All-in-one Simulation and DoE Methodology for the Evaluation and Optimisation of HEV Configurations

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1. Motivation
2. Hybrid concepts
3. Significance of the simulations
4. Structure of the universal hybrid-vehicle model
5. An example of results based on a parallel hybrid concept
6. Use of the integrated DoE approach
7. Summary
8. Outlook
1. Introduction

Hybrid vehicles worldwide

Growing hybrid-vehicle markets in all classes
1. Introduction

Volkswagen will launch the Touareg Hybrid on the market in 2010.
2. Hybrid concepts

Parallel hybrid

Serial hybrid

Power split

Other concepts?
3. Significance of the simulations

- Optimisation of components
- Functional analyses
- Optimisation of strategies
- Reduction of tests
4. Model structure

General aspects of the simulation model
- Comparability of concepts in respect of performance and consumption
- Speedy preparation and execution of the simulation
- Simple handling
- Use of power losses based on engine maps
- High degree of precision
4. Model structure

Basic idea:
One model for different concepts

- EM
- ICE
- C
- W
- Bat
- TM
- C
- EM
- C
- W

- ICE: Internal combustion engine
- EM: E machine
- TM: Transmission
- Bat: Battery
- W: Wheel
- C: Clutch

- Mechanical
- Electrical
- Control
4. Model structure

Parallel hybrid

- ICE: Internal combustion engine
- EM: E machine
- TM: Transmission
- Bat: Battery
- W: Wheel
- C: Clutch

Mechanical Electrical Control
4. Model structure

Serial hybrid

- **ICE**: Internal combustion engine
- **EM**: E machine
- **TM**: Transmission
- **Bat**: Battery
- **W**: Wheel
- **C**: Clutch

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**Mechanical**

- **Electrical**
- **Control**
4. Model structure

Power split

- ICE: Internal combustion engine
- EM: E machine
- TM: Transmission
- Bat: Battery
- W: Wheel
- C: Clutch

Control
- ICE
- EM
- TM
- Bat
- W

Mechanical

Electrical

Control
4. Model structure

Solution: All-in-one model

Fig.: GT Suite model without control system
4. Model structure

Solution: All-in-one model with following characteristics

- One file for all models (3 files in the case of power split)
- Assignment of data via the user interface
- Integration of improvements by means of DoE
- Computing time faster than real time or the several hours needed for DoE
4. Model structure

Modelling of the control system

Fig.: Control system of the model
### 4. Model structure

#### Model levels

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1. Parallel hybrid
2. Parallel operation

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![Diagram of a vehicle's powertrain system](image-url)
4. Model structure

Strategy of the operating states

**Condition**

SOC < SOC\text{min,bat}

Load demand > Limit

**Logic**

SOC < SOC\text{target}

ICE on

SOC > SOC\text{min,bo}

**State**

Recharging

Boosting

Dependency of the recharging, boosting and electric driving operating states (ICE off) on the battery's state of charge (SOC) and the load demand.
5. Results

Parallel hybrid example

Compact Class vehicle
Cycle: NEDC
State of charge

![Graph showing state of charge (SOC) and vehicle velocity over time.](image-url)
5. Results

Parallel hybrid example

Compact Class vehicle
Cycle: NEDC
Engine Speed

![Engine Speed Graph]

- ICE
- EM1
- EM2

Date: 09.11.2009
Aggregateentwicklung
5. Results

Parallel hybrid example

Compact Class vehicle
Cycle: NEDC
Engine power
6. Design of Experiment

Steps involved

1. Model making
2. Parameter optimisation
3. Variant for comparison
4. Parameter optimisation
6. Design of Experiment

Target magnitudes

- Fuel consumption $\rightarrow$ Minimum
- State of charge $\rightarrow$ Initial value

Compact Class vehicle
Cycle: FTP 72
General condition:
End SOC = Start SOC
Inclusion of the GT Suite model in the Volkswagen simulation environment

Model depth

High

Component simulation

Coupled simulations

Component

Vehicle

GT Suite model
7. Summary

A universal vehicle model has been developed for vehicle simulations with the following main characteristics:

**Functionality**
- Simulations of consumption and performance for hybrid and electric vehicles

**User-friendliness**
- Parameter list for inputs
- Simple file handling
- Clear model
- Easy to change

**Postprocessing**
- Time curves
- Integral variables
- DoE
7. Outlook

• Specifying the details of individual components
• Taking the thermal management into account
• Coupling in the context of component simulations
Thank you!