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Adaptive Filtering Strategies for HESS in EVs using EMR

- Context and Objective -

Energy management strategy (EMS) of a hybrid energy storage system in electric vehicles

Conventional filtering strategies

Light computation resources

Challenge for calculating the cut-off frequency for the system

[Salmasi 2007]

EMS

Rule-based

Optimization-based

Deterministic

Artificial intelligence

Filtering algorithms

Simple adaptive methods

[NguyenHHT 2021]
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- Outline -

1. Modeling and control of a battery/supercapacitor EV
2. Adaptive filtering strategies
3. Simulations, experiments, and results
4. Conclusions and perspectives
« Modeling and control of a battery/supercapacitor EV »
Adaptive Filtering Strategies for HESS in EVs using EMR

- System representation using EMR [Bouscayrol 2012] -
Adaptive Filtering Strategies for HESS in EVs using EMR

- System representation using EMR -

\[ i_{sc} = \frac{1}{L_s + r} (u_{sc} - u_{ch}) \]
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- System representation using EMR -
Adaptive Filtering Strategies for HESS in EVs using EMR

- System representation using EMR -

![Diagram of HESS system](image)

1. **Battery (Batt.)**
   - Voltage: $u_{bat}$
   - Current: $i_{bat}$

2. **Supercapacitor (SC)**
   - Voltage: $u_{sc}$
   - Current: $i_{sc}$

3. **Inductor**
   - Current: $i_{sc}$

4. **Chopper**
   - Voltage: $u_{bat}$
   - Current: $i_{ch}$

5. **Coupling**
   - Voltage: $u_{bat}$
   - Current: $i_{trac}$

6. **Gearbox**
   - Torque: $T_m$
   - Angular velocity: $\omega_m$

7. **Wheel**
   - Force: $F_{trac}$

8. **Environment**
   - Force: $F_{env}$

9. **Vehicle (v_veh)**
   - Velocity: $v_{veh}$

**Equations:***

- $i_{bat}$
- $u_{bat}$
- $i_{ch}$
- $u_{ac}$
- $u_{bc}$
- $i_g$
- $T_m$
- $\omega_m$
- $F_{trac}$
- $F_{env}$
- $v_{veh}$
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- System representation using EMR -
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EMR’21, Lille, June 2021
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- System representation using EMR -
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- Inversion-based control -

Focus of this work
« Adaptive filtering strategies for energy management »
The main idea:

If SC have more “ability”, it can more support the battery

\[ i_{bat} \sim (1 - \text{SC "ability"}) \]

What is the SC “ability”? [NguyenHLT 2021]

→ 3 ways to calculate the \( i_{bat \ ref} \)

→ 3 real-time strategies with only SC voltage and traction current measurements.
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- Adaptive filtering strategies -

Adaptive low-pass filter transformation:

\[
\begin{align*}
\frac{1}{\tau s + 1} & \quad \rightarrow & \quad \frac{1}{\tau s} \\
+ & \quad \rightarrow & \quad + \\
\end{align*}
\]

SoC-based strategy

\[
k_a = \frac{u_{SC\ meas} - u_{SC\ min}}{u_{SC\ min}}
\]

Energy-based strategy

\[
k_a = \frac{u_{SC\ meas}^2 - u_{SC\ min}^2}{u_{SC\ min}^2}
\]

Voltage-based strategy

\[
k_a = \left(\frac{u_{SC\ meas} - u_{SC\ min}}{u_{SC\ min}}\right)^2
\]
« Simulations, experiments, and results »
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- Experimental reference model -

**Specifications**

<table>
<thead>
<tr>
<th>EV (i-MiEV)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle total weight $M_{tot}$</td>
<td>1250 kg</td>
</tr>
<tr>
<td>Gear box ratio $k_{gear}$</td>
<td>7.065</td>
</tr>
<tr>
<td>Wheel radius $R_{wheel}$</td>
<td>0.2844 m</td>
</tr>
<tr>
<td>Aerodynamic standard $C_d A_f$</td>
<td>0.8295 m$^2$</td>
</tr>
<tr>
<td>Rolling friction coefficient $c_r$</td>
<td>0.02</td>
</tr>
<tr>
<td>Air density (at 20°C) $\rho$</td>
<td>1.25 kg/m$^3$</td>
</tr>
</tbody>
</table>

**IPMSM**

| Maximum power $P_{max}$       | 49 kW  |
| The number of polar pairs $z_p$ | 4      |
| Pole flux $\phi_p$            | 0.06 Wb|
| Stator inductance $L_{ad}$    | 140 $\mu$H |
| Stator inductance $L_{sq}$    | 210 $\mu$H |
| Windings resistance $R_{sd} = R_{sq}$ | 12 m$\Omega$ |

**Battery module (LEV50 Li-ion)**

| Cell storage capacity $Q_{bat}$ | 50 Ah  |
| Cell OCV $u_{cell_{nom}}$       | 3.7 V   |
| Cell OCV (at 20% SOC) $u_{cell_{min}}$ | 3.06 V |
| Cell resistance $r_{bat}$       | 1.7 m$\Omega$ |
| Number of cells in series $n_{se_{bat}}$ | 88     |
| Number of cells in parallel $n_{pa_{bat}}$ | 1      |

**SC module (NESSCAP EMHSR-0062C0-125R0SR2)**

| SC module nominal voltage $u_{sc\_nom}$ | 125 V |
| SC module nominal capacitance $C_{mod}$ | 62 F  |
| SC module internal resistance $r_{sc\_mod}$ | 10 m$\Omega$ |

System parameters
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- Simulations results -

1. Vehicle speed (NEDC)

2. Vehicle speed (Artemis)

3. Battery rms currents

4. Battery current standard deviations
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- Experiments Using Signal Hardware-In-the-Loop Simulation -

Signal HIL system for real-time experimental validation [Vo-Duy 2020]
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- Experimental test bench setup -

1. Host computer
2. Emulated ECU
3. Control ECU
4. Interface circuit

Vehicle velocity (WLTC class 2)

Experimental driving cycle

With control ECU
computational time: 0.5 ms
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- Experimental results -

1. HESS currents (energy-based)

2. Zoom shape of HESS currents (energy-based)

3. SC voltage (energy-based)

4. Zoom shape of SC voltage (energy-based)

Error < 3%
« Conclusions and perspectives »
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Conclusions

- HESS EV Modeling and control using EMR
- Propose three simple but effective adaptive filtering strategies
- Simulations and experimental validations using signal HIL simulation

Future work:
- Real-time optimization-based strategy
- Reduce-scale power HIL
« Thank for your listening and have a good time at EMR Summer School 2021 »
« BIOGRAPHIES AND REFERENCES »
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« Time for questions »