Multi-Objective Design Optimization of a Hybrid Electric Vehicle

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Optimus World Conference, Paris
Multi-Objective Design Optimization of a Hybrid Electric Vehicle

1. Setup and HEV Model
2. Automation and Process Integration
3. Selection of Parameters
4. Optimization Strategy
5. Conclusion and Results
Process Integration and Optimization of a Mathematics-based HEV

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1. HEV Challenges

- Many new components
- Less experience
- More interaction of more components
- New thermal effects
- More need for sharing

→ More need for optimization
1. Hybrid and E-Vehicle Components
## 1. Variable Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description [unit]</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MinSoCThreshold</td>
<td>Minimum SOC Threshold</td>
<td>0.3 – 0.6</td>
</tr>
<tr>
<td>ncell</td>
<td>Number of battery cells</td>
<td>100 – 200</td>
</tr>
<tr>
<td>Vmanifold</td>
<td>Engine manifold volume [m$^3$]</td>
<td>0.003 – 0.005</td>
</tr>
<tr>
<td>Bore</td>
<td>Engine bore [m]</td>
<td>0.0855 – 0.1</td>
</tr>
<tr>
<td>Stroke</td>
<td>Engine stroke [m]</td>
<td>0.0814 – 0.19</td>
</tr>
<tr>
<td>Apos</td>
<td>Area of battery pos.electrode [cm$^2$]</td>
<td>100 – 500</td>
</tr>
<tr>
<td>Aneg</td>
<td>Area of battery neg.electrode [cm$^2$]</td>
<td>100 – 500</td>
</tr>
<tr>
<td>apos</td>
<td>Specific surface of Apos [cm$^2$/cm$^3$]</td>
<td>3000 – 5000</td>
</tr>
<tr>
<td>aneg</td>
<td>Specific surface of Aneg [cm$^2$/cm$^3$]</td>
<td>2000 – 4000</td>
</tr>
<tr>
<td>Va</td>
<td>Nominal voltage of e-motor [V]</td>
<td>400 – 1000</td>
</tr>
<tr>
<td>Ia</td>
<td>Nominal current of e-motor [mA]</td>
<td>50 – 100</td>
</tr>
<tr>
<td>Vas</td>
<td>Phase voltage of e-motor [V]</td>
<td>50 – 150</td>
</tr>
<tr>
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1. Setup and HEV Model
1. Setup and HEV Model

**Goal**: the optimization goal is to minimize fuel consumption, while simultaneously keeping the maximum torque at a maximum.

- **Two objective functions have to be considered**
- **Multi-objective optimization strategies have to be applied**
1. Setup and HEV Model

Constraints: Two target requirements have to be considered during the optimization process

- Maximum temperature < 315 K
- Battery current < 500 A

Violation of these constraints leads to a non-feasible design and it will be marked as a failed experiment
## 1. Output Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Output parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power loss</td>
<td></td>
</tr>
</tbody>
</table>

### Objective

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Fuel consumption</td>
<td>Minimization</td>
</tr>
<tr>
<td>Engine torque</td>
<td>Maximization</td>
</tr>
</tbody>
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### Constraint

<p>| | |</p>
<table>
<thead>
<tr>
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<tr>
<td>Battery temperature</td>
<td>Smaller than 315 K, because higher values can damage the durability of the battery (&lt; 315)</td>
</tr>
<tr>
<td>Battery current</td>
<td>Smaller than 500 A, because higher values can damage the durability of the battery (&lt; 500)</td>
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</table>
Process Integration and Optimization of a Mathematics-based HEV

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5. Conclusion and Results
2. Automation and Process Integration

- **Integration of external methods**
  - HPC and Queuing Systems
  - Python API

**METHOD-LEVEL**

**WORKFLOW-LEVEL**

**INTERFACES**

Integration of software-tools
2. Automation and Process Integration

![Diagram of Process Integration for Optimization](image)

- **MapleSim**
- **C / C++**
- **Modelica**
- **Maple connector**

**Optimus**

*ISKO engineers*

*Optimus* 2014 World Conference
2. Automation and Process Integration

Workflow in OPTIMUS

- Design Variables
  - MinSoCThreshold
  - ncell
  - Stroke
  - Apos
  - Va
  - Vas
  - Bore

- Modified Input for MapleSim
- Vector Output
- Scalar Output

- Starting MapleSim and Extraction of Results
  - series_hev.mpl
  - series_hev_out.mpl

- Vector Output
  - vecthrmq
  - vecbcurr
  - vectemp
  - max_thrmq
  - max_bcurr
  - max_temp

- Scalar Output
  - objfuel
  - objtrackng
  - objtracng
  - objbcurr
  - objtemp
  - objloss

- ISKO engineers
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3. Selection of Parameters

### Linear Correlation Factors

<table>
<thead>
<tr>
<th>Pearson (Spearman)</th>
<th>objfuel</th>
<th>objtracking</th>
<th>objploss</th>
<th>objcurr</th>
<th>objtemp</th>
<th>objetorque</th>
</tr>
</thead>
<tbody>
<tr>
<td>objfuel</td>
<td>0.377 (0.429)</td>
<td>-0.087 (-0.239)</td>
<td>0.012 (0.006)</td>
<td>0.023 (0.002)</td>
<td>0.029 (0.011)</td>
<td>-0.531 (-0.611)</td>
</tr>
<tr>
<td>objtracking</td>
<td>-0.120 (-0.074)</td>
<td>-0.090 (-0.037)</td>
<td>0.004 (0.004)</td>
<td>0.009 (0.022)</td>
<td>-0.065 (-0.025)</td>
<td>-0.076 (-0.049)</td>
</tr>
<tr>
<td>objploss</td>
<td>0.027 (0.087)</td>
<td>0.241 (0.264)</td>
<td>-0.010 (-0.010)</td>
<td>0.005 (0.018)</td>
<td>-0.028 (-0.069)</td>
<td>-0.087 (-0.145)</td>
</tr>
<tr>
<td>objcurr</td>
<td>-0.137 (-0.165)</td>
<td>-0.252 (-0.245)</td>
<td>-0.027 (-0.035)</td>
<td>0.156 (0.164)</td>
<td>0.482 (0.563)</td>
<td>0.126 (0.174)</td>
</tr>
<tr>
<td>objtemp</td>
<td>0.011 (0.070)</td>
<td>0.273 (0.273)</td>
<td>-0.017 (-0.003)</td>
<td>-0.019 (-0.038)</td>
<td>-0.065 (-0.082)</td>
<td>0.019 (0.046)</td>
</tr>
<tr>
<td>objetorque</td>
<td>-0.117 (-0.124)</td>
<td>-0.332 (-0.226)</td>
<td>-0.025 (-0.027)</td>
<td>0.173 (0.159)</td>
<td>0.553 (0.555)</td>
<td>0.153 (0.156)</td>
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Red boxes indicate correlation factors ≥ 0.3.
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4. Optimization Strategy

1. Decide for an optimization strategy

2. Study: Investigate the behavior of the system and the Pareto points

3. Study: Investigate the influence of swarm size on mPSO
4. Optimization Strategy

**STEP 1** Design of Experiments
Exploration of the design space
Latin Hypercube Sampling with n experiments

**STEP 2** Response Surface Model
Describing the system behavior using mathematical models (Kriging)

**STEP 3** Multiobjective Optimization
Determine an optimal parameter combination on the model using evolution strategies (NSEA+/mPSO algorithm)
4. Optimization Strategy

1. Decide for an optimization strategy

2. Study: Investigate the behavior of the system and the Pareto points

3. Study: Investigate the influence of swarm size on mPSO
4. Optimization Strategy

All experiments during the optimization process

Algorithm: mPSO

Nominal experiment

2,200 evaluations
4. Optimization Strategy

Algorithm: mPSO

Nominal experiment

All feasible experiments during the optimization process

2,200 evaluations
4. Optimization Strategy

Algorithm: mPSO

All feasible experiments during the optimization process

Nominal experiment

9.500 evaluations
4. Optimization Strategy

All experiments during the optimization process

All feasible experiments during the optimization process

Algorithm: NSEA+

Nominal experiment

10,000 evaluations
4. Optimization Strategy

Algorithm: NSEA+

All feasible experiments during the optimization process

Nominal experiment

50,000 evaluations
4. Optimization Strategy

Algorithm: mPSO

- Optimum for max torque
- Optimum for fuel consumption
- Compromise solutions
- Nominal experiment
- 2,200 evaluations
- Pareto Points

max_torque vs. obj_fuel
4. Optimization Strategy

- NSEA+ (50,000 exp.)
- NSEA+ (10,000 exp.)
- mPSO (2,200 exp.)
- mPSO (9,500 exp.)
- Pareto Front
- Nominal experiment
4. Optimization Strategy

1. Decide for an optimization strategy

2. Study: Investigate the behavior of the system and the Pareto points

3. Study: Investigate the influence of swarm size on mPSO
4. Optimization Strategy

Pareto Front

Swarm: 50 → exp: 2500
4. Optimization Strategy

Best objfuel value

Swarm: 5
High values in the first iteration

Swarm: 10

Swarm: 15
Already good values in the first iteration

Swarm: 20

Swarm: 25

Swarm: 30

Swarm: 35

Swarm: 40

Swarm: 50

Already good values in the first iteration
4. Optimization Strategy

Best max_torque value

Swarm: 5

Swarm: 10

Swarm: 20

Swarm: 25

Swarm: 30

Swarm: 35

Swarm: 40

Swarm: 50

Small swarm can lead to local behavior

High values in the last iteration
4. Optimization Strategy

# valid points

Swarm: 5

Swarm: 10

Swarm: 15

Swarm: 20

Swarm: 25

Swarm: 30

Swarm: 35

Swarm: 40

Swarm: 50

Lower number of valid points in the last iteration

High number of valid points in the last iteration
4. Optimization Strategy

# better points (compared to nominal)

Swarm: 5

Swarm: 10

Swarm: 15

Swarm: 20

Swarm: 25

Swarm: 30

Swarm: 35

Swarm: 40

Swarm: 50

Increasing number of better points with increasing iteration number (>10)

Many better points in the last iteration
4. Optimization Strategy

# Pareto points

Swarm: 5

Swarm: 10

Swarm: 15

Swarm: 20

Swarm: 25

Swarm: 30

Swarm: 35

Swarm: 40

Swarm: 50

Low total number of Pareto points found BUT: High number compared to number of evaluations

High total number of Pareto points found BUT: Low number compared to number of evaluations
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5. Conclusion and Results

- Optimus offers the user a lot of flexibility by allowing the selection of many options for the algorithm.
  - For inexperienced users good default values are predefined.
  - Advanced users have the possibility to change the settings to improve the optimization behavior.
5. Conclusion and Results

• In case of expensive simulations or a small amount of time, the user can afford less evaluations than suggested

→ The user can decrease the swarm size and therefore perform more iterations
5. Conclusion and Results

✓ Easy-to-use procedure to set up and handle a complex vehicle model in MapleSim

✓ Efficient automation possibility using OPTIMUS

✓ Application of advanced optimization algorithms without additional effort
QUESTIONS ? ? ?

Thank you for your attention

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