A Hybrid ERS Cost Perspective

Mats Alaküla

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Swedish Electromobility Centre is...

...a national Centre of Excellence for research and development of electric and hybrid vehicles and charging infrastructure. It is an arena where Sweden’s automotive industry, universities and government agencies meet and collaborate to generate new technology, insights and competence for the future.
Lund University

- Founded 1666
- 8 faculties, 3 campuses in Skåne
- 40000 students, 840 profs, 4200 researchers
- 400 PhD awarded, over 4900 publications, 73\textsuperscript{th} in QS Ranking
- 830 M€ (2/3 to research)
- World leading research facilities ESS, Max IV
- Bluetooth, fingerprint reader, Ink-jet, Tetra-pack, respirator, artificial kidney, cancer diagnosis...
Research question

• What is the best way to utilize an ERS?
  – *The ERS track is NOT continuous*
  – *The ERS coverage is an optimisation parameter*
  – *In between ERS tracks and on non-ERS roads, the vehicle can be run in battery mode or hybrid mode*

• The answer is searched with a simplified road model
Assumptions 1 – the vehicle

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle weight</td>
<td>40 000</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Battery size ($W_{batt}$)</td>
<td>25 ... 400</td>
<td>kWh</td>
<td>System level</td>
</tr>
<tr>
<td>Battery Cost</td>
<td>200</td>
<td>Euro/kWh</td>
<td>System level</td>
</tr>
<tr>
<td>Max C-rate</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calendar lifetime</td>
<td>6</td>
<td>years</td>
<td></td>
</tr>
<tr>
<td>Max DoD</td>
<td>70</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Fuel cons</td>
<td>0.24</td>
<td>liter/km</td>
<td>Hybrid mode</td>
</tr>
<tr>
<td>Cycle life</td>
<td>-</td>
<td>-</td>
<td>See Figure 1.3</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>1.5</td>
<td>€/liter</td>
<td></td>
</tr>
<tr>
<td>El energy cons</td>
<td>1</td>
<td>kWh/km</td>
<td>Electric mode</td>
</tr>
<tr>
<td>El energy cost</td>
<td>0.1</td>
<td>Euro/kWh</td>
<td></td>
</tr>
<tr>
<td>Work hours</td>
<td>16</td>
<td>Hours/day</td>
<td></td>
</tr>
<tr>
<td>DC/DC conv. cost</td>
<td>100</td>
<td>€/kw</td>
<td></td>
</tr>
<tr>
<td>Work days</td>
<td>200</td>
<td>Days/year</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>80</td>
<td>km/h</td>
<td></td>
</tr>
<tr>
<td>AAADT</td>
<td>100 ... 2000</td>
<td>vehicles/day</td>
<td>Incl. both directions</td>
</tr>
</tbody>
</table>
Assumptions 2 – the ERS

• **ERS installation cost**
  - \( C_{ers} = k_0 \cdot P_{ers} + k_1 \cdot L_{ers} + k_2 \cdot k_{ers} \cdot L_{ers} \cdot N_{ers} \)
  - \( P_{ers} \) = total power of modelled road length
  - \( L_{ers} \) = modelled road length
  - \( N_{ers} \) = number of modelled ERS lanes (normally 2, one in each direction)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_0 )</td>
<td>300</td>
<td>k€/MW</td>
<td></td>
</tr>
<tr>
<td>( k_1 )</td>
<td>150</td>
<td>k€/km</td>
<td></td>
</tr>
<tr>
<td>( k_2 )</td>
<td>500</td>
<td>k€/km</td>
<td></td>
</tr>
<tr>
<td>( k_{ers} )</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Static charger cost</td>
<td>200</td>
<td>€/kW</td>
<td></td>
</tr>
<tr>
<td>Isol DC/DC cost</td>
<td>100</td>
<td>€/kW</td>
<td></td>
</tr>
</tbody>
</table>

• **ERS maintenance cost**
  - 2% of installation per annum
Four scenarios
1: Max full electric, charge @ end stop

- 0.5 h: Half cycle
- SOCmin: State of Charge minimum
- DODmax: Depth of Discharge maximum
- k_ERS: Kinetic Energy Storage System factor
- dERS: Distance of Energy Recovery System

- Full Charge: XX km with ERS
- YY km without ERS

- Full Charge: YY km without ERS
2: Max full electric. No charge @ end stop

Half cycle

SOCmin

DODmax

100 %

0.5 h

k_{ERS} \cdot dERS

dERS

XX km with ERS

YY km without ERS

YY km without ERS

Full Charge

A₀

A₁

B₀

B₁
3: Hybrid only on end route, no charge @ end stop

![Graph showing hybrid vehicle performance with and without ERS.]
4: Hybrid everywhere, except on ERS tracks

Half cycle

100 %

SOCmin

DODmax

0.5 h

0.5 h

A₀ A₁ B₁ B₀

XX km with ERS

YY km without ERS

YY km without ERS

k_{ers} d_{ERS}

d_{ERS}
Parameter Sweeps (reference case in RED)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Unit</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT</td>
<td>[50 100 1000 1500 2000]</td>
<td>Veh/day</td>
<td>Incl both directions</td>
</tr>
<tr>
<td>L_{road}</td>
<td>[50 100 150 200 250]</td>
<td>km</td>
<td>A_1 to B_1 in Figure 1.1</td>
</tr>
<tr>
<td>L_{end}</td>
<td>[10 20 30 40 50]</td>
<td>km</td>
<td>A_1 to A_0 to A_I, same for B</td>
</tr>
<tr>
<td>d_{ers}</td>
<td>[4 8 12 16 20]</td>
<td>km</td>
<td></td>
</tr>
<tr>
<td>ESS lifetime</td>
<td>[2 4 6 8 10]</td>
<td>years</td>
<td></td>
</tr>
<tr>
<td>ERS lifetime</td>
<td>[5 10 15 20 25]</td>
<td>years</td>
<td></td>
</tr>
</tbody>
</table>
Scenario 1

- Max full electric charge @ end stop

- Battery wear cost [Euro/kWh]
- Fuel energy cost [Euro/kWh]
- ERS aging cost [Euro/kWh]
- Total Cost [Euro/kWh]
Scenario 2

2: Max full electric. No charge @ and stop

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AadHnl</td>
<td>1.6x10^3 Vehicles/day</td>
</tr>
<tr>
<td>Locd</td>
<td>1.0x10^9 km</td>
</tr>
<tr>
<td>Load</td>
<td>3.0x10^3 [m]</td>
</tr>
<tr>
<td>dErs</td>
<td>1.5x10^3 [m]</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>5.5x10^-6 [Euro/m]</td>
</tr>
<tr>
<td>El cost</td>
<td>1.2x10^-4 [Euro/kWh]</td>
</tr>
<tr>
<td>Bst cost</td>
<td>2.0x10^-2 [Euro/kWh]</td>
</tr>
<tr>
<td>Bst cal life</td>
<td>6.0x10^7 [Years]</td>
</tr>
<tr>
<td>Ers lifetime</td>
<td>1.0x10^-6 [Years]</td>
</tr>
<tr>
<td>Roundtrip velocity</td>
<td>2.0x10^2 [kph]</td>
</tr>
<tr>
<td># of Veh in Op</td>
<td>4.6x10^2</td>
</tr>
<tr>
<td># of Veh out Op</td>
<td>2.1x10^2</td>
</tr>
<tr>
<td># of Veh Charging</td>
<td>0.1x10^3</td>
</tr>
</tbody>
</table>

Paper describing the calculations behind the figures.
Scenario 3

3: Hybrid only on end route, no charge @ end stop

- AADThd = 1.0e+03 Vehicles/day
- Lload = 1.5e+02 [km]
- Lend = 3.0e+01 [km]
- dERS = 1.0e+01 [km]
- Fuel cost = 1.5e+00 [Euro/km]
- ERS cost = 2.0e+02 [Euro/kW]
- Battery life = 6.0e+02 [Years]
- ERS lifetime = 1.0e+01 [Years]
- # of Yeh in Op = 4.6e+02
- # of Yeh on ERS = 3.1e+02
- # of Yeh Charging = 0.0e+00

Paper describing the calculations behind the figures.
Scenario 4

- **AADTHd**: 1000 Veh/day
- **Lroad**: 150 km
- **Lend**: 30 km
- **dERS**: 12 km
- **ESS lifetime**: 6 years
- **ERS lifetime**: 15 years
- **Scenario**: 4

**Hybrid everywhere, except on ERS tracks**
- AADTHd = 1.3x10^3 Veh/day
- Locost = 3.5x10^5 [€/veh]
- Lcost = 5.3x10^3 [km]
- dERS = 1.2x10^3 [km]
- Fuel cost = 1.1x10^6 [€/veh/yr]
- El cost = 1.4x10^6 [€/veh/yr]
- Battery cost = 2.6x10^6 [€/veh]
- Battery cost life = 6.1x10^6 [Yrs]
- ERS Runtime = 1.5x10^6 [Yrs]
- Roundtrip veh/day = 2.2x10^6 [veh]

**Battery cost [EUR/veh]**

**El energy cost [EUR/veh]**

**Fuel energy cost [EUR/veh]**

**ERS ageing cost [EUR/veh]**

**Total Cost [EUR/veh]**

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*Paper describing the calculations behind the figures*
Sensitivity analysis
Minimal cost for the scenarios
Conclusions

• Scenario 1, i.e. utilizing the battery as much as possible always gives the lowest total operational cost.

• The more vehicles (expressed as AADThd) that shares the ERS the lower the cost. Cars are not included in this study, but had they been, they would have contributed significantly to increase the AADT and thus to even lower cost.

• The sensitivity to the road length is low. This should be expected, as long as the AADThd is constant.

• The sensitivity to sectioning, i.e. to dERS, is also low. It affects the battery cycling, but only marginally pushes different combinations
Do you want to try?

- http://www.ers.waytoteam.com
THANK YOU!! :)

WELCOME TO CONTACT US
mats.alakula@volvo.com
http://emobilitycentre.se/eng