# Panel 4 – Energy Saving On Board

# On Board Efficient Energy Management

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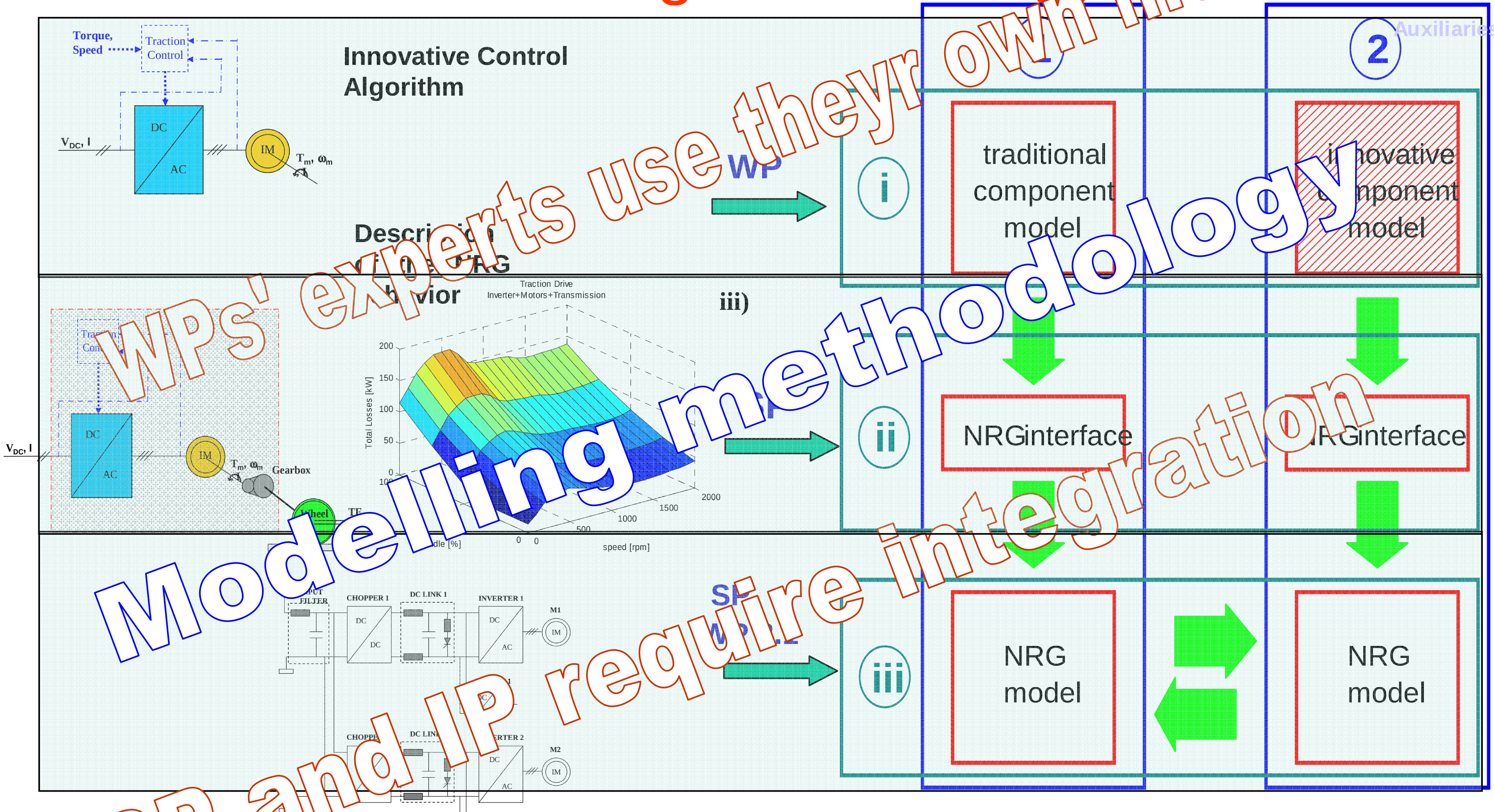
# Scope & Objectives

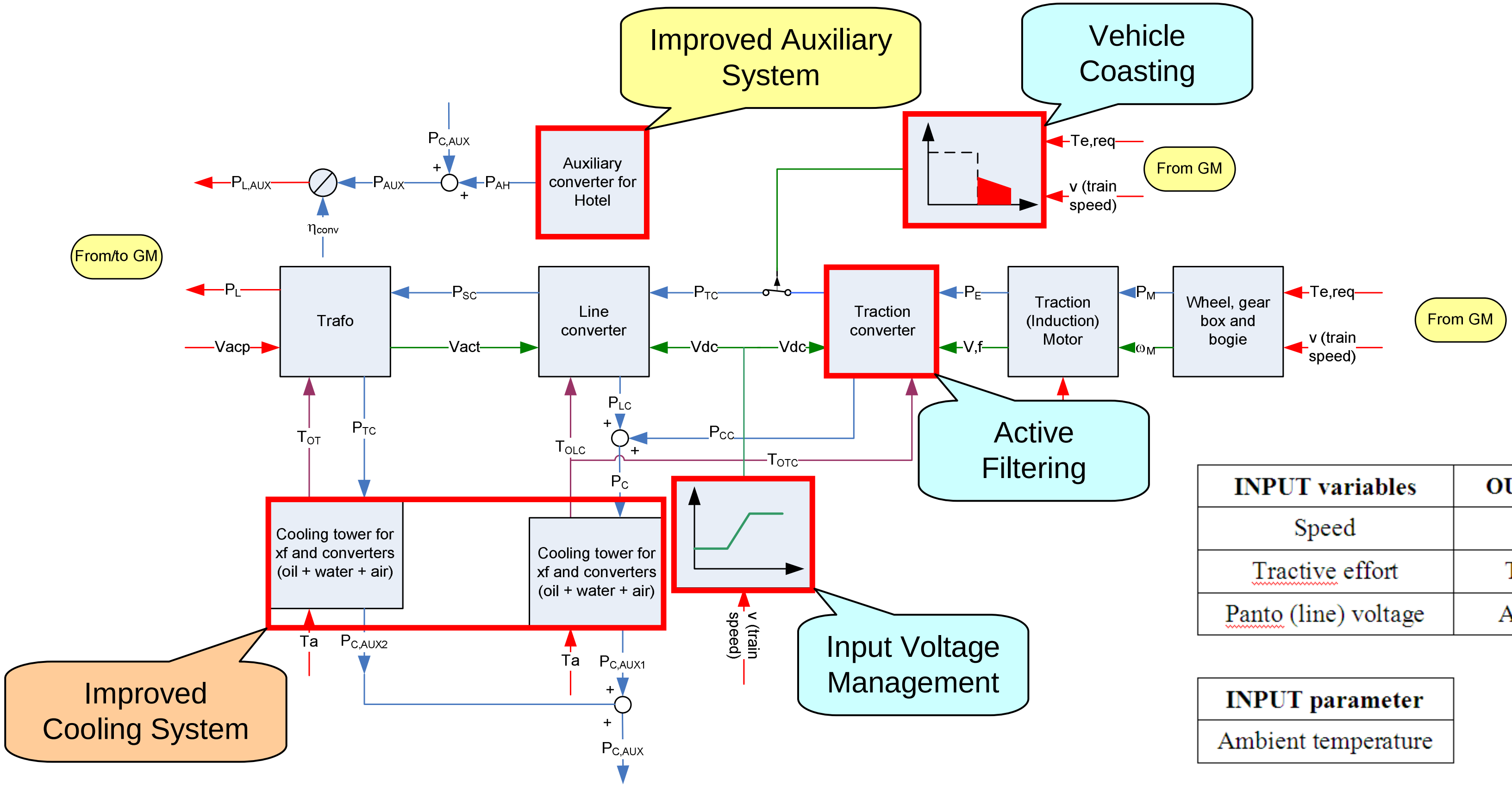
- To get a significant contribution to the overall energy efficiency of the railway system by means of a more efficient on-board energy management of all the major equipment, related to the complete power train, auxiliary systems and cooling devices.
- ***Innovative outputs***
  - Modelling methodology for NRG calculation in propulsion and auxiliary
  - Optimised control for on-board traction
  - Optimised energy architecture and operation for auxiliary systems
  - Centralized cooling system for traction and auxiliary converters
- ***Expected benefits***
  - Energy saving ➡ **0.5%**
  - General design optimization
  - Weight and dimension reduction

# Modelling Methodology



# Modelling Methodology

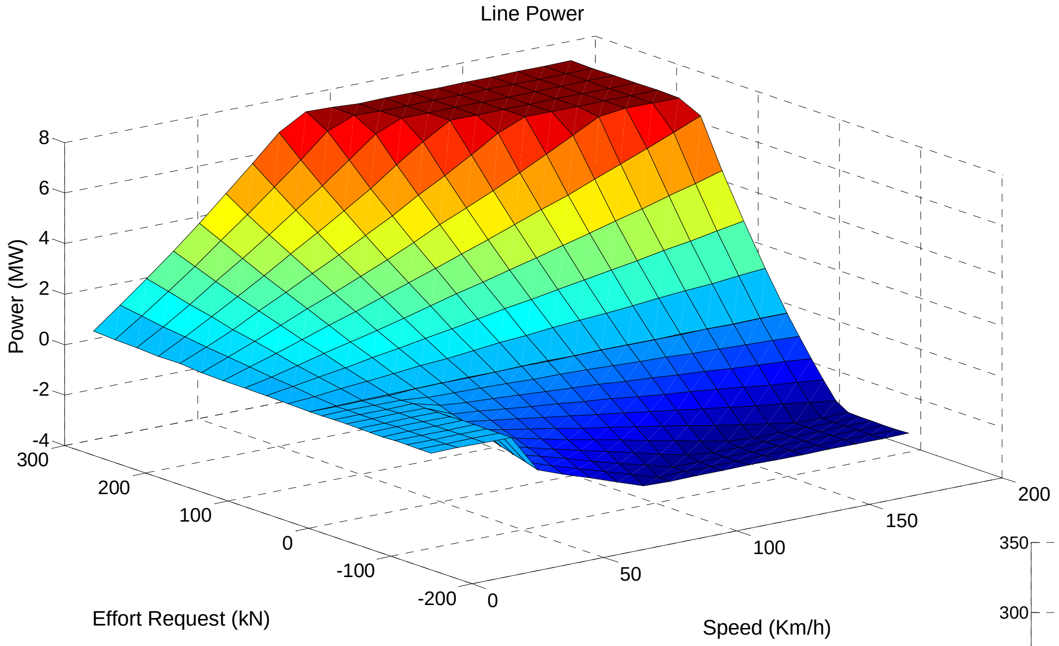
- Each component with an impact on the energy behavior of the traction system is represented by means of an Energy Model.




| INPUT variables | OUTPUT variables |
|---|---|
| Speed | Efficiency |
| Tractive effort | Traction power |
| Panto (line) voltage | Auxiliary Power |

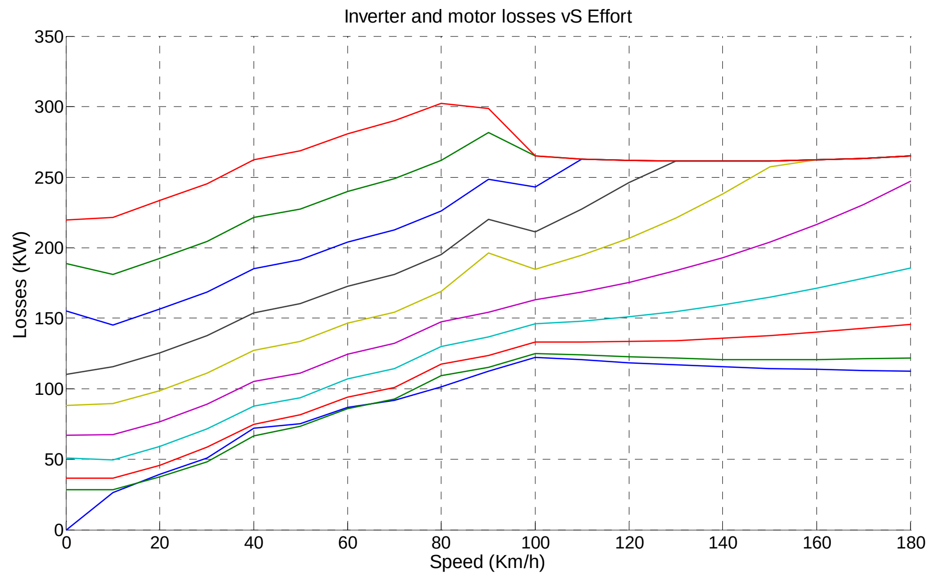
| INPUT parameter |
|---|
| Ambient temperature |

# Modelling Methodology




Vehicle Energy Consumption

Component Losses



# On-board Traction

- Reduction of energy consumption during Vehicle Coasting.
- Case Study: AC EMU for Regional Traffic. Swedish Route Märsta – Södertälje

| | time(s) | EIn(kwh) | EIn_T(kwh) | EIn_B(kwh) |
|---|---|---|---|---|
| Märsta – Södertälje_C | 4548 | 1183.4 | 1662.1 | 478.7 |
| Turn around Södertälje_C | 5087 | 1236.7 | 1715.4 | 478.7 |
| Södertälje_C – Märsta | 9503 | 2319.3 | 3286.6 | 967.3 |
| Turn around Märsta | 9983 | 2366.7 | 3334.0 | 967.3 |

| | time(s) | EIn(kwh) | EIn_T(kwh) | EIn_B(kwh) |
|---|---|---|---|---|
| Märsta – Södertälje_C | 4548. | 1118.1 | 1597.4 | 479.3 |
| Turn around Södertälje_C | 5087 | 1171.4 | 1650.6 | 479.3 |
| Södertälje_C – Märsta | 9503. | 2190.5 | 3159.0 | 968.4 |
| Turn around Märsta | 9983 | 2238.0 | 3206.4 | 968.4 |


**Total Catenary Energy Consumption = 2238.0 kWh**

**Energy Saving = (2366.7-2238.0) = 128.7 kWh → 5.44%**

# Cooling System – MV Loads Management

- Efficient MV loads management (fans, pumps…) allows to reduce:
  - Energy consumption when maximum cooling performances are not requested (during stops in the stations, favourable climatic conditions)
  - Environmental impact (noise, dust hoisting, clogging for snow presence)

- Case Study: EMU on International Route Amsterdam – Brussels

$$P(f_2) = P(f_1) * \left(\frac{f_2}{f_1}\right)^3$$

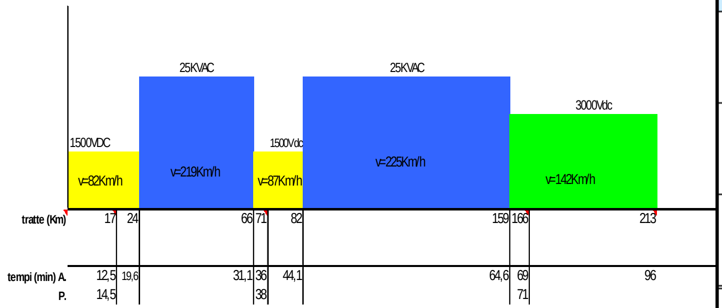
**Fan Application Example**

| Fan Operation | Rotation Speed | Static Pressure (Pa) | Air Flow (l/s) | Power (kW) | Power Reduction (%) |
|---|---|---|---|---|---|
| 2 poles (Max Speed) | 2900 | 763 | 2000 | 3 | |
| 4 poles (Half Speed) | 1450 | 190 | 1000 | 0.375 | 87.5 |

**Pump Application Example**

| Feeding Frequency (Hz) | Water Flow (Hz) | Flow Reduction (%) | Head (Bar) | Head Reduction (%) | Power (kW) | Power Reduction (%) |
|---|---|---|---|---|---|---|
| Nom 50 | 202.07 | | 3.13 | | 3.19 | |
| 40 | 161.65 | 20.0 | 2.00 | 36.1 | 1.63 | 48.9 |

# Cooling System – MV Loads Management

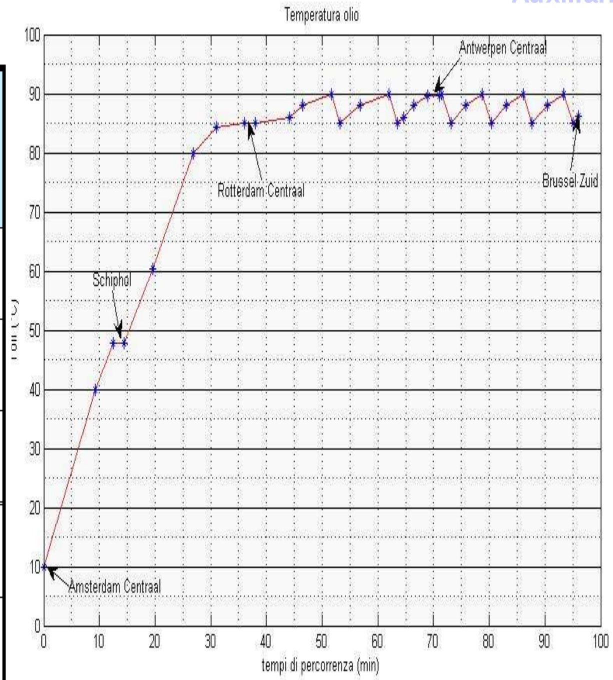



***EMU on the Route:***

***Amsterdam - Brussel***

***Loads management strategy***

| Water Temperature Range / Train Speed | Loads Configuration | Loads Absorbed Power KW |
|---|---|---|
| TH2O ≥ 60°C<br>v > 5 Km/h | Couple fans MAX SPEED<br>Pump 50 Hz | 9.19 |
| 58°C ≤ TH2O < 60°C<br>v > 5 Km/h | Couple fans HALF SPEED<br>Pump 50 Hz | 3.95 |
| TH2O < 58°C<br>v > 5 Km/h | Couple fans HALF SPEED<br>Pump 40 Hz | 2.39 |
| TH2O ≥ 60°C<br>v ≤ 5 Km/h | Couple fans HALF SPEED<br>Pump 50 Hz | 3.95 |
| 58°C ≤ TH2O < 60°C<br>v ≤ 5 Km/h | 1 Fan HALF SPEED<br>Pump 50 Hz | 3.57 |
| TH2O < 58°C<br>v ≤ 5 Km/h | 1 Fan HALF SPEED<br>Pump 40 Hz | 2.01 |

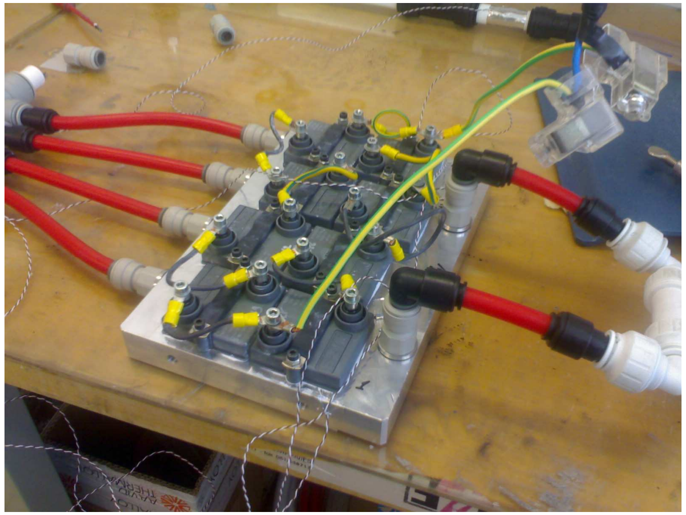



***Liquid temperature profile***

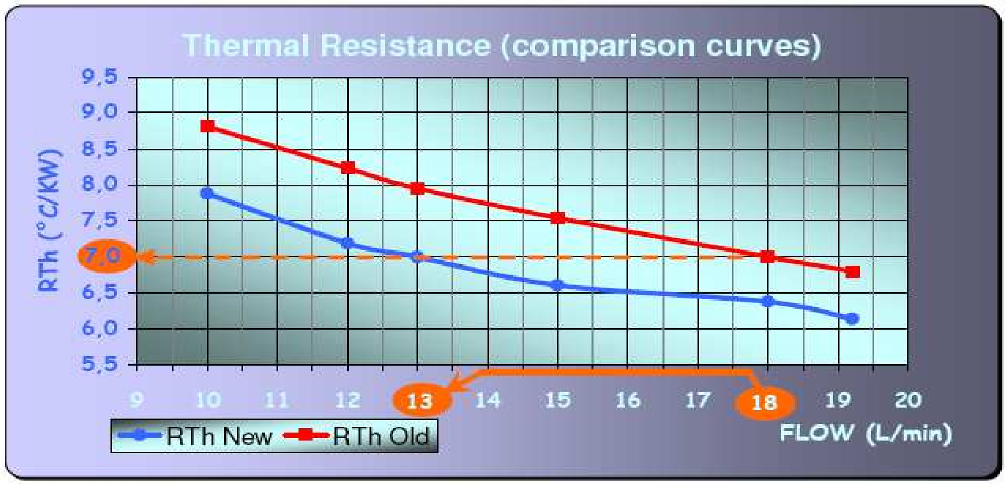
| **ET**: Total Energy absorbed by the vehicle on the planned route [kWh] | Energy absorbed by MV loads [kWh] | Energy absorbed by MV loads with Optimized Management [kWh] | **ES**: Energy Saving [kWh] | Energy Saving **ES / ET** (%) |
|---|---|---|---|---|
| 10752 | 149.32 | 46.48 | 102.84 | **0.96** |

# Cooling System – High Efficiency Cold Plates

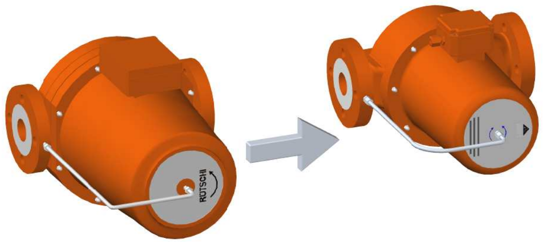
- Lower operating temperature of electric devices → Higher reliability
- Lower cooling flow → Use of pumps with lower consumptions and cost
- Optimisation of the whole hydraulic circuit → Reduction of weight and dimension



The proposed technology uses particular offset fins ("turbulators"), to insert in a machined groove, in order to increase the turbulence of cooling liquid and then to increase the thermal behaviour.



# Cooling System – High Efficiency Cold Plates




| | | Power Converter | Train (Power Converter x 4) |
|---|---|---|---|
| Pump in use | Maximum absorbed power (KW) | 3,14 | 12,56 |
| | Absorbed energy * (KWh) | 5,02 | 20,08 |
| New Pump (with high efficiency cold plates) | Maximum absorbed power (KW) | 1,61 | 6,44 |
| | Absorbed energy * (KWh) | 2,58 | 10.32 |
| | Energy saving (KWh) | 2,44 | 9.76 |
| | Energy saving (%) | 48.6 | |

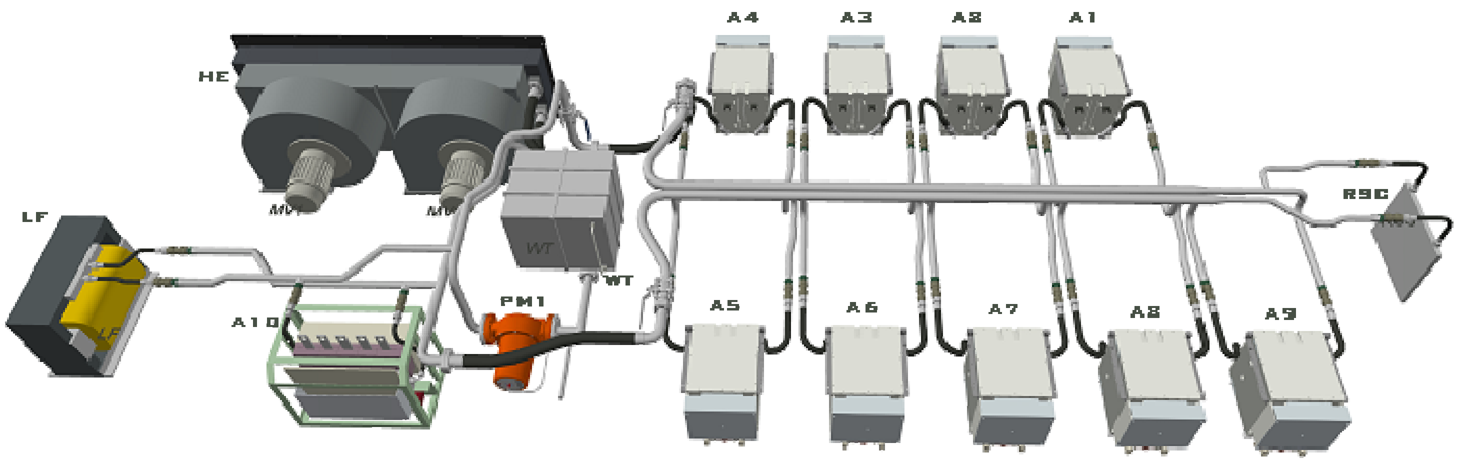
- Case Study: EMU on International Route Amsterdam – Brussels

| **ET**: Total Energy absorbed by the vehicle on the planned route [kWh] | **ES**: Energy Saving [kWh] | Energy Saving **ES / ET** (%) |
|---|---|---|
| 10752 | 9.76 | **0.10** |

# Centralized Cooling System

- "Centralize" means to concentrate all the equipments that need to be cooled in the same cooling system, in order to achieve:
  - Reduction of Weight and Dimensions
  - Improvement of Cooling Efficiency
  - Reduction of MV loads (energy consumption and noise)

- Case Study: EMU on International Route Amsterdam – Brussels



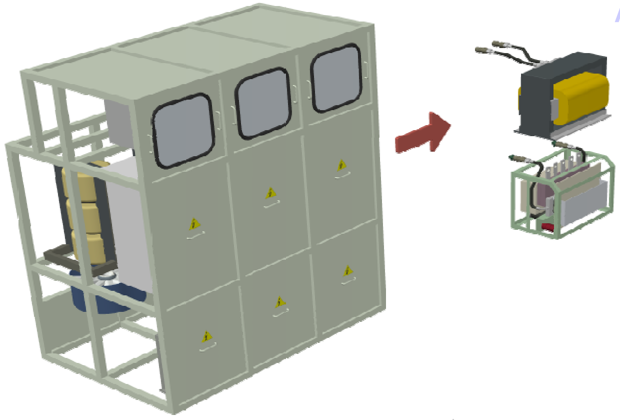
# Centralized Cooling System

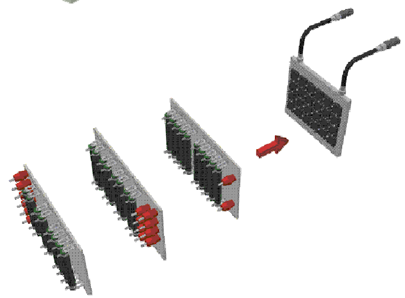
| apparatus | Volume | apparatus | Volume | reduction |
|---|---|---|---|---|
| Auxiliary Inverter Box for E403 Loco | 2719 $cm^3$ | Auxiliary Inverter module EMU V250 + Auxiliary chopper inductor | 210 $cm^3$ | **93 %** |
| Filter discharge resistor assembly for E403 loco (q.ty 3) | 50 $cm^3$ | Filter discharge resistor Cold Plate assembly EMU V250 | 11 $cm^3$ | **78 %** |

| apparatus | weight | apparatus | weight | reduction |
|---|---|---|---|---|
| Auxiliary Inverter Box for E403 Loco | 830 Kg | Auxiliary Inverter module EMU V250 + Auxiliary chopper inductor | 350 Kg | **58 %** |
| Filter discharge resistor assembly for E403 loco (q.ty 3) | 23 Kg | Filter discharge resistor Cold Plate assembly EMU V250 | 12 Kg | **48 %** |

↑ Forced Ventilation Solution

↑ Centralized Cooling Solution





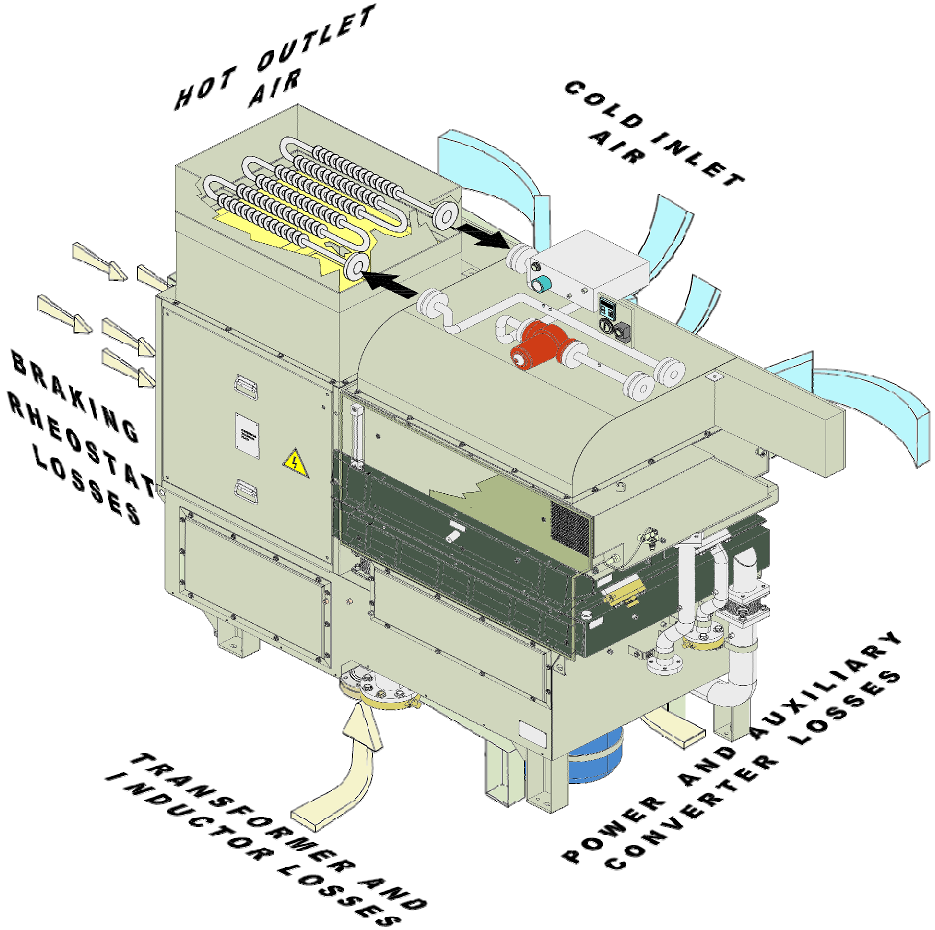
- Weight reduction for each EMU: about 2 tons

| **ET**: Total Energy absorbed by the vehicle on the planned route [kWh] | **ES**: Energy Saving [kWh] | Energy Saving **ES / ET** (%) |
|---|---|---|
| 10752 | 17.28 | **0.16** |

# Recovered Heat System

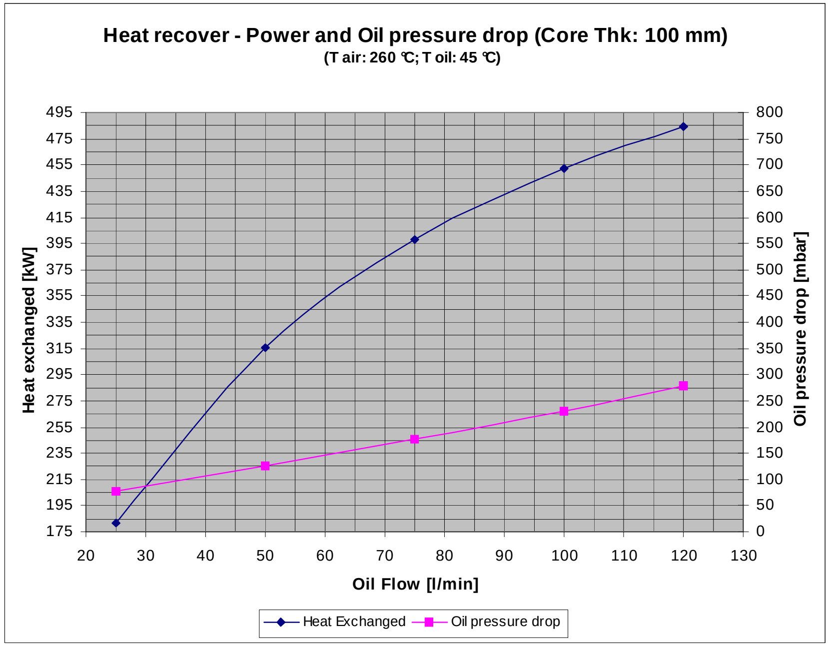
- Typical Cooling System for liquid cooling system
- The cold inlet air, moved by a centrifugal fan, crosses before the water cooler, then the inductor tubes, at the end the braking rheostat.
- The hot air, moving along the cooling tower, increases its temperature and goes out in the external ambient.

- Recovered Heat System
- On the top of the outlet channel has been located a dielectric oil heat exchanger. The outlet hot air transfers the heat to the oil and so heat recovered then to the oil.
- The hydraulic system provides to the circulation and controls of the dielectric oil for the heat recovery.



# Recovered Heat System

- Energy recovery evaluation: up to 25% of waste energy recovered for a possible reuse on the vehicle




- Heating Power evaluation

merak

**RAILENERGY: Heating Power**

**Features of the oil:**

Density 872 kg/m3
Volume flow 120 l/min
→ **1,744 kg/s**

Specific heat 1.92 kJ/kg/K
→ **Heat Transmission: 3.348 kW/K**

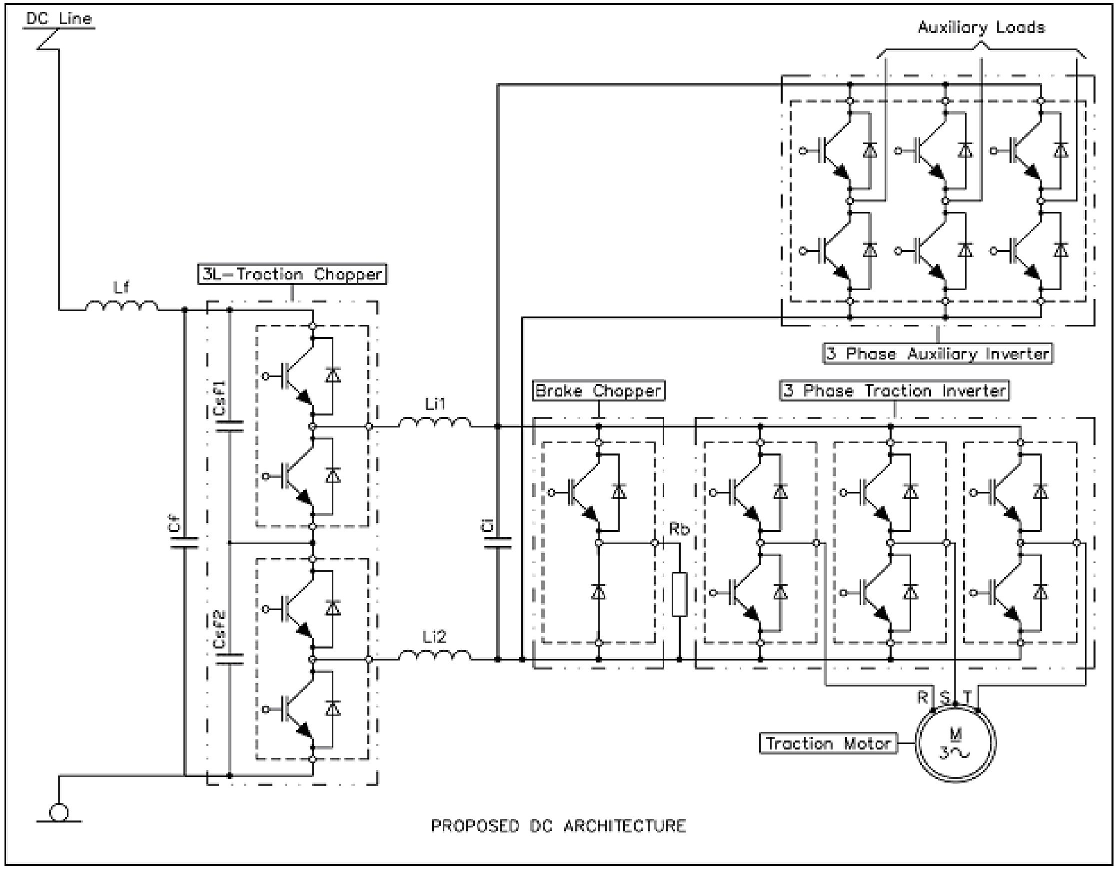
Heating Power (ΔT= 9K)= 30 kW

Knorr-Bremse Group 1

- Case Study: DC Loco on the Route Gijon – Leon

| **ET**: Total Energy absorbed by the vehicle on the planned route [kWh] | **ES**: Energy Saving [kWh] | Energy Saving **ES / ET** (%) |
|---|---|---|
| 8104 | 60 | **0.74** |

# Traction and Auxiliary converters integration




- Common components:
  - Line filter: (**Lf**, **Cf**)
  - DC-DC chopper (3 levels)
  - Intermediate filter (**Li**, **Ci**)
  - DC-AC converter (inverter)
- Traction side:
  - DC-AC converter (inverter)
- Auxiliaries Side:
  - Line filter (Lfas, Cfas)
  - DC-DC chopper (step-down)
  - Intermediate filter (Lias, Cias)
  - DC-AC converter (inverter)
- Traction side:
- Auxiliaries Side:
  - *Line filter (Lfas, Cfas)*
  - *DC-DC chopper (step-down)*
  - *Intermediate filter (Lias, Cias)*
  - DC-AC converter (inverter)

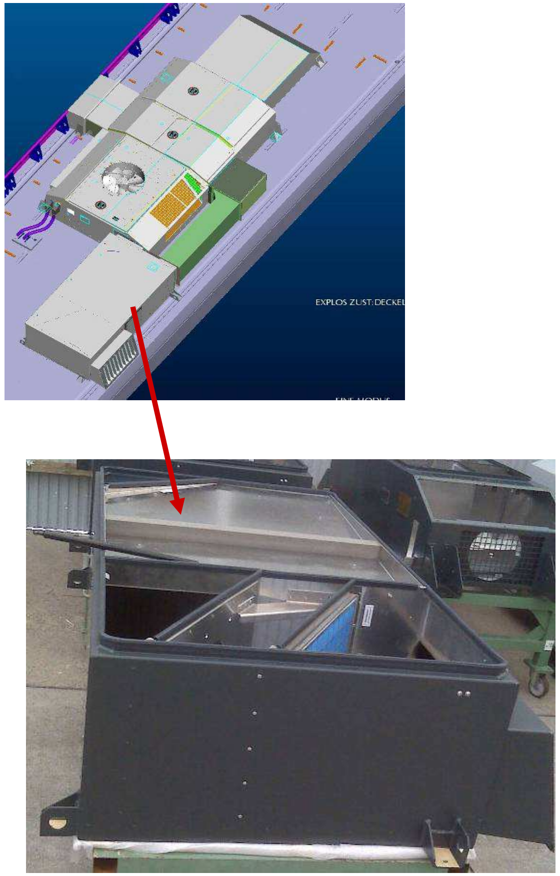
# Case Study – DC EMU for Regional Traffic

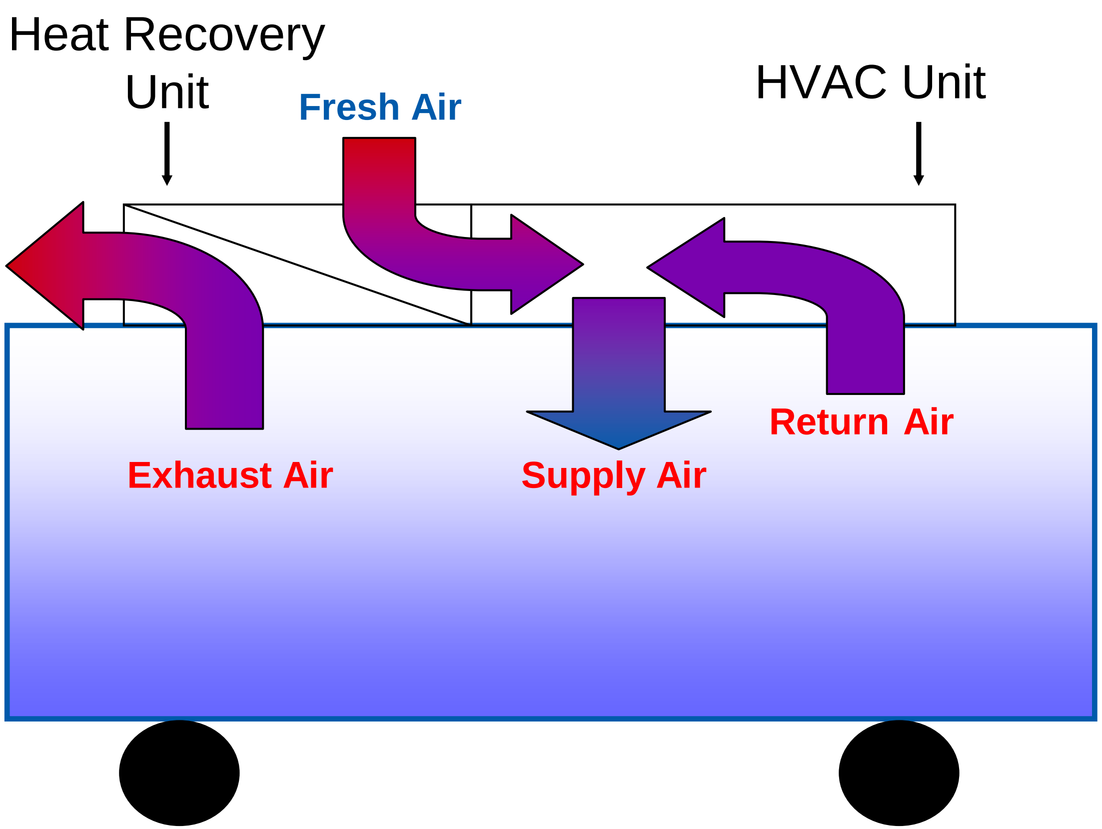
| | |
|---|---|
| **Vehicle Type** | **4 coaches DC EMU** |
| **Vehicle Composition** | **Bo'2' + 2'2' + 2'2' + 2'Bo'** |
| **Nominal line voltage** | **3000 Vdc** |
| **Max output power for propulsion** | **3.7 MW** |
| **Output power for auxiliary services** | **300 kW** |
| **Full loaded weight** | **273 t** |

- Weight reduction for each EMU: about 5 tons (2% of full loaded weight)
- After a preliminary evaluation, no appreciable reduction of electrical losses.
- As a consequence of weight reduction, an overall energy saving expected during the normal service.

- Components to be removed:
  - Line filter inductor
  - Line filter capacitor
  - GTO stack assembly
  - FW diode assembly
  - Intermediate filter inductor
  - Intermediate filter capacitor
- New auxiliary inverter:
  - six snubberless IGBT inverter (4500V/900A IGBT modules)
  - single aluminium plate water cooled
  - direct connection to the DC link at 2400Vdc
  - Output characteristics: 400V-50Hz / 300kW

# Improved HVAC – Heat Recovery



# Improved HVAC

| HVAC Technology | Heat Pump | Heat Recovery | Fresh Air Optimization | Refrigerant Supervision / Leakage Detection |
|---|---|---|---|---|
| Function | Reversion of the refrigeration circuit | Pre-heating / pre-cooling of external fresh air by exhaust air | Supply of fresh air depending on the real number of passengers | Supervision of the amount of refrigerant in the system circuit |
| Actual Applications | Not in Railways application because of wide temperature range requirements and poor efficiency below 5℃ | - | - | - |
| Railways Existing Technology | To aid the existing technologies with the Heat Pump when it can be efficient | Wastage of the energy of warm/cool exhaust air | Supply of fresh air depending on the number of seats | Refrigerant amount check during regular maintenance |
| Preliminary Analysis Results | Up to 40 % reduction of energy consumption (climatic zone II) | Up to 30 % reduction of energy consumption (climatic zone II) | Up to 30 % reduction of energy consumption (climatic zone II) | Increase of reliability<br>Limit the reduction of the C.O.P. because of refrigerant leakages |

# Results achieved and possible implementation

- Energy Modelling
  - N.5 **Energy Models** (Look-Up Tables) for Baseline Simulation at System Level: DC Loco for Pass. and Freight, AC Loco for Pass. and Freight, AC EMU.
  - N.3 **Energy Models** (Look-Up Tables) of AC Loco with "Coasting Losses Reduction", "Input Voltage Management", "MV Loads Management".
- On-board Traction
  - "**Coasting Losses Reduction**": Single Train run for **AC EMU** on **Regional Traffic**, **+5%** Energy Saving.
- Cooling System
  - "**MV Loads Management, Centralized Cooling System, High Efficiency Cold Plates**": a total of **+1.2%** Energy Saving for Multivoltage Passenger **EMU** on **International Route**. Additional Energy Saving due to **weight reduction**.
  - **"Recovered Heat System"**: **+0.7%** Energy Saving for **Passenger Intercity DC loco**.
- Auxiliaries
  - "**Propulsion and Auxiliary Converter Integration**": **2%** of weight reduction for **DC EMU** on **Regional Traffic**.
  - "**Improved HVAC with Heat Recovery**": up to **30%** reduction of HVAC Energy consumption.

# Next Steps & Outlook

- **Energy Models** (Look-Up Tables) set of the proposed innovations to be finalized for the simulation at System Level.
- **Simulations** of the proposed innovations at Subproject / Workpackage level to be finalized, according to the Technology Matrix, for the relevant Demo Scenes.
- **Evaluation** and **Validation** of the results at Subproject / Workpackage Level.