« EMR AND OPTIMAL ENERGY MANAGEMENT STRATEGY OF A PARALLEL HYBRID ELECTRIC VEHICLE »

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EMR’17, Lille, June 2017

- Context & Objective -

• Economic and Environmental issues lead to Hybrid Technology [Citepa 15]

Objective: Achieve an optimized Energy Management Strategy of a parallel Hybrid Electric Vehicle
« EMR and optimized EMS of a parallel hybrid Electric Vehicle »

- Context & Objective -

- Energy Management Strategy [Trigui 04]

- by Optimization-based (Dynamic Programming, etc)
  - Compatible with any system model
  - Optimal results
  - Not usable in real time
  - Important IT resources
  - Long time simulation

- by Rule-based
  - Usable in real time
  - Very fast simulation
  - Requires some expertise
  - Not necessarily optimal results

Objective: define a Rule-based EMS from a DP EMS
1. **Energetic Macroscopic Representation**
   - Studied vehicle
   - EMR of the vehicle

2. **Inversion Based Control**
   - Control scheme
   - Reduced Model

3. **Energy Management Strategy**
   - EMS by Dynamic Programming
   - Rule-based algorithm

4. **Conclusion & Perspectives**
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June 2017

Summer School EMR'17
“Energetic Macroscopic Representation”

« EMR of the Vehicle »
• The studied vehicle

Parallel Hybrid Electric Vehicle architecture

Parameters: Nickel Metal Hydride Battery 7.2V/6Ah /38 modules // Electric Machine 20 kW // ICE 43 kW // Vehicle Mass: 1,2 T

The energetic study of the vehicle is done without its clutch
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- Energetic Macroscopic Representation -

EMR (forward approach)

\[ T_{ice} = \frac{1}{\tau_{ice}} \int (T_{ice\_ref} - T_{ice}) \, dt \]

\[ \begin{cases} T_{blt} = k_{blt} T_{em} + T_{ice} \\ \omega_{em} = \frac{1}{k_{blt}} \omega_{blt} \end{cases} \]

\[ \begin{align*} v_{s-dq} &= [P(\theta_{d/s})]v_s \\ i_{im} &= [P(\theta_{d/s})]^{-1} i_{s-dq} \\ i_{s-dq} &= \frac{1}{\tau_{eq}} \int (v_{s-dq} - e_{s-dq} - R_s i_{s-dq}) \, dt \\ \varphi_{rd} &= \frac{R_r}{L_r} \int (M_{sr} i_{sd} - \varphi_{rd}) \, dt \\ T_{em} &= p M_{sr} (\varphi_{rd} i_{sq} - \varphi_{ra} i_{sd}) \\ F_{br} &= F_{br\_ref} \\ F_{veh} &= F_{veh} - F_{br} \end{align*} \]
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- Energetic Macroscopic Representation -

- backward model deduced from EMR

\[ T_{ic} = \left( 1 - k \eta_T \right) T_{blt} \]
\[ \Omega_{ic} = \frac{1}{k_{mt} r_{wh}} V_{veh} \]

- Used for EMS studying, the sizing and design of powertrains

- There local control is assumed ideal [Horrein 15]
<Inversion Based Control>
« EMR and optimized EMS of a parallel hybrid Electric Vehicle »

- Inversion Based Control (forward approach) -
• Reduced model for EMS studying (quasi-static model)

\[
\begin{align*}
T_{em} &= T_{em\_ref} \\
i_{bat} &= \frac{T_{em} \Omega_{em}}{\eta_{em} v_{bat}}
\end{align*}
\]

\[T_{ice} = T_{ice\_ref}\]

EMS is focused on the power flows between ICE and Electric Machine
« ENERGY MANAGEMENT STRATEGY »
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- EMS using Dynamic Programming -

- Dynamic Programming principle [Guzzella 10]

- Basic relation

\[ J^* = \min(J) = \min \left\{ \sum_{k=0}^{N-1} [L(x(k), u(k), k)] \right\} \]

- Constraints

\[ \text{SoC}_{\text{min}} \leq x(k) \leq \text{SoC}_{\text{max}} \]
\[ x(k_{\text{final}}) = x(k_{\text{initial}}) \]

with:

- J, the cost function
- L, the cost function between two samples
- x, State of Charge of the battery
- u, the coefficient of distribution of the traction torque

DP is not usable in real time
- Deduced Rule-based EMS -

- Rule-based algorithm for EMS

![Diagram showing deduced rule-based EMS algorithm for a parallel hybrid electric vehicle](image)

- Electric Mode: $kd_T = 1$
- Thermal Mode: $-1 \leq kd_T \leq 0$
- Hybrid Mode: $0 \leq kd_T < 1$

**RB-EMS is usable in real time**
Results based on the «forward» model of the vehicle

<table>
<thead>
<tr>
<th></th>
<th>DP-EMS</th>
<th>RB-EMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE Fuel Consumption [L/100 Km]</td>
<td>3.52</td>
<td>3.6</td>
</tr>
<tr>
<td>Computation time [s]</td>
<td>420</td>
<td>2</td>
</tr>
</tbody>
</table>

INTERNAL CHARGING OF THE BATTERY BY THE ICE TO OBTAIN THE INITIAL SOC

DP / RB : Difference of 2% over all
« CONCLUSION & PERSPECTIVES »
Conclusion

• Realization of the EMR and the IBC of a parallel HEV
• Optimal Energy management strategy using DP
• Deduction of Rule-based algorithm from DP-EMS results

Perspectives

• Experimental validation of the Rule-based EMS (real time)
• Take into account more parameters for the ICE
« BIOGRAPHIES AND REFERENCES »
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