Impact of Component Sizing On PHEVs Energy Consumption Using Global Optimization

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Electric Components Are Key Elements for PHEVs Development

- In a PHEV, the electric system has to:
  - get good environmental performance
  - stay within available technology barriers
  - be affordable to make PHEVs marketable

- **Power and energy** sizing is a capital factor

- Global optimization is used to fairly evaluate the impact of different power and energy sizing
Outline

- Study Main Principles
- Control Patterns
- Influence of Battery Energy
- Influence of Battery Power
Baseline Powertrain
Parallel Pre-Transmission

Component Specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Specifications</th>
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<tbody>
<tr>
<td>Engine</td>
<td>2.3 L, 100 kW Ford Duratec</td>
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</table>
| Electric machine| Various power
Based on Toyota Prius MY04 motor                  |
| Battery         | Various capacity and power
Based on Li-ion – Saft VL41M                         |
| Transmission    | 5-speed automatic transmission
Ratio: [3.22, 2.41, 1.55, 1, 0.75]                   |
| Frontal Area    | 2.76 m²                                             |
| Final Drive Ratio| 3.58                                               |
| Drag Coefficient| 0.395                                               |
| Rolling Resist. | 0.008 (plus speed related term)                    |
| Wheel radius    | 0.33 m                                              |
| Vehicle mass    | 1710 kg + motor mass + battery mass                 |
| Electric accessories| 240 kW                     |

- **Comparables to:**
  - Ford Escape
  - Argonne’s MATT
Study Methodology

Baseline Powertrain

Different Energy (5 vehicles)
Different Power (5 vehicles)

UDDS, HWFET, LA92
10, 20, 40 miles

Backward-Looking Model, including Global Optimization

Optimal Control, Optimal Results
Algorithm Outputs Results for Different $\Delta$SOC

1 vehicle
1 cycle
1 distance
1 run

Plug-to-Wheel Wh/km
Outline

- Study Main Principles
- Control Patterns (20-mi AER)
- Influence of Battery Energy
- Influence of Battery Power
“Engine On” Is Linked to Wheel Power

- Power at wheels above which ICE is on 95% of the time, similar to wheel power threshold used in rule-based controls
- Higher Electric Energy Use → ICE starts “later”
- Wheel Power Threshold follows linear trend
- Little influence of driving cycle
Engine Power Depends on Cycle and Electricity Use

- UDDS: ICE power increases with Wh/km
- LA92: ICE power constant, because cycle is aggressive enough for the ICE to operate efficiently
Charging from ICE Likely When ICE is Predominant and Wheel Power is Low

- UDDS: when ICE is used often, it has to operate often above requested wheel power
- LA92: ICE operates efficiently, even in CS mode because average ICE power is high
Outline

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- Influence of Battery Energy
- Influence of Battery Power
5 Vehicles with Different Energy and AER

Power to meet EV-mode requirements on UDDS...

...Different UDDS All-Electric Range

![Bar chart showing battery capacity (Ah) vs. all-electric range (miles)]

- Battery Capacity (Ah)
- All-Electric Range (miles)

- 10 miles AER on UDDS
For a Given Electric Consumption, AER Has Little Influence on Control

- For a given electric consumption, ICE-On behavior does not depend on the energy sizing...
- ...but possible electric energy consumption is limited: same electric consumption corresponds to different $\Delta$SOC
Minimal Fuel Consumption

- Distance Traveled < AER
  - On a given cycle, little sensitivity to energy sizing
  - LA92 leads to a 34% increase in electric Wh/km compared to UDDS

- Distance Traveled > AER
  - Decrease in fuel consumption is proportional to increase in AER
  - 1.5 L/100 km difference between UDDS and LA92
Outline

- Study Main Principles
- Control Patterns
- Influence of Battery Energy
- Influence of Battery Power
5 Vehicles With Different Power

Same Battery Energy... + ... Different Electric Power

![Bar chart showing battery power (kW) vs. power scaling ratio for 5 vehicles with different electric power. The chart indicates that as the power scaling ratio increases, the battery power also increases. The chart highlights the 10 miles AER on UDDS improvement with increased power.](chart.png)
Maximum Power Impacts Wheel Power Threshold for Engine ON

- The engine starts “earlier” when the electric system has lower power
Less Electric Power Results in Higher Fuel Consumption

- Especially true on aggressive cycle (LA92), and distance traveled close to AER
- Higher electric power does not significantly reduce fuel consumption
- UDDS seems to be a good choice for power requirements (In terms of energy use)
Conclusions

- Global Optimization allows fair comparison between different vehicles
- It also allows to see all combinations of thermal Vs electric energy use
- Optimal control shows:
  - Engine is operated close to its maximal efficiency
  - A power threshold for ICE to be ON has been identified
  - Control depends on electric consumption (Wh/km)
- Energy sizing impacts fuel displacement when distance traveled > AER
- Electric power downsizing has a negative impact on fuel displacement
- Future work: use optimization output to generate a rule-based control in PSAT, evaluate emissions using MATT