« EMR and energy management of a Hybrid ESS of an Electric Vehicle »

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http://www.emrwebsite.org/
Electric Vehicles is a key component to **Sustainable Mobility**!

- **Electric Vehicles:**
  - the key components to **Sustainable Mobility**!

- **Barriers…**

- **Energy Storage…**
  - 100 years old problem!

- **Batteries** (best suitable energy storage for vehicles):
  - expensive, heavy, bulky, low specific energy and/or power, and limited cycles-life;

**Objective:**
- A structuring method for energy management definition;
- For battery lifetime improvement.

**Possible Solution:** Hybridization using SCs
1. Power System Description
2. Modelling and Control of the System Using EMR
3. Management Strategy Definition
4. Simulation Results (using ECE 15 Driving Cycle)
5. Conclusions
« Power System Description »
**Tazzari Zero characteristics**

- Neighborhood Electric Vehicle (NEV)
- Vehicle mass (tare): 407.60 kg
- Motor power: 15 kW;
- Lithium-ion: 24 x 5.6 = 134.4 kg
- Driving Range: 140 km
- Maximum speed: 85 km/h;
- Maximum Acceleration: 0-50 km/h < 5 s;
- DC bus Voltage: 80 V.
- Current Topology Configuration:
  - Li-ion Batteries fed directly the traction system;
  - No control on the DC bus voltage;
  - The batteries voltage decrease

⇒ the powertrain current increase!
NEW TOPOLOGY CONFIGURATION:

- Active parallel topology with Batteries and Supercapacitors;
- A DC/DC converter per source is used;
- The input voltage of these converter can be different and the output can be adjustable to a shared DC bus supplying the traction system.

- NiMH Batteries
  - 5.8 kW; 13 A.h
  - Total Weight: 48 kg

- Supercapacitors
  - 48 kW; 125 F
  - Total Weight: 35.6 kg
« Main Objective… »
Hierarchical structure of the EMS.

- Strategy Level
- Decision Level
- Operational Level (EMR Inversion-based control)

EV Management Layer
EV Control Layer
« Modelling and Control of the System Using EMR »
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« EMR AND ENERGY MANAGEMENT OF A HYBRID ESS OF AN ELECTRIC VEHICLE »

- EMR of the Hybrid ESS EV -
- Modelling the Energy Storage Elements;
  - with \( j \in \{ \text{bat}; \text{SC} \} \);
- Modelling the DC/DC converter;
- Modelling the parallel coupling.

\[
\sum_{j \in \{ \text{bat}; \text{SC} \}} i_{\text{ch},j} = i_T
\]

\[
\begin{cases}
  v_{\text{ch},j} = m_j v_{\text{DC}} \\
  i_{\text{ch},j} = m_j i_j \eta_{\text{Conv}}^\beta
\end{cases}
\]

\( m_j \in \{0, 1\} \) and \( \beta = 1, \text{ for } P_{\text{Conv}} \geq 0 \) \( \beta = -1, \text{ for } P_{\text{Conv}} < 0 \)

\[
L_j \frac{d}{dt} i_j = v_j - v_{\text{ch},j} - R_j i_j
\]
"EMR AND ENERGY MANAGEMENT OF A HYBRID ESS OF AN ELECTRIC VEHICLE"

- EMR of the Hybrid ESS EV -

- Modelling the Environment;
- Modelling the Chassis;
- Modelling the Gearbox;
- Modelling the Electric motor and its controller;
- Modelling the Parallel coupling;
- Modelling the DC bus.

\[
C \frac{d}{dt} v_{DC} = -i_C
\]

\[
i_C = i_{load} - i_T
\]

\[
i_{load} = \frac{T_{em} \Omega_m \eta_m \beta}{v_{DC}}
\]

\[
\frac{d}{dt} v_{EV} = F_{tr} - F_{env}
\]

\[
F_{env} = \mu_{rr} M_{eq} g + \frac{1}{2} \rho A_f C_d (v_{EV} + v_{wind})^2 + M_{eq} g \sin(\theta)
\]

\[
F_{tr} = \frac{g_{gb}}{r} T_{em} \eta_m \beta
\]

\[
\Omega_m = \frac{g_{gb}}{r} v_{EV}
\]

with
\[
\begin{align*}
\beta &= 1, \text{ for } P_{mec} \geq 0 \\
\beta &= -1, \text{ for } P_{mec} < 0
\end{align*}
\]
Objectives: control the EV velocity and DC bus voltage

Tuning variable: modulation ratio of the DC/DC converters and motor torque reference
Maximum Control Structure:
- inversion of each element step-by-step (4 controllers and 1 strategy algorithm)
"Management Strategy Definition"
**REMEMBER:**

**OBJECTIVE ⇒ HIERARCHICAL STRUCTURE.**
Original EMR

Equivalent EMR for EMS definition
A. STRATEGY LEVEL.

Dynamically restricts the space search \( (C_j \text{ space}) \) that represents the possible combination of the power sources:

\[ C_j \in [LB_j, UB_j], \text{ with } LB_j \geq -1 \text{ e } UB_j \leq 1 \]
B. DECISION LEVEL

Linear Programming

\[
\min_{C_{bat}, C_{SC}} \left| P_{dem}[k] - \left[ C_{bat}[k] \cdot P_{bat}^{max}[k] + C_{SC}[k] \cdot P_{SC}^{max}[k] \right] \right|
\]

One-dimensional Problem

Two-dimensional Problem

K_D
« EMR AND ENERGY MANAGEMENT OF A HYBRID ESS OF AN ELECTRIC VEHICLE »

- Strategy Definition -

B. DECISION LEVEL.

\[ \begin{align*}
SB_j[k] & \leq C_j[k] \leq UB_j[k]; \\
J_{j}[k] = f_{j}[k]C_{j}[k]P_{j}^{max}[k]; \\
P_j^{max}[k + 1] &= v_j[k]I_{j,max}. 
\end{align*} \]
« Simulation Results »
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- Simulation Results -

EMS

STRATEGY LEVEL

DECISION LEVEL
« Conclusions »
- Conclusions -

- The new **hybrid power system** is addressed.
- **EMR and its control** is developed and presented.
- **Management Strategy** is structured based on EMR.
- **Management Strategy**: **strategic level** + **decision level**:
  - to determine the best power sharing solution under strategic orientations.
- The results **demonstrate** that the **EMS may be used effectively**.

The approach fulfills the **main objectives** of hybridization:
  - Reducing the battery requirements;
  - Controlling the SCs to support power peaks/store regenerative energy.

As main results:
  - Batteries’ lifetime improvement;
  - More power for accelerations/better usage of regenerative energy.