Electrified Vehicles as Platforms for Complex System Control

DENSO INTERNATIONAL EUROPE
Technical Research Department

Hasan Esen

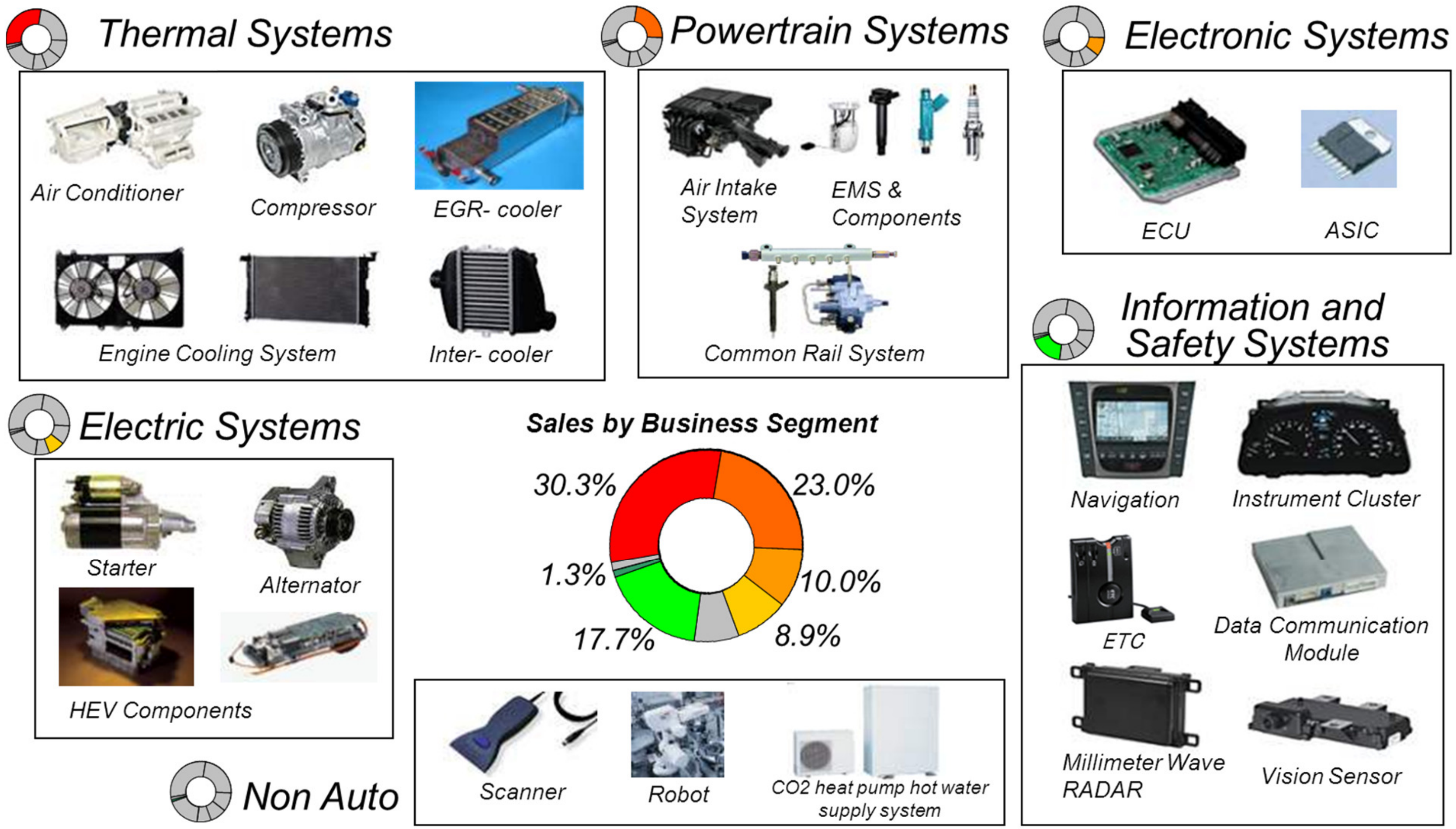
03.09.2012
HYCON2 WORKSHOP ON ENERGY

AGENDA

1. DENSO Corporation Company Profile
2. Increasing Complexity of Automotive Systems
3. Example Studies
4. Outlook

1. DENSO Corporation Company Profile

global supplier of automotive technology, systems and components

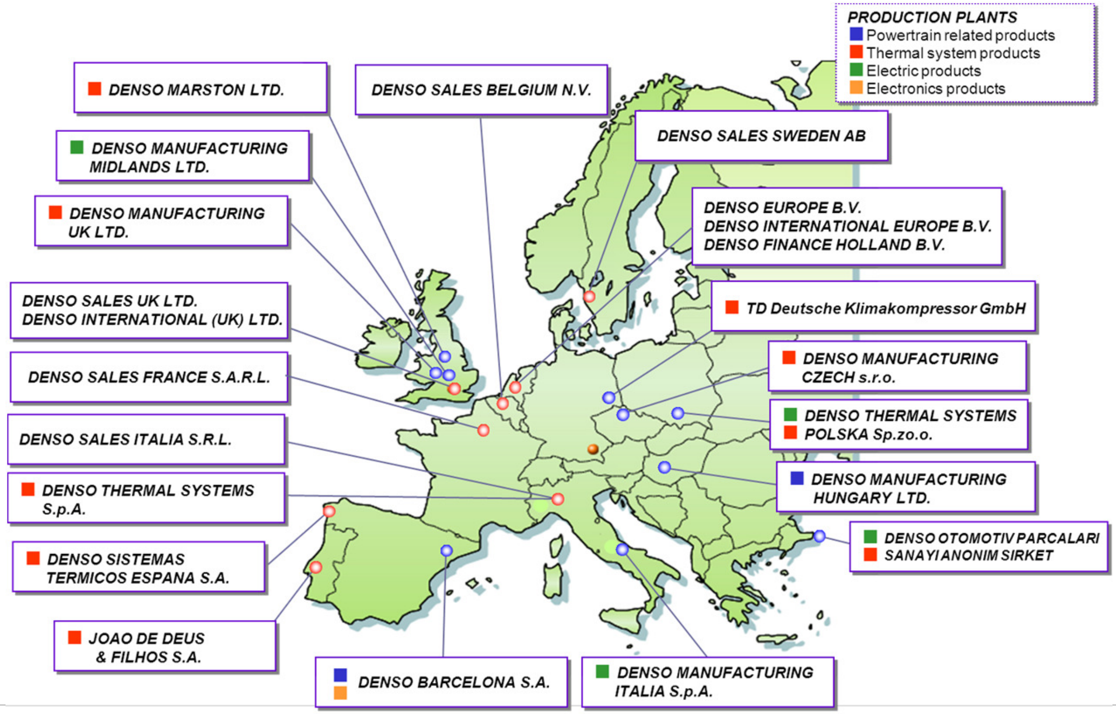


1. DENSO Corporation Company Profile

global supplier of automotive technology, systems and components

- Established : 1949
- Employees (31.3.2010) : 120,812
- Subsidiaries and affiliates:
  - Japan (80)
  - Asia and Oceania (57)
  - North & South America (39)
  - Europe (36)

Headquarters: Nagoya, Japan



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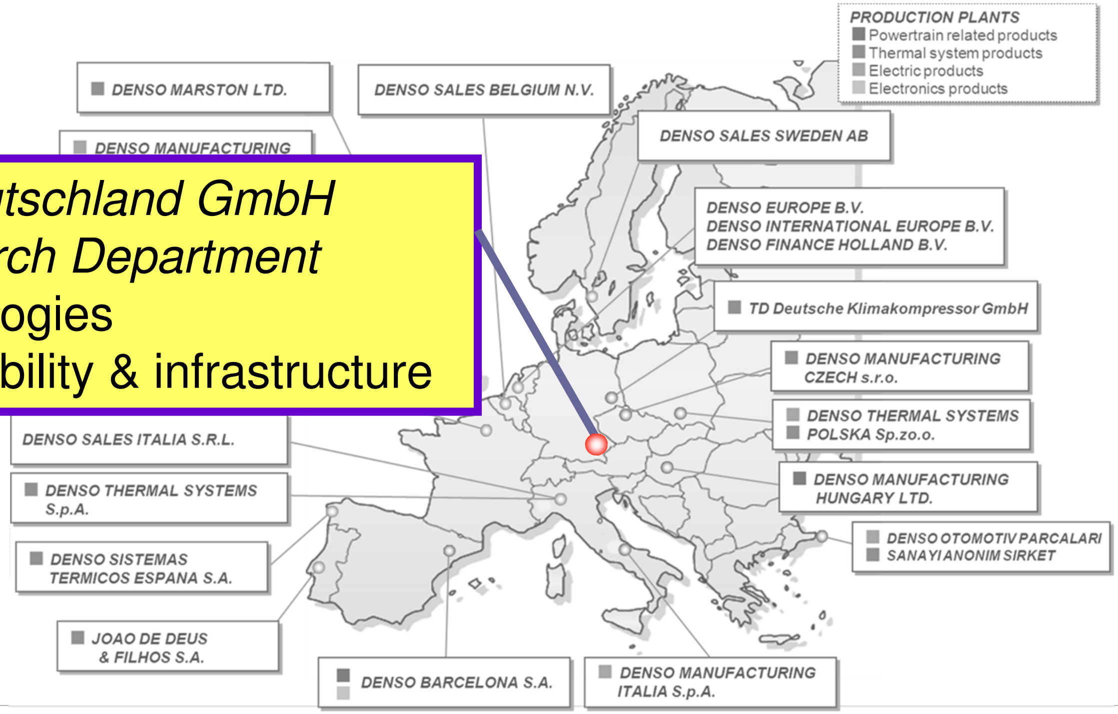
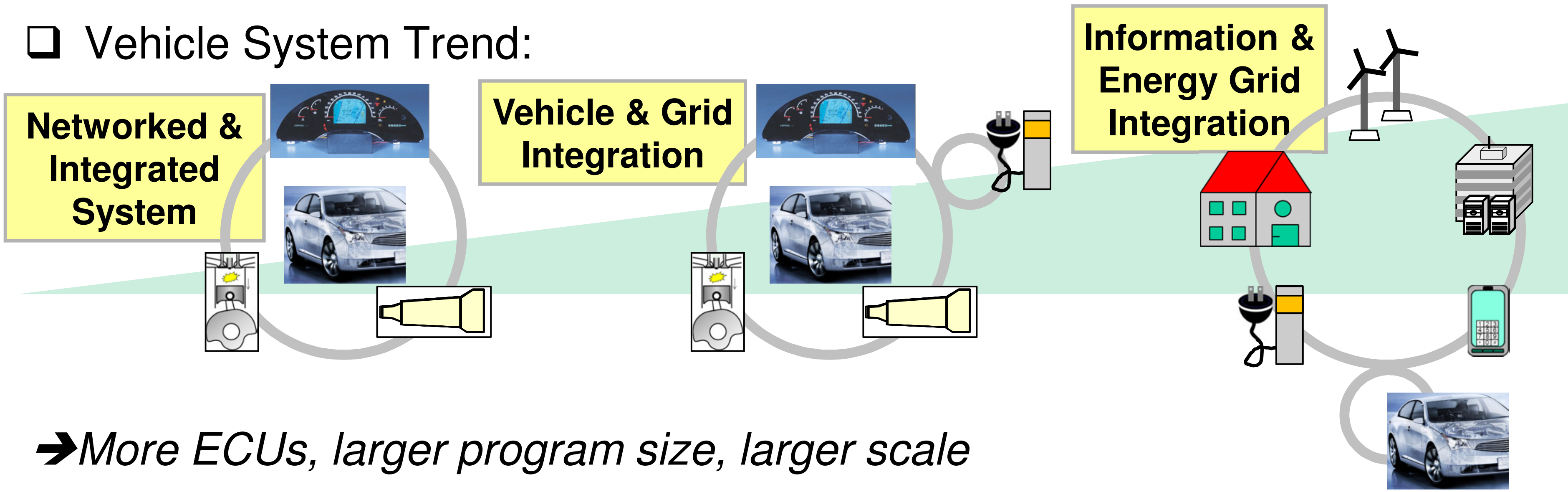
***DENSO** AUTOMOTIVE Deutschland GmbH*
European Technical Research Department

- E/E Platform & System Technologies
- ICT & Safety, Powertrain, E-mobility & infrastructure

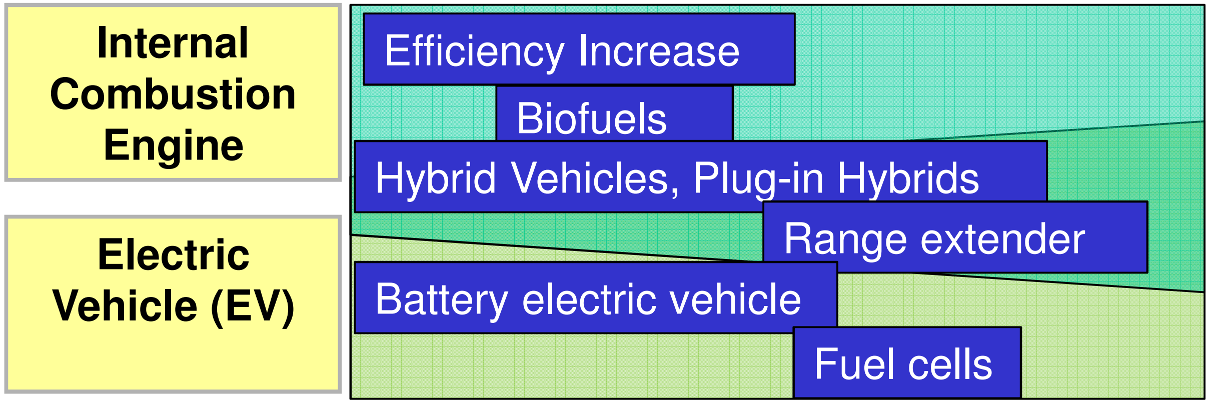


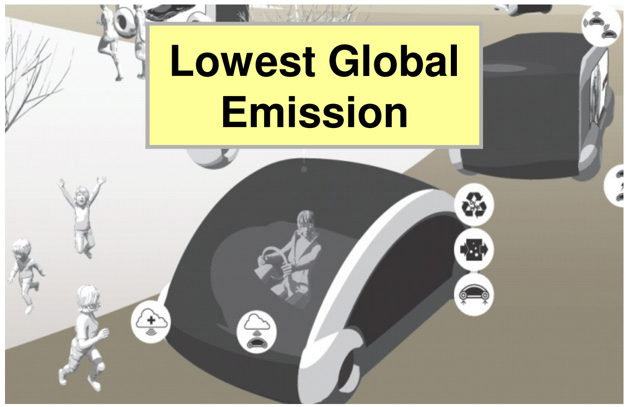
- Vehicle System Trend:



➔*More ECUs, larger program size, larger scale*

- Powertrain Trend: Increasing diversity

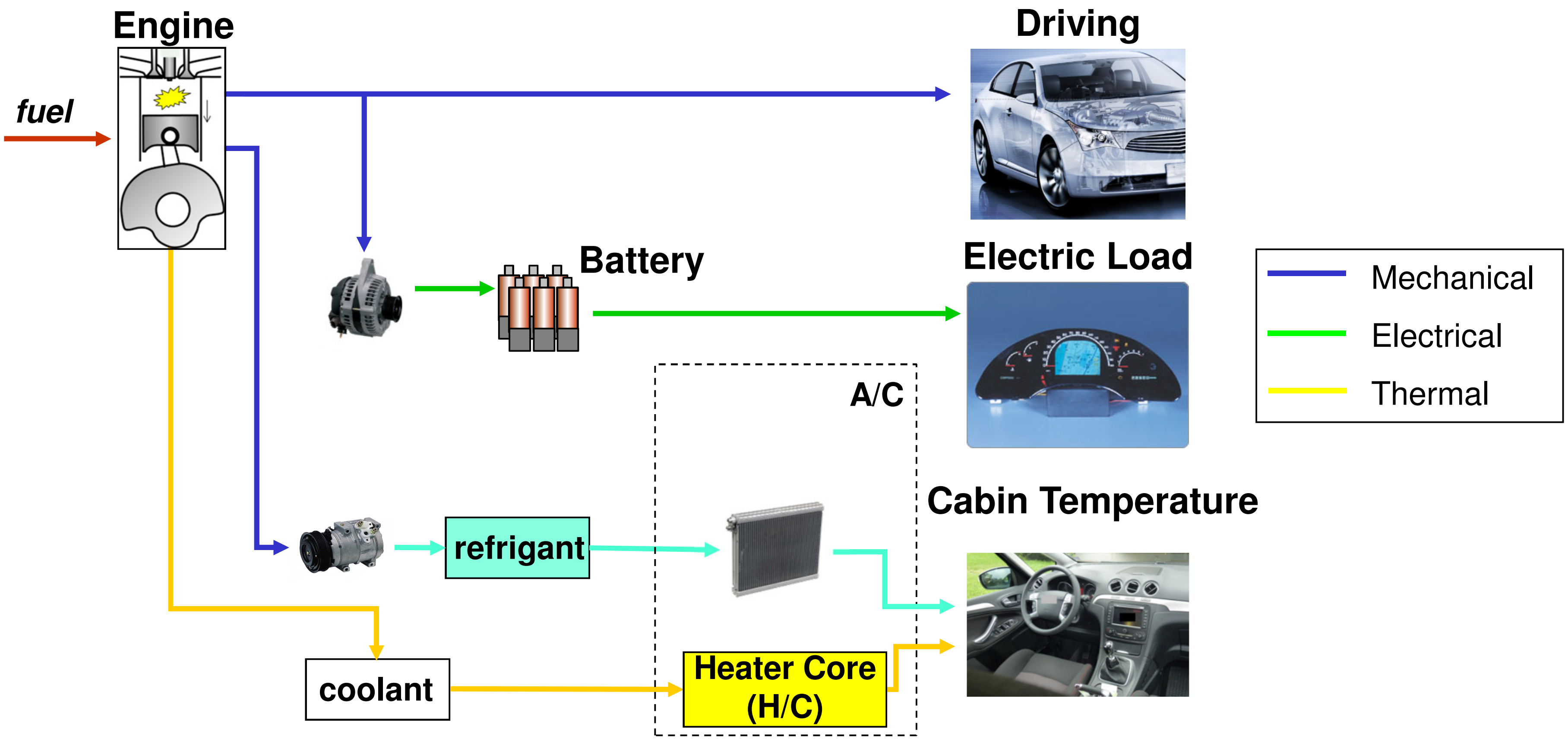




➔*Increasing powertrain diversity*

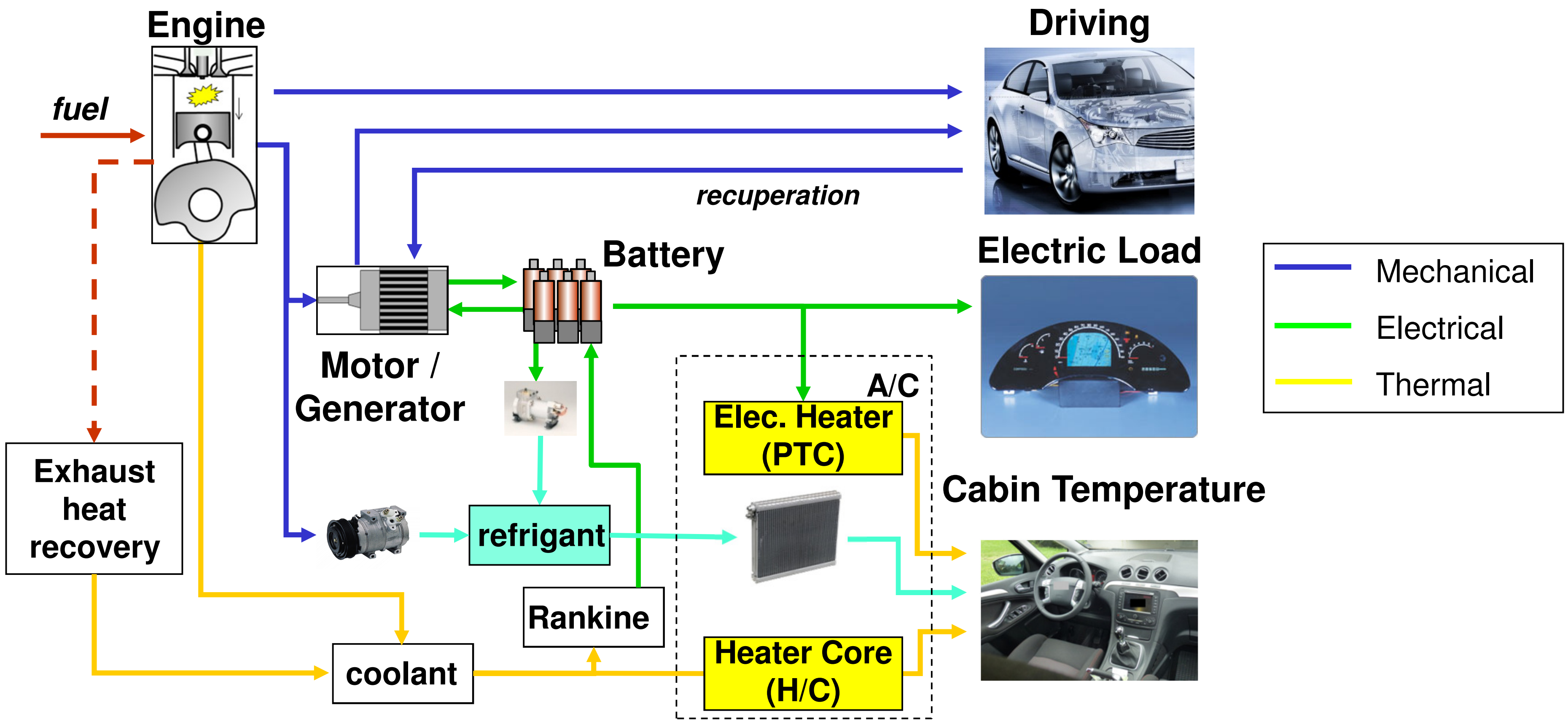
2. Increasing Complexity of Automotive Systems

- Energy Flow (conventional vehicle):



1 function – 1 component

- Energy Flow (hybrid, low fuel consumption vehicle):



➔ *1 function – multi component*

2. Increasing Complexity of Automotive System

Challenging control problems today as a result of increasing complexity & scale

- Architectural problems
- Fault-tolerance
- High control freedom & optimality
- …

New control design concept and methodology are necessary for automotive systems

- DENSO Example Studies

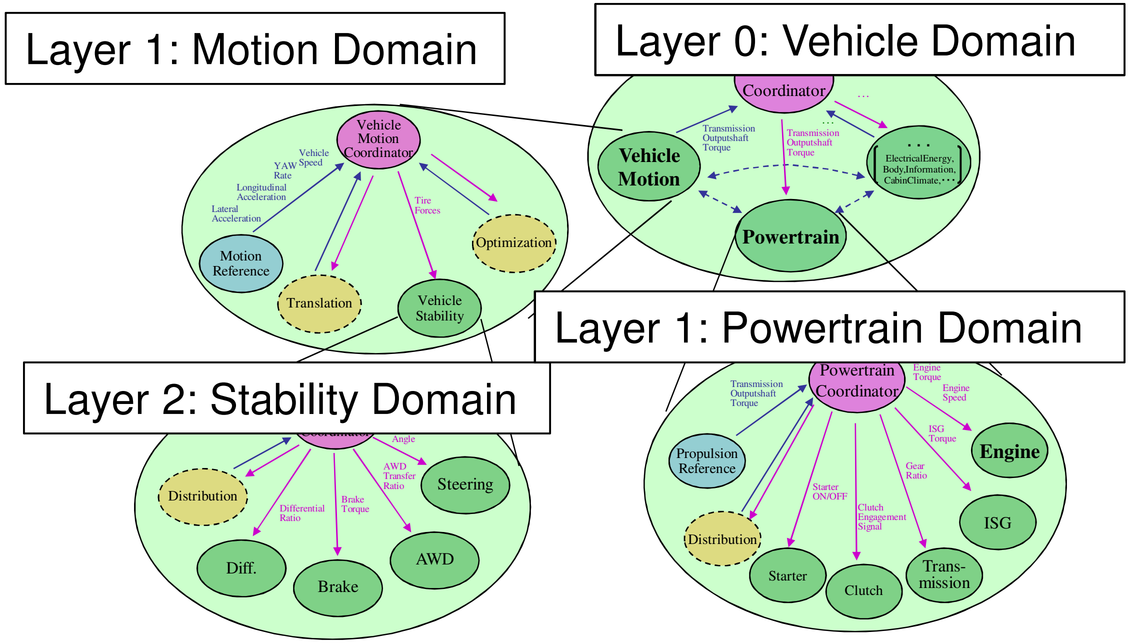
3.1 Functional Architecture based Control System Design

3.3 Fault Tolerant Battery Control in Electrified Vehicles

3.2 Model Predictive Control for Cabin Heat Thermal Man."

3.1 Functional Architecture based Control System Design*

- Aim: structuring the control system that gets larger and more complex



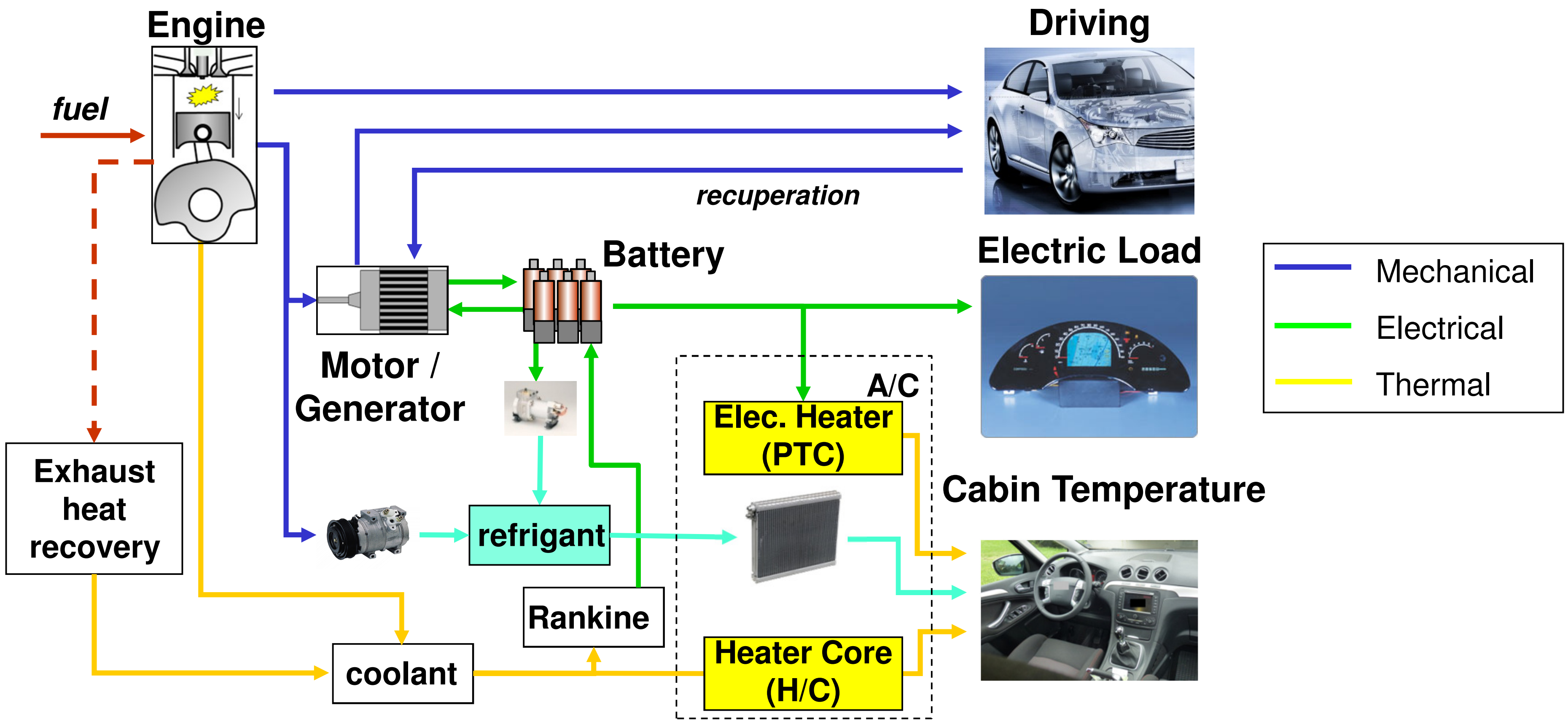
Main features:

- Restructure vehicle control under simple rules.
- Redefine and allocate all of control function appropriately
- Standardize interface of each component.
- Hide localized information for outside of the component.
- Parallel development of each component

- This hierarchical structure serves as a framework. It has been gradually embodied

**T. Tashiro, S. Akiyama (DENSO Corp.) Global Powertrain Conference 2003, Ann Arbor, MI, 2003*

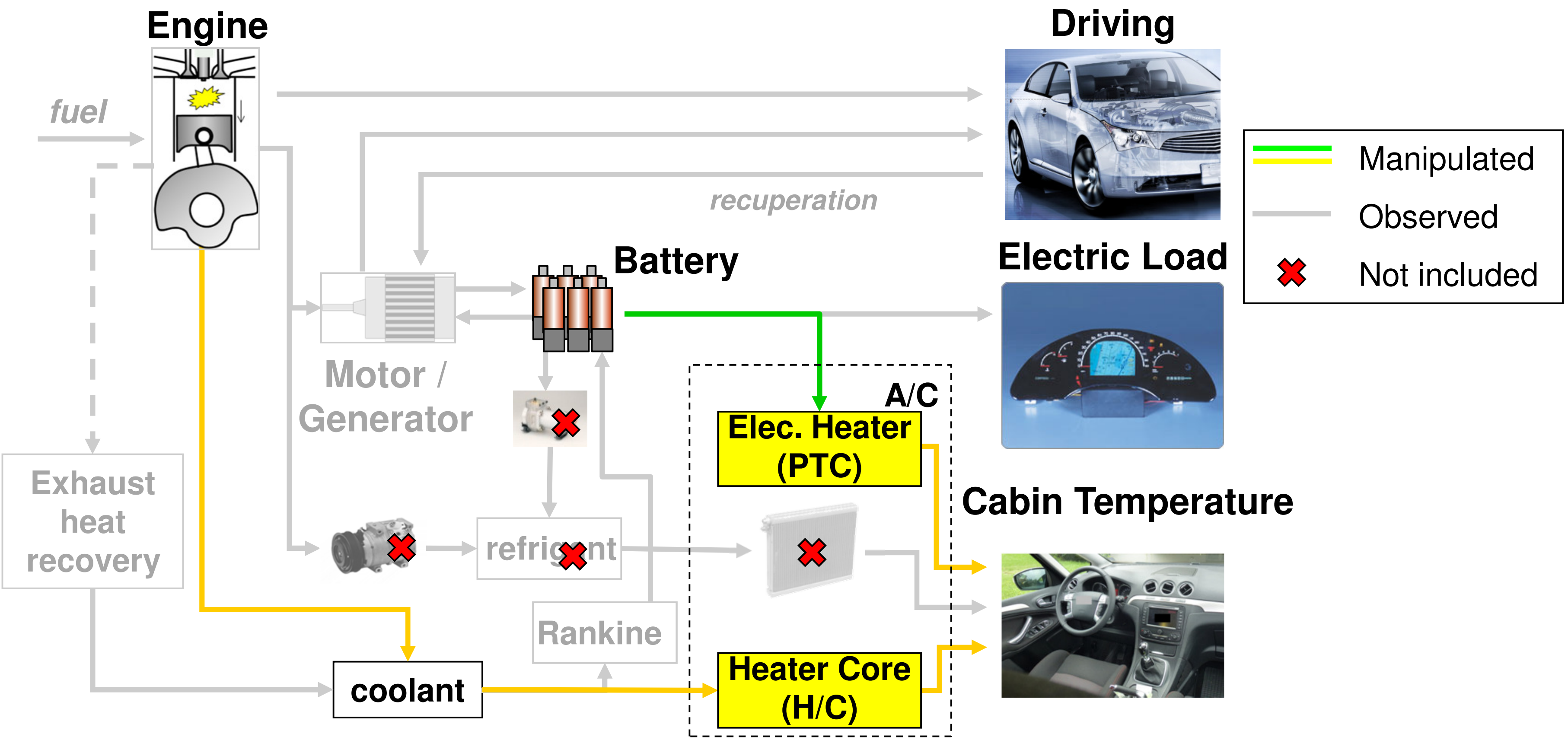
❑ Energy Flow (hybrid, low fuel consumption vehicle):



distribute the workload between** components to heat the cabin in order to achieve **real-world** (driving, electric and thermal domains) **fuel efficiency

3.2 Model Predictive Control for Cabin Heat Thermal Man.*

❑ Cabin Heat Problem Covering Range

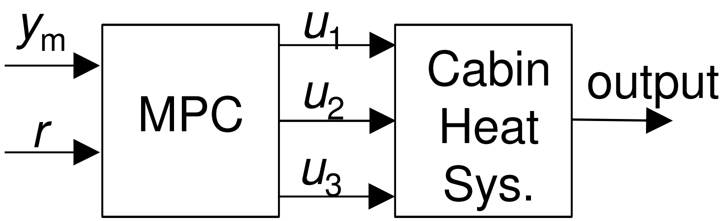


Manipulate: Some options of engine, Electrical heater, (PTC), Heater Core (H/C)

Observe/Evaluate: Battery, engine, M/G, other electrical and thermal loads

** In collaboration with Prof. A. Bemporad (IMT Lucca) & his team*

❑ Control Problem



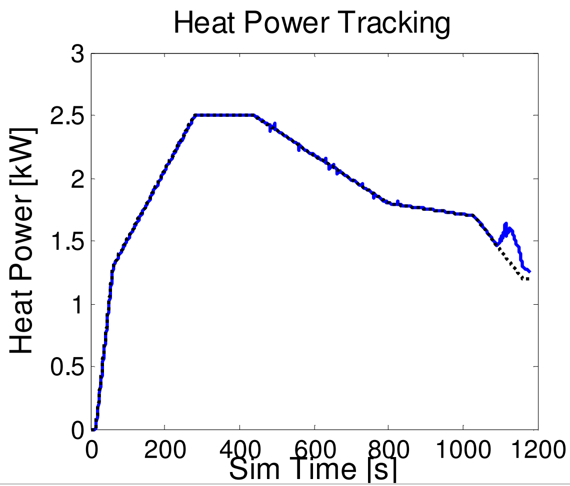
For given measurements (y_m) and references (r), manipulate H/C (u_1), PTC (u_2), and engine power (u_3) to achieve the control objectives:

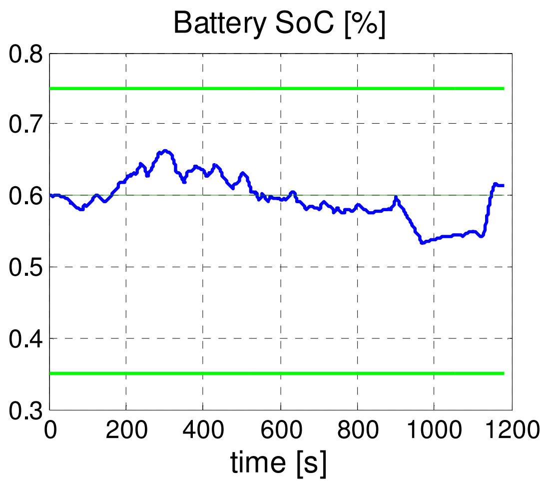
- heat power reference tracking
- maintaining battery SOC in its limits
- minimizing fuel consumption

Complex relations are identified & simplified as linear-time variant (LTV) models

Multi-objective MPC is formulated s.t. LTV prediction models and constraints

❑ Simulation Results (NEDC, Ambient Temp 5°C)



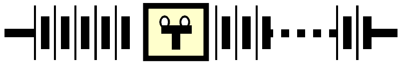
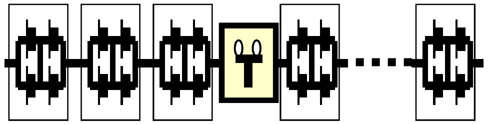
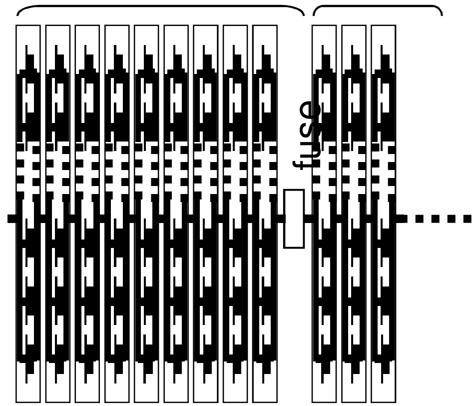


Fuel savings w.r.t. baseline: ~ 3%

Benefit: Better competitiveness

3.3 Fault Tolerant Battery Control in Electrified Vehicles*

❑ Different Battery Topologies

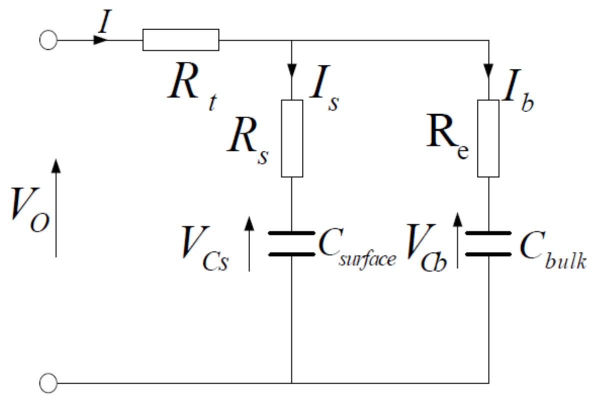
Type	Single String	Double String	Multi-String
	 1 parallel x n series	 2 parallel x n series	 m parallel x n series
Complexity			
Sensitivity to 1-cell failure			

improve the reliability of *simpler topologies (single string) using*
active fault detection and control *mechanisms*

* *In collaboration with Prof. J. Stoustrup (Uni Aalborg) & his team. Published in Safeprocess'12 Conference*

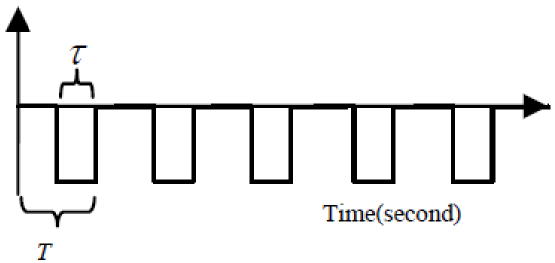
- Software modifications: Active Fault Detection (AFD)

1. State space battery model
Input : current I
Output : voltage Vo
States : voltage across bulk and surface capacitorsVcb, Vcs



2. Estimate the bulk capacity Cb and the terminal resistance Rt using Extended Kalman Filter (EKF)

3. Design the input current signal I
increase the sensitivity of parameter changes
Non-convex optimization problem



4. Compare the estimates with nominal values for fault detection

- Results
  - Reliability of single-string topology increases with AFD
  - Early warning to the driver, before severe failures occur

4. Outlook

Challenging control problems tomorrow as a result of increasing complexity & scale

cyber-physical systems, large-scale distributed systems, systems of systems

- Vehicle as a component of system of systems
- Zero emission, zero fatality
- Absolute fault-tolerance
- Secure V2G communication
- Utilizing advanced computing technologies
- Standardization
- Information management

SEVENTH FRAMEWORK PROGRAMME

HORIZON 2020 THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

HYCON2 TAMING HETEROGENEITY AND COMPLEXITY

powerUp

parMERASA

DENSO EU Technical Research strategy:
support and actively develop the technology together with diversified EU partners

DENSO