Beach Hybrid Motor Group
presents

Citroën Méhari

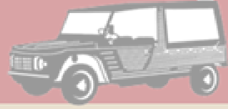
an old-fashioned recreative vehicle

Group 9

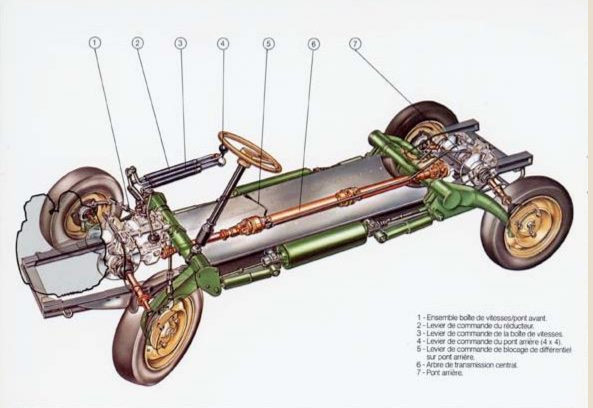
Jacopo Brazzoduro

Enkeled Hoxha

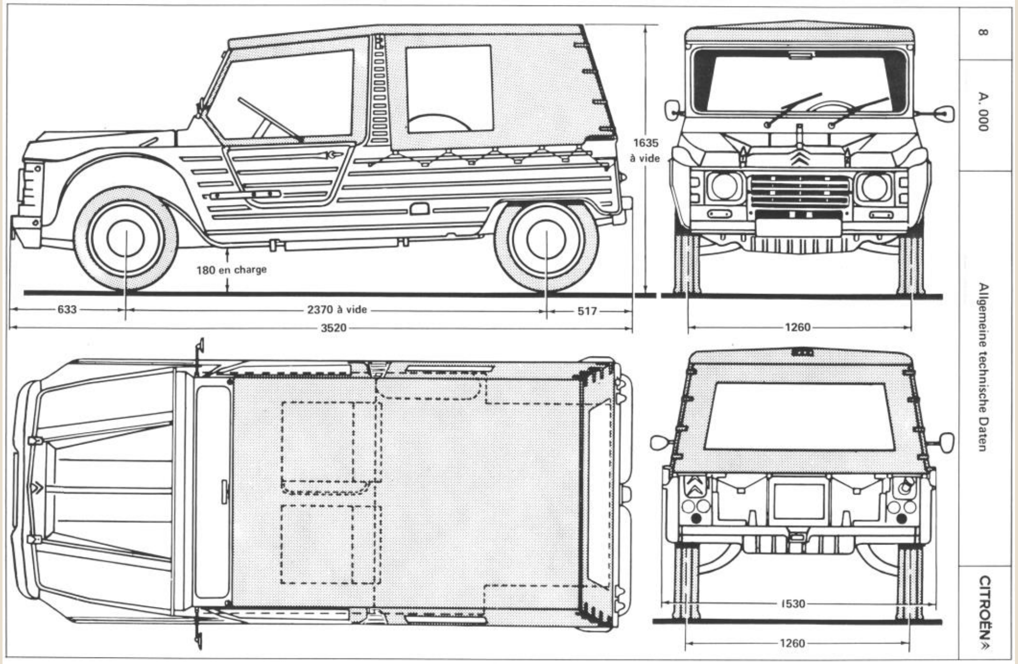
Giovanni Reposo



Vehicle Presentation



- 1968 – 1987 production
- Available in both FWD and AWD
- 600cc flat-twin petrol engine, maximum power 21 kW, maximum torque 39 Nm
- Top speed < 100 km/h
- 237x352x152 mm, 570 kg weight
- Low power output required, full electric has been chosen among alternatives

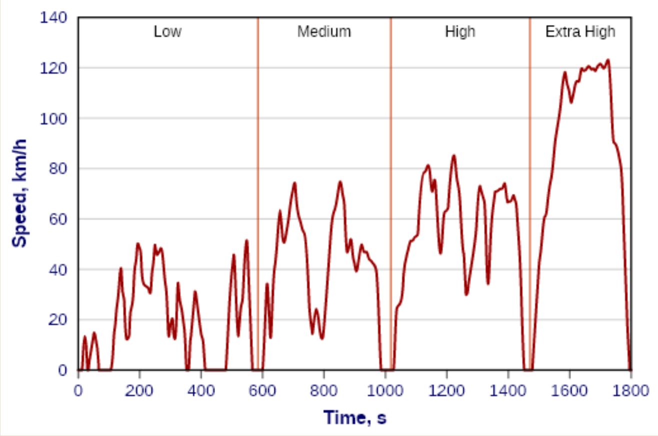


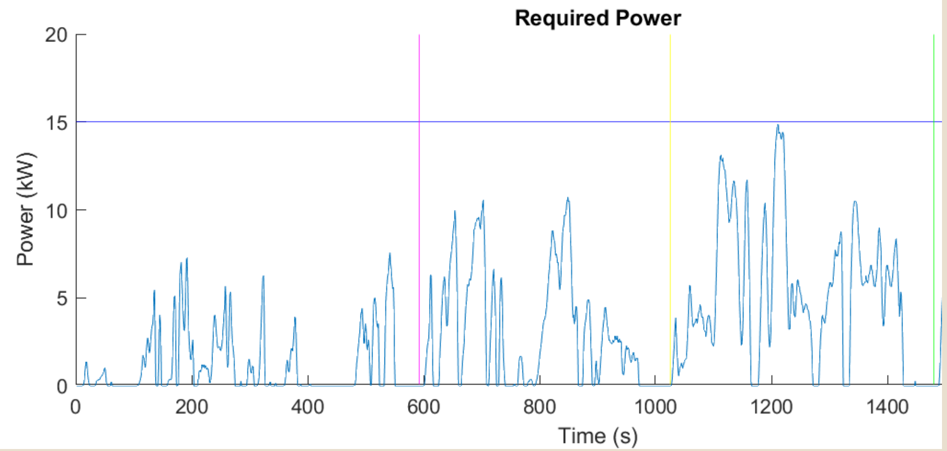
Electric Vehicle Configuration

- Dual IPM 48V motor, maximum power 15 kW, rated power 8 kW, maximum torque 69 Nm
- All wheel drive vehicle, one engine per axle
- 36 kWh $LiFePO_4$ battery
- Top speed < 100 km/h limited for homologation purposes
- Same sizes, 700 kg weight including batteries
- Full electric chosen as very low power makes useless hybrid system
- Also recreative purpose of the vehicle suggests full electric traction: using electric vehicle on the beach reduces particulate emissions and pollution of it
- Available space issues if engine and tank are kept
- Vehicle is made of ABS: plastic material, stricter heat management bounds

Vehicle category and homologation

- ICE vehicle’s specifications and limited top speed include the vehicle in WLTP Class 2 homologation candidate. Cycle specifications will be used for classification purposes (weight to power max ratio)
- However, cycle results are not useful for real use of the vehicle: WLTP is a benchmark based on flat roads, Citroën Méhari is used on hills and on the sand
- Simulate the vehicle behavior not only on benchmark scenarios but also on real cases: different roads, different slope
- Many attempts to replace ICE in Citroën Méhari with an electric motor, but low power motors installed





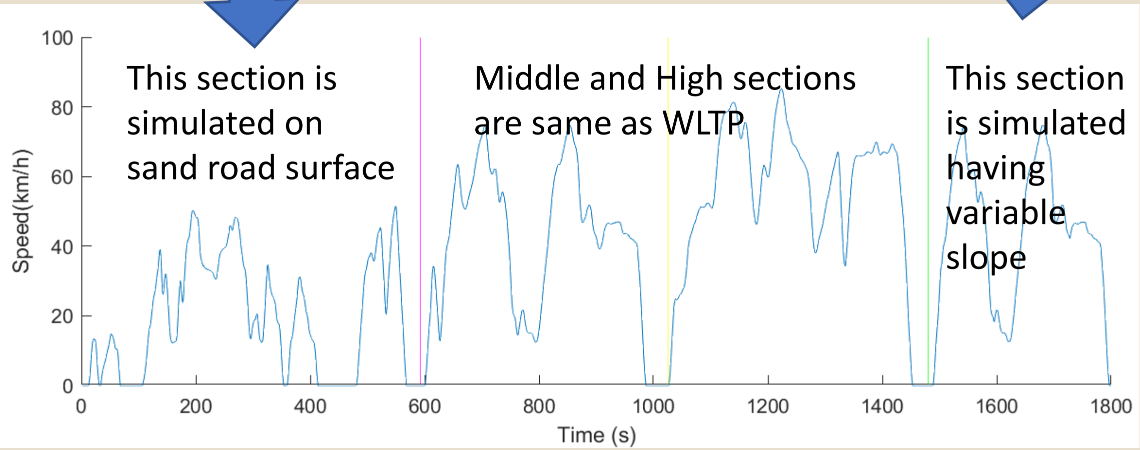
Customized Cycle

Customized cycle is still based on WLTP Class 2, having the following modifications:

- First sector is simulated using road parameters corresponding to a sand road surface
- Second and third sectors are same as WLTP Class 2
- Fourth sector, instead of repeating previous sections, is performing accelerations and decelerations considering slope variations

First sector will be the most stressful benchmark for the vehicle.

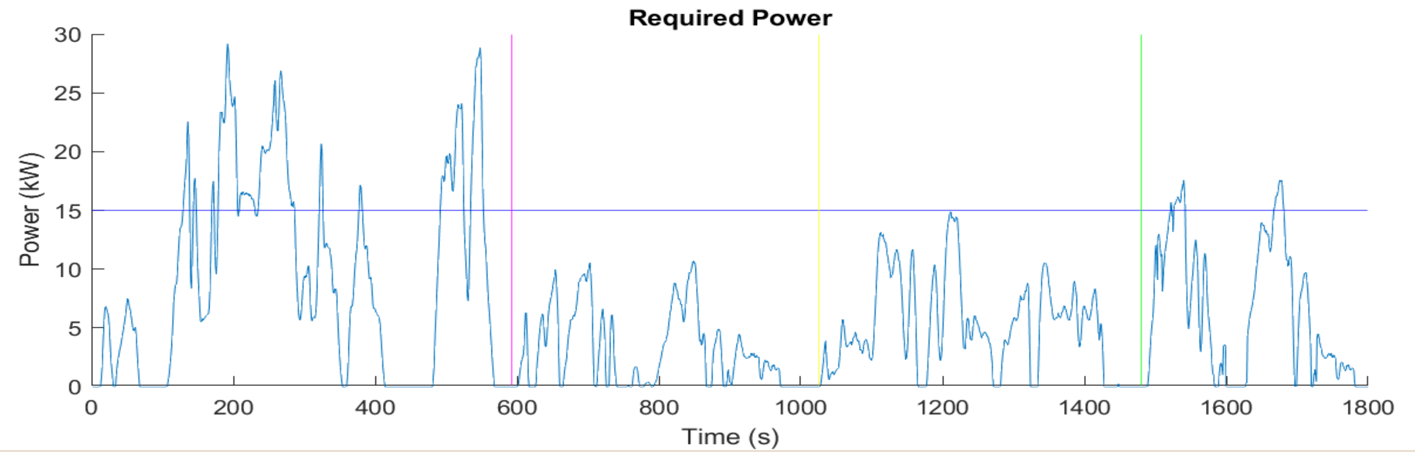
In the given customized cycle, the motor will be forced to reach the maximum power output (for which was sized) and the temperature will reach the limit values for motor and battery.

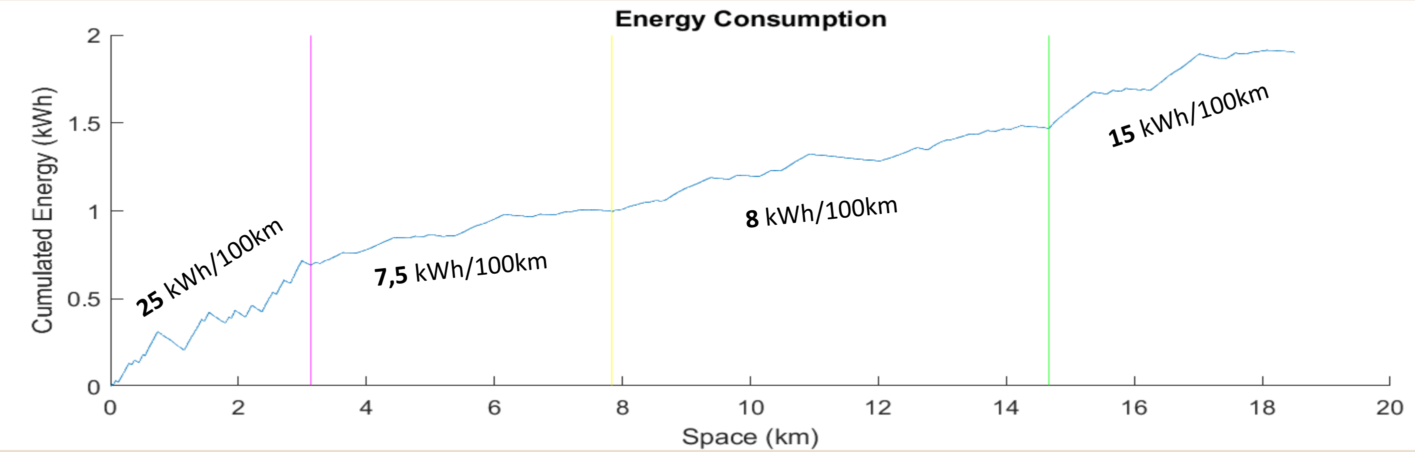


Energetic Requirements

Based on the customized WLTP Class 2 cycle, the following results are considered:

- Maximum power: 29,1 kW
- Average power: 6 kW
- Energy consumption per cycle: 1,9 kWh
- Energy consumption for mission (10 cycles): 19kWh





Motor specifications

Internal Permanent Magnet Motor IPM 200-50, a low voltage motor suitable for light vehicle applications because of its high efficiency, compactness and light weight.

Based on the power requirements, the designed solution consists of a dual motor configuration, one per axle, which allows:

- Better traction in sandy areas with high rolling resistance coefficient
- Improved management of heat dissipation

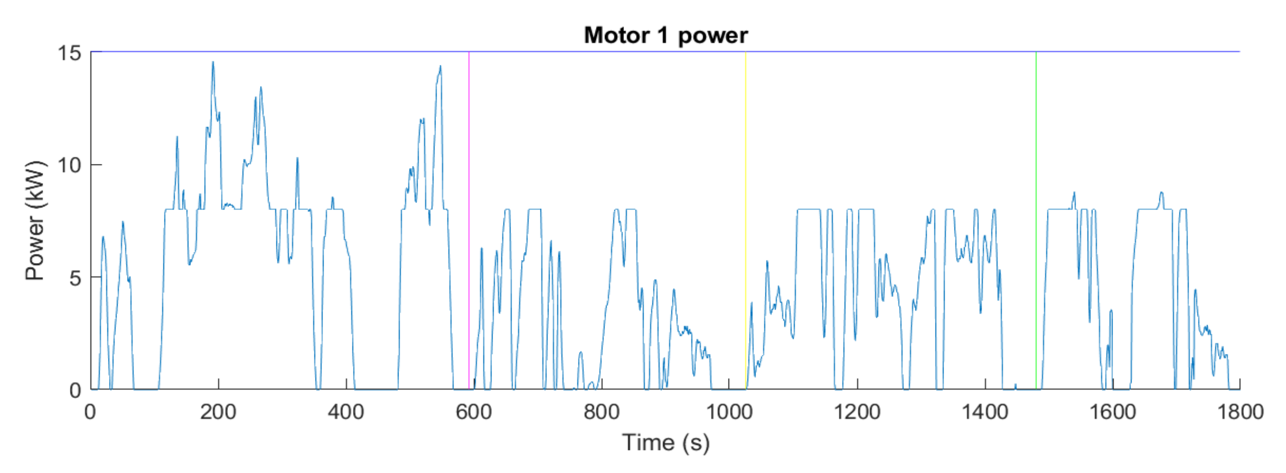
Voltage (V)	48
Peak power (kW)	15
Continuous power (kW)	8
Operating speed (RPM)	0 - 6750
Peak torque (Nm)	69
Weight (kg)	15

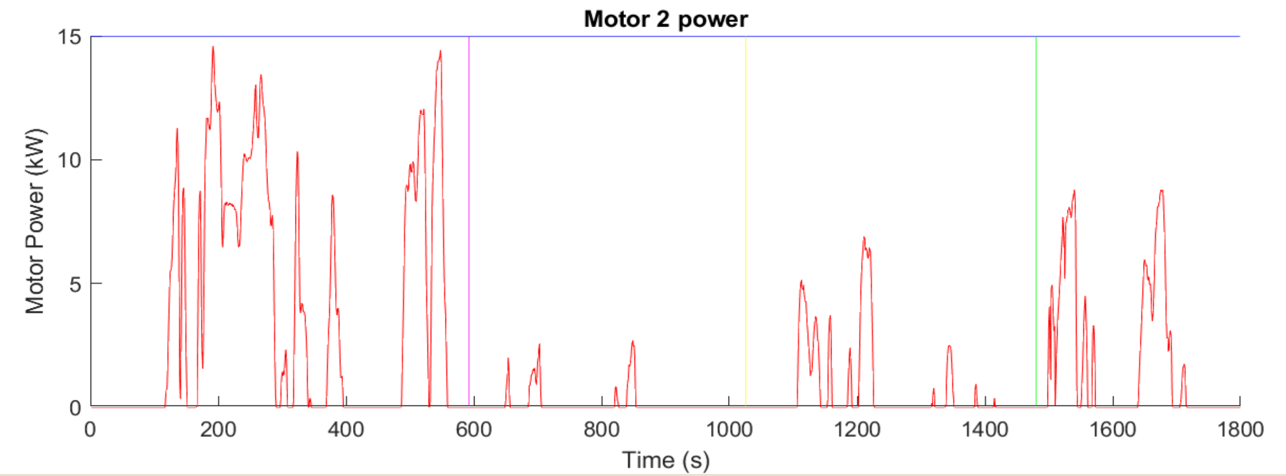
Motors simulation

The distribution of loads on the two motors is managed by a control algorithm, which ensures:

- A higher overall efficiency of the two motors
- A better motors temperature management

The algorithm allows only one motor to be used for low power, and turns on the second motor only when the required power exceeds 8 kW, keeping the first motor at constant power. Once the required power exceeds 16 kW, the algorithm distributes the load equally to both motors.



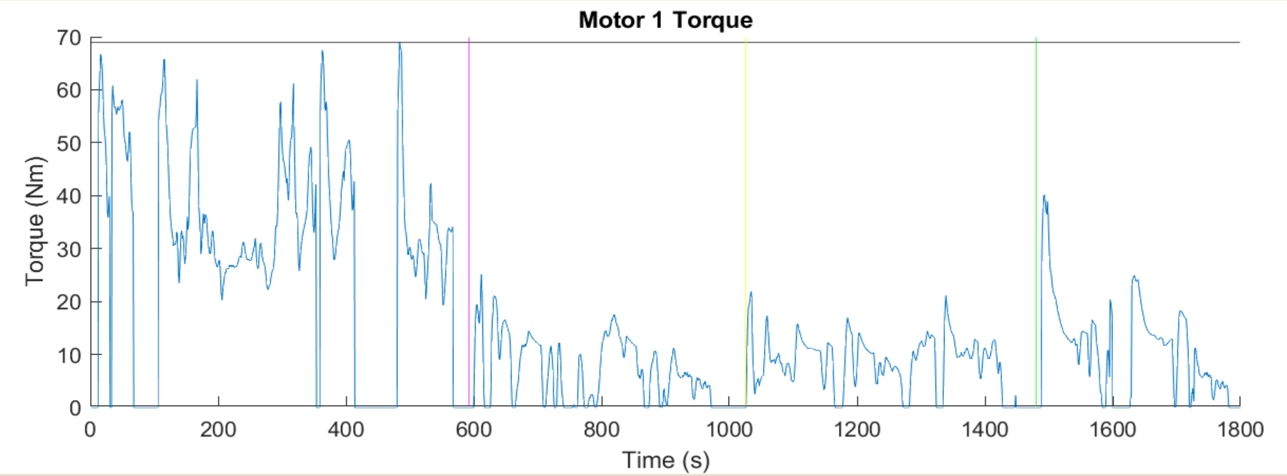


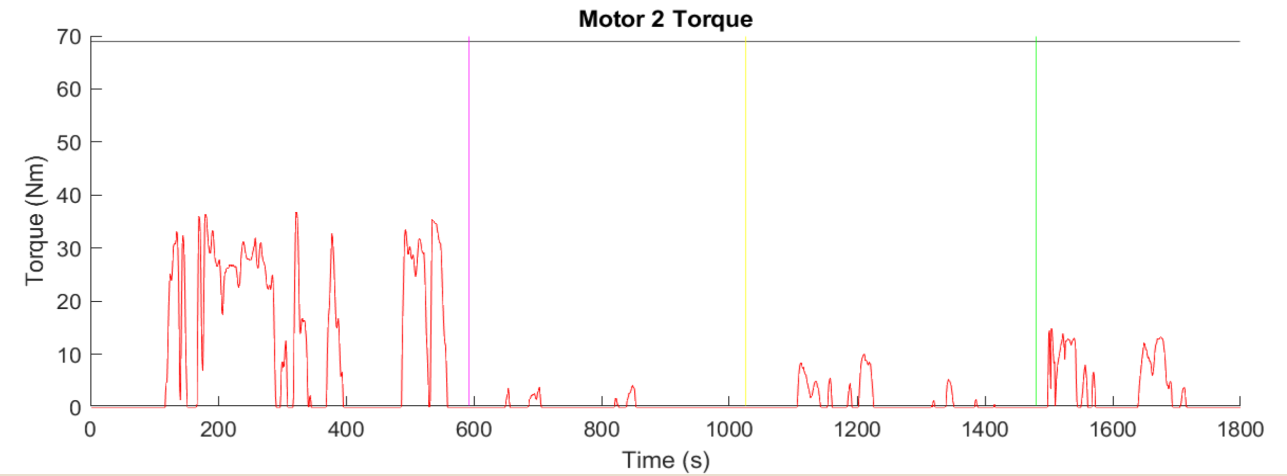
Motors simulation

The distribution of loads on the two motors is managed by a control algorithm, which ensures:

- A higher overall efficiency of the two motors
- A better motors temperature management

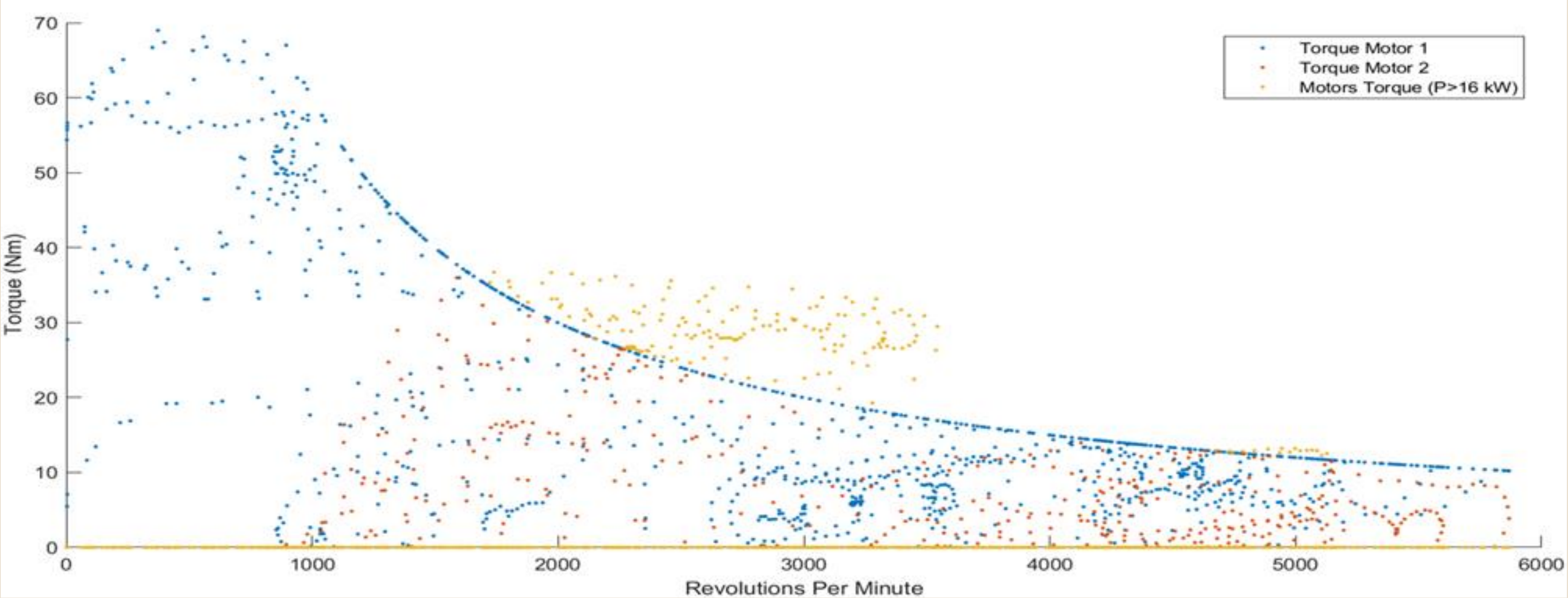
The algorithm allows only one motor to be used for low power, and turns on the second motor only when the required power exceeds 8 kW, keeping the first motor at constant power. Once the required power exceeds 16 kW, the algorithm distributes the load equally to both motors.





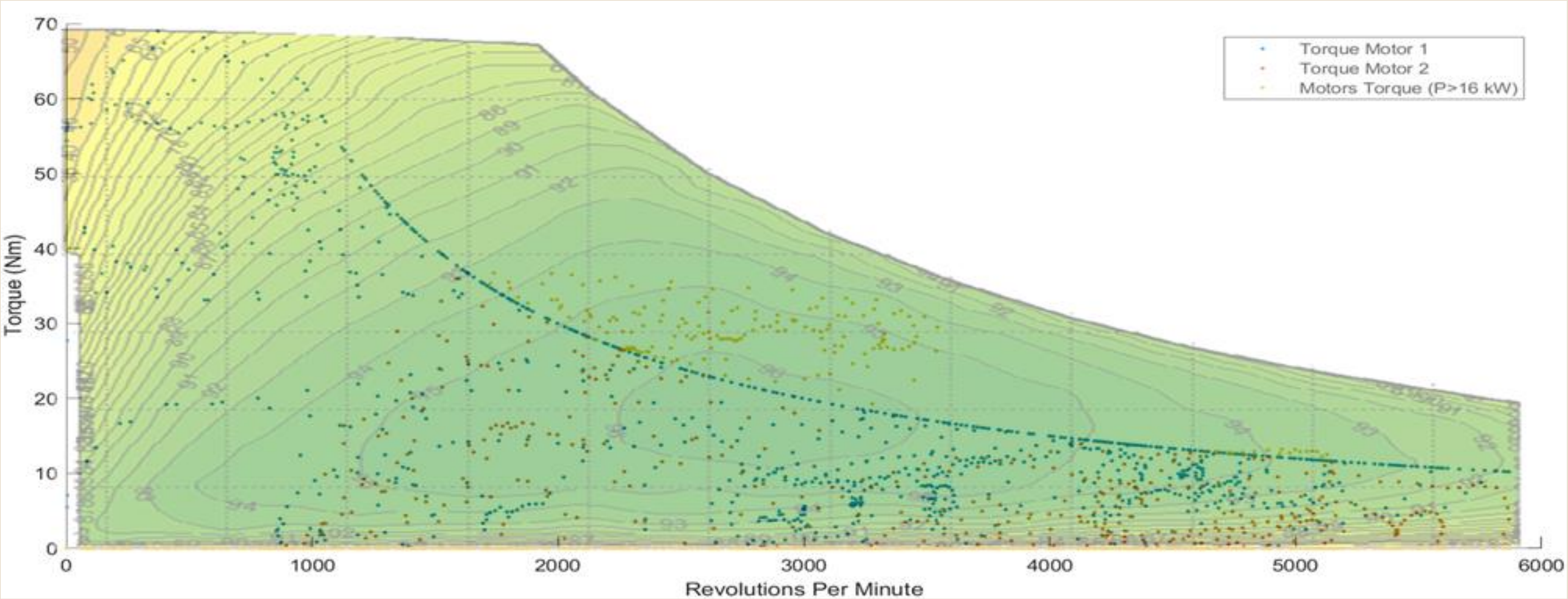
Motors simulation

Motors operating point and efficiency map



Motors simulation

Motors operating point and efficiency map

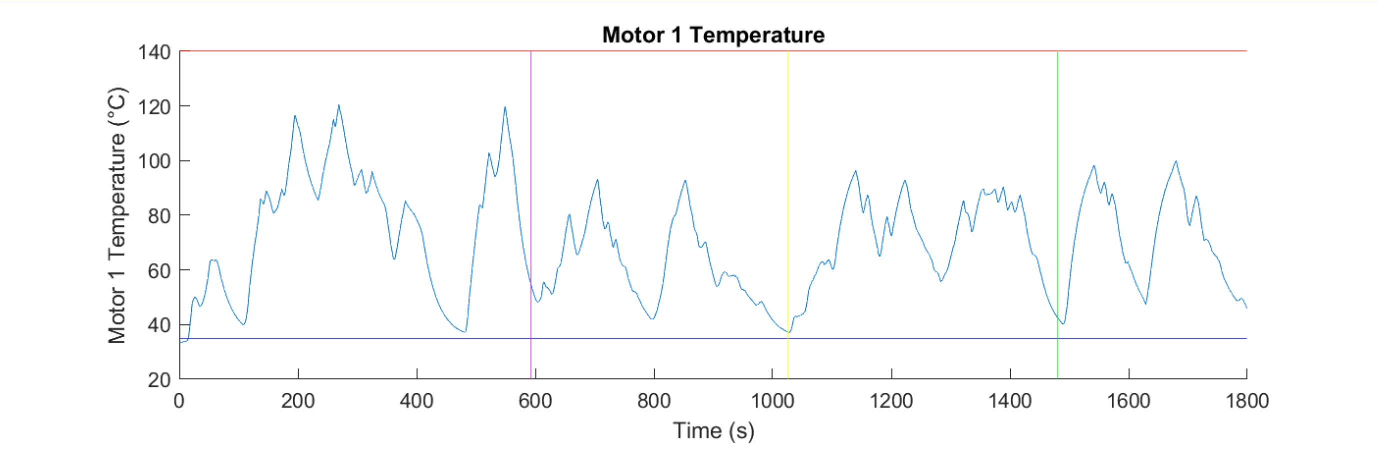


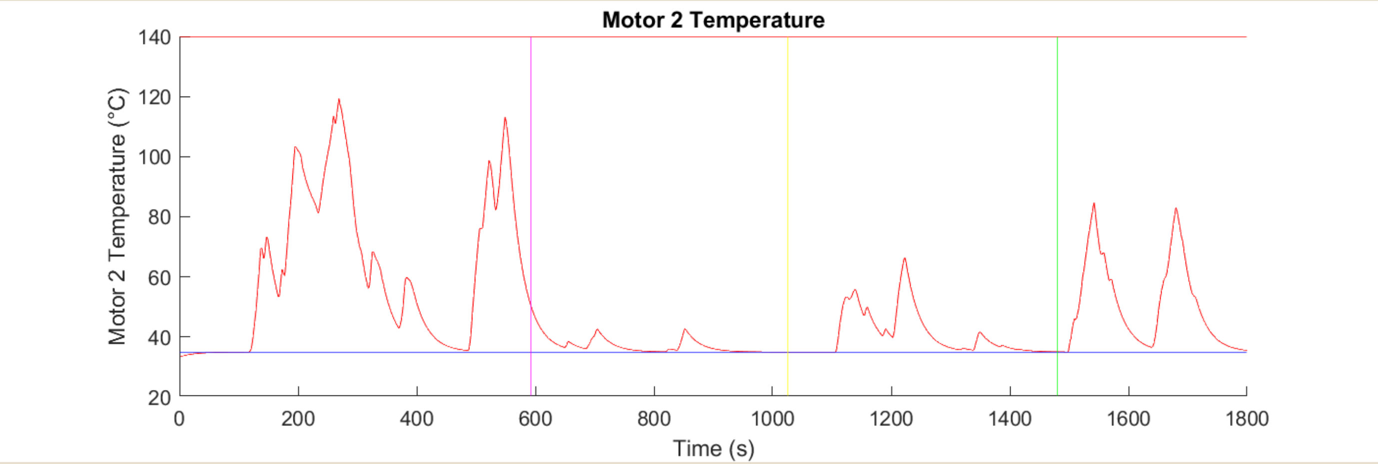
Thermal analysis of motors

The following temperatures were considered for the thermal analysis:

- Enviromental temperature is 35°C.
- Maximum motors temperature is 140°C.
- Maximum chassis temperature is 120°C.

The dual motor configuration and the control algorithm allows a better heat management, since the installation of a single 30 kW motor would have been less effective in heat dissipation and would have reached 165°C.





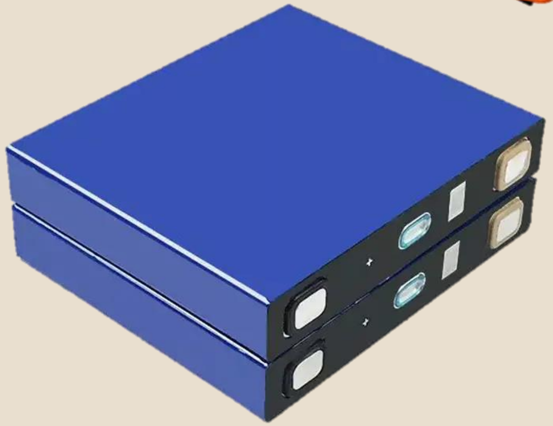
Batteries Comparison

Examining different types of batteries, taking into account specific criteria:

Criteria	$LiFePO_4$ (Lithium Iron Phosphate)	NMC (Lithium Nickel Manganese Cobalt Oxide)	$LiCoO_2$ (Lithium Cobalt Oxide)
Safety	Excellent	Concerns in some formulations	Concerns, more prone to thermal runaway
Cycle Life	Long	Good	Shorter
Energy Density	Lower	Higher	High
Compact Size	Bulkier, Heavier	Compact	Compact
Environmental Impact	Environmentally friendly	Concerns (cobalt content)	Concerns (cobalt content)

Battery

LiFePO$_4$ technology has been chosen among the different alternatives for battery.



- The vehicle will run in difficult roads and safety is an important concern. Also working temperatures are a considered issue
- LiFePO$_4$ are already used in small voltage applications, for example baggage handlers and golf carts
- One of future goal will be trying to suggest a more environmentally friendly alternative
- Voltage related to State of Charge is almost stable during the discharging cycle

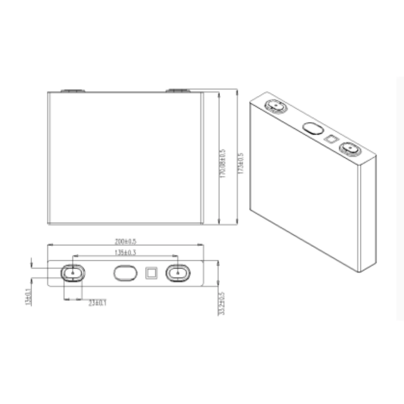
Battery

Lishen 3.2V 125Ah Lithium LiFePO4 Power Battery Cell

- Number of cells: 90 (6p 15s)
- Single cell energy: 0.4 kWh
- Max battery power: 36 kW
- Battery volume: 0.1 m3
- Battery mass: 225 kg
- Battery rated voltage: 48 V
- Battery peak current: 750 A

(fits the vehicle's chassis available space)

Vehicle's charging frequency is assumed as once a day during summertime and negligible using during winter. Assuming 200 recharges a year, vehicle's useful life is shorter than battery's life cycle



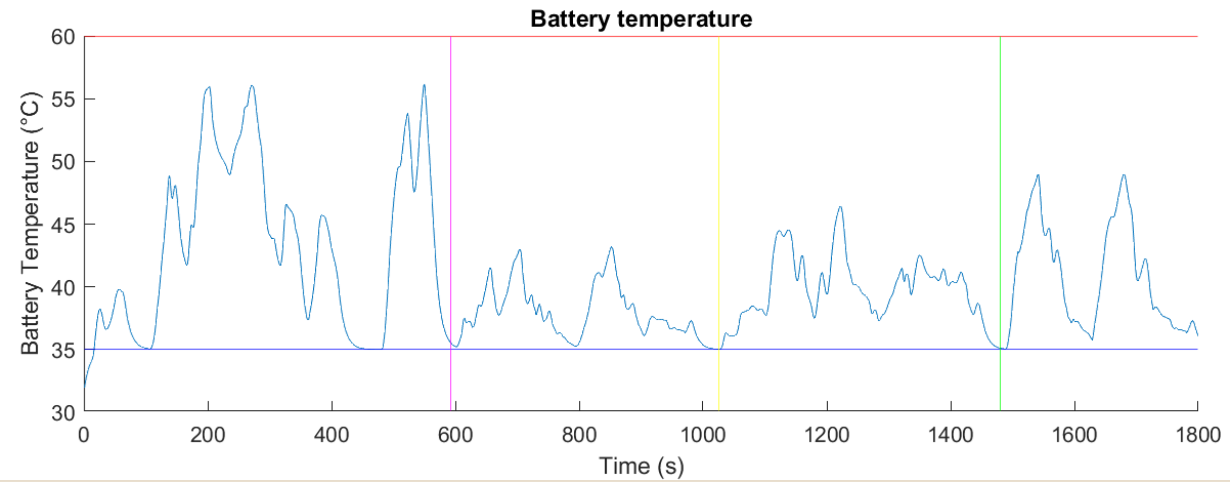
Percentage (SOC)	1 Cell	48V
100% Charging	3.65	58.4
100% Rest	3.40	54.4
90%	3.35	53.6
80%	3.32	53.1
70%	3.30	52.8
60%	3.27	52.3
50%	3.26	52.2
40%	3.25	52.0
30%	3.22	51.5
20%	3.20	51.2
10%	3.00	48.0
0%	2.50	40.0

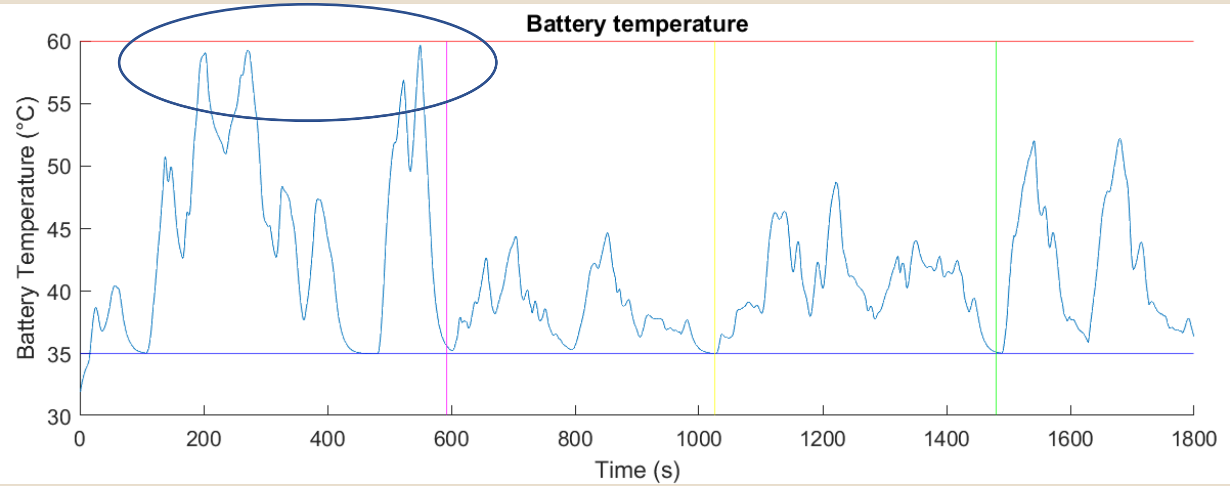
Item	Specification
Cell Type	Lithium-ion power cell
Cell Model	LP33200173-125Ah
Nominal Capacity	125Ah (The NEW BATTERY)
Nominal Voltage	3.2V
AC-impedance(1000Hz)	≤0.5mΩ
Weight	2450±100g
Maximum Charge Current at Room Temperature	1C (Continuous) 2C (60s)
Charging Voltage	3.65V
Maximum Discharge Current at Room Temperature	1C (Continuous) 3C (60s)
Discharge End Voltage	2.5V (＞0℃) 、2.0V(≤0℃)
Max Operating Temperature Range	Charge: 0℃ ~ 60℃
	Discharge: -30℃ ~ 60℃
Optimal Operating Temperature Range	Charge: 15℃ ~ 35℃
	Discharge: 15℃ ~ 35℃
Storage Temperature	1 month: -40℃~ 45℃
	6 months: -20℃ ~ 35°C
Cycle life	3000cycles @80%DOD
Dimension	173*33.2*200mm
Weight	2450±100g

Battery Temperature

Most stressful situations are related to the higher required power peak during the first section.

Customized cycle, run having initial SoC of 95%, reported no significant temperature concerns.
However, having a initial SoC lower than 30% reported a higher temperature increase due to current. The case has been added to control algorithm and power output is limited





Inverter

The current required by the motors has to be in AC, so the inverter has the mission to convert the battery current:

$$I_{phase,rms} = 319\ A \text{ for single motor}$$

$$P_{max,battery} > P_{in,inverter} > P_{in,motor}$$

36 kW   31 kW   30 kW

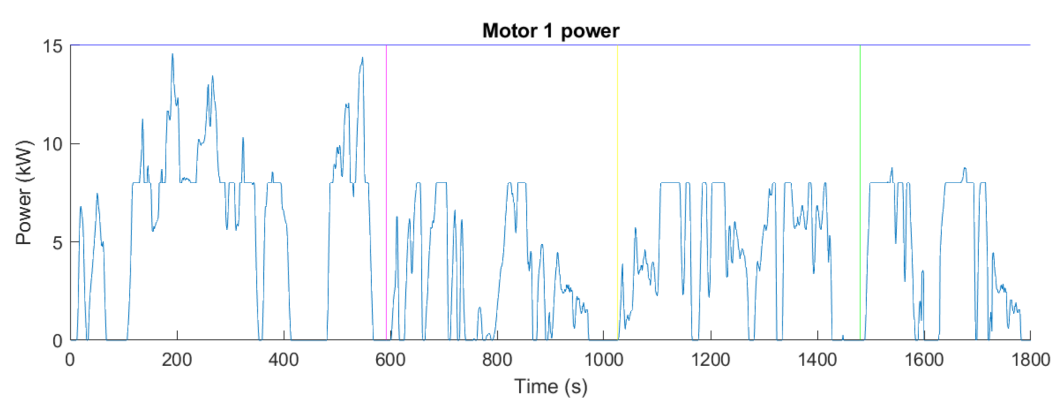
ACE3

- Chosen inverter is ACE3 Power produced by ZAPI
- Chosen inverter can provide a peak current of 650 Arms that is enough for both the motors at the max power and 325 Arms in continuous.

Model	Nominal voltage	Voltage range	2-min current rating [Arms]	S2 60-min current rating [Arms]
ACE3	**36/48V**	10 V ÷ 65 V	600	300
	80V	30 V ÷ 115 V	450	225
ACE3 Power	**24V**	10 V ÷ 35 V	700	350
	36/48V	10 V ÷ 65 V	650	325
	80V	30 V ÷ 115 V	550	275

Control Algorithm

- Control Algorithm is necessary due to energy efficiency and thermal management related issues
- Fuzzy logic algorithm implemented as simple logic vehicle
- Required power output is automatically limited by the algorithm in order to extend battery range
- Changes the load of the motor and switches on the back motor when necessary for both thermal and power reasons (as can be seen from the simulation power output diagram)




```
if Power <= 8 kW
        frontMotor.power = Power;
        rearMotor.power = 0;
        else if Power <= 16 kW
                frontMotor.power = 8;
                rearMotor.power = RequiredPower-8;
                else
                        frontMotor.power = Power /2;
                        rearMotor.power = Power /2;
```

Control Algorithm

- Different driving modes are available for the vehicle, but the Control Algorithm overrides manual configuration if necessary
- Specifications on the State Of Charge of the battery, on the reference power output and on the temperature of the single motors. Also maximum power of the single motors is limited in order to avoid inverter peaks

subject to following bonds

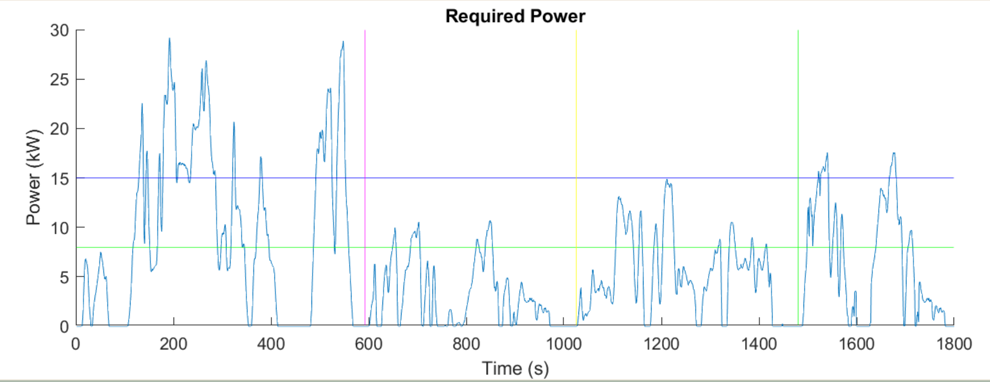
0 < motor Power < 15 kW (maximum power)

5 < StateOfCharge < 100 (maximum discharge tested)

```
if battery.StateOfCharge <= 30% then drivingMode = 3;
if battery.Temperature > 55 then drivingMode = 3

if drivingMode = 1 (off-road)
        frontMotor.power = RequiredPower/2;
        rearMotor.power = RequiredPower/2;

Override rule for emergency, i.e. front engine is reporting failure
if frontMotor.failure = true
        drivingMode = 2 (emergency)
        rearMotor.power = RequiredPower;
        frontMotor.status = off;
Override rule for efficiency
if drivingMode = 3 (efficiency)
        frontMotor.power = RequiredPower;
```



Citroën Méhari
an old-fashioned recreative vehicle

BHMG
BEACH HYBRID MOTOR GROUP

Hybrid and Electric Vehicle – A.Y. 2023/2024

Group 9

Jacopo Brazzoduro 225165

Enkeled Hoxha 226443

Giovanni Reposo 103104