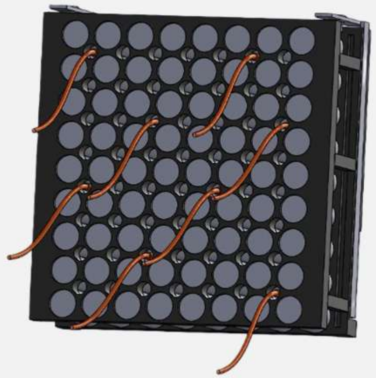
- In the space for battery system **components**, called «pocket», the main components are:
    - AIRs
    - Precharge
    - Shunt
    - BMS master
    - Main fuse
    - Voltage indicator
    - IMD
- The position of the pocket is designed to **facilitate** battery maintenance operations and limit the system's overall **weight** and **volume**.



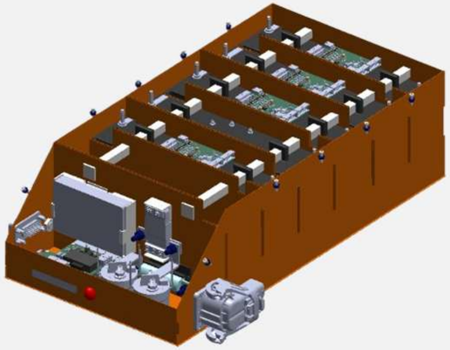
COMPARISON WITH 2024

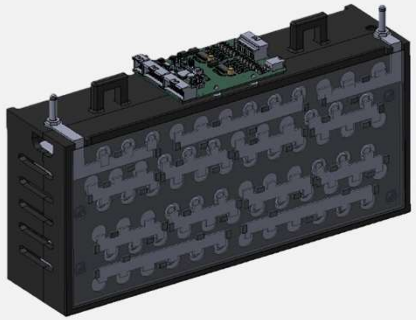
- **Lowered** Center of Gravity: In **2024** it was **130** mm from the base; **this year** it is **90 mm**
- With the same cells weight, by purchasing the new Molicel cells, we were able to achieve 8 kWh compared to last year's 7.2 kWh
- This results on lowered the battery **CoG** by **30%** and increased the **energy density** by **11%**
- Lowered total mass from **51** kg to **48** kg (~**6%**)

2024



2025





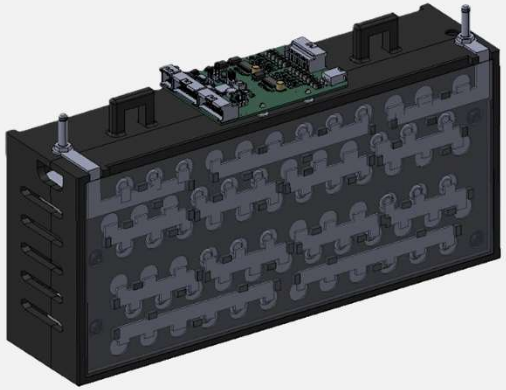
POSSIBLE IMPROVEMENTS

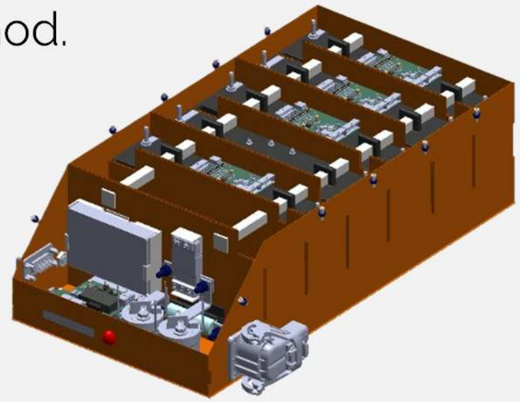
- **Cooling** needs to be implemented to utilize the available power for more time, **reducing the need** to manage it to keep battery temperature low

- To reduce **weight**, the TSAC can be made of **carbon fiber**.

- Cells welding with **nickel-copper sandwich** busbar to decrease the total resistance

- Develop a more **accurate SOC** estimation method.



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Powertrain modeling

Outline

- Battery electrothermal model
- Inverter model
- Motors electrothermal model
- Wires model
- Future developments

*Note: all the models are developed on **OpenModelica** software -> open-source and Modelica language*

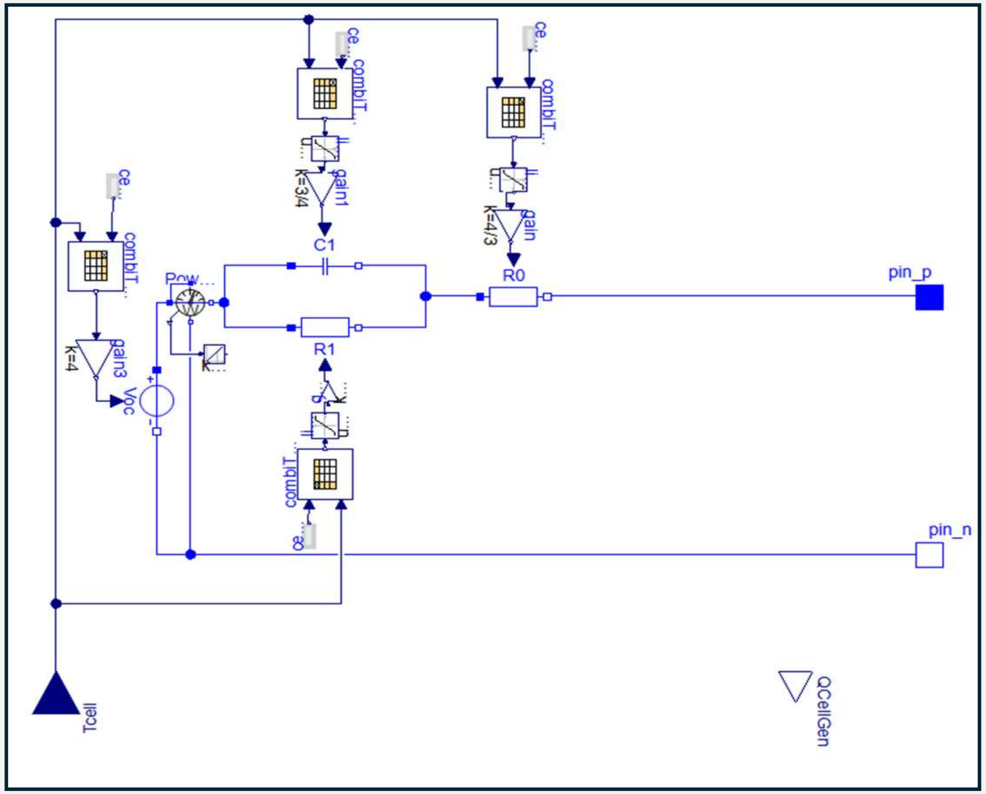
Battery electrothermal model

Cell electrical model:

- Cell modeled as voltage source + R_O + one RC block experimentally calibrated, function of SOC and temperature

- Single RC block balances accuracy and simplicity

Input	Output
Initial SOC	Cell voltage
Cell temperature	Cell SOC
	Thermal power gen.

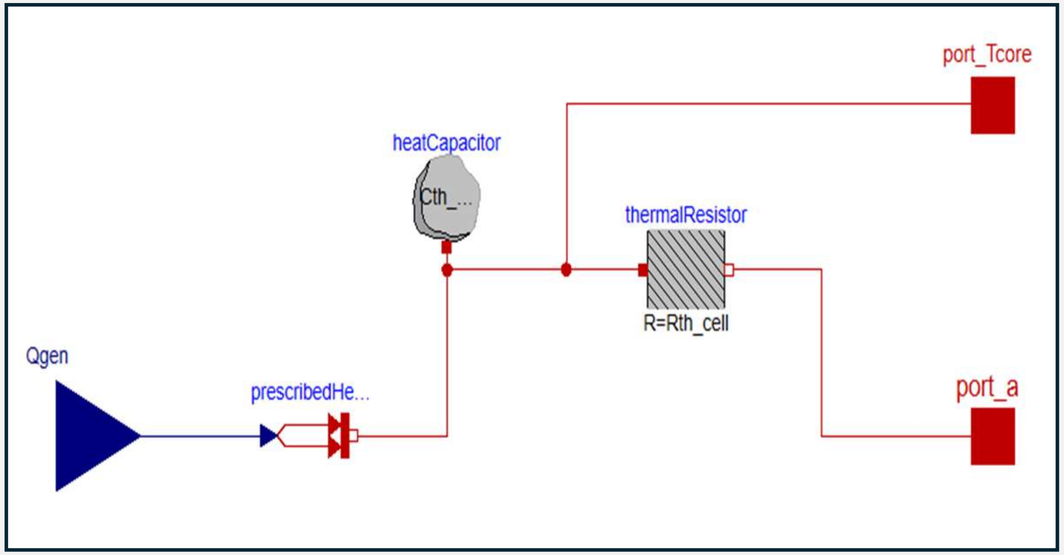


Battery electrothermal model

Cell thermal model:

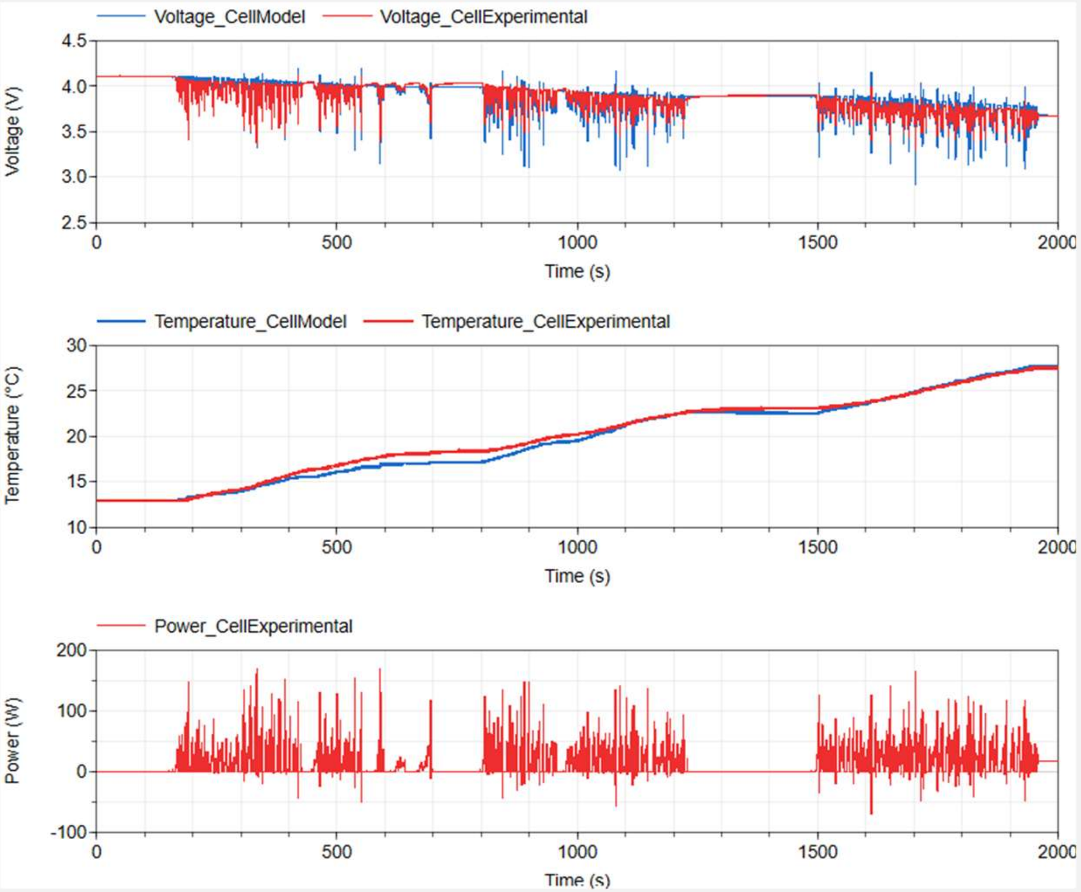
- Thermal resistance to simulate the heat distribution and temperature reached
- Thermal capacity to simulate heat absorption (literature value)

Input	Output
Initial temperature	Cell internal temperature
Thermal power gen.	Cell surface temperature



Battery electrothermal model

Cell electrothermal model validation:

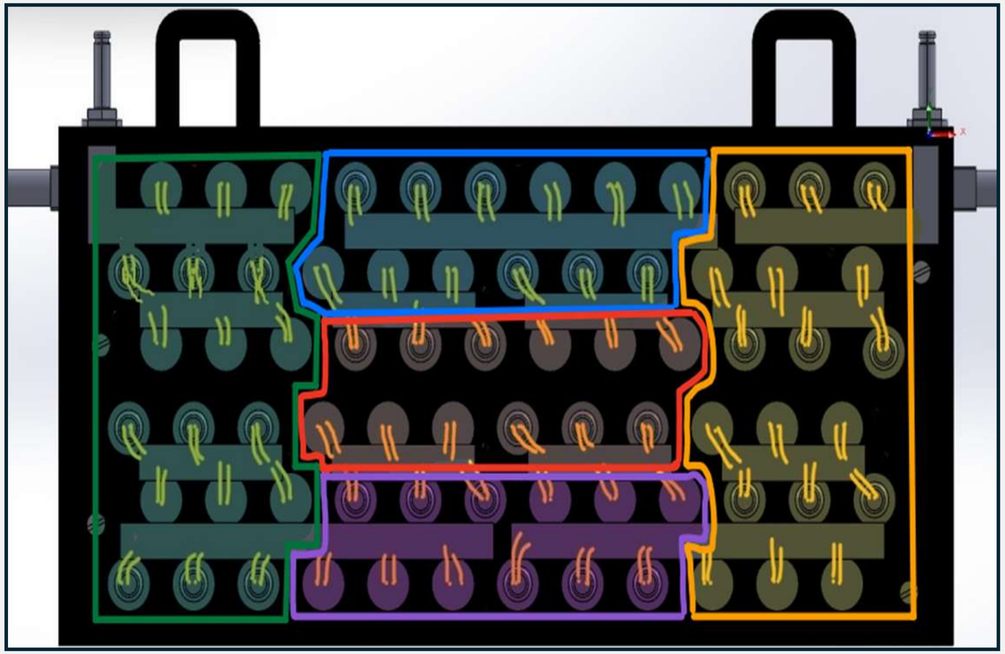


- The **model** results are in **blue** and the **experimental** results (extracted from a simulated endurance test) are in **red**
- **Electrothermal validation at cell level reached**

Battery electrothermal model

Electro-thermal battery module model

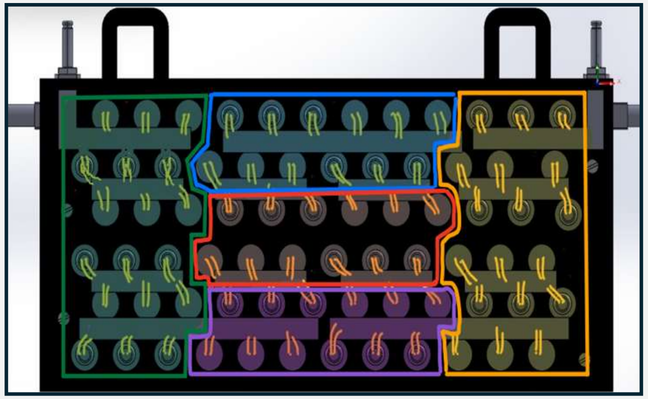
- The module is divided into five sections based on similar thermal and electrical behavior.
- Neighboring cells are assumed to have the same temperature to simplify modeling.
- The layout consists of two outer 6s3p blocks and three inner 4s3p blocks.
- The "red" zone is the most thermally stressed and, along with "purple", is electrically simplified as 4s3p blocks.

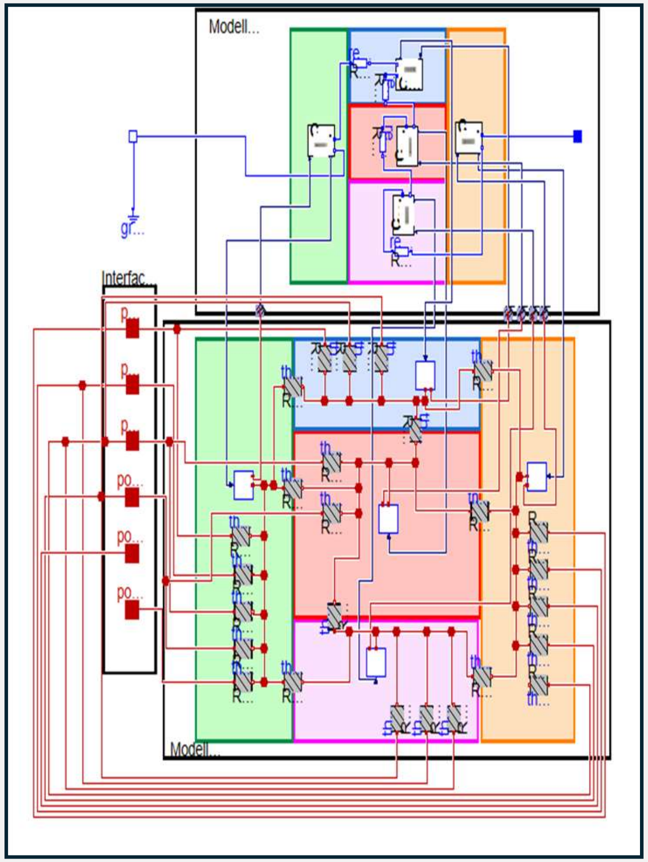


Battery electrothermal model

Electro-thermal battery module model

Input	Output
Ambient temperature	Module voltage
Initial cells temperature	Module SOC
Initial SOC	Module temperature
	Heat exchanged between modeled parts





Electric part

Thermal part

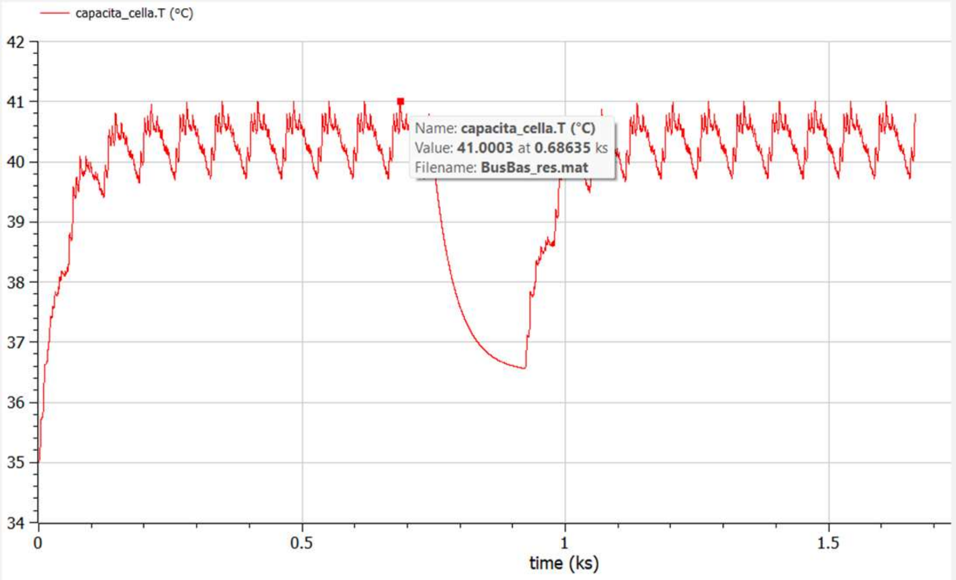
Battery electrothermal model

Use of the electrothermal battery model to calibrate the BMS-VCU driver inputs

- The model allows defining torque and current **thresholds** between simulations.
- These thresholds help manage energy use and temperature during the endurance test, with the aim to maintain at the end **5% of SOC** and a maximum **temperature of 60°C**.

ΔSOC (%)	Current requested (%)
100-30	100
30-15	80
15-5	67

Cell temperature during Varano endurance simulated (with cooling on)

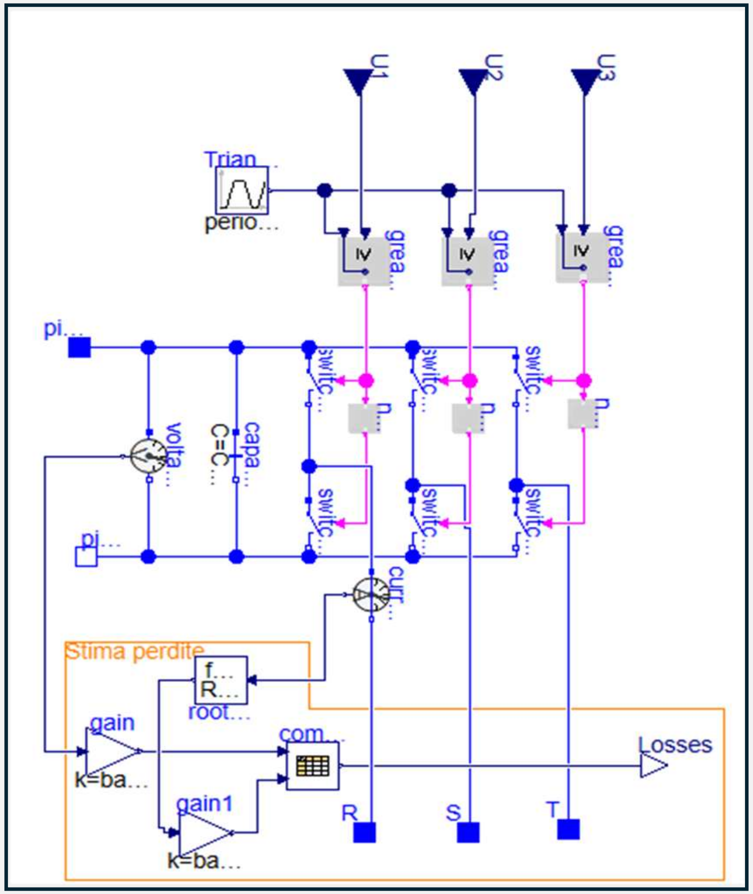


Inverter model

Inverter model:

- Model uses ideal switches to reduce complexity and equation count.
- Simplification enables full powertrain simulations.
- Line-to-line voltages are unipolar and twice the frequency of bipolar phase references.

Input	Output
Reference for PWM modulator	Power losses
DC battery interface	3-phase electrical interface

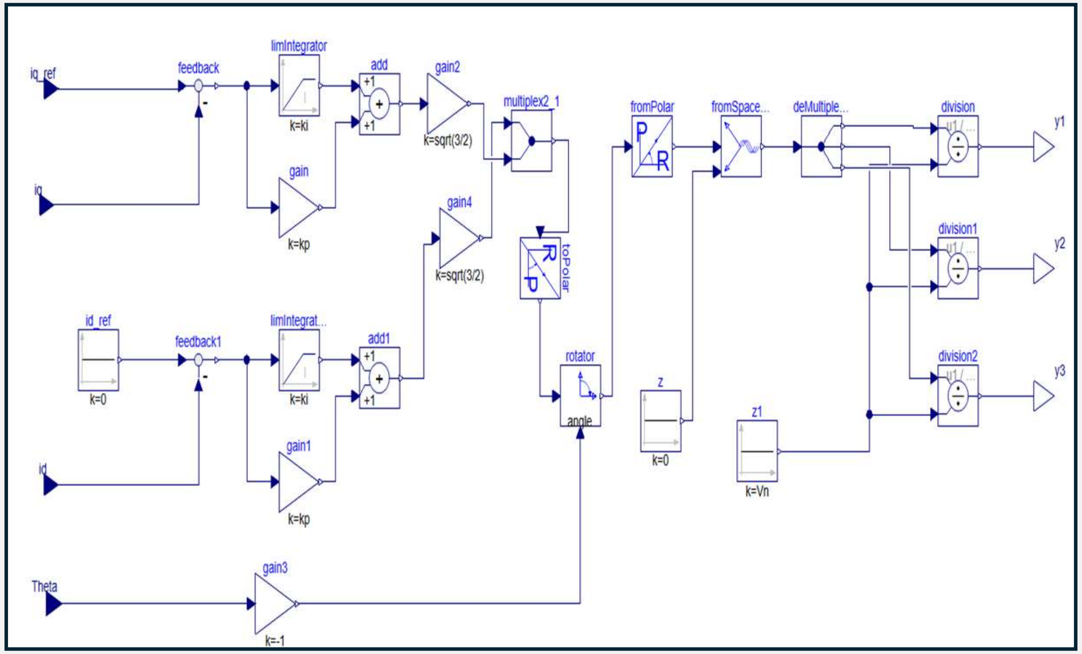


Inverter model

Inverter controller:

- PI controller includes anti-windup saturation for stability.
- Control is performed in the Park domain, then converted to phase voltage references.

Input	Output
Reference and measurements of direct (d) and quadrature (q) currents	Reference for PWM modulator



Motors electrothermal model

EMRAX Electrical model:

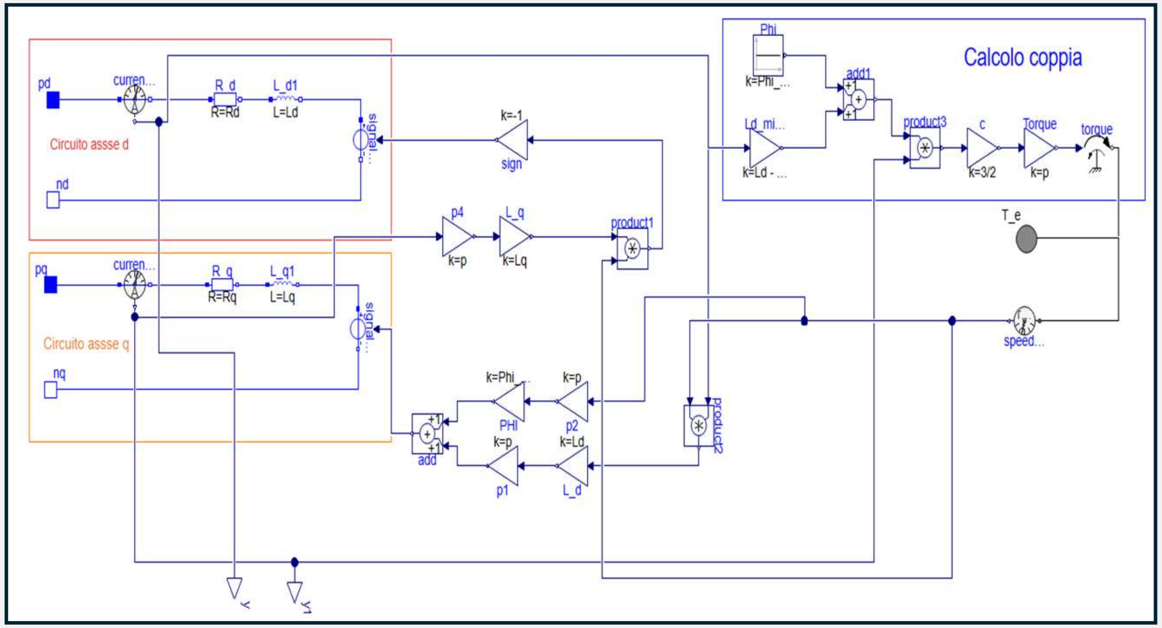
Input	Output
Rotor speed	Torque
Voltage interface	Direct and quadrature currents

Equations of the dq electrical model

$$v_d = R_d i_d + L_d \frac{di_d}{dt} - p\omega L_q i_q$$

$$v_q = R_q i_q + L_q \frac{di_q}{dt} + p\omega(L_d i_d + \Psi_{pm})$$

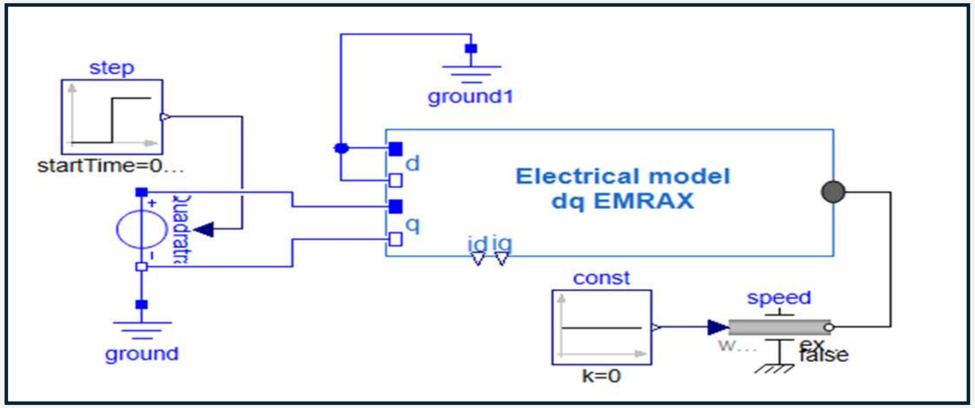
$$T = \frac{3}{2} i_q p(i_d(L_d - L_q) + \Psi_{pm})$$

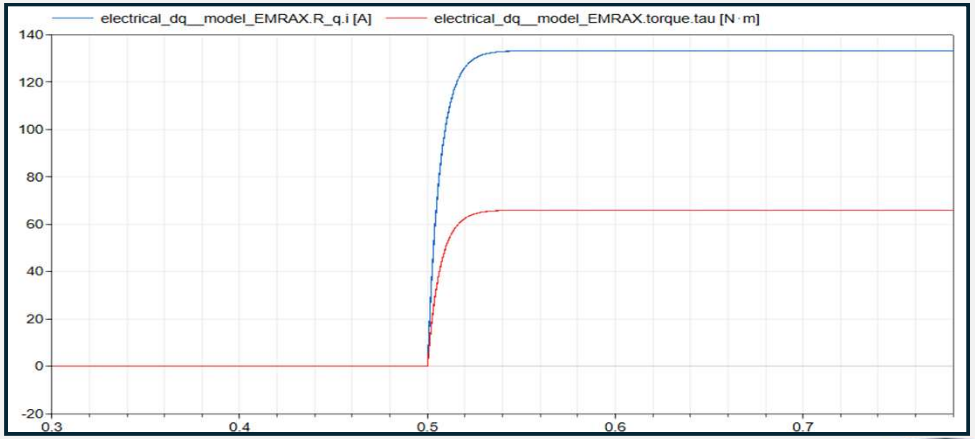


Motors electrothermal model

Locked rotor simulation:

- Simulated step input on quadrature voltage with direct axis shorted and zero speed.
- Torque and current respond with exponential behavior, as expected.
- Useful for comparison and validation against locked rotor test on real motor.



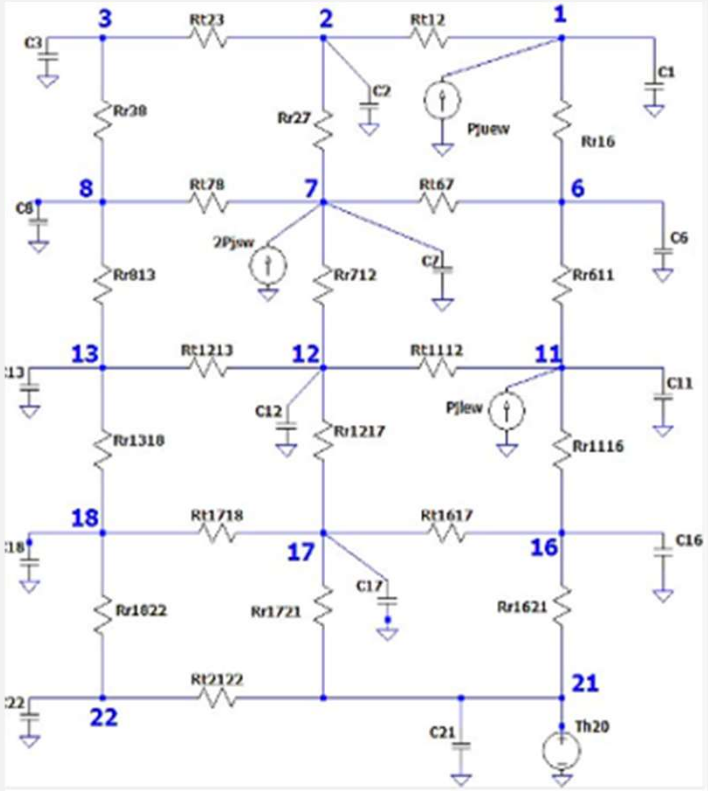


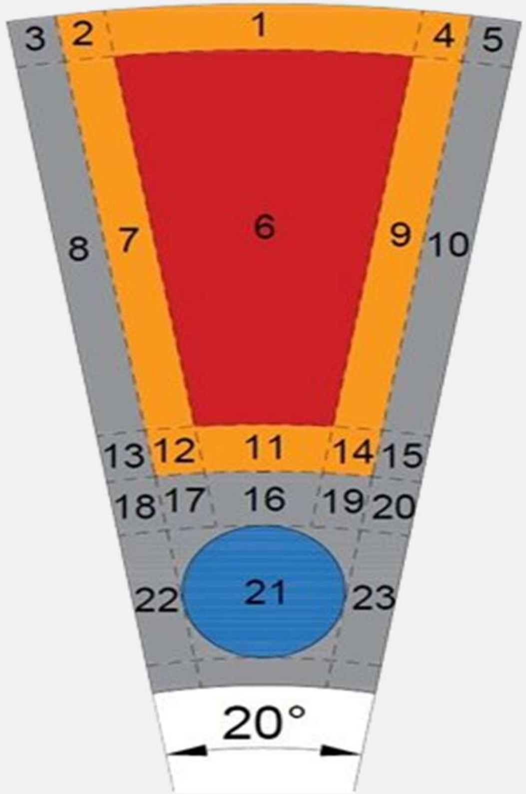
Motors electrothermal model

Stator thermal model

- Thermal model estimates temperature distribution at key internal points.
- Initial analysis used online references of an air-cooled EMRAX motor.

Input	Output
Motor time-current profile	Time-temperature profile of all mesh nodes
Cooling water-temperature profile	Thermal power exchanged with water
Measured copper time-temperature profile	



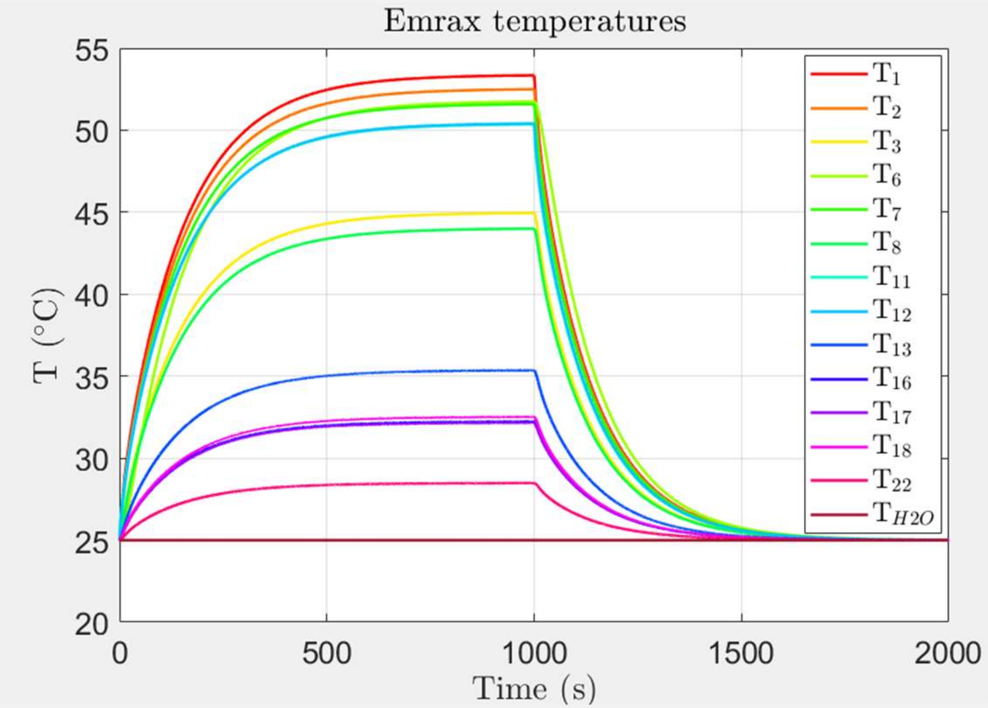


Motors electrothermal model

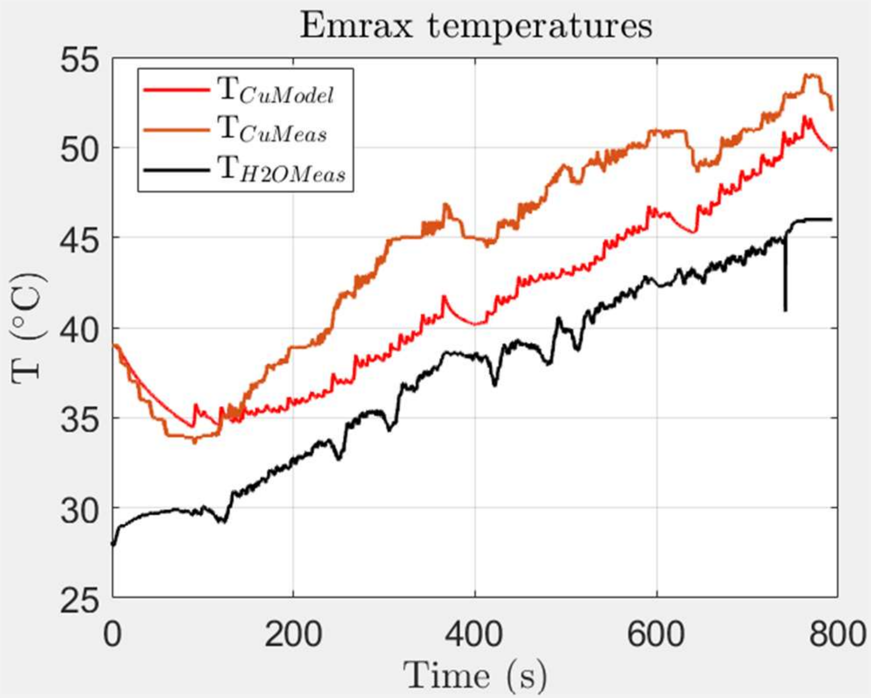
Stator thermal model

- Simulations

Steady state condition at motor rated current



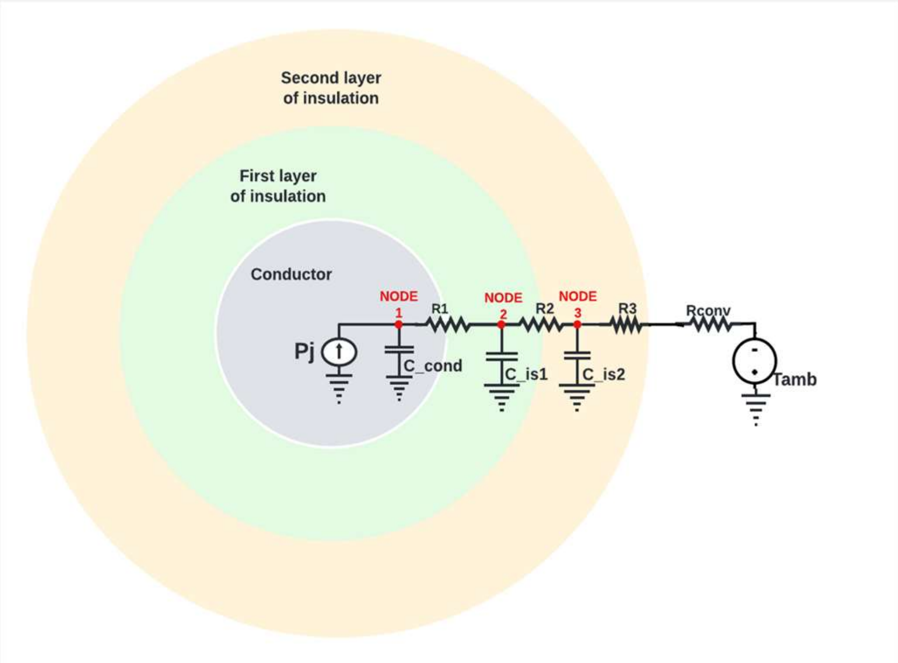
Dynamic conditions during endurance



Wires model

We split the cable into **3 isothermal zones**:

- Conductor (centered in node 1)
- First insulating layer (centered in node 2)
- Second insulating layer (centered in node 3).

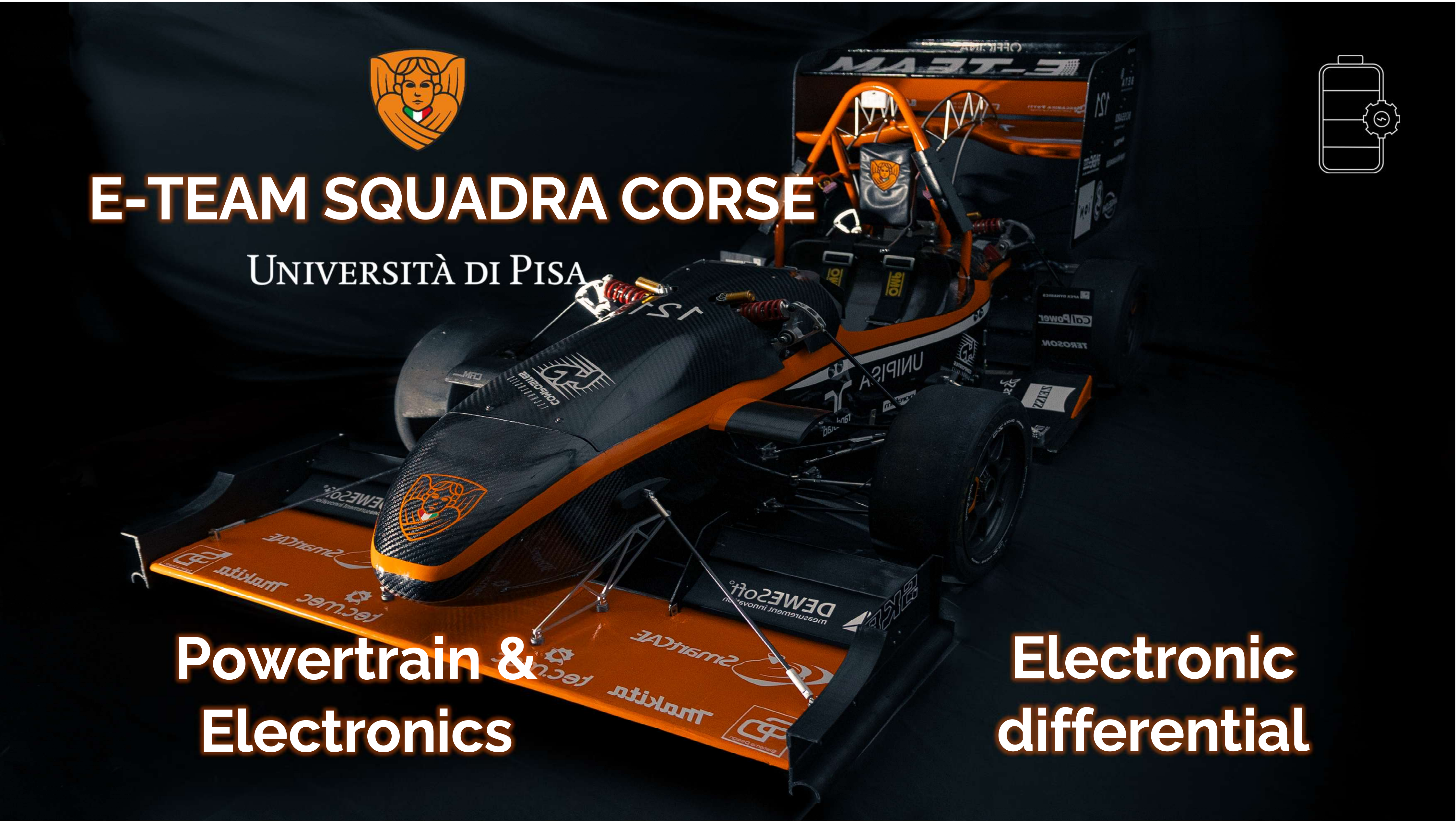


Cables	Wires section 2024 (mm^2)	Wires section 2025 (mm^2)
Inside TSAC	25	16
TSAC to TS enclosure	10	10
TS enclosure to inverters	16	10
Inverters to motors	16	10

Weight reduction by 30%

Future developments

- Expansion of module model to battery model, including the TSAC
- Calibrate experimentally the inverter electric model and the electrothermal motors model
- Thermal model of the inverters
- Development of a model for the whole cooling system integrating the single parts' models


E-TEAM SQUADRA CORSE
Università di Pisa
Powertrain & Electronics
Electronic differential

Project in 2024

- In ET-16 we used the following process to obtain the resulting **torque on each side**.
- To obtain the $\boldsymbol{I_{diff}}$ **parameter** the team could chose between two different relations, depending on the challenge that the vehicle had to face.

Torque-current motor relation

$$T_{sx} = k_{mot} \cdot I_{sx}$$

$$T_{dx} = k_{mot} \cdot I_{dx}$$

$$k_{mot} = 0.479 \frac{Nm}{A}$$

Driver input (linear map)

$$I_{rqst}\Big|_{throttle100\%} = I_{max}$$

$$I_{rqst}\Big|_{throttle0\%} = 0$$

Torque vectoring idea

$$I_{sx} = I_{rqst} \cdot (1 + \frac{I_{diff}}{2})$$

$$I_{dx} = I_{rqst} \cdot (1 - \frac{I_{diff}}{2})$$

Project in 2024

Skidpad

Measure $v_{avg} = \frac{\omega_{ant_{sx}} + \omega_{ant_{dx}}}{2} \cdot \mathrm{r_r} \cdot 3.6$

Control $I_{diff} = \frac{\omega_{ant_{sx}} - \omega_{ant_{dx}}}{v_{avg}} \cdot \mathrm{k_{skid}} \cdot \mathrm{r_r} \cdot 3.6$

Parameter $k_{skid} = 5 \div 8 \ \frac{1}{rad}$

Pros:

- Less noise in the input signal
- Simple and easy to tune
- Works well in low-speed and controlled conditions

Evo

Measure Wheel speed ω_{dx} and ω_{sx}

Control $I_{diff} = \mathrm{k_{EVO}} \cdot (\omega_{an\ sx}^2 - \omega_{an\ dx}^2)$

Parameter $k_{EVO} = 0.007 \div 0.01 \ \frac{s^2}{rad^2}$

Pros:

- Adjusts torque split in real time so it reacts to actual wheel speed difference
- Obtain better dynamic and a more responsive map

BUT

Both formulas are unreliable because they depend on front wheel speed, which is affected by soil roughness and ignores wheel slip

Project in 2025

- This year, the main change involves the **acquisition side** of the electronic differential
- To avoid any lack of critical information during dynamic maneuvers, we decided to introduce **suspension potentiometer** data as a primary input
- Real-time **load transfer** analysis enhances vehicle attitude estimation and steering response, improving rear axle torque distribution accuracy

1° ingredient

$$\boxed{steeringAngle = \frac{lf \cdot 2 \cdot k_{spring} \cdot delta_{lat}}{mass \cdot vehicleSpeed^2}}$$

k_spring	Spring stiffness (N/m)
lf	Pace of the car (m)
$delta_{lat}$	Lateral imbalance of the vehicle
$vehicleSpeed$	Car speed, average between front wheels speed (m/s)

Project in 2025

- The current differential logic applies **two additional functions** to better adapt to real-world driving conditions.

$TorqueBiasFactor$	A function estimating how the vehicle's dynamics (roll/pitch/load transfer) influence torque distribution.

2° ingredient

3° ingredient

$$slip_{\mathrm{RL}} = \frac{(\omega_{RL} - vehicleSpeed)}{\max(vehicleSpeed, 0{,}1)}$$

Where ω_{RL} is the left rear wheel speed and $vehicleSpeed$ the estimated vehicle speed

Final control law

$$I_{sx} = I_{rqst} \cdot (1 - (TorqueBiasFactor \cdot steeringAngle)) \cdot (1 - |slip_{RL}|)$$

$$I_{dx} = I_{rqst} \cdot (1 + (TorqueBiasFactor \cdot steeringAngle)) \cdot (1 - |slip_{RR}|)$$

Planned improvements for 2026

Increasing the accuracy of the input:

- Possible adding sensors capable of capturing more detailed and reliable data

Upgrading the Slip Control function:

- Higher accuracy and frequency in state estimation enable earlier slip detection
- Faster response improves traction and vehicle stability.

Better estimation of forces acting on the vehicle:

- Enhanced sensor data enables precise load distribution estimation, supporting smarter torque strategies like RearBias.
- These improvements boost performance, consistency, safety, and tire management during dynamic driving.

E-TEAM SQUADRA CORSE

Università di Pisa

Powertrain & Electronics

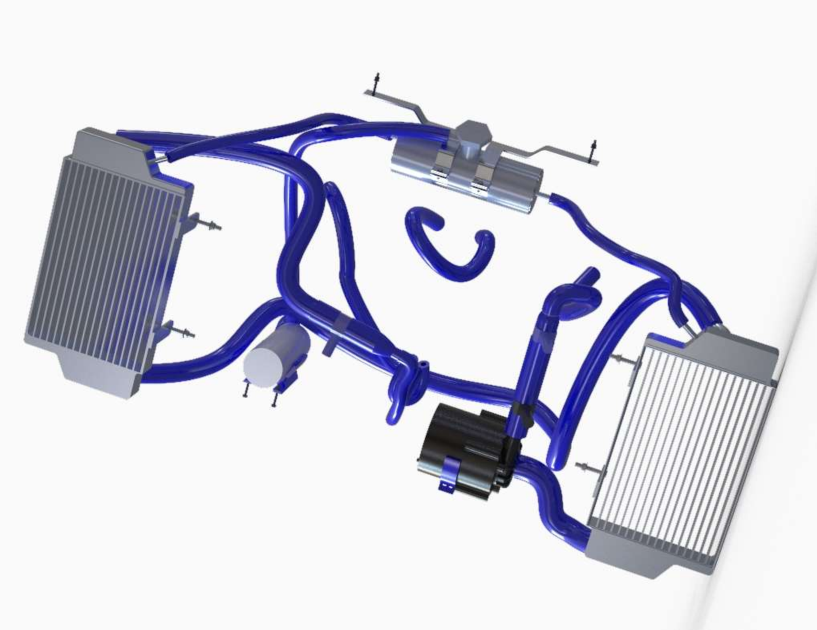
Cooling system

Project overview and 2025 Goals

Reduce the **weight** of the entire cooling system

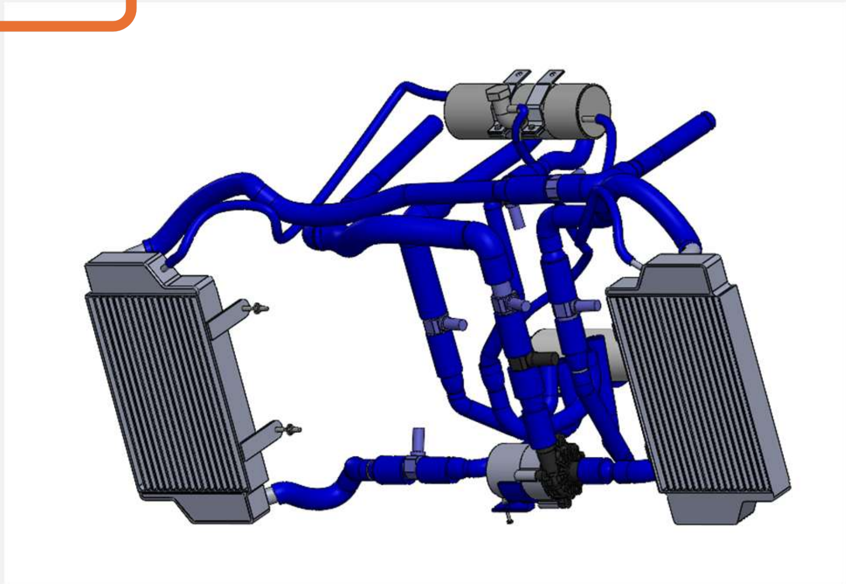
Ensure safe **operating temperature** with refrigeration for **motors**, **inverters** and **battery**

Re-engineer **layout** with battery liquid-cooling focus



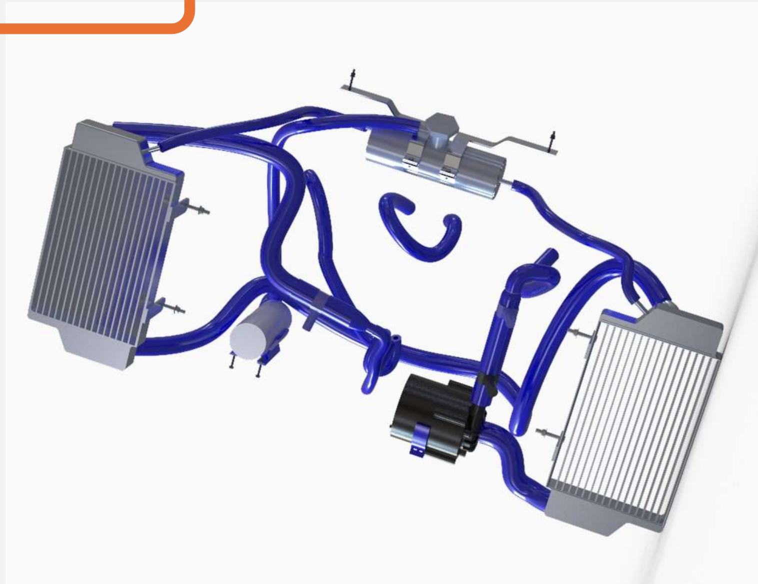
2024 vs 2025 generality

2024



- **No battery refrigeration**
- More **layout complexity**
- **Inefficient Pump**
- **High** reference **temperature**, more work for radiators (35°C)

2025

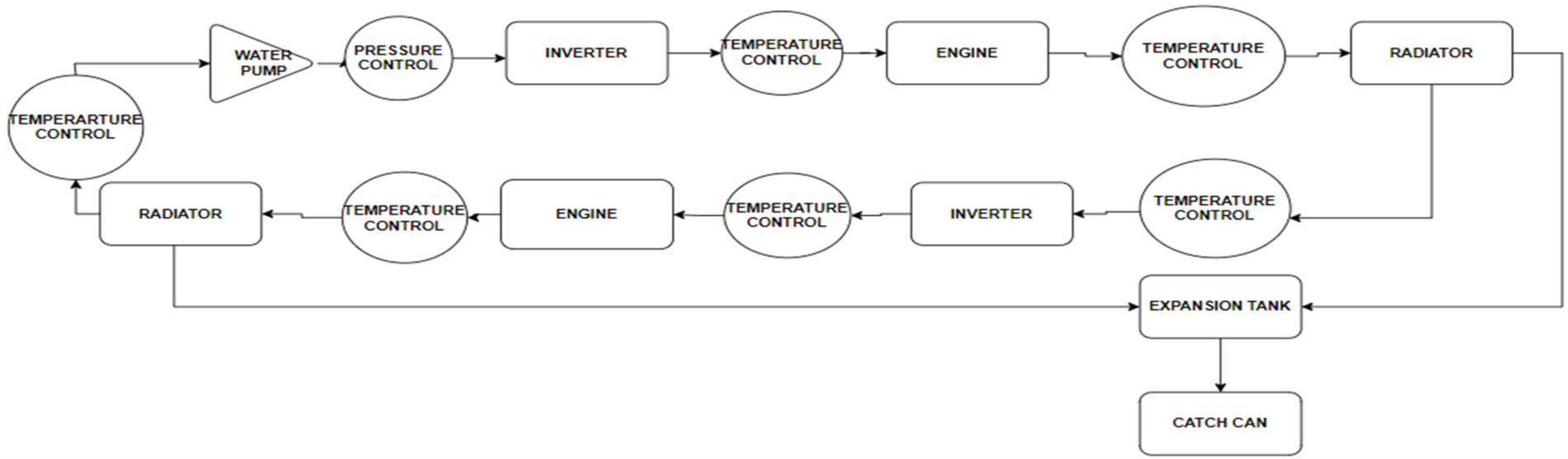


- Design of **battery cooling system**
- **Layout** more **easy**
- New pump
- Low reference temperature

2024 vs 2025 layout

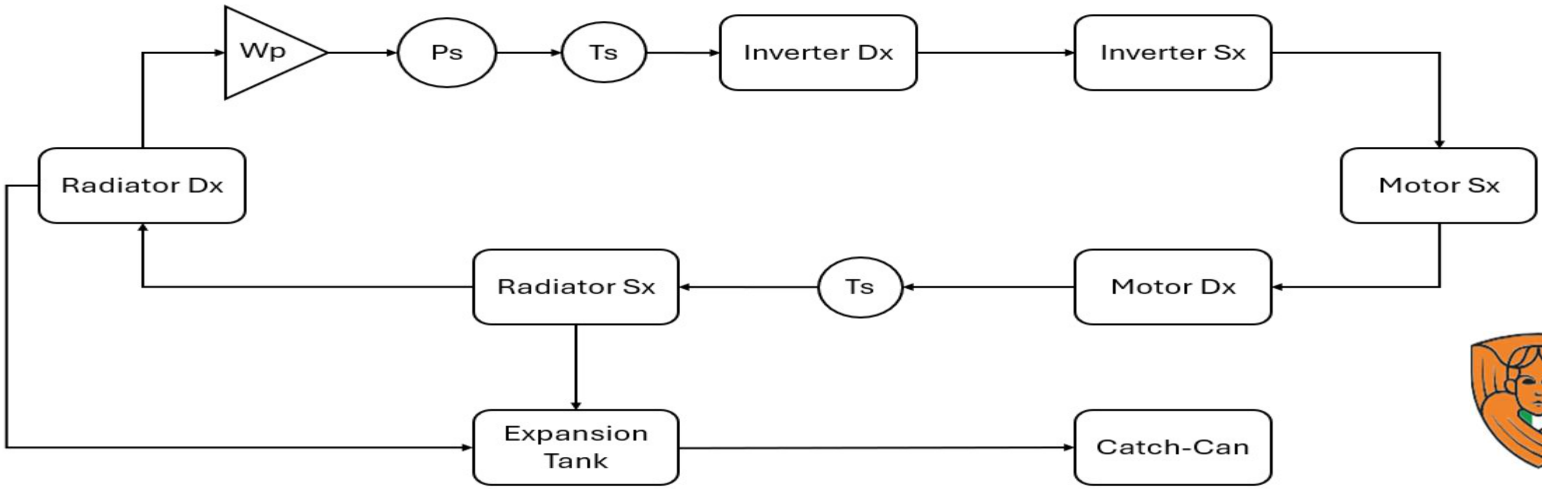
2024

- **Series** system monitored by **multiple sensors**



2025

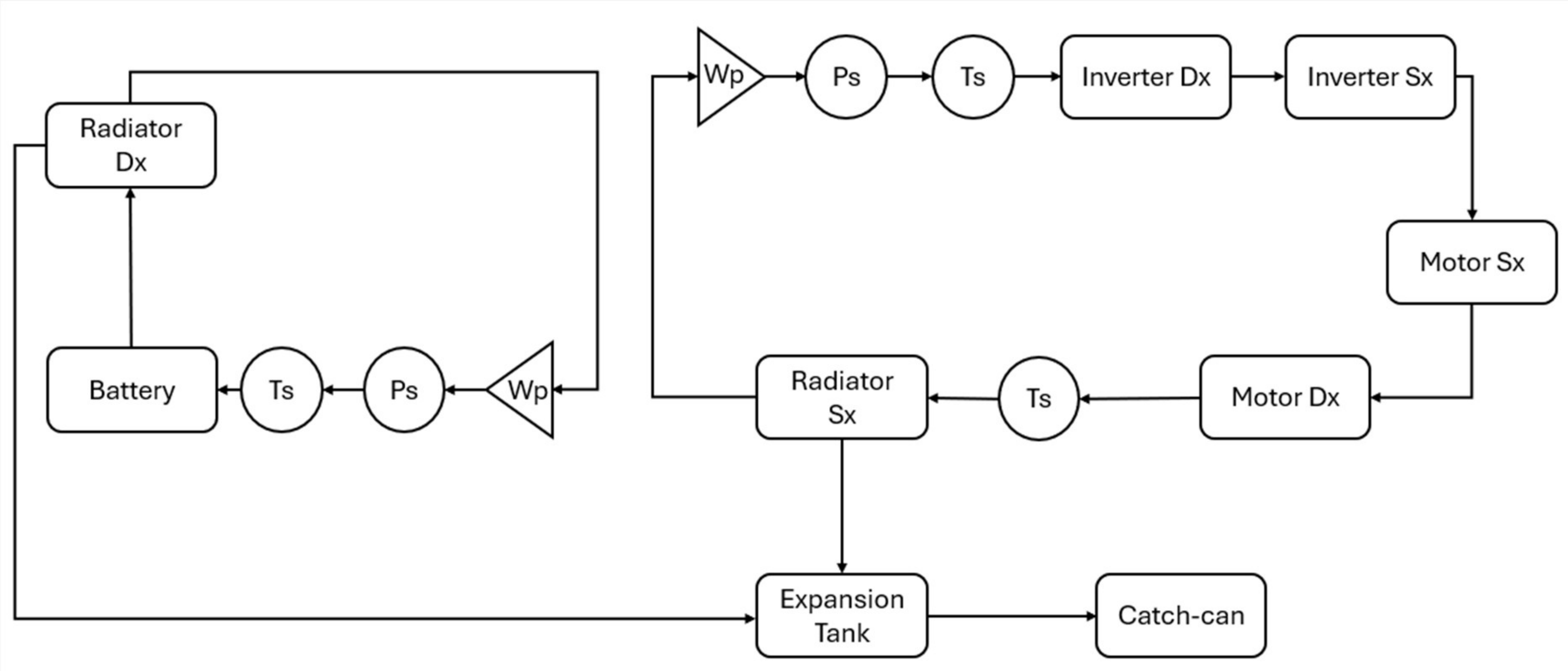
- **Series** system with new layout monitored **only** by **2 sensors**



2026...

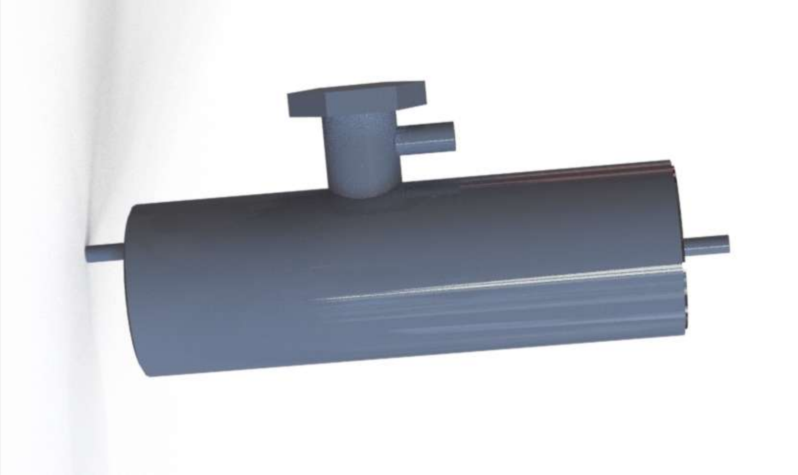
2026

- **Two-series** system with **battery** integrated in the layout



Expansion Tank

The expansion tank accounts for the **variation** of the water's **volume** due to a change in pressure:

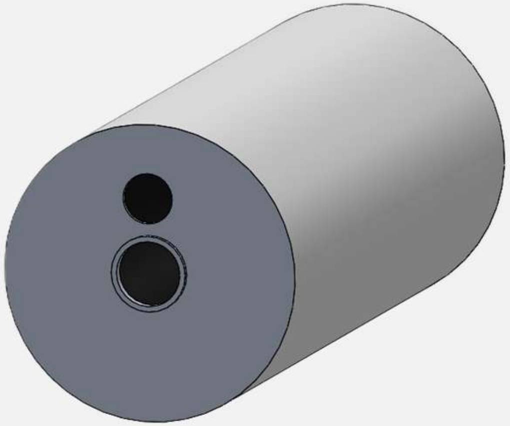


$$V = \frac{eC}{P_{atm}\left(\frac{1}{P_{atm}} - \frac{1}{P_{max}}\right)}$$

Catch can

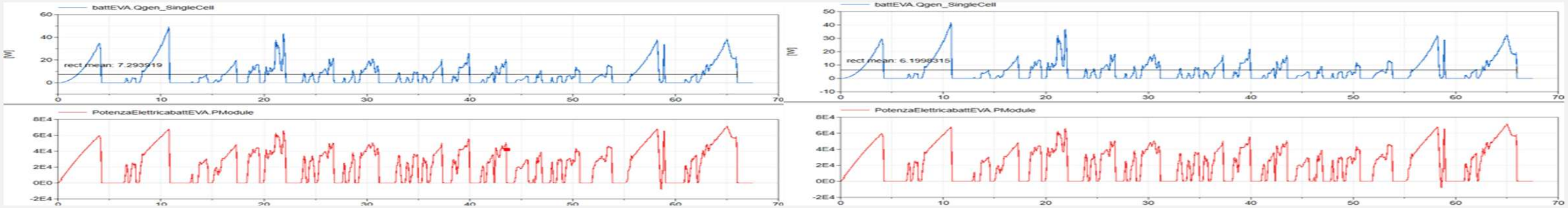
- **Actual** cooling system = **2 L** of demineralized water -> Catch can ≥ 200ml volume.
- Cooling system with **battery** = **3 L** of demineralized water -> Catch can ≥ 300 ml volume.

- **Actual volume** = **250 ml**



How to cool down the battery?

Model simulation lap – current profile from Varano autocross



- Trend “**power vs time**” from Varano’s **autocross** runs for battery temperature at 20˚C and 40˚C and 3-C discharge rate
- **Mean power** produced by a single cell.
  $\dot{Q}_{mean,produced} = 6{,}75\ W$
- **Power** on unit **volume** per single cell
  $\dot{Q}_{\frac{mean,,produced}{unit\ volume}} = 2{,}79E + 05\ W/m^3$

How to cool down the battery?

Data extrapolation and literature comparison

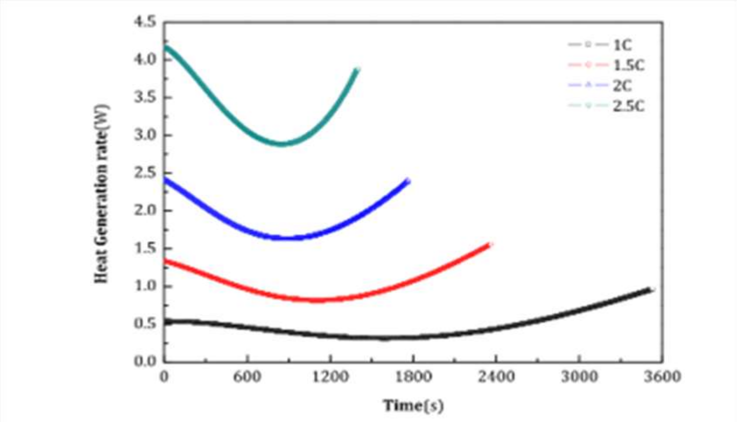
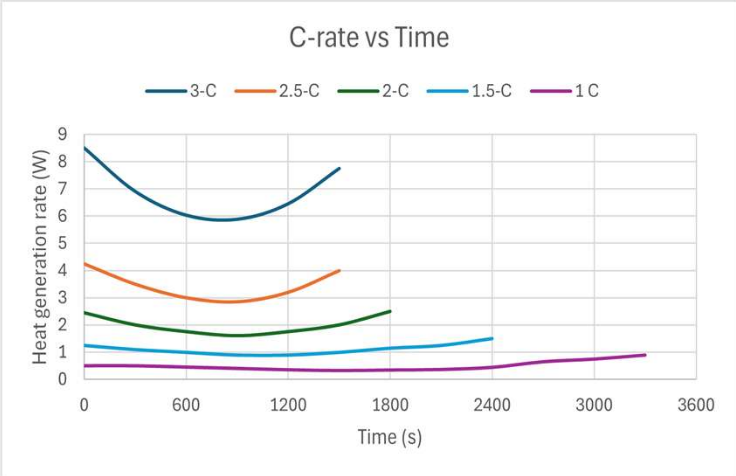


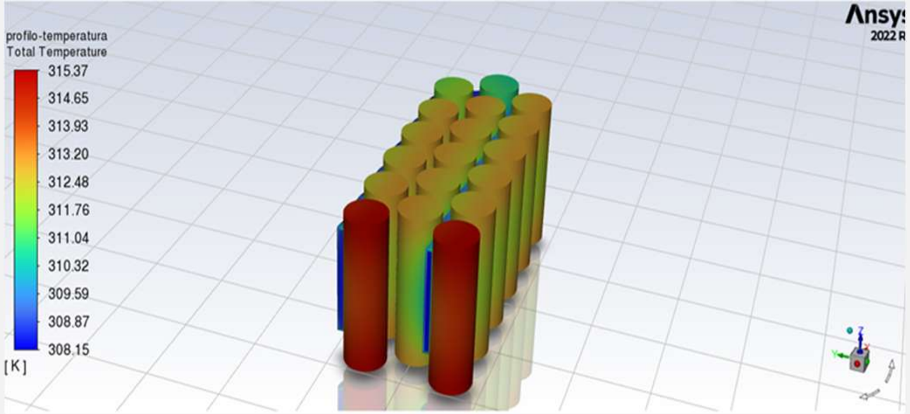
Fig. 7. Curves of battery heat generation rate during different discharge rates.



- **Extrapolation** and **comparison** of data with scientific literature
- **Compatibility** found -> Data used for simulation

How to cool down the battery?

Simulation

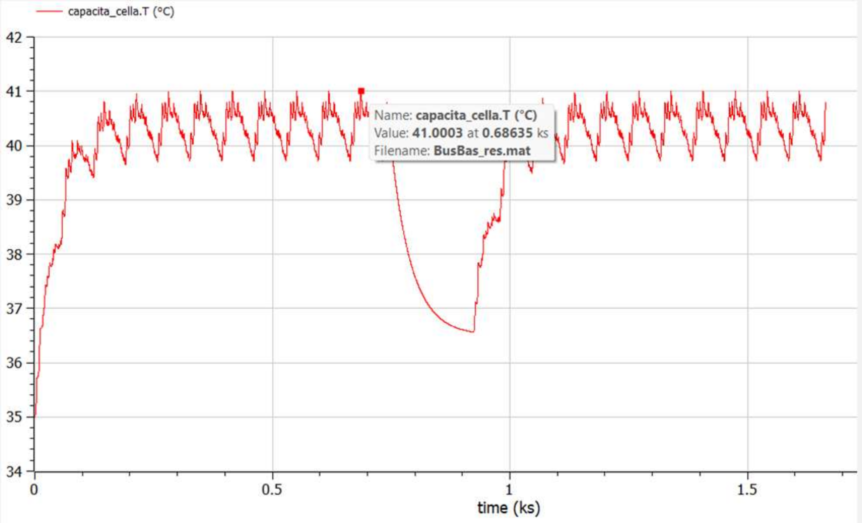


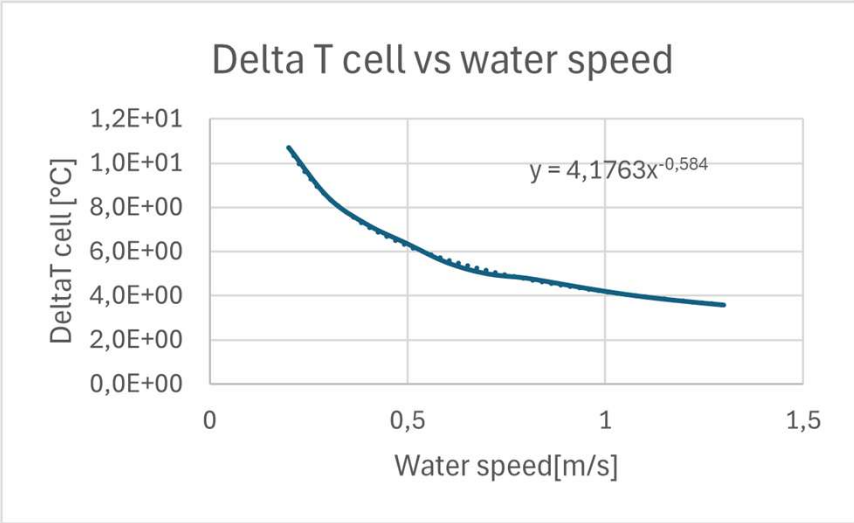
- **Design** of a **Serpentine coils** heat exchanger "battery-based"
- **Simulation** of its behavior on "Ansys Fluent"
- Simulation **parameter**:

Parameter	Value
Water speed	0,7 [m/s]
Water temperature	35 [°C]
Power Cell	2,79°+05 [W/m^3]

How to cool down the battery?

Final comparison with Modelica

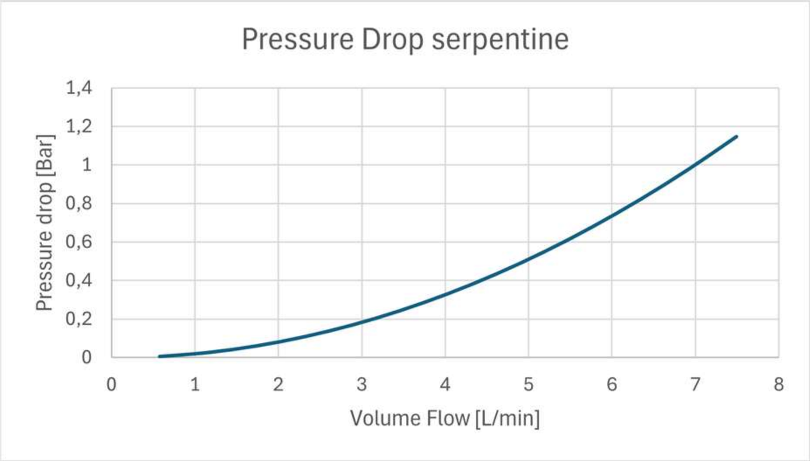


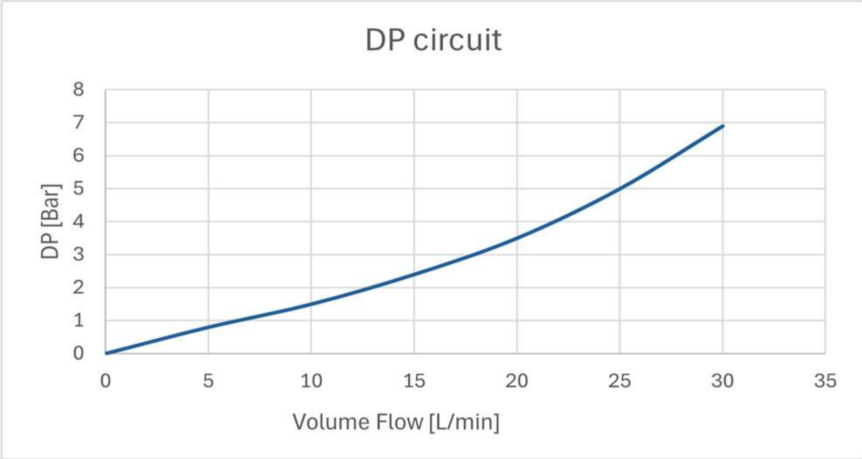


- **Comparison** between "**Ansys Fluent**" simulation and "**Modelica**" results with the same starting data.
- **Validation**
- Expression of **ΔT vs water speed** -> **Target** < 8°C of overheating.

How to cool down the battery?

Pressure Drops

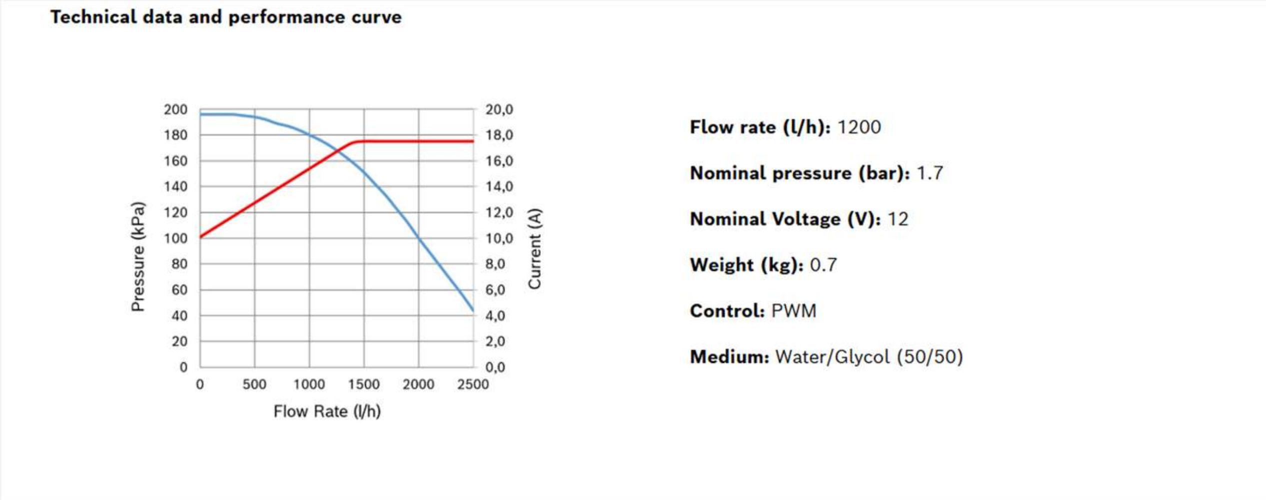




- Major **pressure drops** are inside the inverters, motors, and radiators -> **Changing** the **layout didn't affect** the calculation much;
- The **minimum** water flow rate value is **6 L/min**, given from the Emrax motor datasheet;
- With all the data acquired before we chose **0,7 m/s** as **water speed** -> **24 L/min** for 6 Coils.
- **Too high** pressure drops for the old pump → **New** (and powerful) pump → **Two different** cooling circuits.

How to cool down the battery?

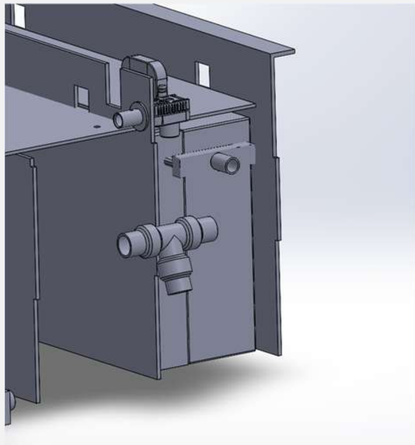
New pump

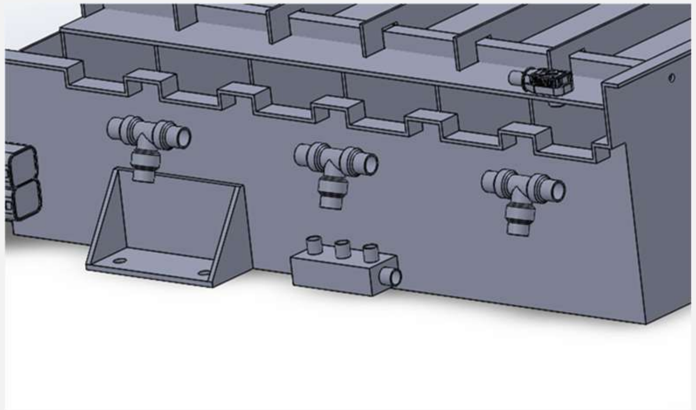


- **Higher power** to overcome the increasing in the pressure drop and guarantee, in every circuit, a water flow higher than the minimum.
- **Less weight** than the previous
- **Less absorbed power** required

How to cool down the battery?

Connection to TSAC





- Coil «**module-designed**» based
- Nozzles **outside** the TSAC, **safety** first
- Design of **junctions** to guarantee **operative conditions**
- Metal 3D printed coils

How «hot» is FSAE? (A lot)

The «old» Competitions

Zalaegerszeg, Hungary
28/07 – 02/08

Hockenheim, Germany
18/08 – 24/08

Varano de' Melegari, Italy
14/09 – 19/09

- **Selection** of E-team competitions
- **Data collection** about **weather conditions** related to **zone** and **period** of the last five years
- **Gaussian mean** creation for **specific circuit** and **overall**

https://it.weatherspark.com/

How «hot» is FSAE? (A lot)

The «new» Competitions

Castelo Branco, Portugal
27/07 – 01/08

Hockenheim, Germany
18/08 – 24/08

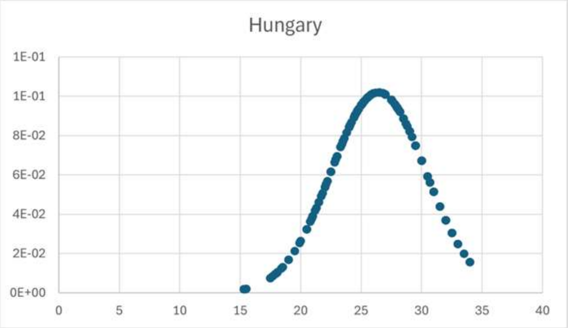
Varano de' Melegari, Italy
14/09 – 19/09

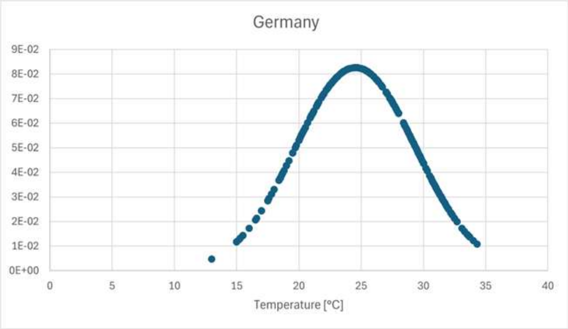
- **Adapting to new conditions**
- **Data collection** about **weather conditions** related to **zone** and **period** of the last five years
- **Gaussian mean** creation for **specific circuit** and **overall**

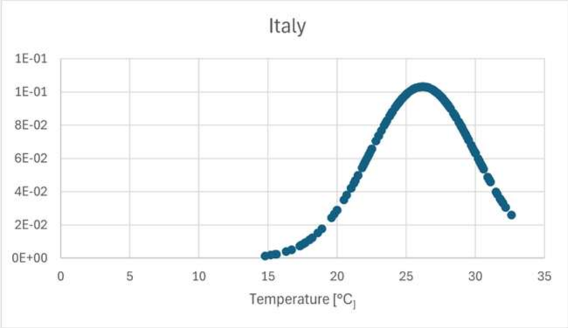
https://it.weatherspark.com/

How «hot» is FSAE? (A lot)

The «old» results





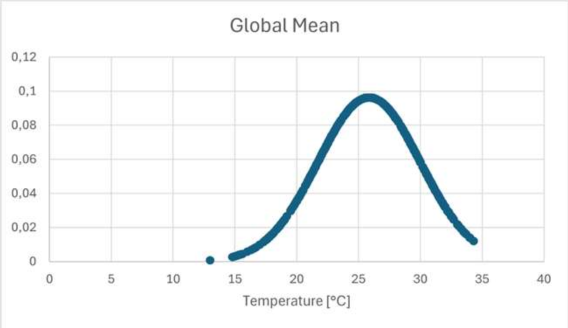


Zalaegerszeg, Hungary
28/07 – 02/08

Hockenheim, Germany
18/08 – 24/08

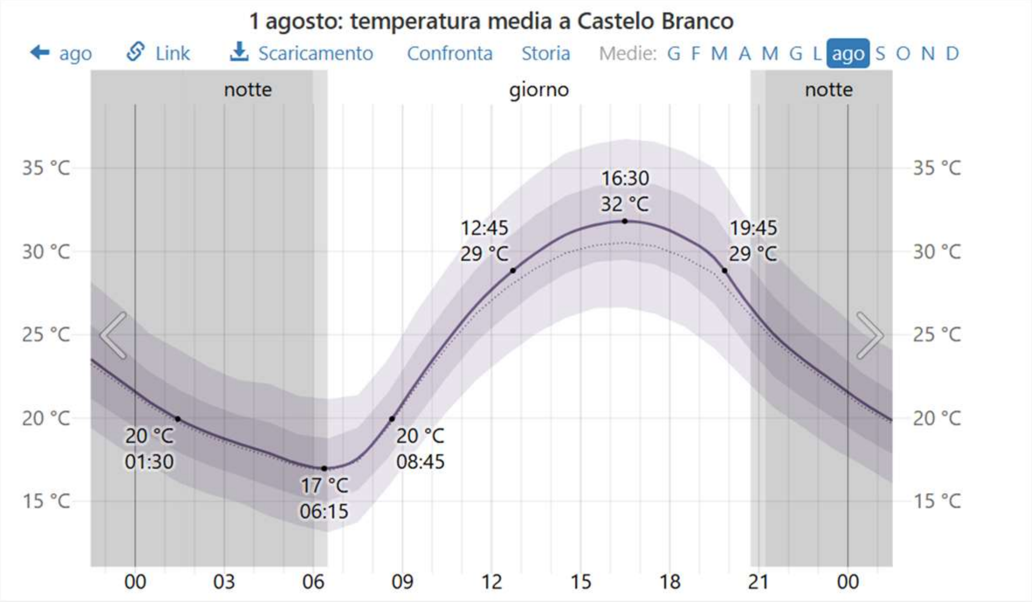
Varano de' Melegari, Italy
14/09 – 19/09

- **Conservative** selection: Global mean + Standard deviation
- Mean = 25,8 °C   Standard deviation = 4,1 °C
- **New** reference t**emperature** = 30 °C
- **Lower value** than old reference **temperature** 30 °C vs 35 °C



How «hot» is FSAE? (A lot)

The new results for Castelo Branco



- **Endurance** day-based
- **Conservative** selection: Global mean + Standard deviation
- Mean = 29 ˚C Standard deviation = 4 ˚C
- **New** reference t**emperature** = 33 ˚C
- **Less value** of reference **temperature** 33 ˚C vs 35 ˚C

Radiator mean Heat dissipation

Is our radiator enough to dissipate $\dot{Q}_{mean}$ for every circuit?

$$\dot{Q}_{tot,dissipated} = U_{tot} * A_{radiator} * (\Delta T_{ml})$$

Target:

- $\dot{Q}_{tot,inverter+motor} = 1{,}4$ kW
- $\dot{Q}_{tot,battery} = 600$ W

Us: Heat Exchange coefficient		
1/hie	7,16E-04	m^2K/W
1/he	3,11E-02	m^2K/W
1/kp/δp	9,8039E-07	m^2K/W
Rsi	8,77E-05	m^2K/W
Rse	3,53E-04	m^2K/W
Us	31,01	W/m^2K

Total exchange area	1,23E+00	m^2
Water side exchange area	0,23	m^2
Air side exchange area	0,99	m^2
As	0,22	m^2

FIN EFFICIENCY		
A_fin	3,00E-06	m^2
A_finned	1,23E+00	m^2
#fins	2154	
L	0,00385	m
m	79,4263107	1/m
η_aletta	0,96995389	
η0	0,999842	

Radiator mean Heat dissipation

We do a linear system that give us the ΔT_{ml} when we know the $\dot{m}_{air}$, $T_{air,i}$, $\dot{m}_{water}$ and we take the worst $T_{water,i} = 55$˚c.

$$T_{fa} = T_{ia} + \left(\frac{U * A * \Delta Tml}{C_{pa} * m_a * 1000} \right)$$

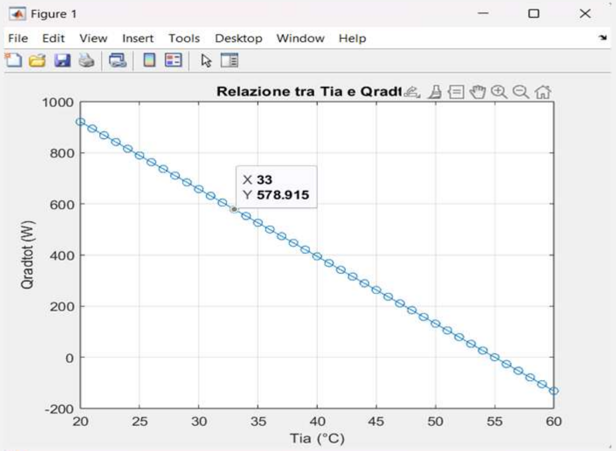
$$T_{fw} = T_{iw} - \left(\frac{C_{pa}}{C_{pw}} * \frac{m_a}{m_w} * (T_{fa} - T_{ia}) \right)$$

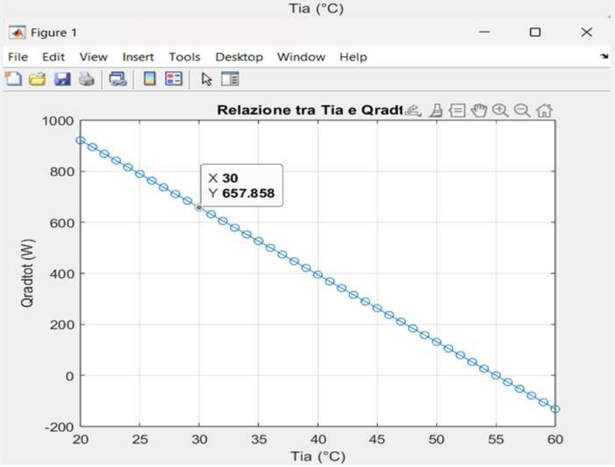
$$\Delta Tml = \frac{(T_{iw} - T_{ia} - T_{fw} + T_{fa})}{\log\left(\frac{T_{iw} - T_{ia}}{T_{fw} - T_{fa}} \right)}$$

Radiator mean Heat dissipation

Now we can estabilish that :

$\dot{Q}_{tot,dissipated} = U_{tot} * A_{radiator} * (\Delta T_{ml})$





If the $\dot{Q}_{tot,dissipated} > \dot{Q}_{motor+inverter}$ and $\dot{Q}_{tot,dissipated} > \dot{Q}_{battery}$ the cooling system is good

We can see, that is a linear function of $T_{environment}$

if the $T_{environment}$=30˚c the

$\dot{Q}_{tot,dissipated}$ = 650 W

$\dot{Q}_{battery}$ = OK

$\dot{Q}_{motor+inverter}$ = Not okay… but resolvable

Solutions:

- Cool down only inverters, critical components.
- Increase air flow for Radiator Sx, better heat exchange
- Decrease energy consumption (< 3-C)

Next Steps in cooling system

- Better **positioning** of the radiators → To increase air flow and downforce
- **3D printing** the cooling coils

Thank you for the attention!

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