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ISEECap2013 – Taormina, June 3-7, 2013

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EVALUATION OF PERFORMANCES OF HYBRID ELECTRIC ENERGY STORAGE SYSTEM (LI-ION BATTERIES/ SUPERCAPACITORS): EV AND HEV APPLICATIONS

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OUTLINE

- Introduction
- Electric vehicle
- Electric energy storage systems
- Hybrid energy storage systems
- Modeling and simulation
- Applications
- Conclusion and perspectives

INTRODUCTION

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- ELECTRIC AND HYBRID ELECTRIC VEHICLES
  - Alternative solutions to reduce the air-pollution, noise and fossil fuel dependence of the transportation sector
  - **Limitations**
    - Energy storage systems must have a sufficient power, energy density and autonomy.
    - Batteries' life time and capacity are limited by the number and the magnitude of current peaks
    - The efficiency depends on the discharge current regime.
    - Cost
  - **Foreseen solution**
    - Peak power units (e.g. supercapacitors, flywheels...)
    - The hybridization of the energy storage systems (Battery&EDLC) allows increasing the life-time of the main energy source in case of a battery-electric vehicle
- The aim of this study is to evaluate the performances of a hybrid energy storage system (Li-ion batteries and EDLC) in the case of an EV.

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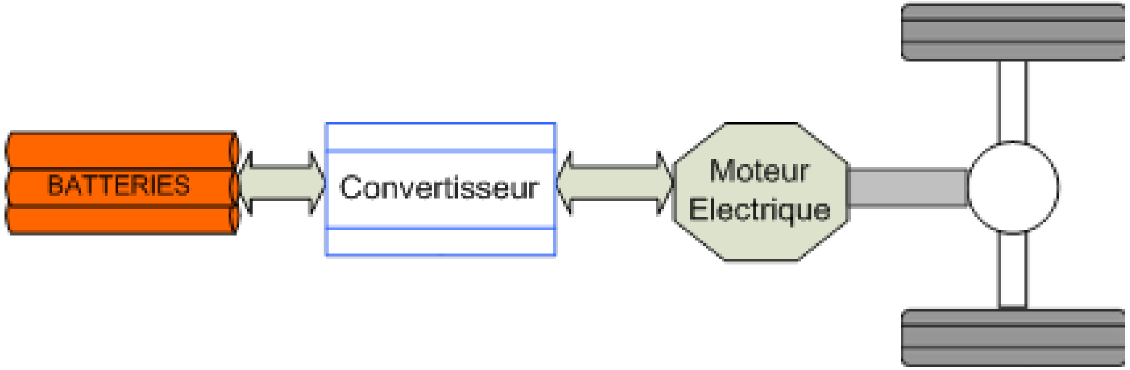
- PRINCIPLE:
  - Electric storage system (i.e. batteries)
  - Electronic unit
  - Electric motor
  - Transmission to wheels



- BATTERIES
  - Improved chemical energy storage
  - High energy density : ~100 Wh/kg
  - Low Power density : ~1 kW/kg
  - Good efficiency (less than 70% to 98%)
  - Limited life cycle : < 5000 cycles
  - Small temperature range : bad efficiency and battery components damages for negative temperatures
  - Recycling not improved

- SUPERCAPACITORS
  - Increasing electric storage interest
  - Low energy density: ~10 Wh/kg
  - Higher power density : ~10 kW/kg
  - High efficiency (95% to 100%)
  - Long life cycle : > 100.000 cycles
  - High temperature range : -45 to 60°C
  - Less pollutant than batteries : easiest to recycle

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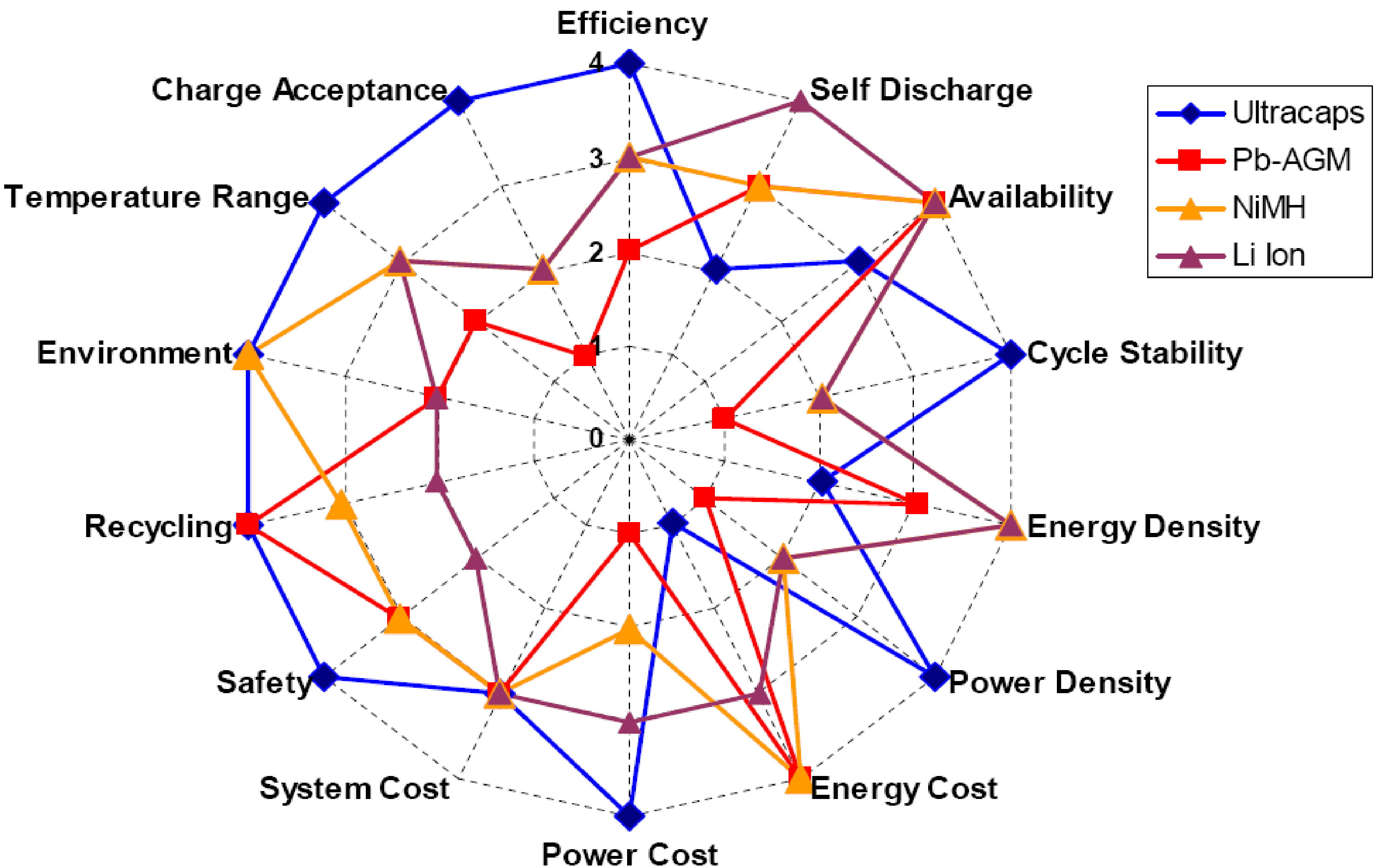
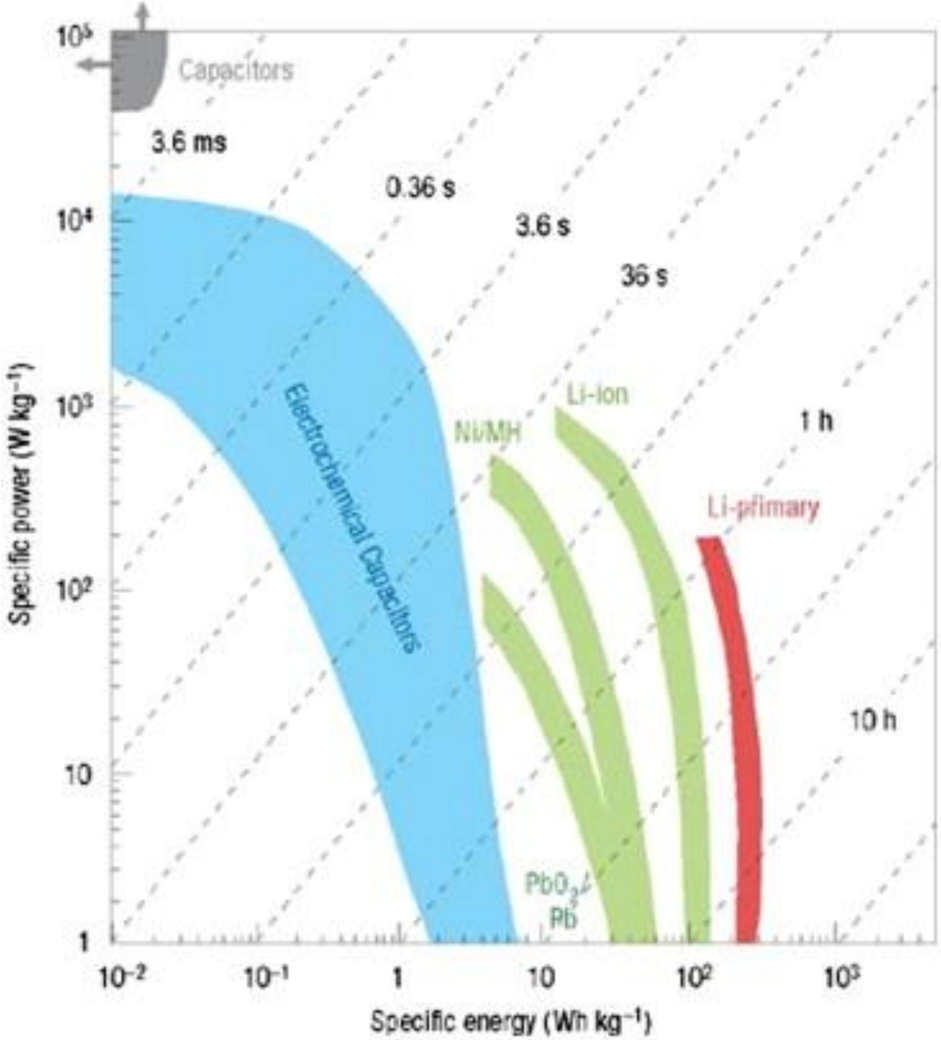
■ COMPARISON BETWEEN BATTERIES AND SUPERCAPACITORS



- COMPARISON BETWEEN BATTERIES AND SUPERCAPACITORS



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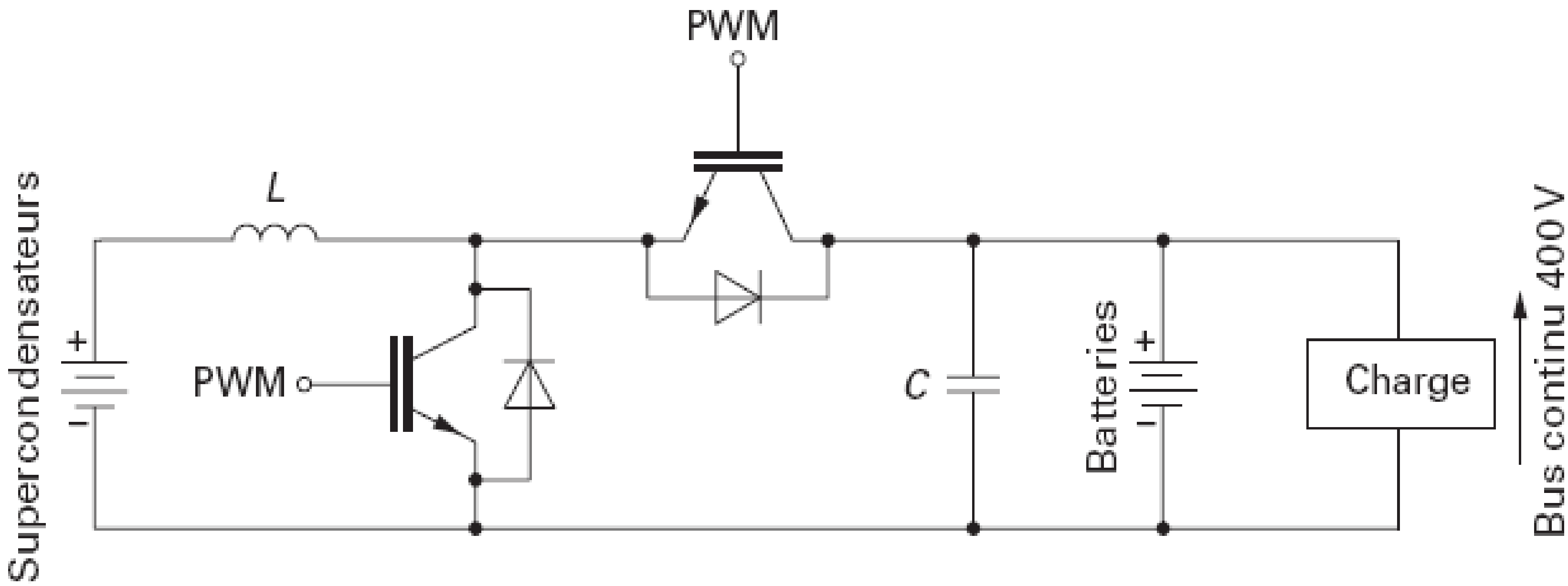
PRINCIPLE

Parallel combination of battery pack directly connected on a power bus (nearly constant voltage) and supercapacitors module linked with a DC/DC converter



- ADVANTAGES
  - Energy < batteries (autonomy)
  - Power < supercapacitors (accelerations)
  - If extra power needed then the 2 systems (battery and scaps) are summed up

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POWER MODEL

- Vehicle dynamic :

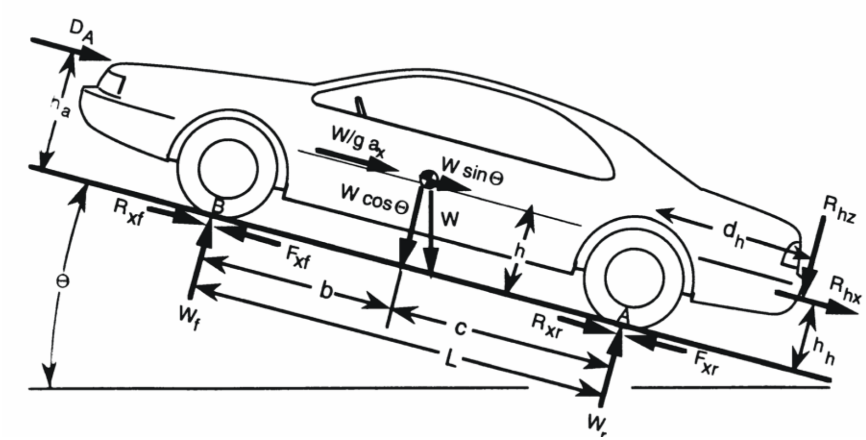
$m_v a_x = F_t - m_v g \sin\theta - F_r - F_a$

F_t : traction force

$m_v g \sin\theta$: grade force

$F_r = c_r(v, p, \ldots) \cdot m_v \cdot g \cdot \cos(\alpha)$: rolling force

$F_a = \frac{1}{2} \rho_a \cdot A_f \cdot c_x(v, \ldots) \cdot v_r^2$: aerodynamic force



- Total power :

$P = P_t - P_R = W / \Delta t = F \, dx/dt = F \cdot V$

- Current :

$P = U \cdot I$

- EFFICIENCY :
  - 90% from energy storage to wheel
  - Batteries : strongly variable (depends on current density and variability, temperature…), 70% to 98% (discrete steps decreasing with current growing)
  - SC : mainly constant and high, 98%
- DRIVING CYCLES : ARTEMIS CYCLES
  - Artemis (Assessment and Reliability of Transport Emission Models in Inventory Systems)
  - Realistic cycles
  - 3 cycle types :
    - urban cycle (distance = 4,870 km)
    - road cycle (distance = 17,272 km)
    - motorway cycle (distance = 29,545 km)

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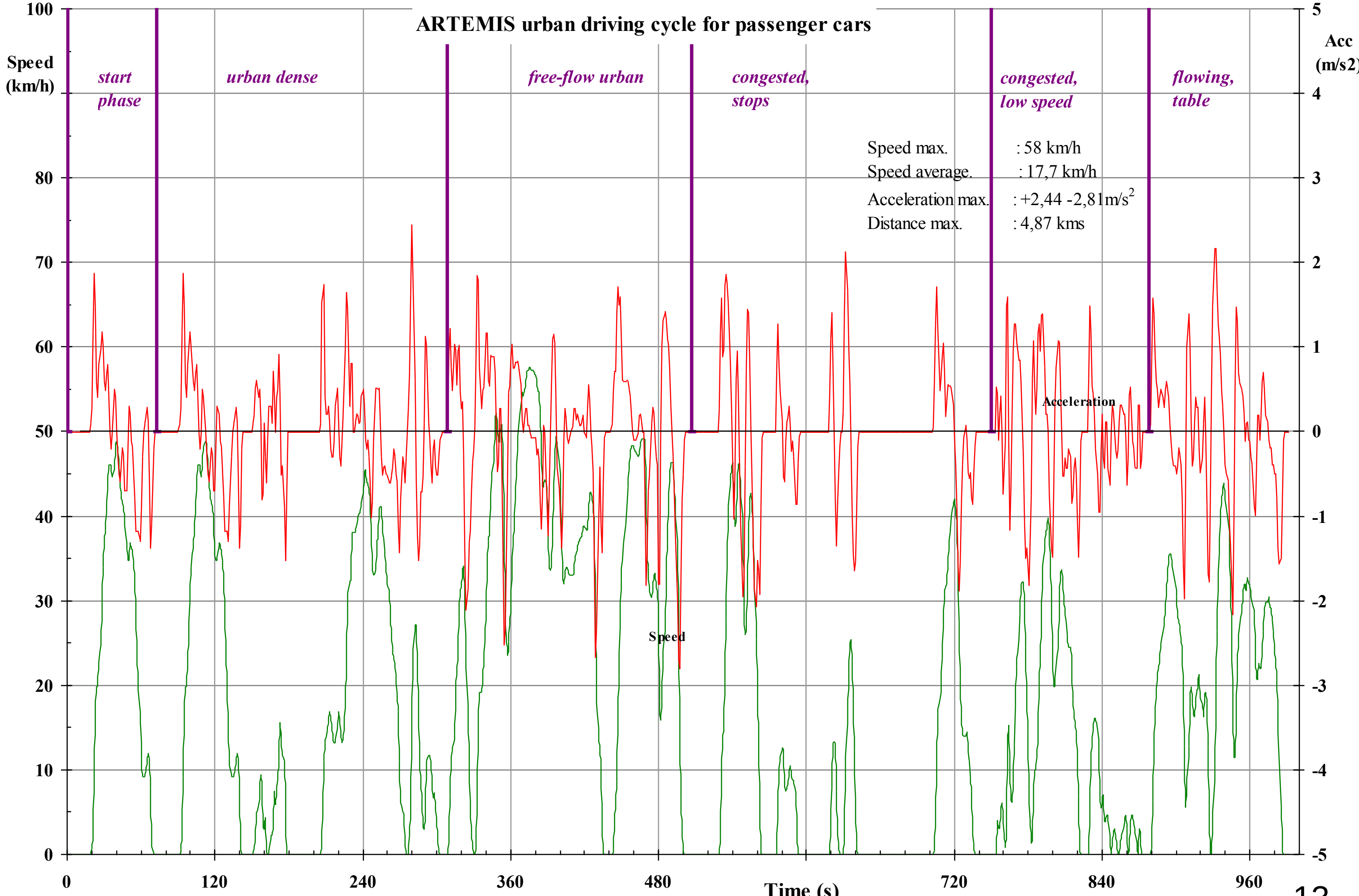
DRIVING CYCLES : ARTEMIS CYCLES



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- VW GOLF VI 100kW :
  - Mass : m ~1500 kg
  - Drag coefficient : C_x ~ 0,31
  - Front surface : A_f ~ 2,6 m²
  - Coefficient of rolling resistance : c_r ~ 0,012
  - Power ICE : P = 100 kW
  - Maximum engine performance : η = 0,35
  - Motorisation mass : ~ 250 kg

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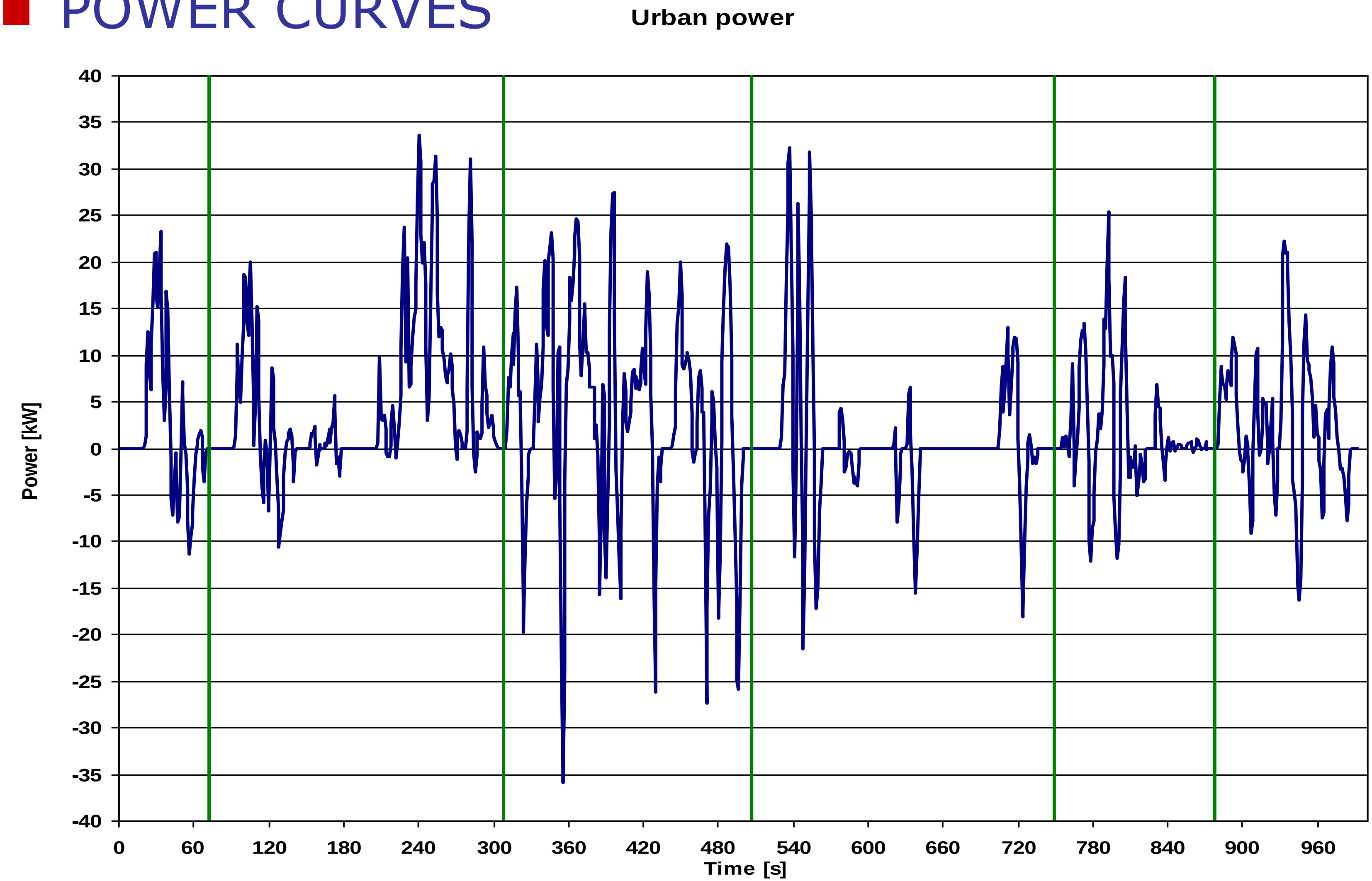
POWER CURVES



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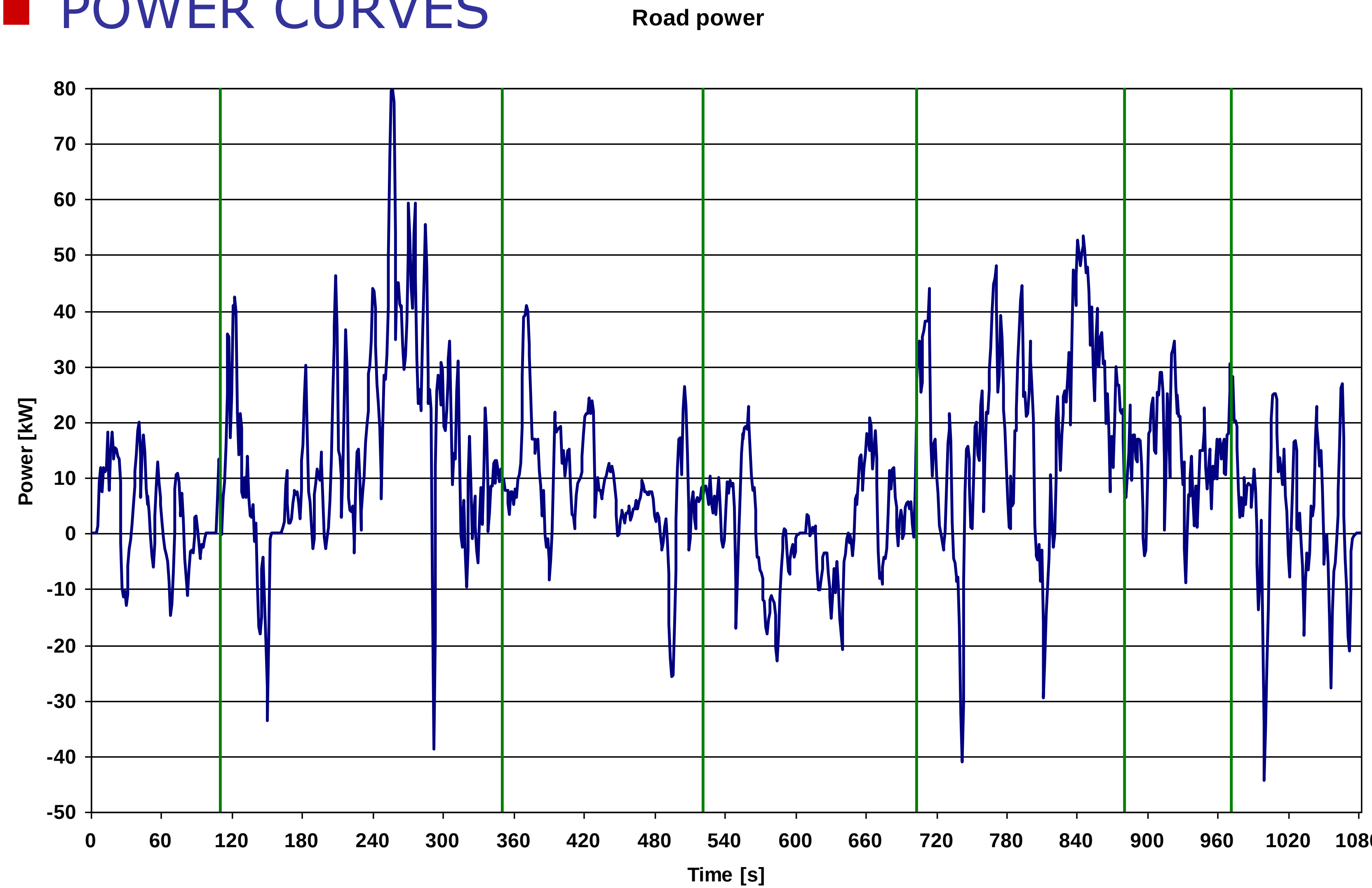
■ POWER CURVES



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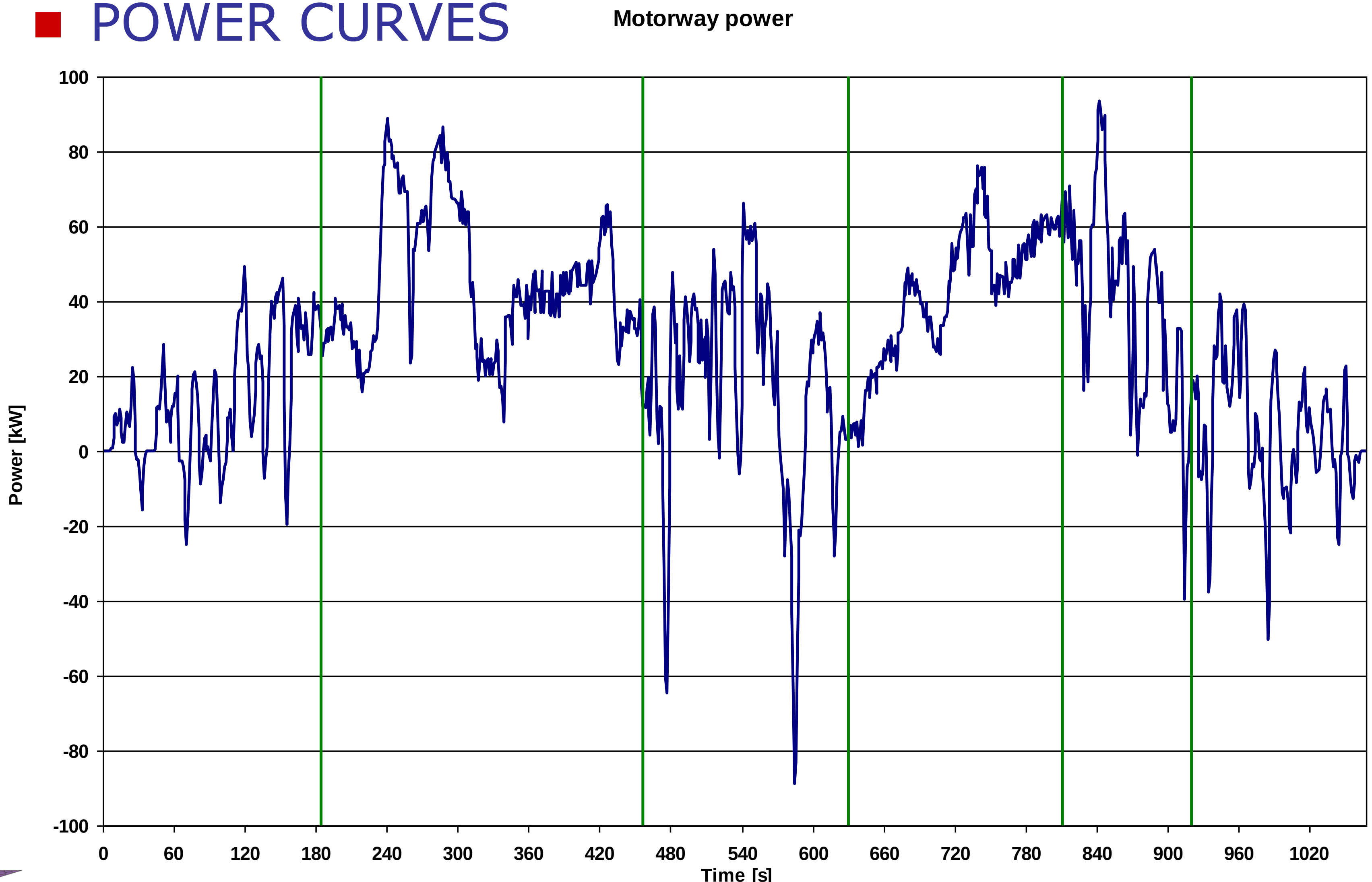
■ POWER CURVES



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ENERGY CAPACITY NEEDED

- Choice of 400V bus voltage
- Initially only from batteries
- Combination of twice the 3 cycles : ~ 103 km
  - ➔ energy needed : 60,84 Ah
- Li-ion battery : not under 80% DoD
  - ➔ final energy : 76,05 Ah

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- BATTERY
  - Dow Kokam Xalt HE 75 (Li-Po)
    - Mass : 1,53 kg
    - V_{nom} : 3,7 V
    - Capacity : 75 Ah
    - Spec. Power : 0,54 kW/kg
    - Spec. Energy : 180 Wh/kg
    - Impedance : 0,5 mΩ
  - Battery pack :
    - Cells’ number : 108 (~400V)
    - Mass : ~ 165 kg
    - Volume : ~ 86 dm³

- BATTERY EFFICIENCY
  - Constant current discharge

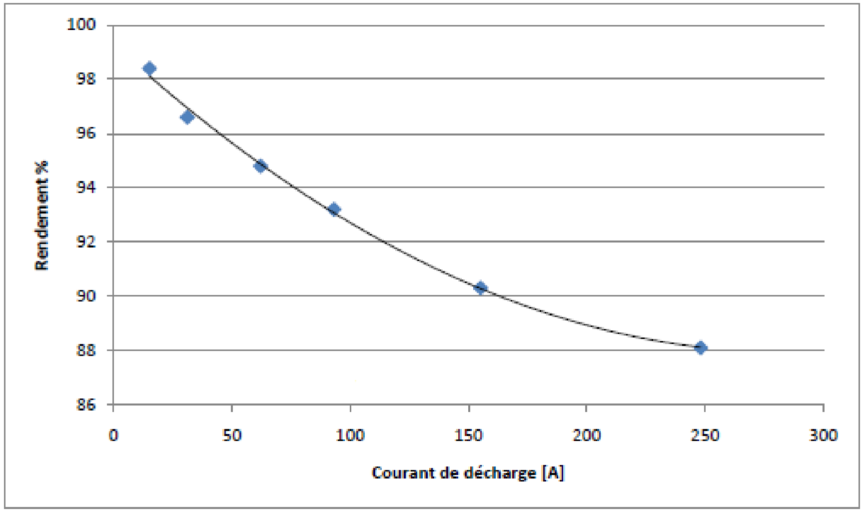

Figure 16 : Evolution du rendement de la batterie en fonction du courant de décharge

  - Variable current discharge

Profile	ADC (A)	BAC (A h)
FUDS	13.08	15.96
FHDS	13.11	25.05
ECE	13.21	13.05
JM10.15	13.12	15.43

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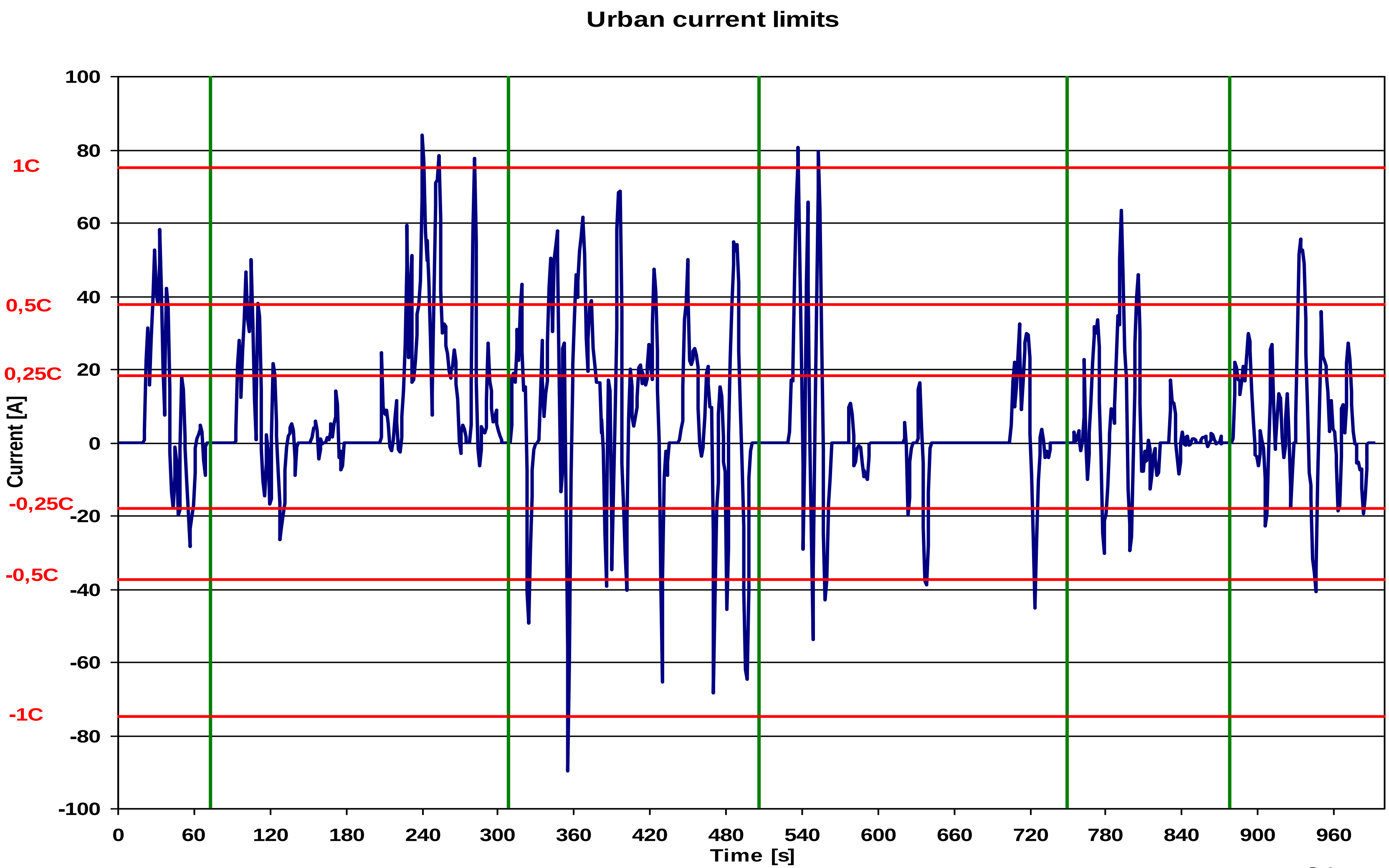
- ## CURRENT CURVES



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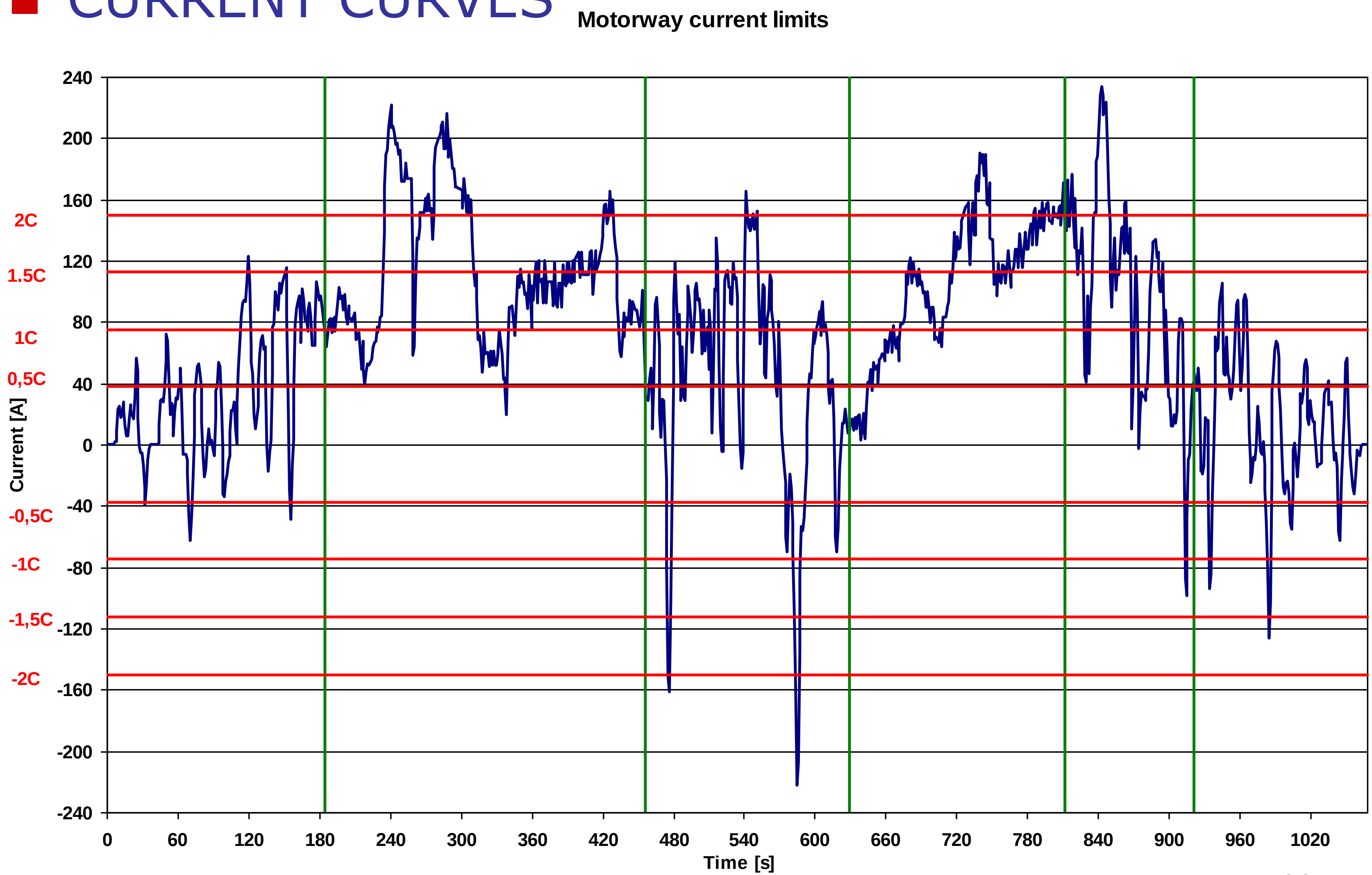
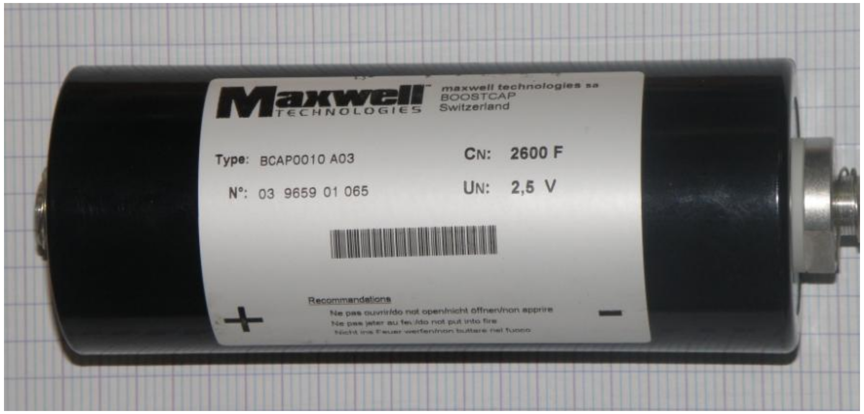
CURRENT CURVES

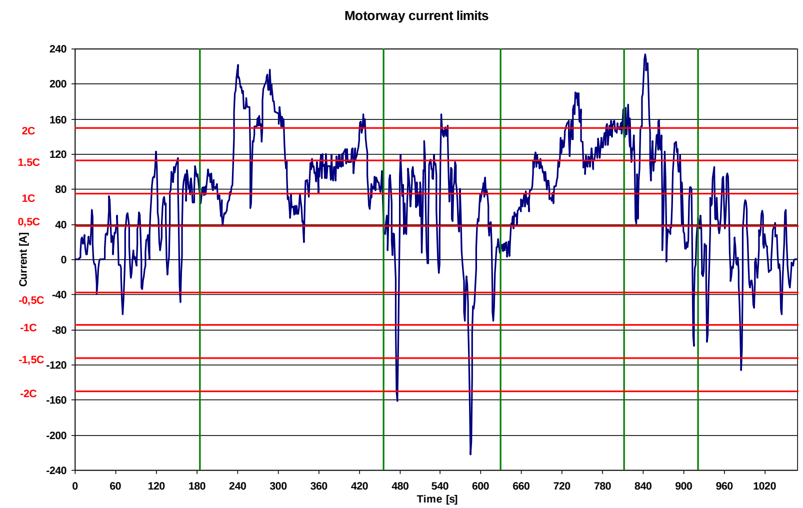


- SUPERCAPACITOR
  - Limits peaks current on batteries
  - Supercapacitor Maxwell BCAP 2600
    - C_N : 2600 F
    - U_N : 2,5 V
    - Mass : 0,52 kg
    - R_{int} : 0,25 mΩ
    - Spec. energy : ~ 4,34 Wh/kg
    - Spec. power : ~ 15 kW/kg



SUPERCAPACITOR MODULE

- Cells' number : optimization between available supercapacitor's energy and additional mass
  ➔ energy depends on driving situation (urban, road or motorway)
  ➔ hardest in discharging is motorway
- SC pack :
  - Cells' number : 160 (in series, 400V max)
  - Mass : 83 kg
  - Volume : 72,38 dm³
  - Energy (U_{nom} – U/2) : 270 Wh ~ 1,13 Ah



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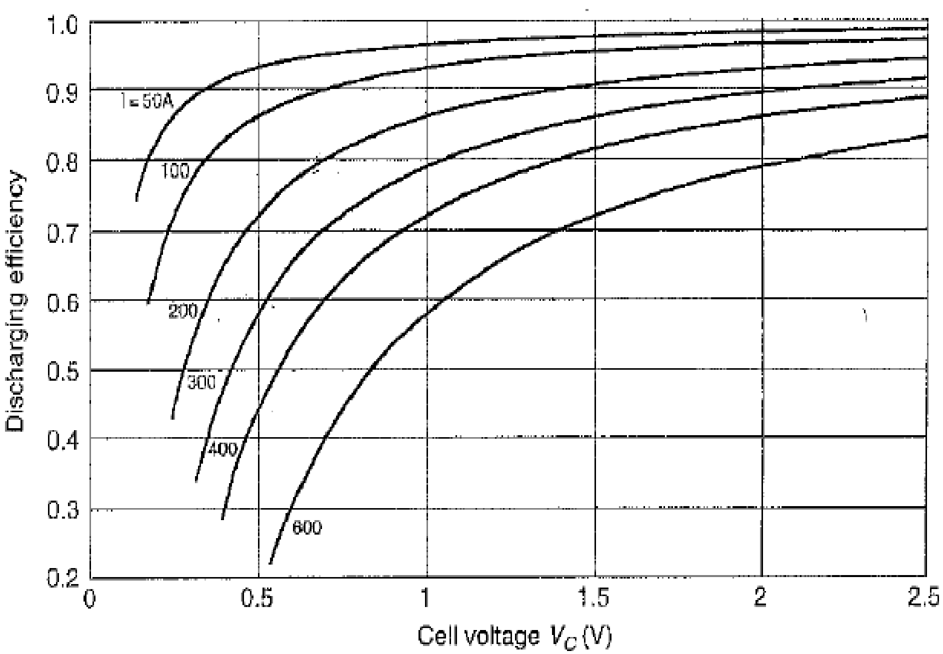
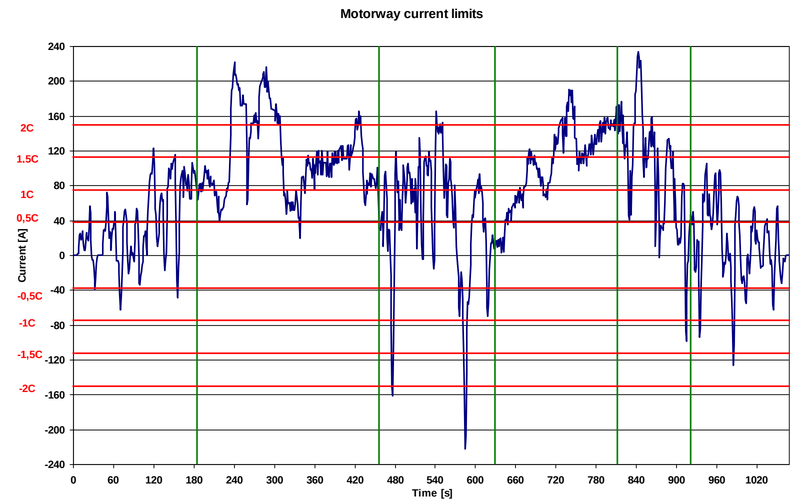
- SUPERCAPACITOR MODULE
  - Efficiency





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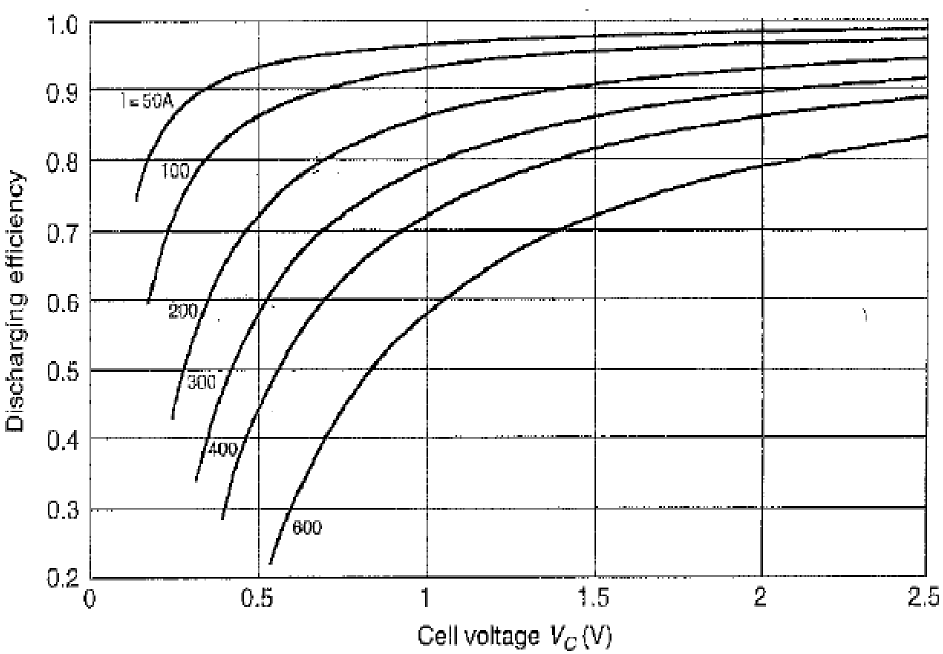
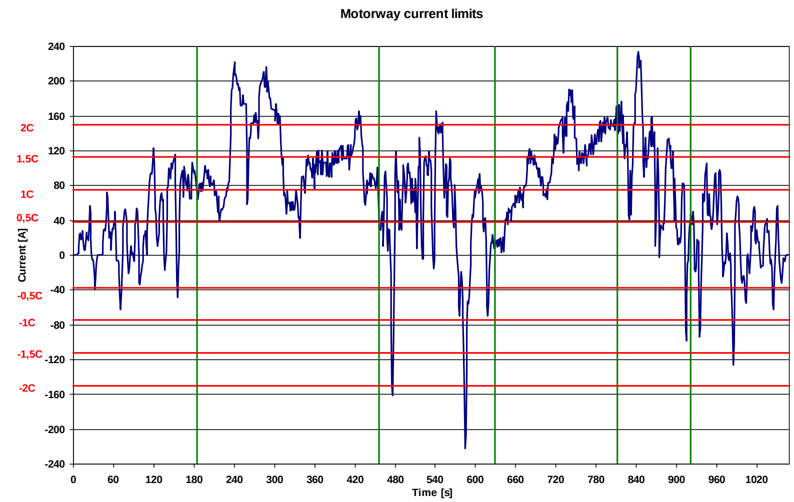
■ SUPERCAPACITOR MODULE

■ Efficiency





- Problem : urban cycle never goes above 1,5C
  ➔ supercapacitors not used in urban cycle!

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- SUPERCAPACITOR MODULE
  - Solutions :
    - selector mode (with bypass : motorway by default and speed over 60 km/h)
    - GPS data (automatic)
  - Different defined limits :
    - Urban : 0C – 0.25C
    - Road : 0C – 1C
    - Motorway : 0C – 2C
    - ➔ breaking only SC!

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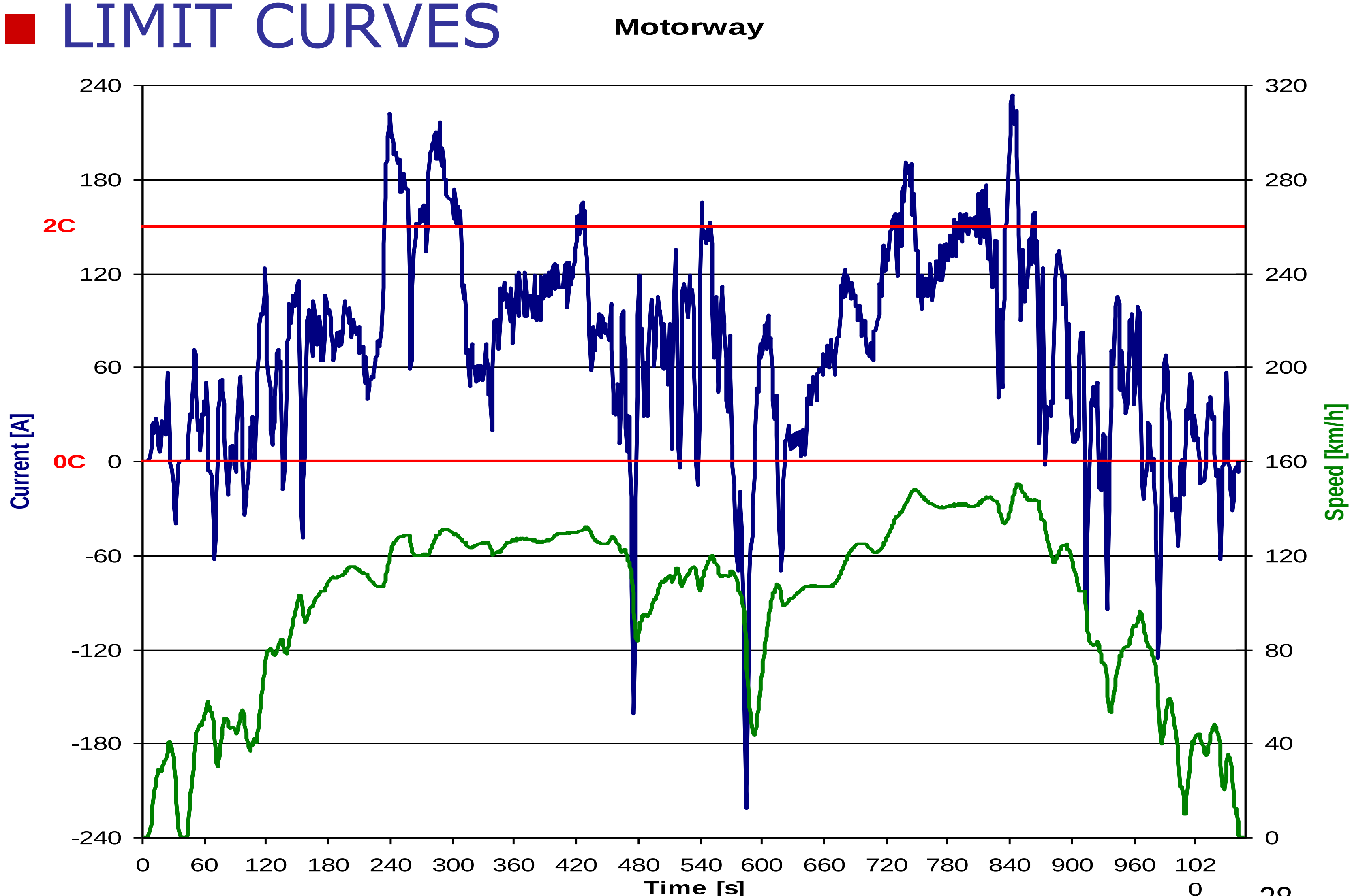
■ LIMIT CURVES



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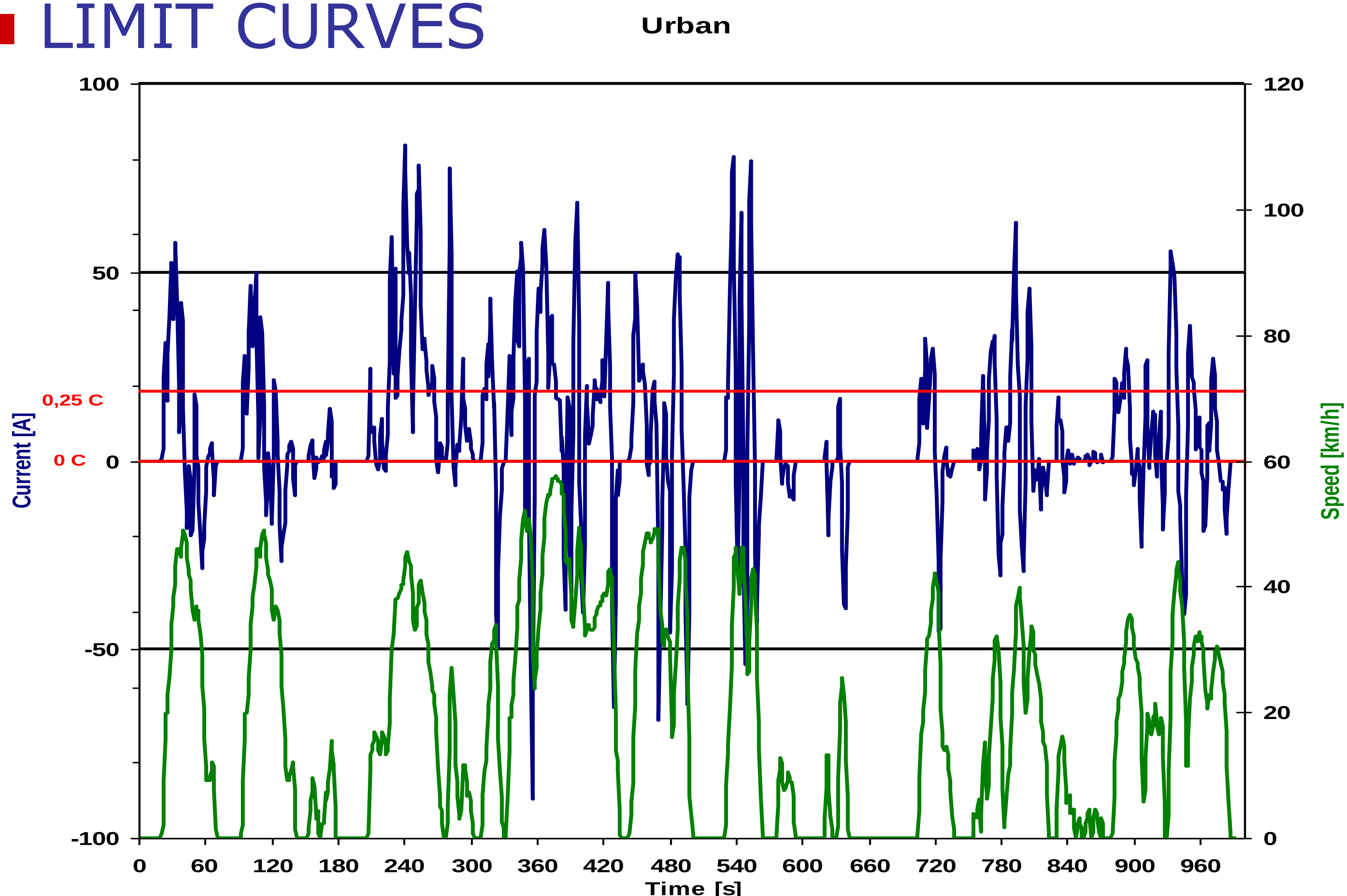
LIMIT CURVES



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- RESULTS
  - Motorway/road cycles : no significant direct gain (3,5 to 5% respectively @ 1C and 2C) but batteries less damaged (limited peaks of current)
  - Urban :
    - Direct energy gain : 17% @ 0.25C
      - ➔ More autonomy
    - Current in batteries nearly constant
      - ➔ Aging limited

LTAS

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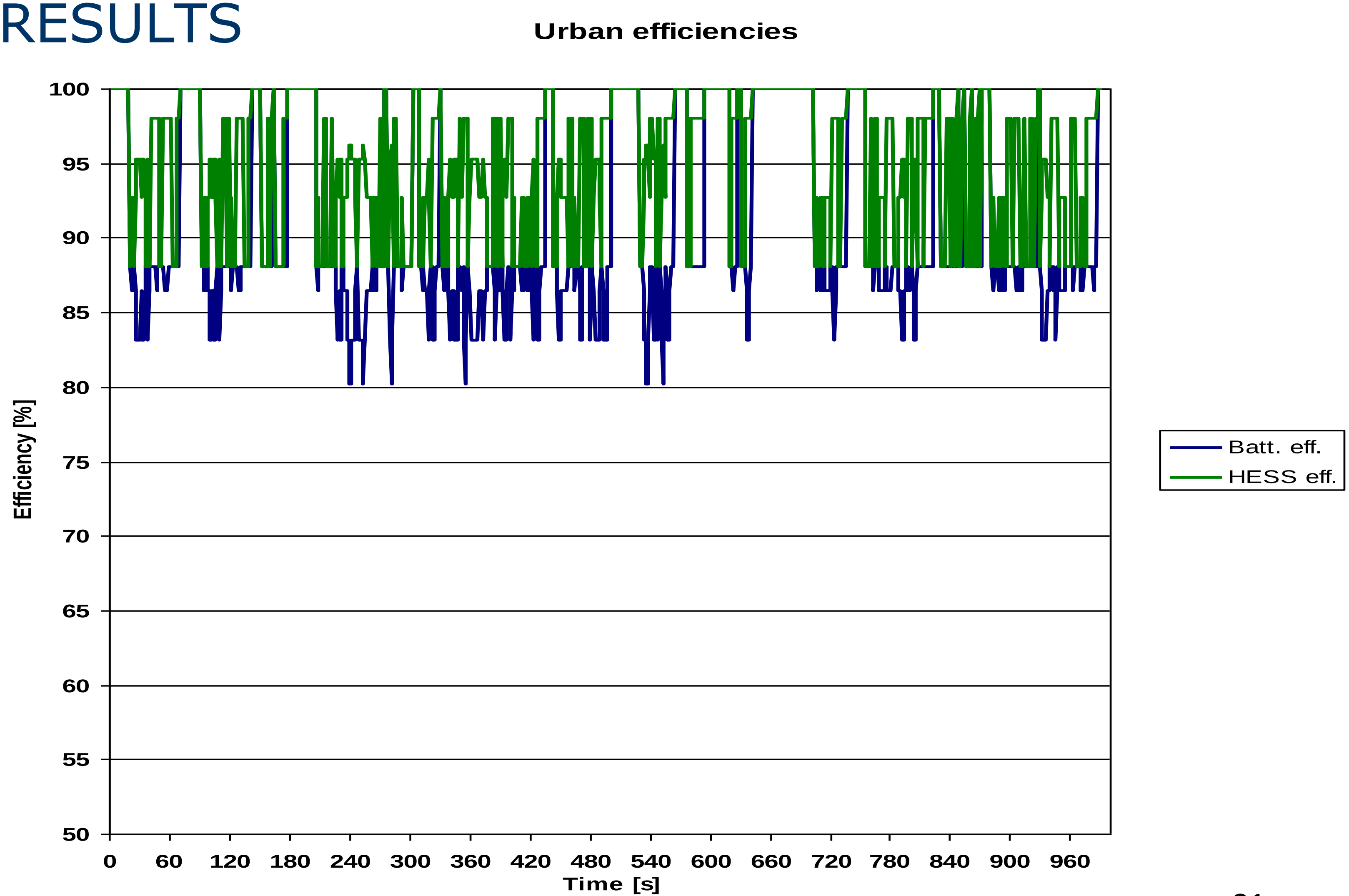
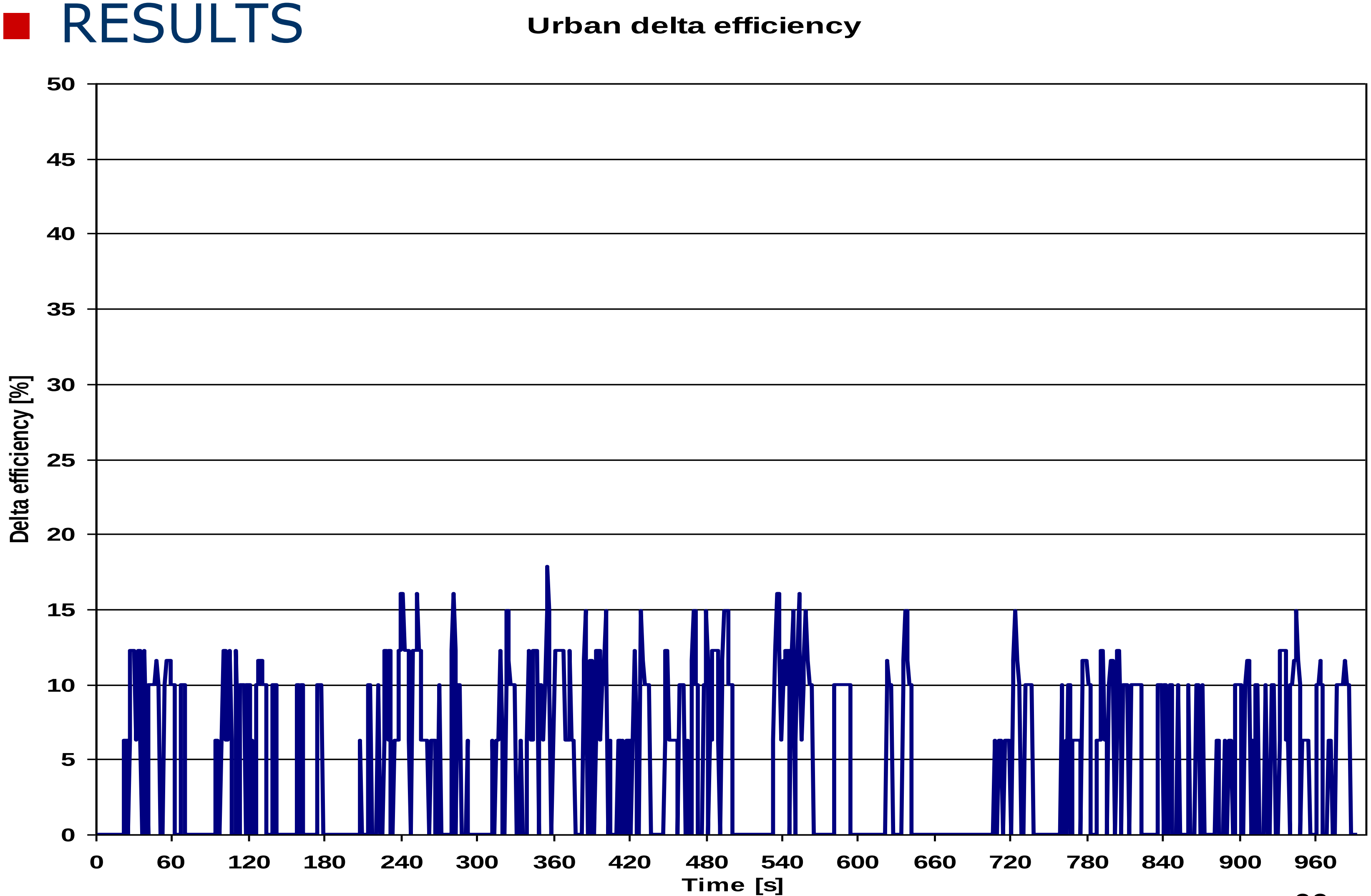
■ RESULTS



RESULTS


Urban delta efficiency
Delta efficiency [%]
50
45
40
35
30
25
20
15
10
5
0
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
960
Time [s]

CONCLUSIONS

- Autonomy improvement mainly in urban situation
- Battery aging limited
- Additionnal cost with supercapacitors but HESS is profitable considering all lifecycle
- HEV : HESS suitable but downsizing limits gain
- Challenge : real battery efficiency in dynamic conditions difficult to measure and to predict

Thank you for your attention !