Driving dynamics and hybrid combined in the torque vectoring

Concepts of axle differentials with hybrid functionality and active torque distribution

Vehicle Dynamics Expo 2009 ‘Open Technology Forum’

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Overview

Driving dynamics and hybrid combined in the torque vectoring

Initiation

- Motivation
- Torque Vectoring and driving dynamics
- Simulation approach

2 Examples of "Hybridization with active torque distribution"

- Design
- Functionality

Evaluation results for longitudinal and lateral dynamics

- Layout and optimization of longitudinal dynamics
- Layout and optimization of lateral dynamics

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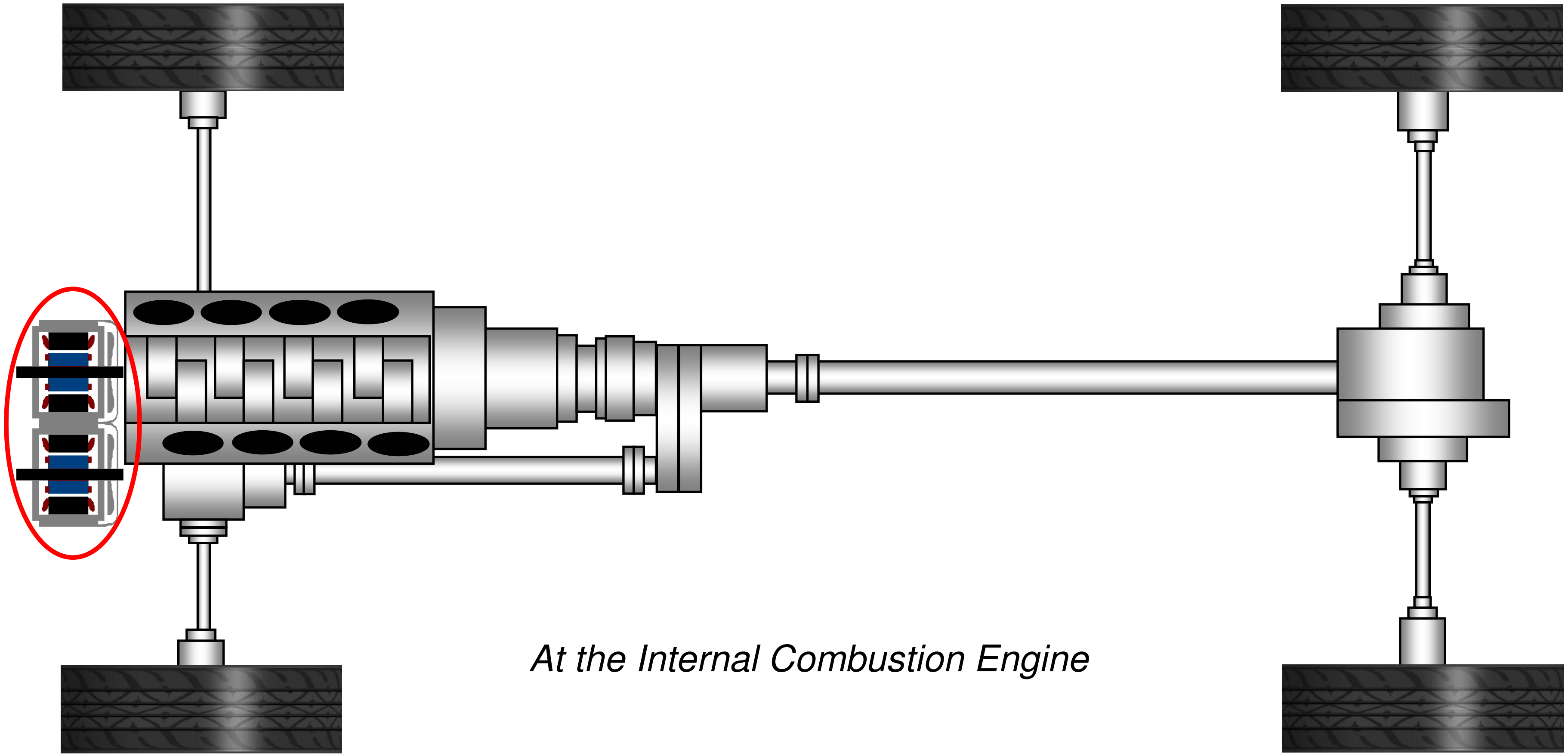
- **Active manipulation of lateral dynamics**
  – Torque Vectoring System
- **Active manipulation of longitudinal dynamics**
  – Traction advancement
  – Advancement of acceleration behavior
- **Hybrid function**
  – Energy recovery and boost function
- **Ease integration**
  – Moderate changes in driveline design and package
  – Preservation of engine and driveline configurations
  – Modularity and ability to retrofit

Positioning possibilities

Integration of electrical machines in the powertrain



At the Internal Combustion Engine

Quelle:vgl. VDI-Berichte Nr. 1943, 2006

Positioning possibilities

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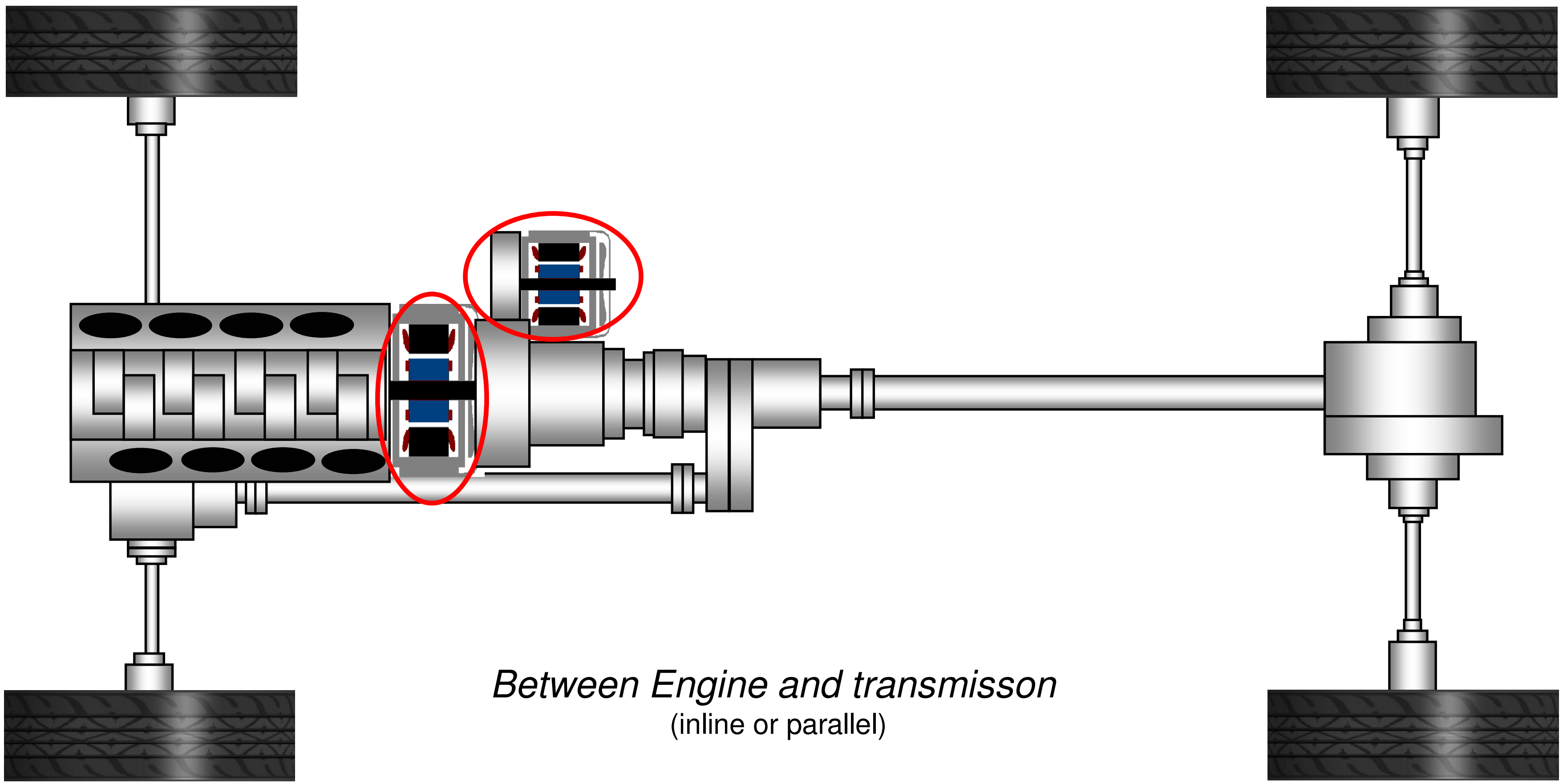

Between Engine and transmisson
(inline or parallel)

Quelle:vgl. VDI-Berichte Nr. 1943, 2006

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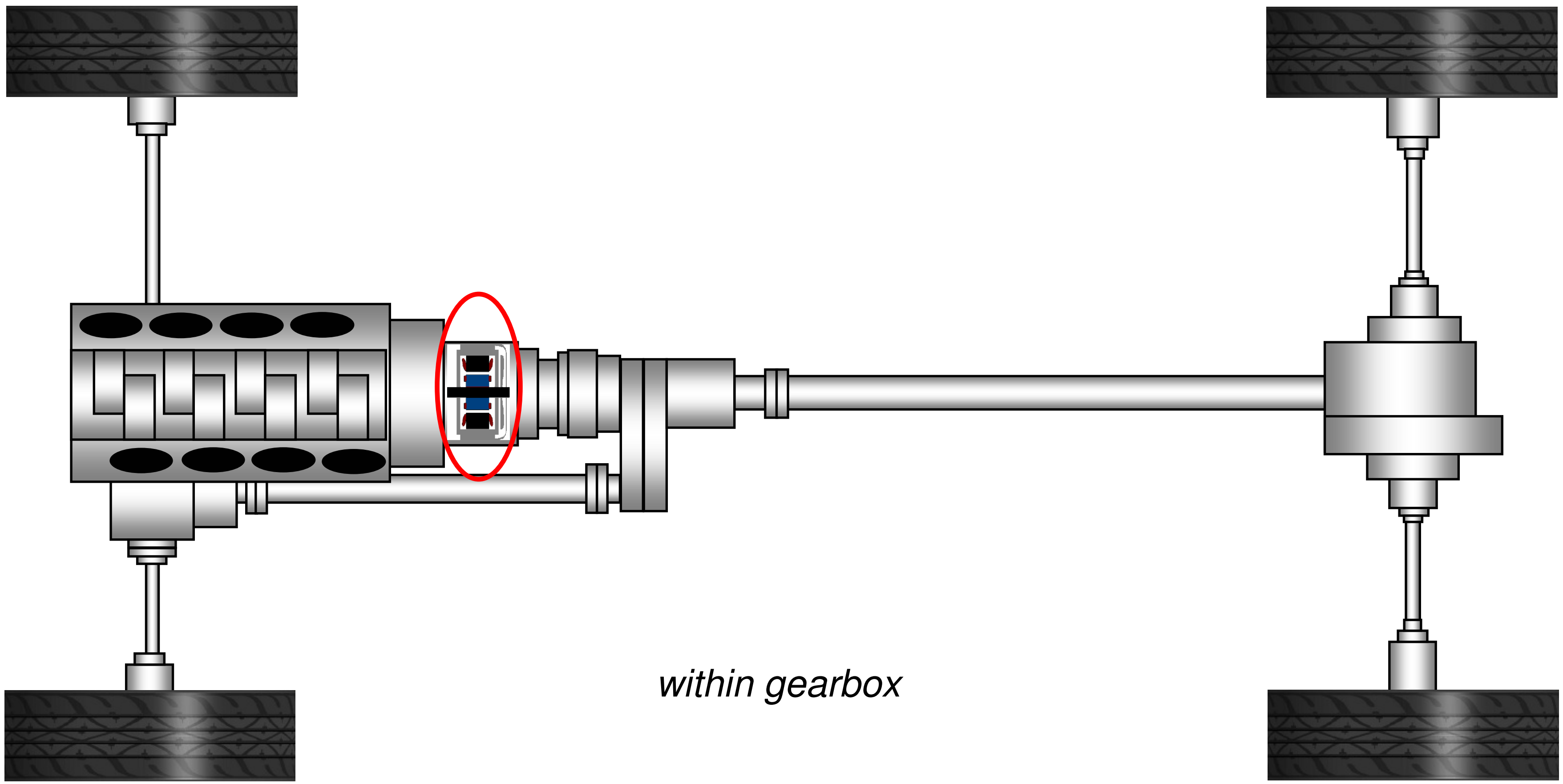

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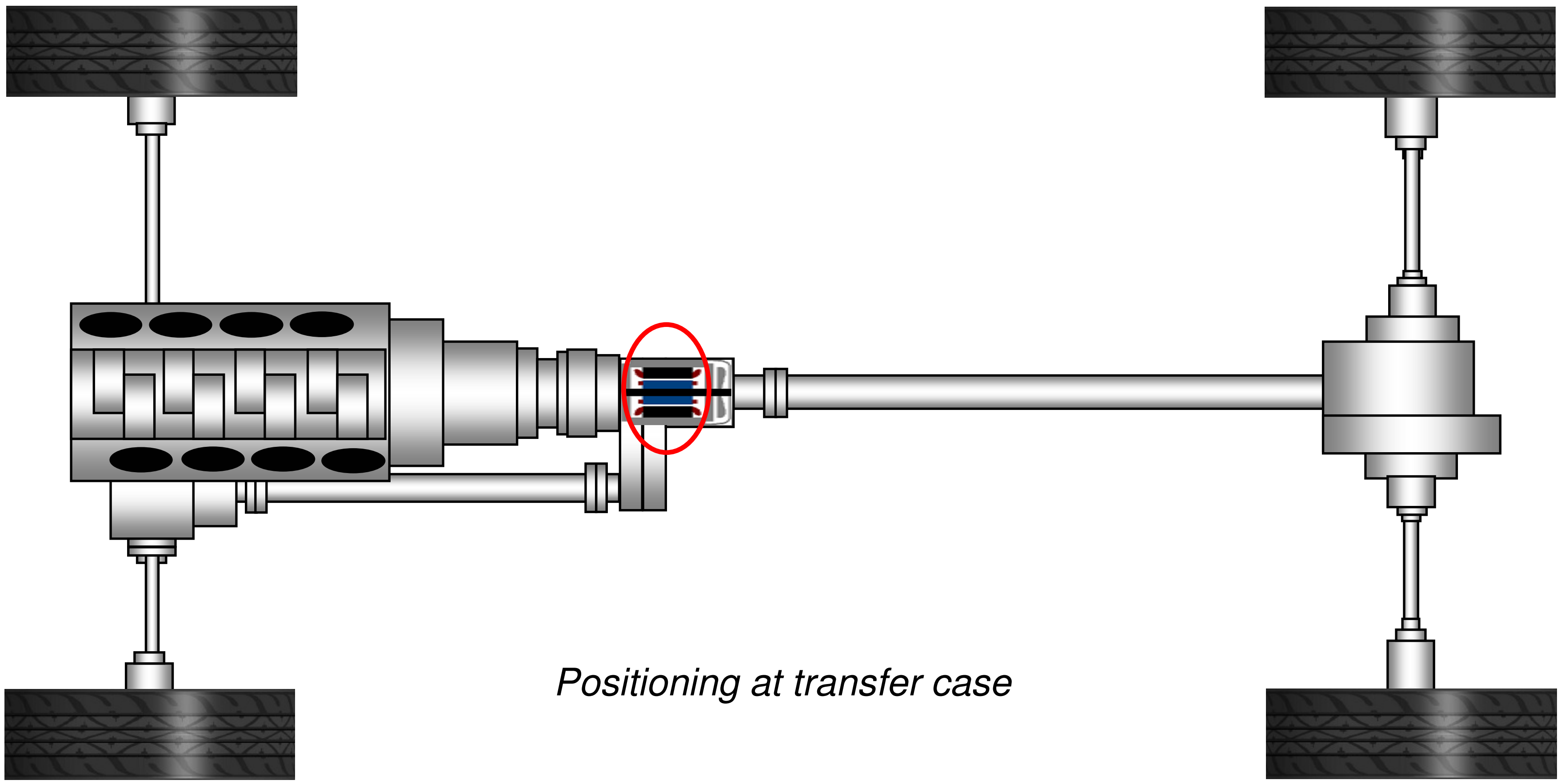
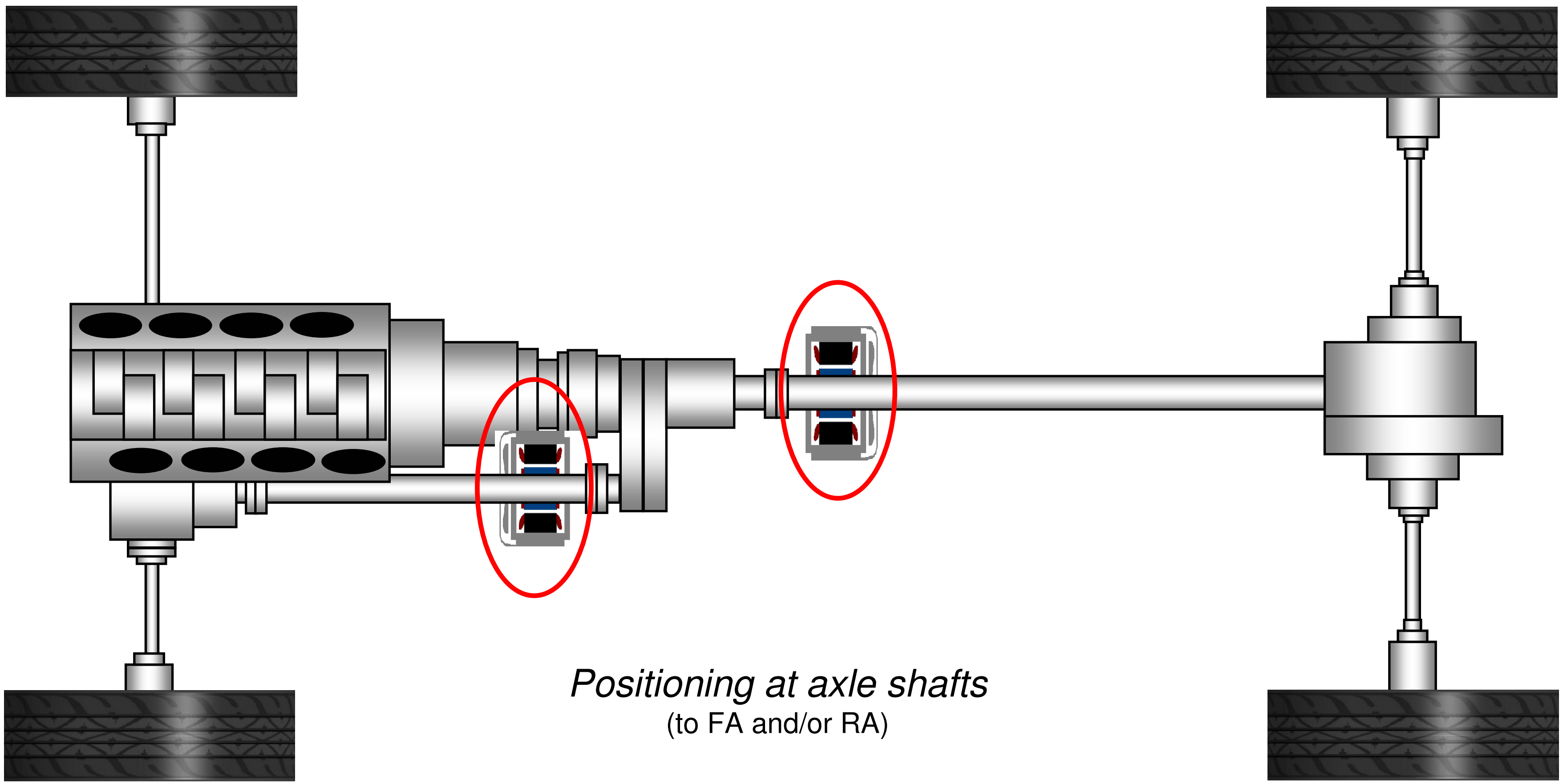


Positioning at transfer case

Quelle:vgl. VDI-Berichte Nr. 1943, 2006

Positioning possibilities

Integration of electrical machines in the powertrain

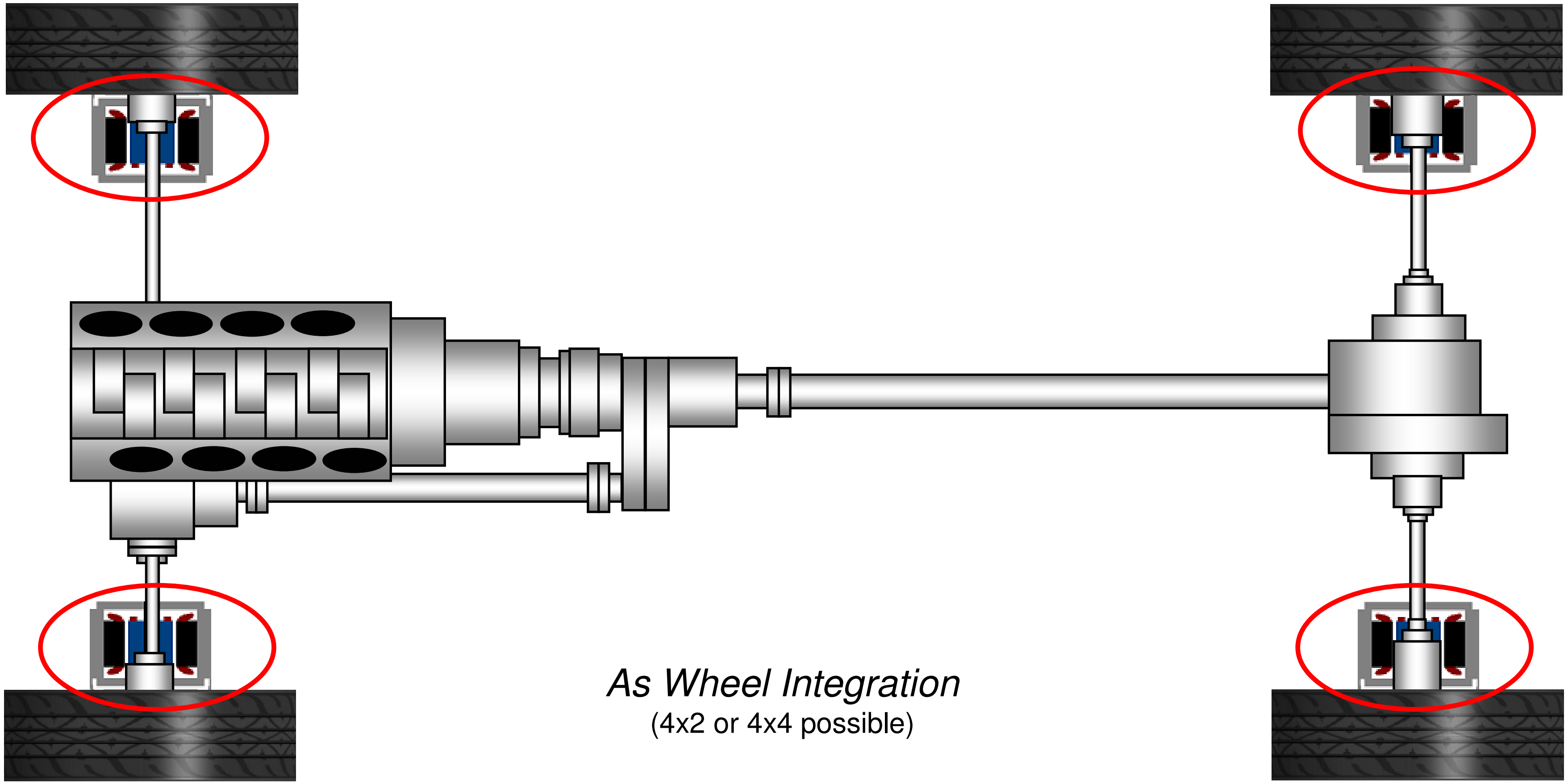


Positioning at axle shafts
(to FA and/or RA)

Quelle:vgl. VDI-Berichte Nr. 1943, 2006

Positioning possibilities

Integration of electrical machines in the powertrain

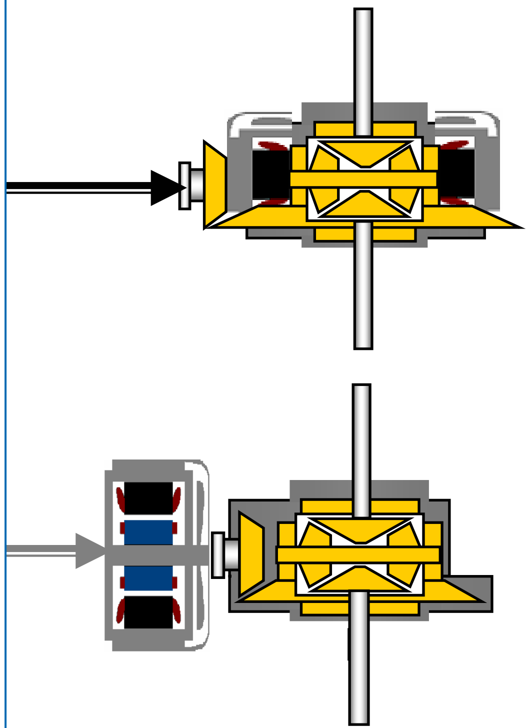
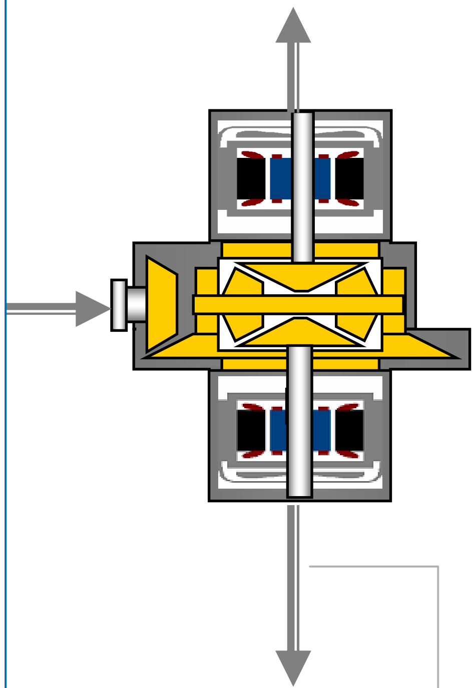
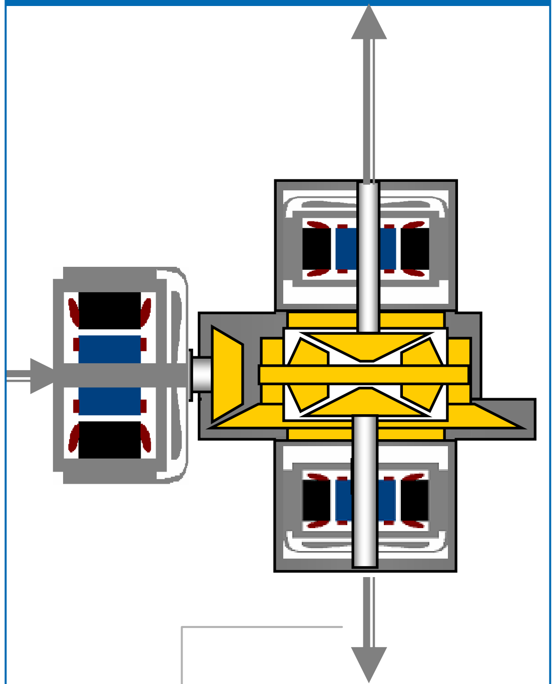


As Wheel Integration
(4x2 or 4x4 possible)

Quelle:vgl. VDI-Berichte Nr. 1943, 2006

Possible positions at the differential

Integration of electrical machines in the powertrain

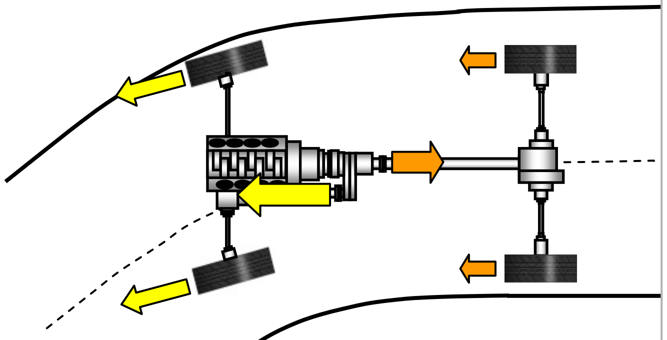
1 electrical machine	2 electrical machines	3 electrical machines
		

Axle Torque Support

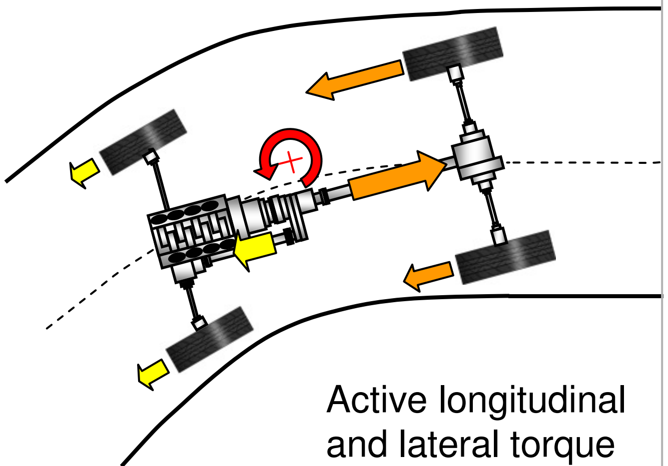
Wheel Individual Torque distribution possible

Axle differential with active torque distribution

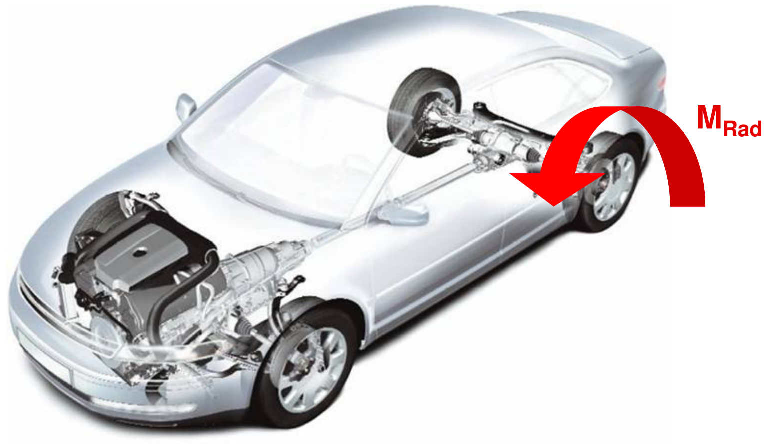
Torque-Vectoring



Understeering driving behavior without active torque distribution



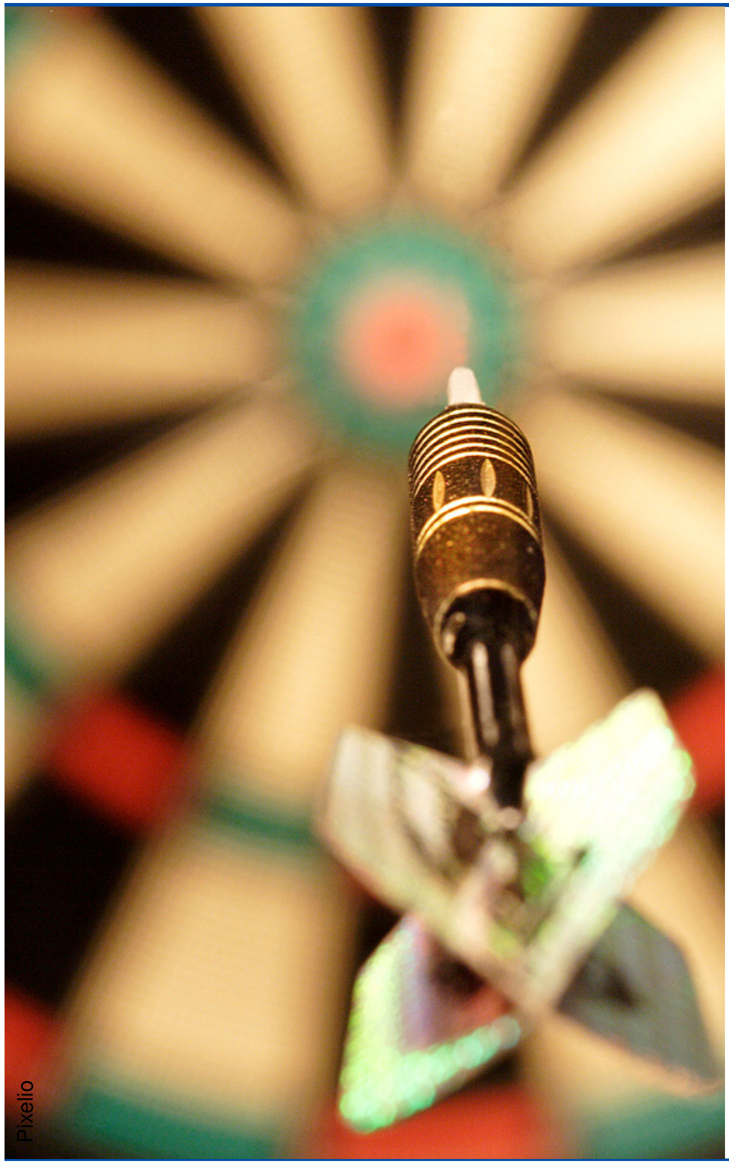
Active longitudinal and lateral torque distribution



Positive effect on

- Traction
- Critical cornering speed
- Self-steering response
- Handling and cornering characteristics
- Agility
- Yaw damping / yaw boosting
- Reducing brake intervention

Basic Optimization Targets
System Definition



- **Longitudinal Dynamics**
  - Optimal E-Machine Concept related to driving Cycle and performance targets
  - Optimal Battery Capacity related to driving Cycle
  - Optimal Hybrid Strategy related to driving Cycle
- **Lateral Dynamics and Driving safety**
  - Optimal E-Machine Concept and set-up for dynamic Torque Vectoring
  - Targets for mass distribution and self steer characteristics
  - Limitations to hybrid strategy under lateral dynamics
  - Necessary sub-controls for ASR/MSR and ESC Intervention

→Networked Simulation approach for Optimization and pre evaluation through virtual test runs

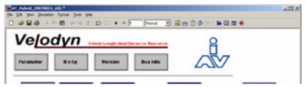
Simulation environment
Networked simulation

Use of EXITE-ACE as co-simulation tool to connect IAV-powertrain model VeLoDyn and common handling simulation tool veDyna

Powertrain model ⟷ **Integration tool** ⟷ **Vehicle model**

Powertrain model

Velodyn



- detailed Powertrain model representing hybrid architecture and contains operational strategy

Integration tool

EXTESSY
EXITE ACE

Vehicle model

TESIS DYNAware veDYNA

- detailed vehicle chassis model
- detailed environmental description including a maneuver controller for longitudinal/lateral maneuver setup

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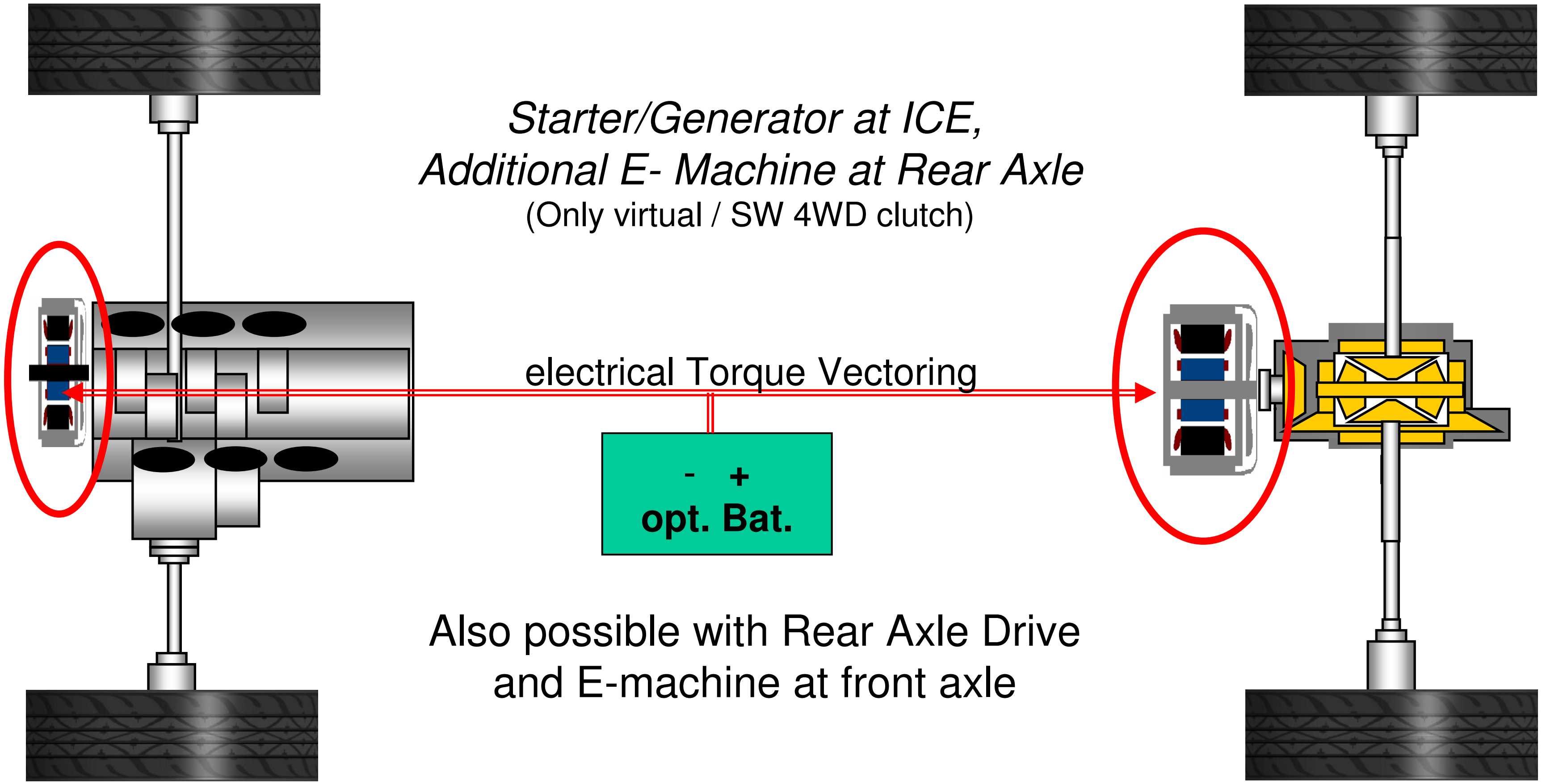
Summary

#1 Example, roughly equiv. to Lexus RX400h

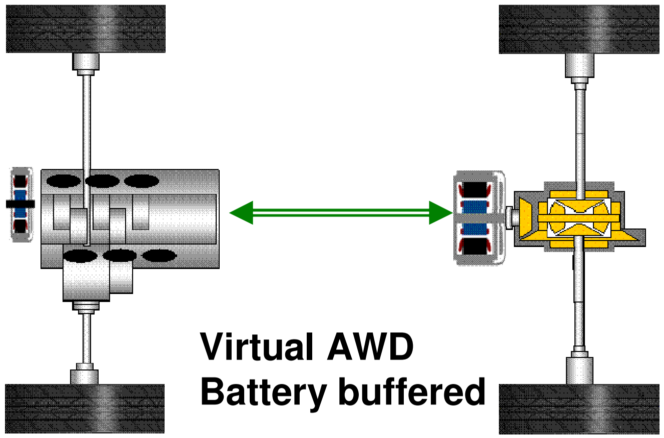
Integration of electrical machines in the powertrain



Quelle:vgl. VDI-Berichte Nr. 1943, 2006

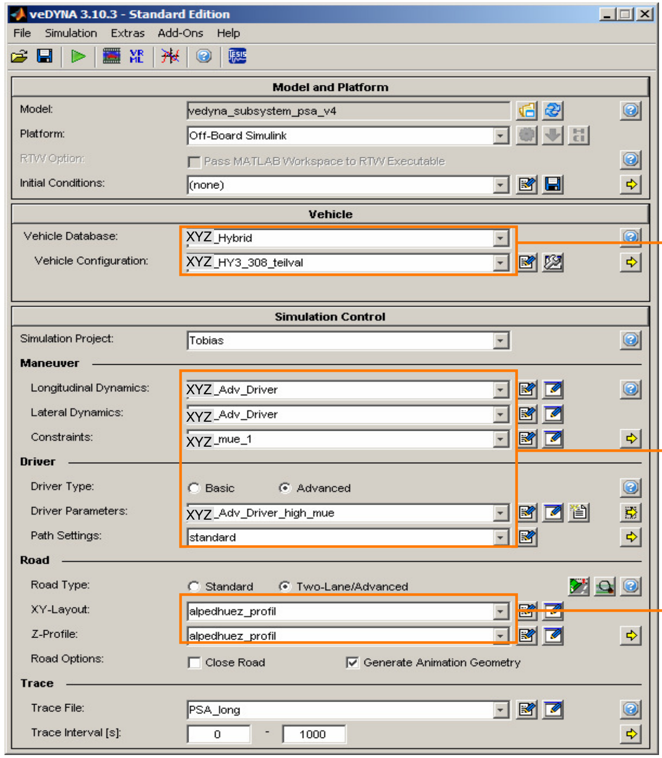
Potential Hybrid strategy (w/ Rear Axle E-Machine)

Integration of electrical machines in the powertrain



- Battery charging during normal driving
- Basic Recuperation
  (engine drag torque superposition)
- Brake recuperation (system blending).
- AMT shift support (boost)
- Driving with E-machine only
- 4WD-strategy and rear axle boost
- Safety strategy for:
  - Driving with E- machine in "Active Short“
  - Erroneous Torque set-point / sign
  - Slip intervention (ASR/MSR)
  - ESC and ABS intervention (e. g. under coupled inertia)

Simulation settings
3d-Alpe d'Huez simulation



Vehicle parameterization

Advanced driver settings and road conditions

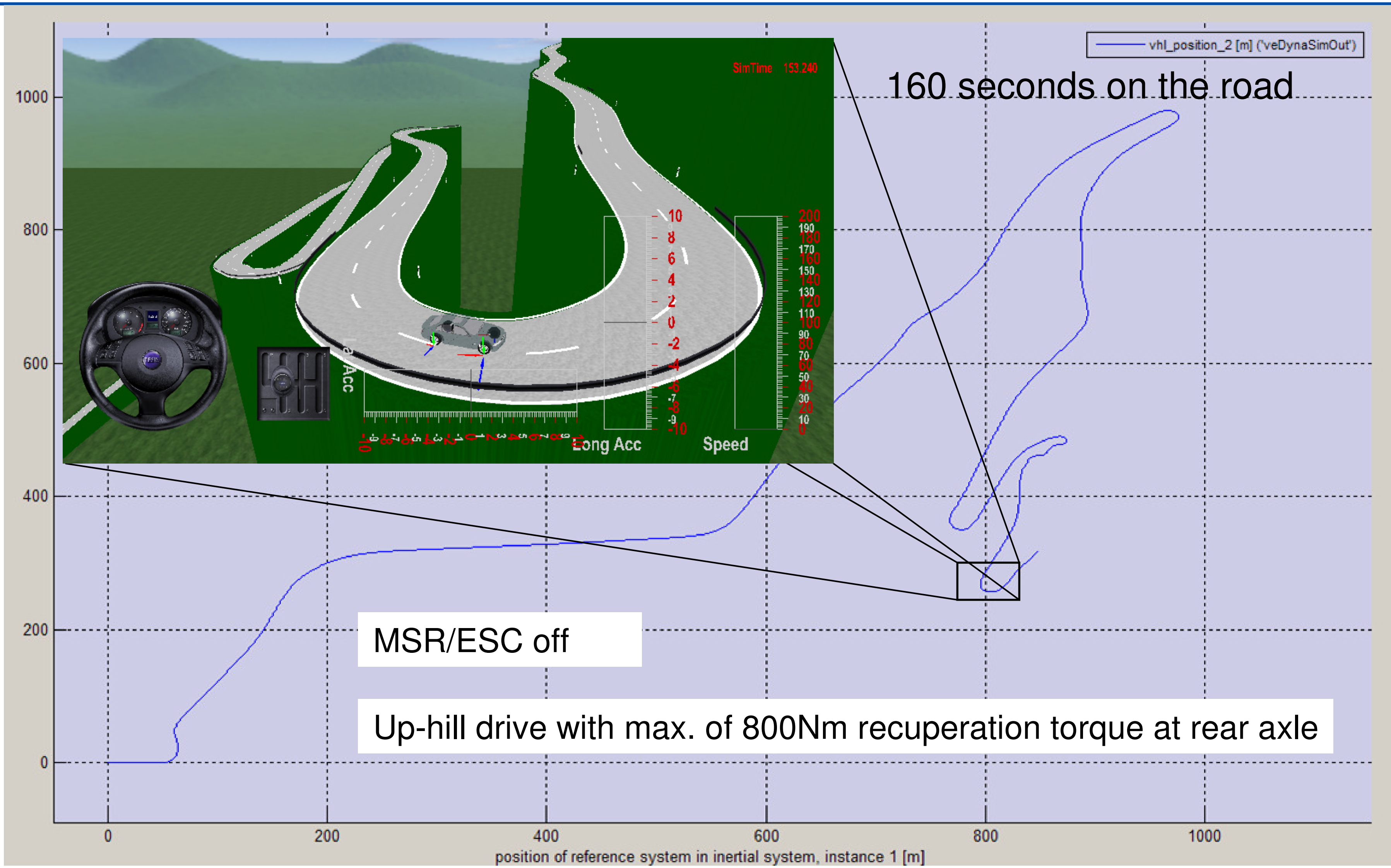
3D-Two-Lane Alpe d'Huez road profile

→ Implementation of a ASR/MSR controller by IAV

- Front and rear E-Machine scaled from longitudinal optimization
- Driver used form veDyna expect gear shifting
- All hybrid functions enabled
- SOC at start: 70 %
- 4WD torque split strategy:
    1. As much as possible with front axle, then add rear axle
    2. Permanent 4WD suport SOC dependent
- ASR on
- MSR on/off

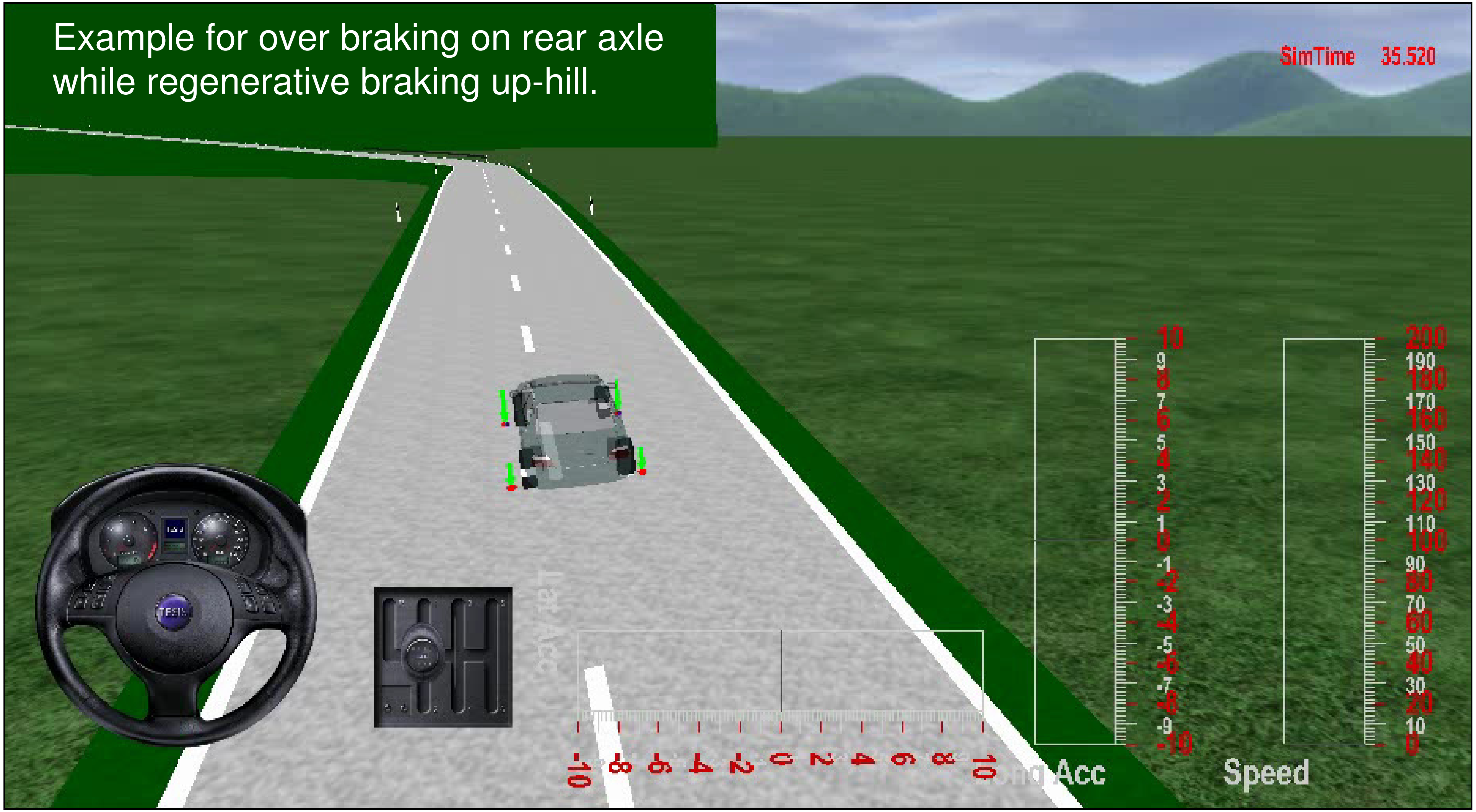
Vehicle behaviour while regen. braking on Alpe d'Huez

3d-Alpe d'Huez simulation



Vehicle behavior while regen. braking on Alpe d’Huez

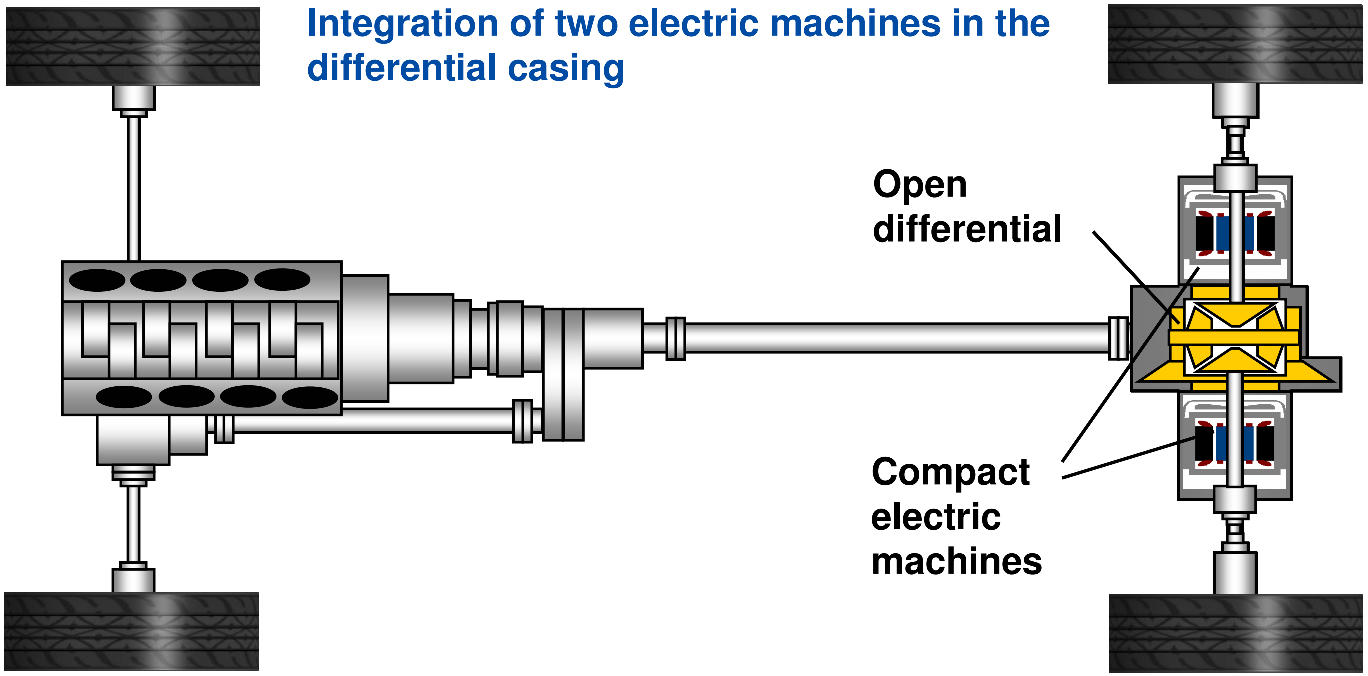
Example for over braking on rear axle while regenerative braking up-hill.



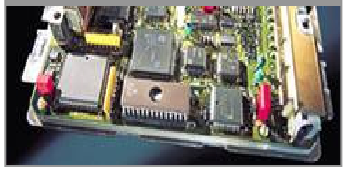
Integration of electric machines in the powertrain

#2 Rear Axle differential with active torque distribution

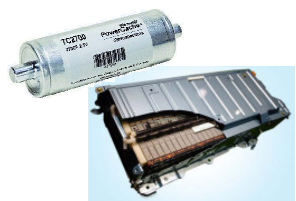
Integration of two electric machines in the differential casing



Control



Energy storage



Optional for hybrid capability

Wheel-specific torque vectoring

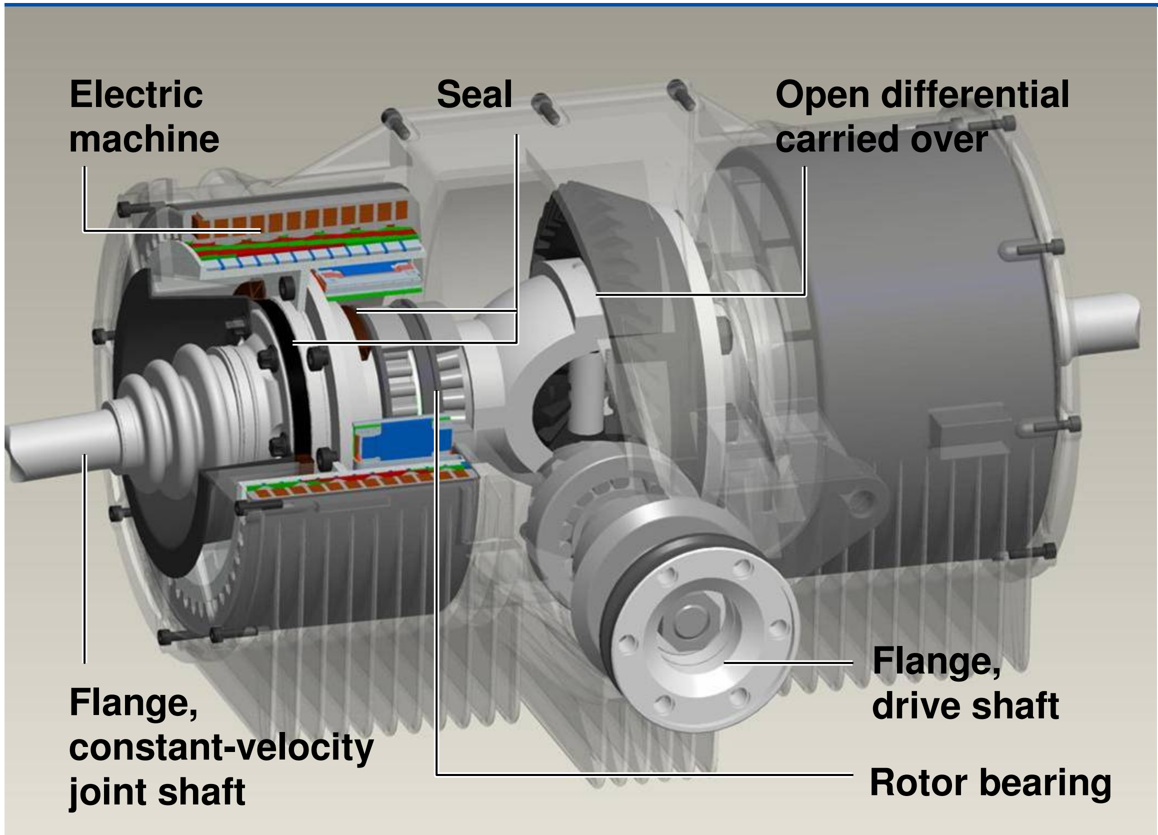
- Existing engine/transmission configurations (MT, AMT, DCT, CVT, AT) can be carried over
- Rear-axle module: supplier add-on
- Utilization of wheel-specific coefficient of friction

Using a suitable storage system

- Parallel hybrid
- Improved longitudinal dynamics
- Avoidance of traction interruption

Design of active differential

Axle differential with active torque distribution



Flexibility and modularity

- Open differential
- Active differential
- ... with hybrid function
- Basis for electric axle
- Capability of integrating gear ratio

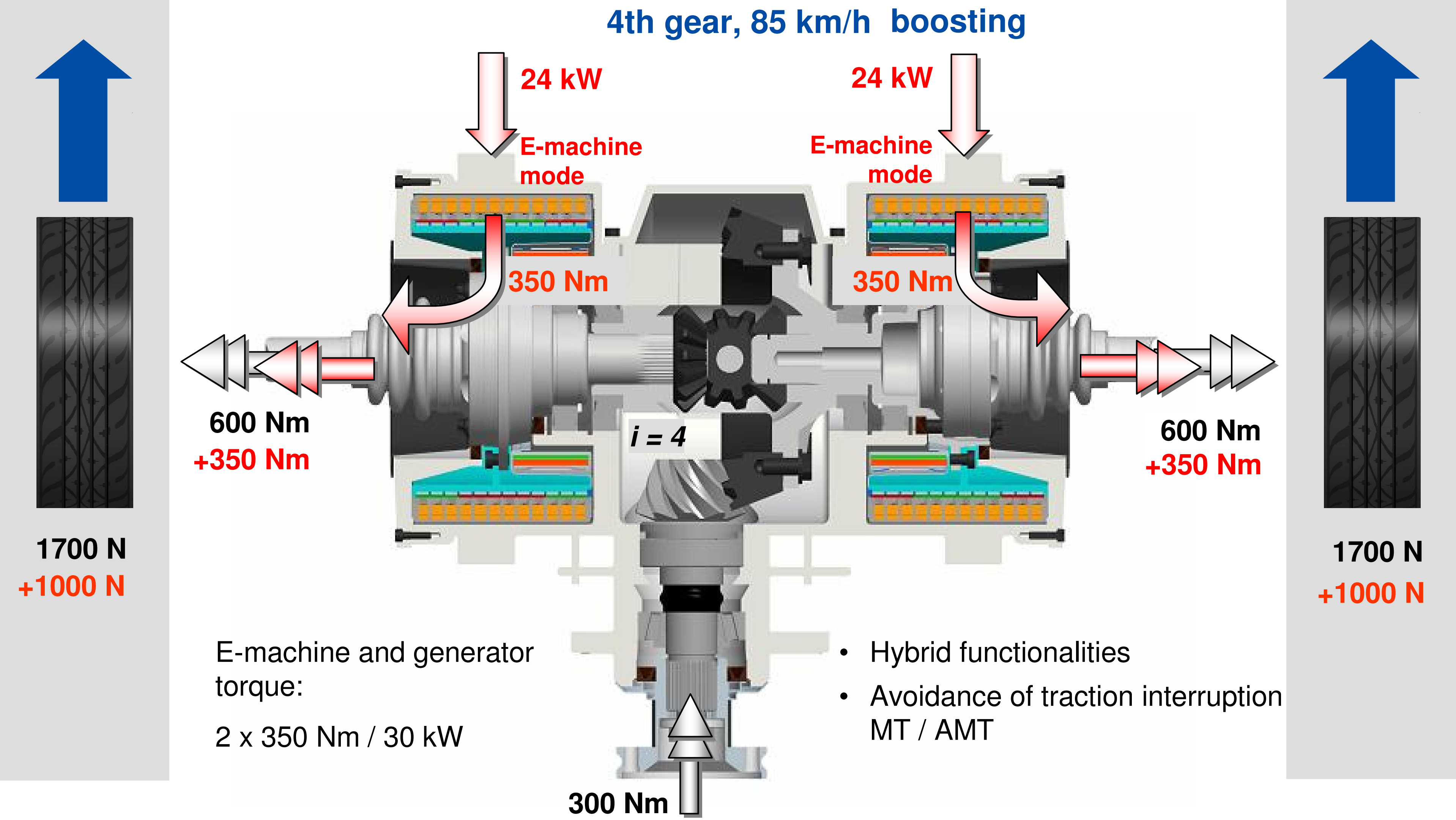
→ High degree of integration for electric machine without gear ratio

→ Existing mechanical structures and technologies carried over

→ Low additional moments of inertia, utilization of existing package

Hybrid functionalities

Axle differential with active torque distribution



E-machine and generator torque:

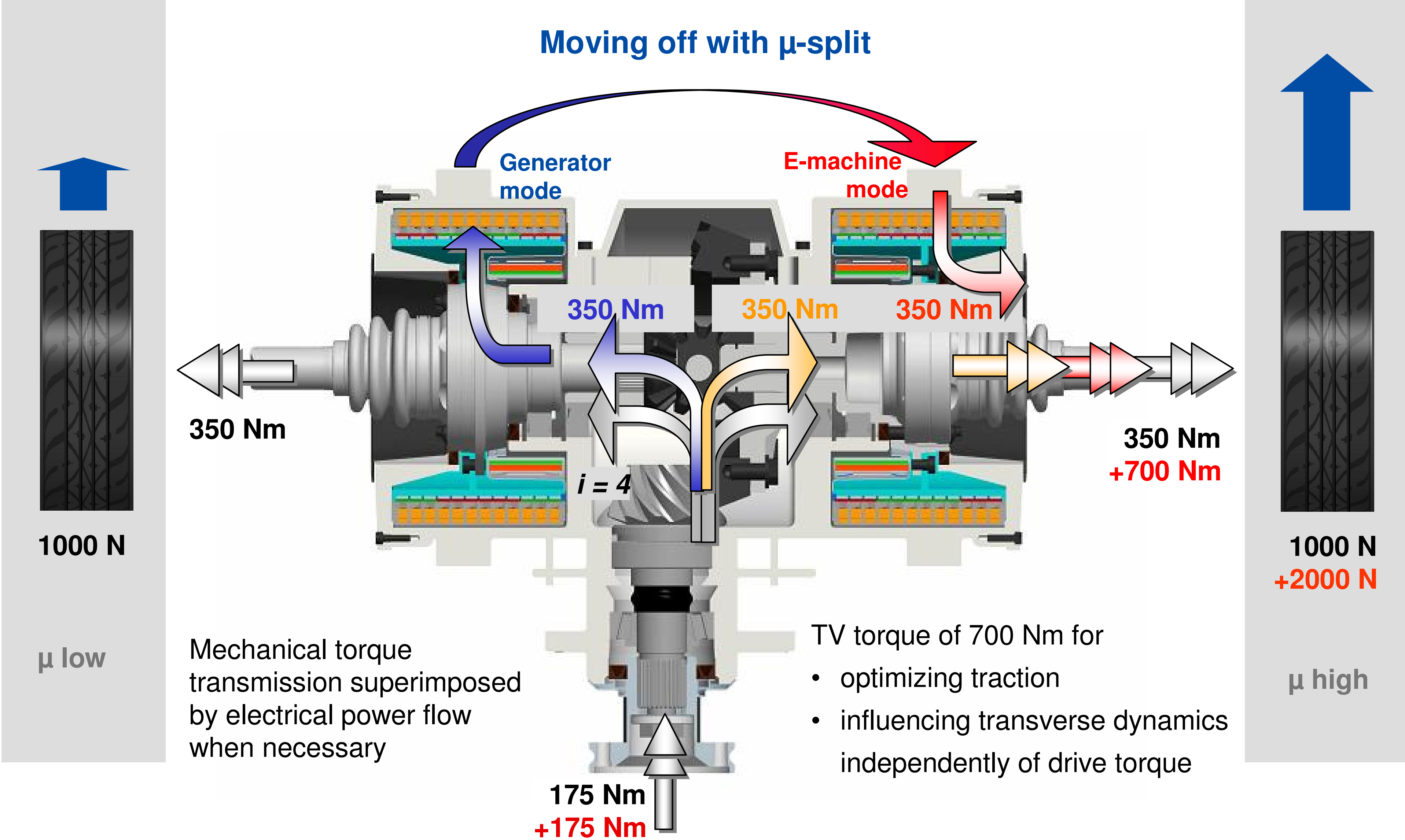
2 x 350 Nm / 30 kW

- Hybrid functionalities
- Avoidance of traction interruption MT / AMT

Torque vectoring functionality

Axle differential with active torque distribution

Moving off with µ-split



Mechanical torque transmission superimposed by electrical power flow when necessary

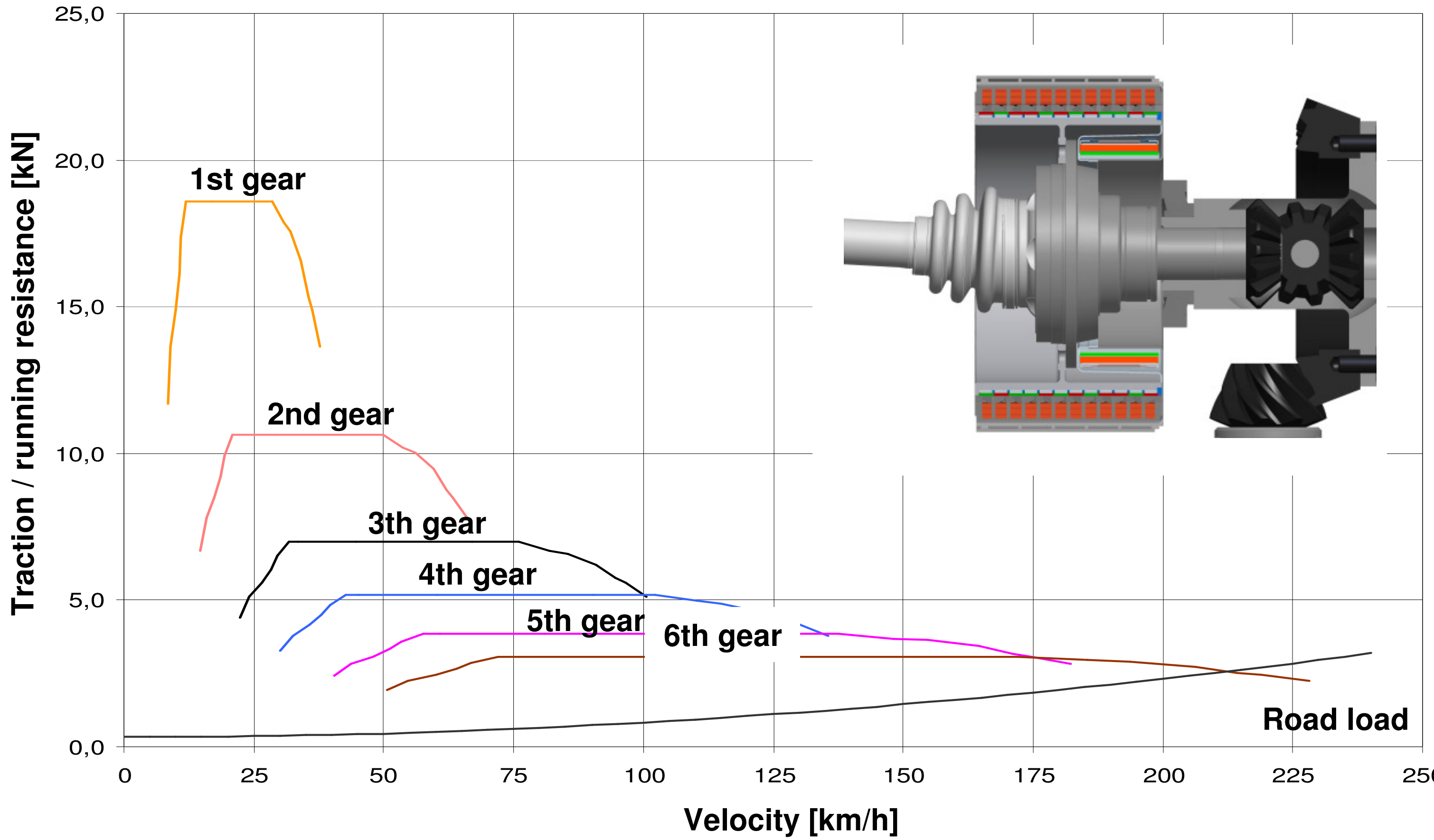
TV torque of 700 Nm for

- optimizing traction
- influencing transverse dynamics independently of drive torque

Traction potential in boosted mode

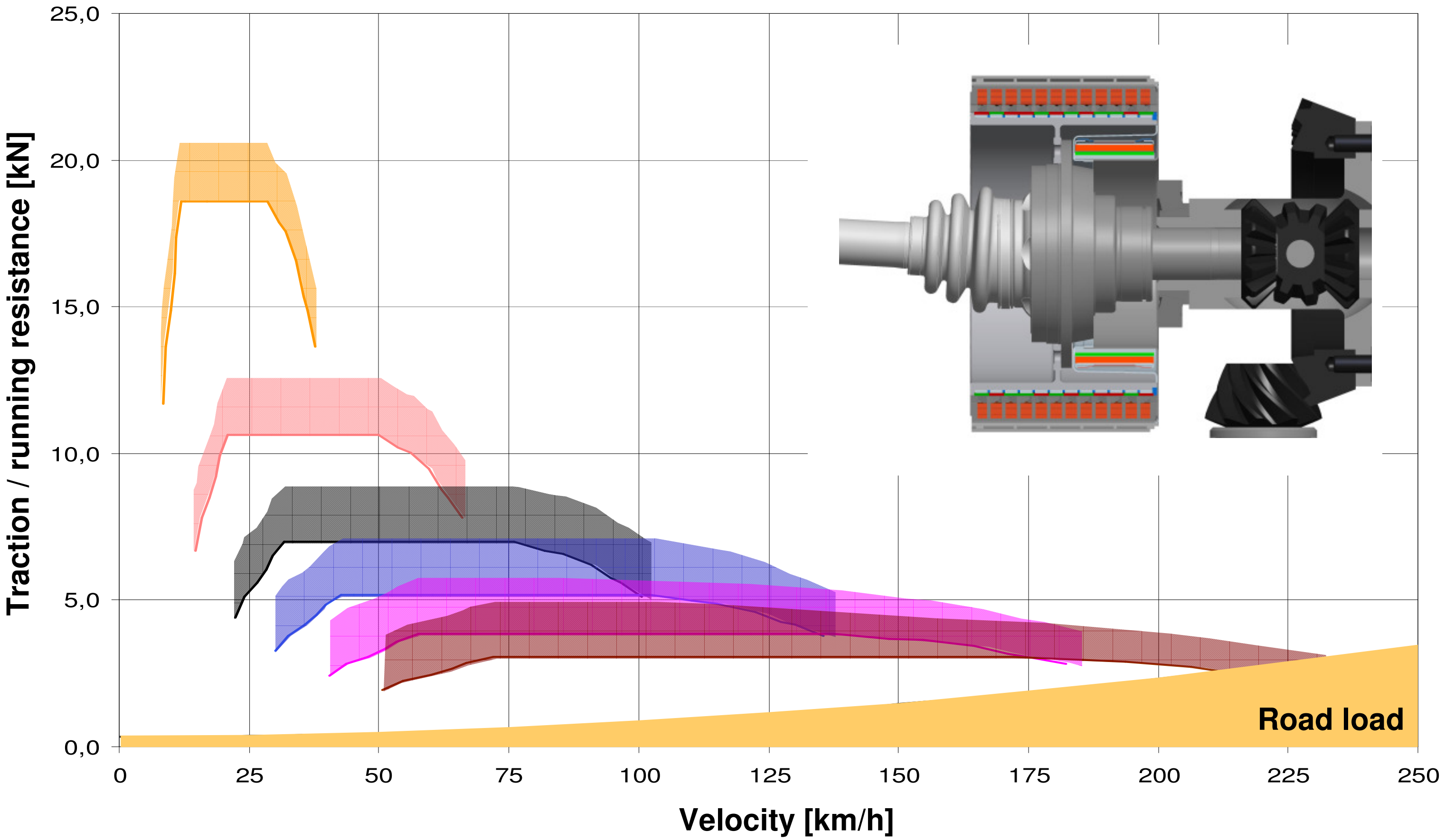
Tractive -power chart

Constant-speed driving without e-machines



Traction potential in boosted mode
Tractive -power chart

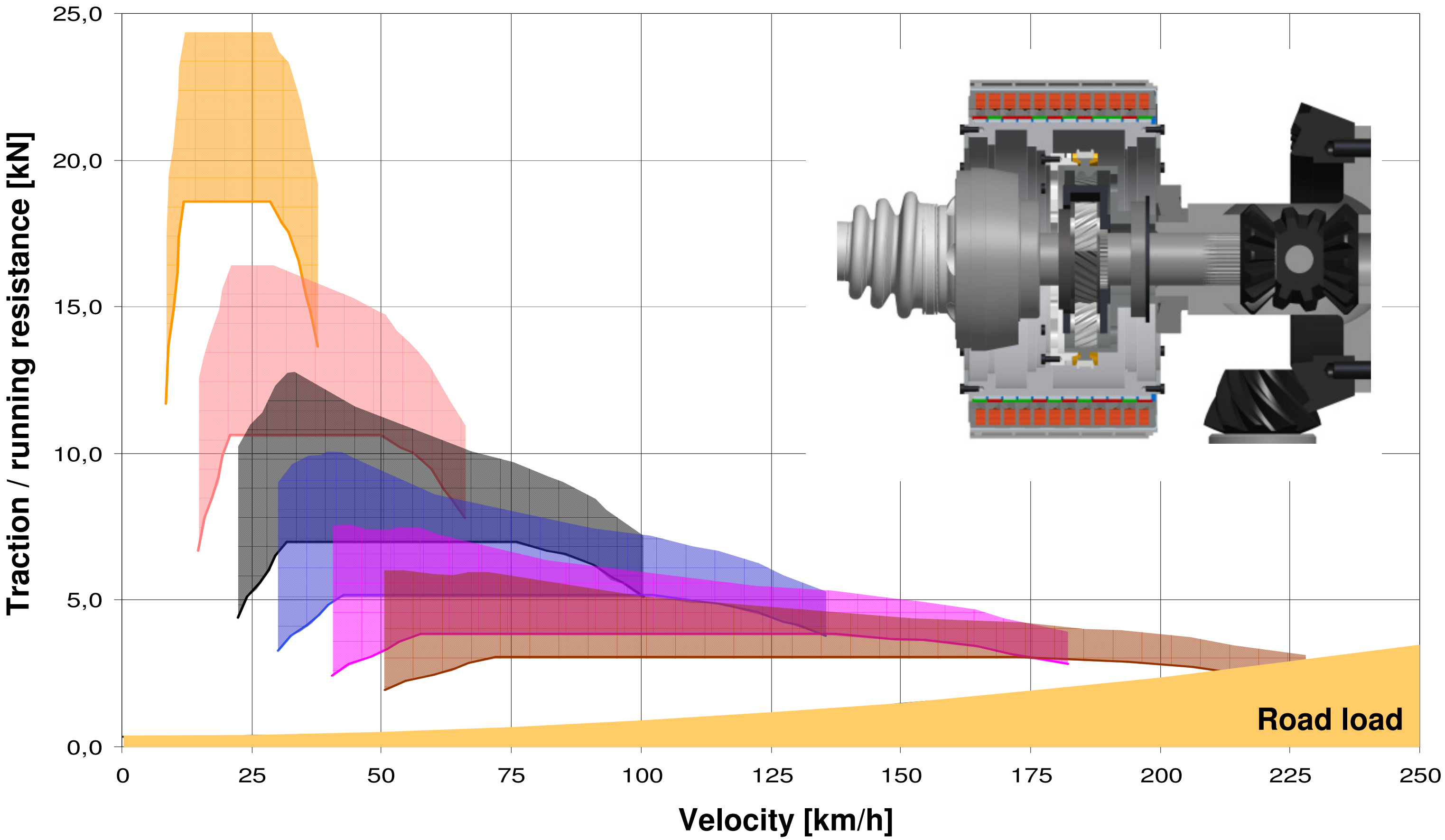
Constant-speed driving boosted by e-machines (2 x 350 Nm)



Traction potential in boosted mode

Tractive -power chart

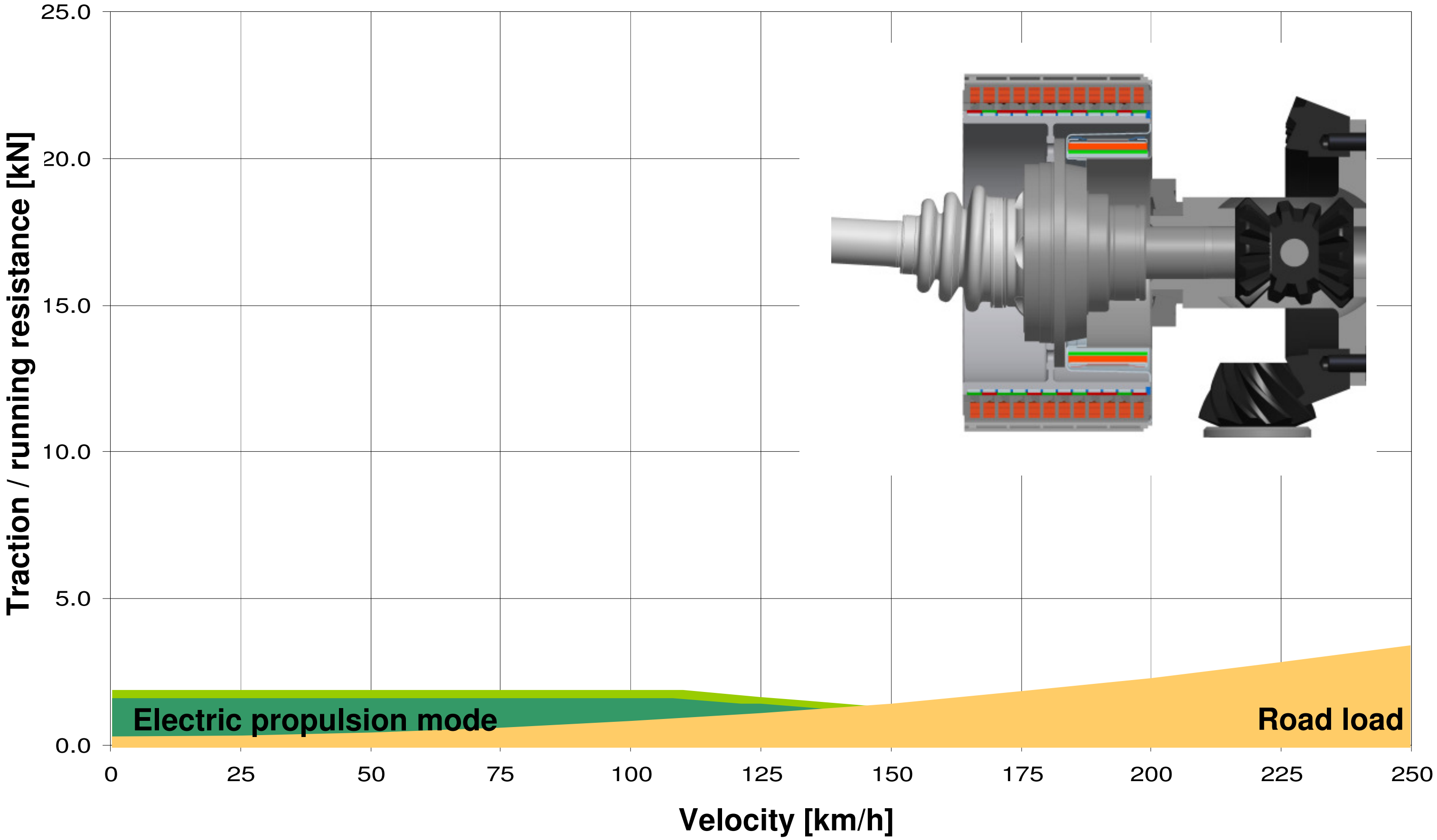
Constant-speed driving boosted by e-machines (2 x 350 Nm) and transmission



Traction potential in boosted mode

Tractive -power chart

Constant-speed driving only with e-machines (2 x 350 Nm)



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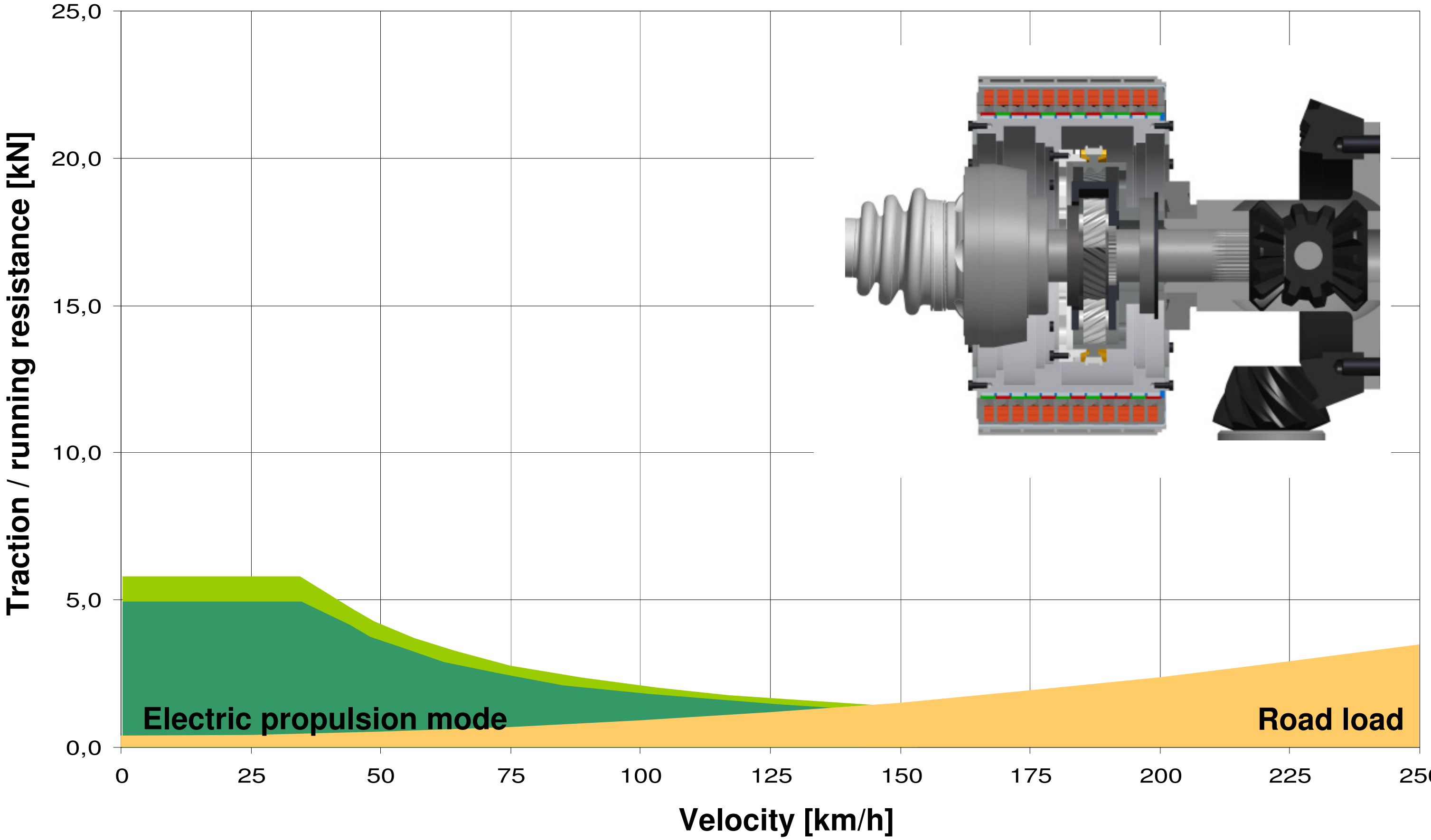

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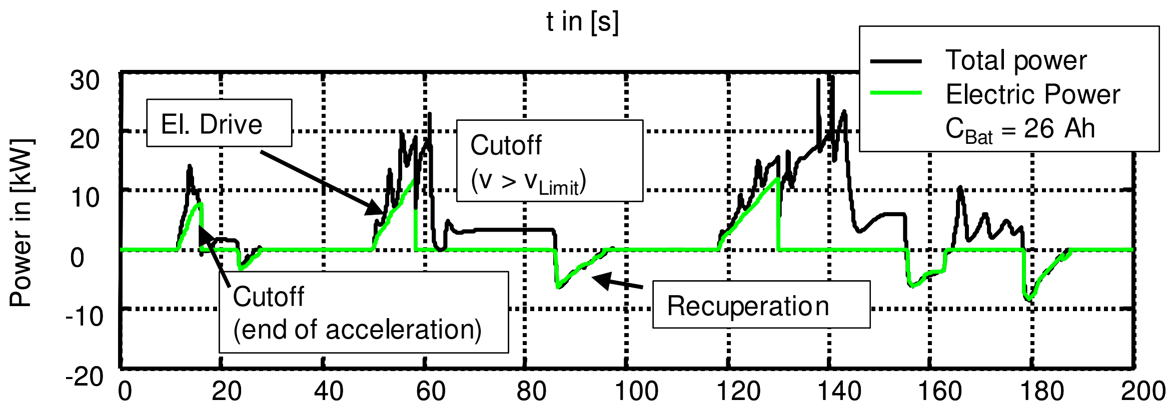
Consumption potential in the NEDC
Simulations results of longitudinal dynamics

Power component from electric machines in NEDC



Example without electric propulsion mode

Full-load acceleration

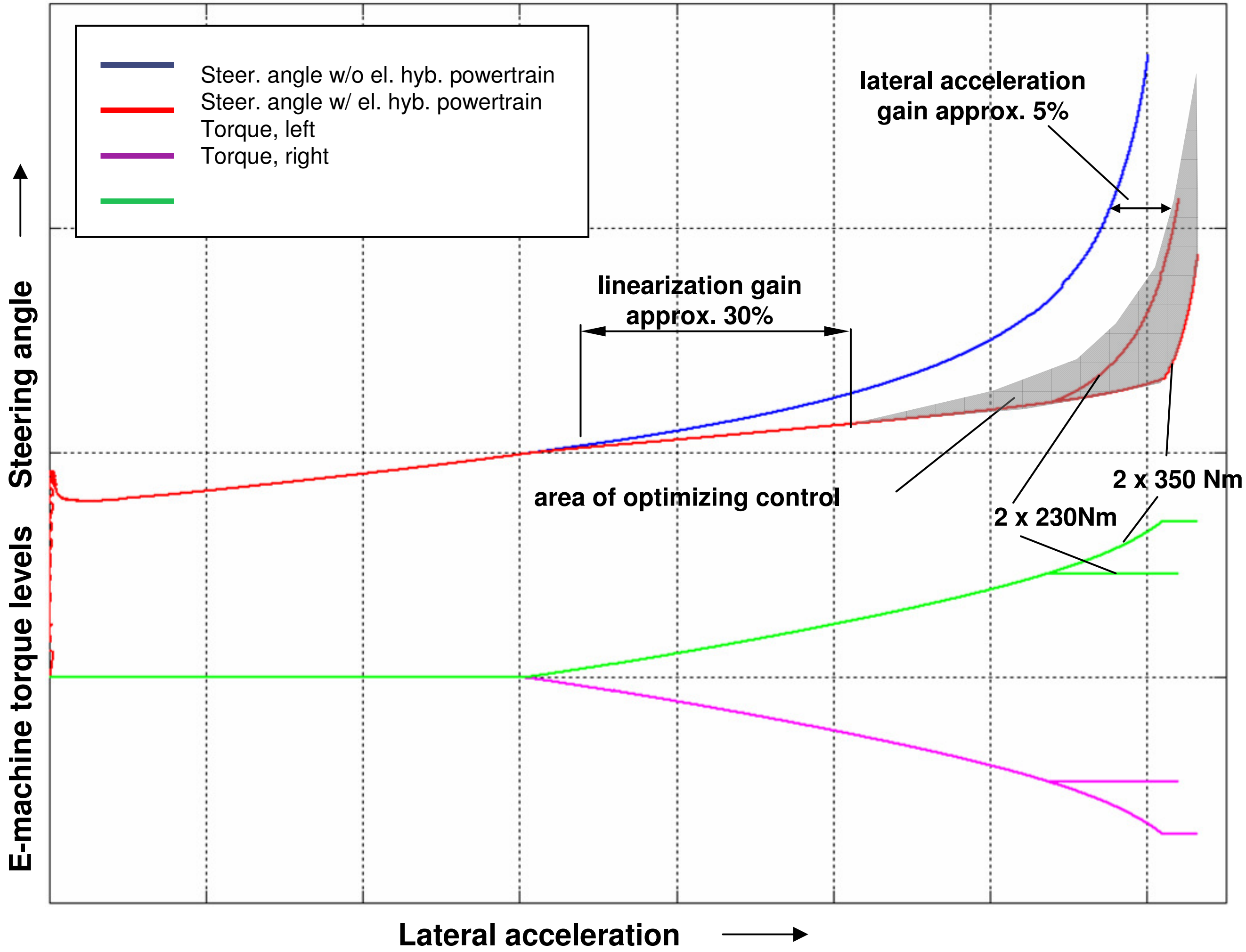
	Boosted versus conventional
Acceleration from 0 – 100 km/h	**-18.9 %**
Acceleration from 80 – 120 km/h	**-27.7 %**
Acceleration from 80 – 160 km/h	**-31.6 %**

Consumption in NEDC

	Start-stop	Dependent on operating strategy
Potential	**- 4.1%**	**-9.5% to -15.5%**

Wheel-specific Torque-Vectoring

Simulations results of lateral dynamics ISO 4138



Steady-state skid-pad driving R = 100 m
(test to ISO 4138)

Self-steering response impact

→ predictable driving behavior also on upper lateral acceleration

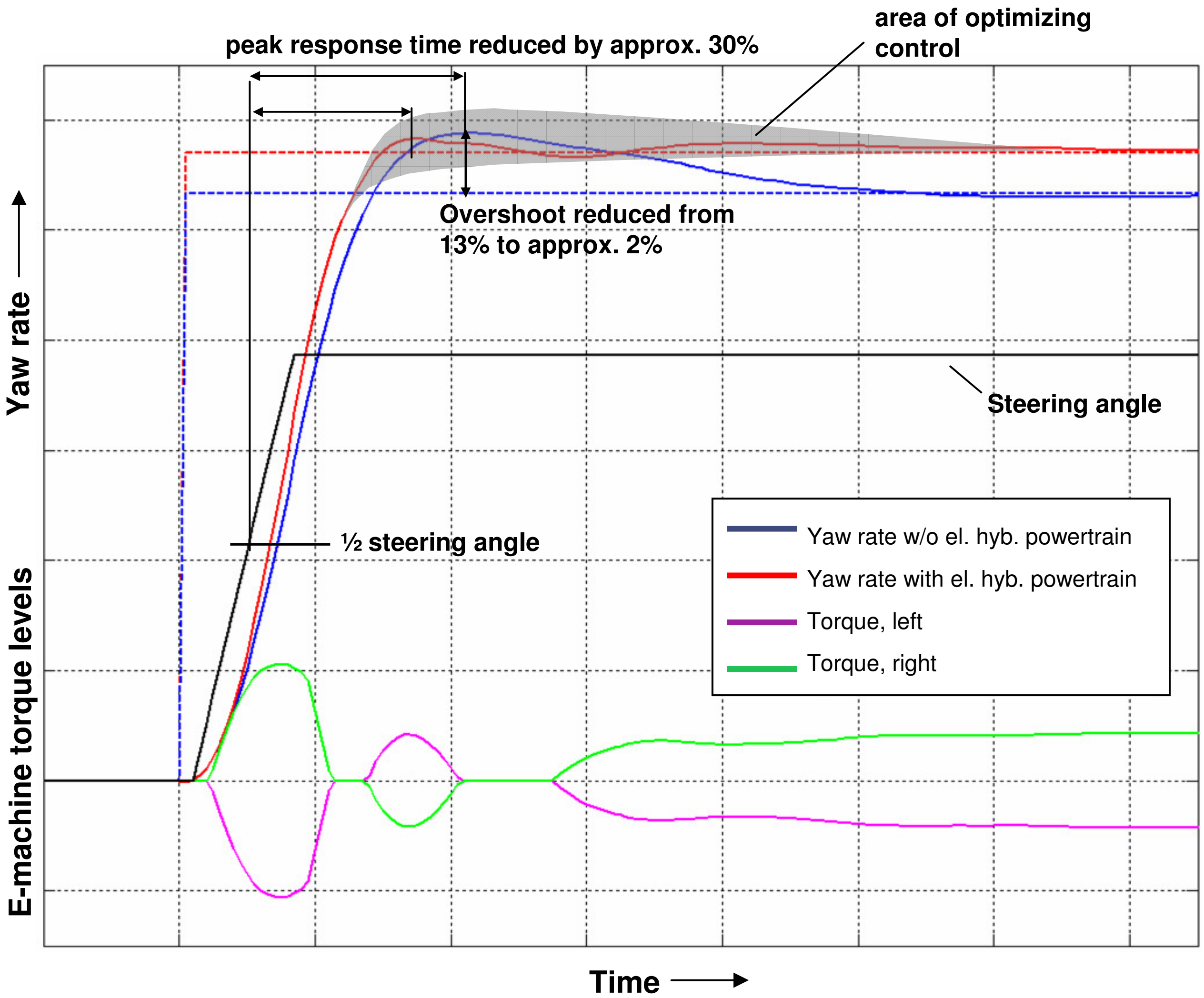
→ increase the speed of cornering

→ possibility to recuperate transversal dynamics energy

→ possibility to realize a lane keeping system

Wheel-specific Torque-Vectoring

Simulations results of lateral dynamics ISO 7401



Step steering-angle change from 0 to 50° (300°/s at 80 km/h, test to ISO 7401)

Driving dynamics impact

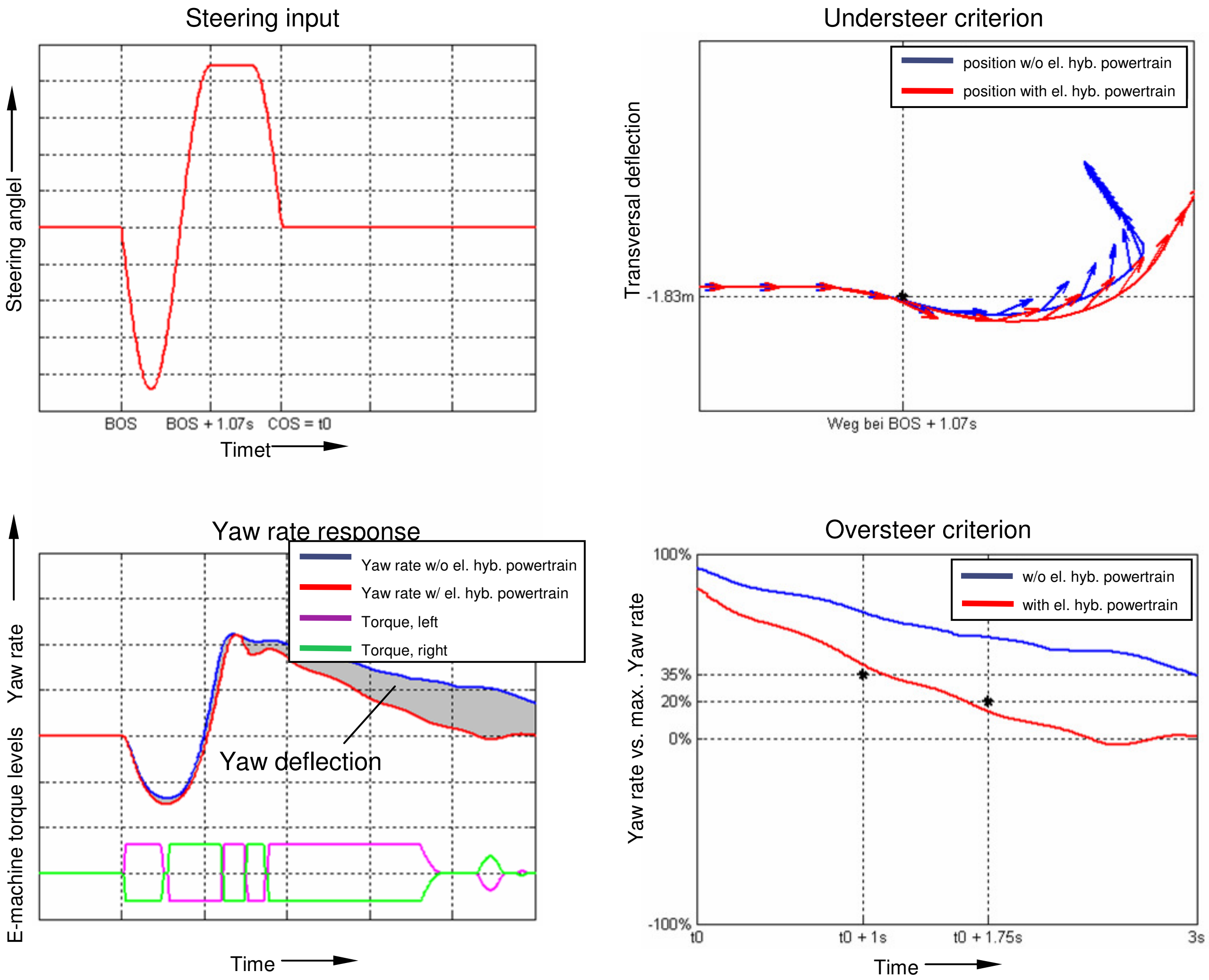
→ low response time by fast actuator speed (~10 ms)

→ enhancement of steering response (yaw rate gain)

→ reduction of undesired yaw rate response (yaw rate amortization)

→ reduction of body motion

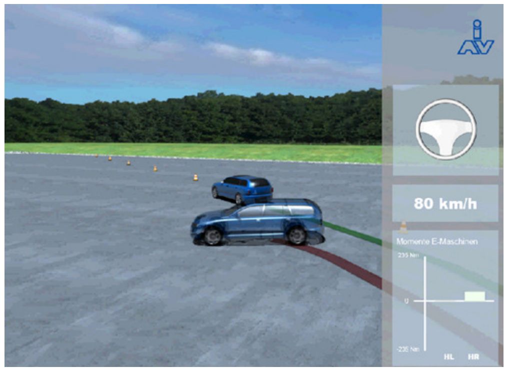
Wheel-specific Torque-Vectoring
Simulations results of lateral dynamics FMVSS 126



Sine with dwell for 6.5xA
(test to FMVSS 126)

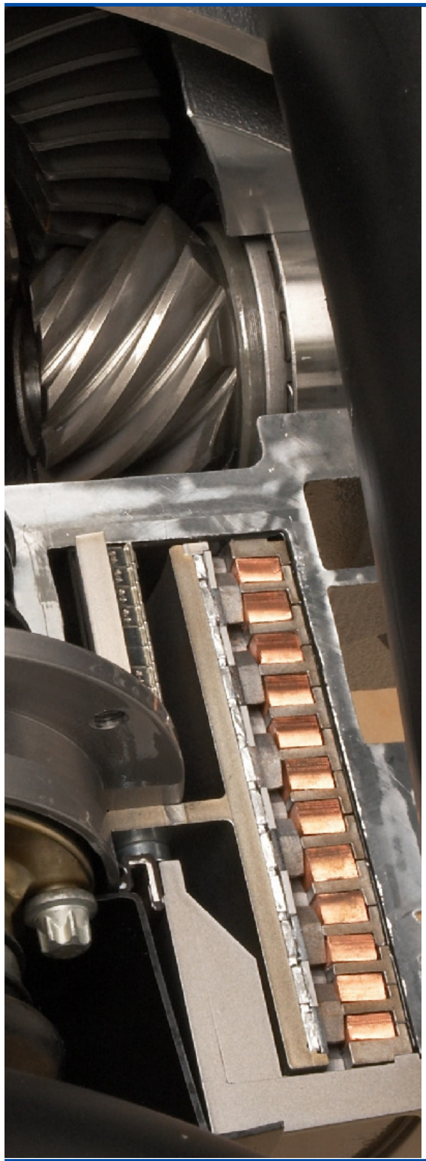
Driving stability impact

- → impact of tracking stability
- → vehicle stabilization without braking
- → increase of driving dynamics by pre controlled intervention



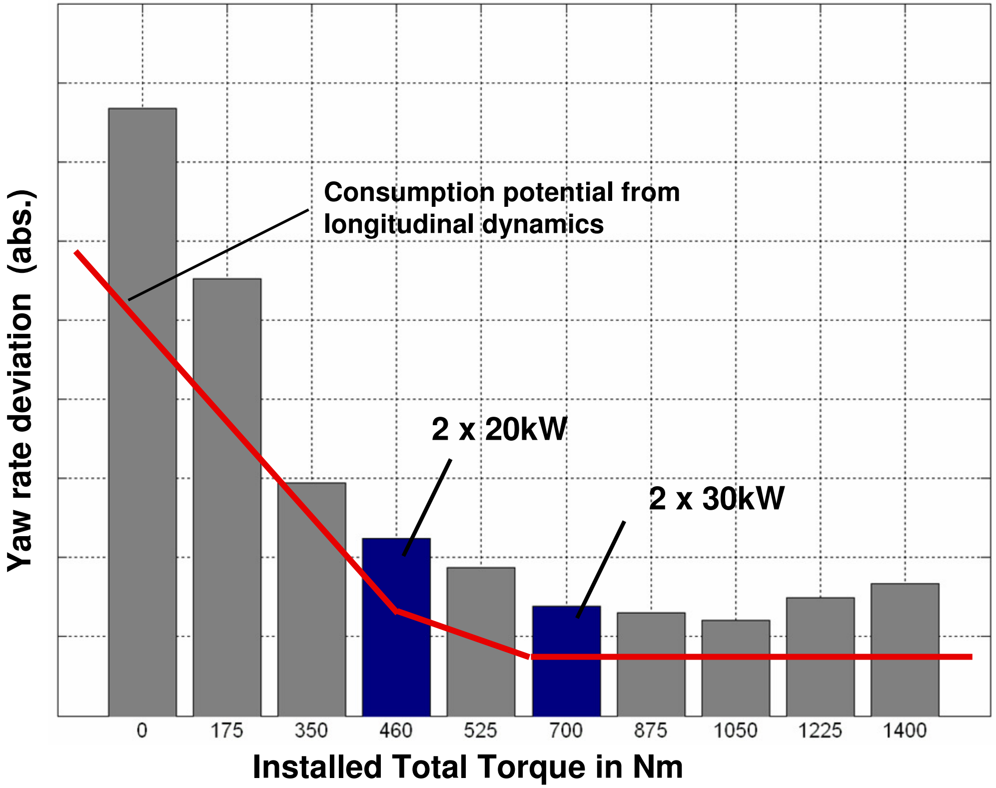
Torque-Vectoring and Hybrid

Combined system layout optimisation



Influence of additional torques for stabilizing potential

Based on: FMVSS 126 at max. steering angle amplification



Simulated Vehicle category: SUV, (not fully verified)

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Hybrid control with active torque distribution

Positive effect on longitudinal and lateral dynamics

- Assist cornering behavior and vehicle stabilization
- Offer traction optimization, boost function and shift support at MT and AMT

Parallel hybrid

- Electric machines provide the basis for hybridized powertrain

Benefits of electric machines direct at the differential

- Use of existing engine/transmission configurations
- Integrative, flexible and modular solution
- Very short control response time to provide the demanded driving dynamics intervention

Drawbacks

- Additional costs and weight related to standard TV
- Advanced control necessary

Thank you

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