Unifying approach to hybrid control software

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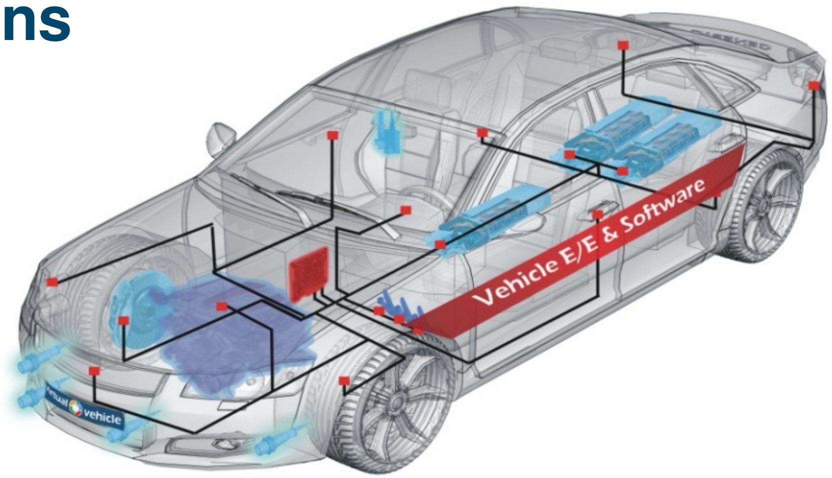
1. Challenges and goals in hybrid electric vehicle control
2. Control methods
3. Dynamics of hybrid vehicle systems
4. Basic principles of the software architecture
5. Software structure
6. Example of hybrid modes and transition control
7. Concept benefits

- Challenges
  - **Increased complexity compared to conventional vehicles**
    - Additional degrees of freedom (E-Motor, separation clutch, battery system, etc.)
    - Demonstrate the promised high potential of hybrid electric vehicles (CO2 reduction, improved drivability, etc.)
  - **Various hardware configurations**
  - **Variable function range**



- Goals
  - **Generic approach**
  - **Reusability of software code**
  - **Support from prototype to series software**
  - **Extensibility (easy integration of new functionalities)**

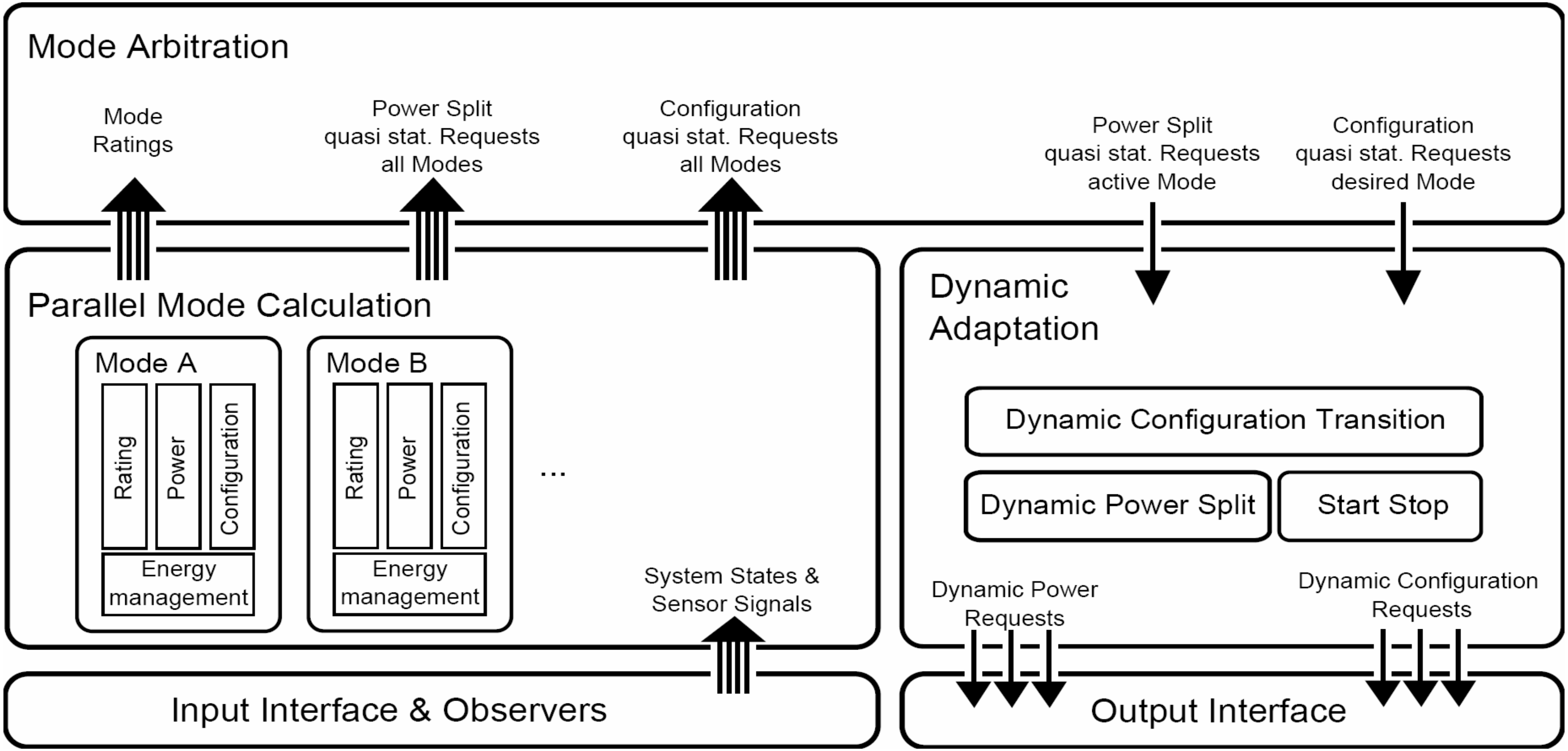
- Optimal control strategies
  - **Requires a-priory knowledge about driving profile**
  - **Includes various optimization methods (static optimization, dynamic programming, genetic algorithms, etc.)**
- Sub-optimal control strategies
  - **Model-based driving condition prediction for relatively short control horizon**
  - **Various optimization methods**
- Heuristic control strategies
  - **Deterministic rules**
  - **Fuzzy rules**
  - **Expert and common knowledge**
  - **Simulation model data**
  - **No a-priory knowledge about driving cycles**

- Switched hybrid dynamical systems
  - Continuous (quasi-stationary) phases interrupted by state jumps
- Continuous phases = hybrid vehicle operation modes
  - Pure electric driving, vehicle standstill with combustion engine switched off, recuperation, power assist,…
- Each mode is characterized by
  - setting for power split ratio between the propulsion sources
  - setting for drive train configuration

- Modes are the basis for the proposed architecture
- Different mode sets for different hybrid vehicle variants
  - One mode set covers whole vehicle operation space
- Definition of independent modes (no information from other modes required for calculation)
- Parallel mode evaluation
- Introduction of mode ratings
  - Determines the beneficence
  - Reflects advantages of keeping the mode or switching into it
- Control parameters are split into 2 groups
  1. Operation mode configuration parameters
     - e.g. drive train configuration
  2. Fast quantities
     - e.g. torque/speed requests

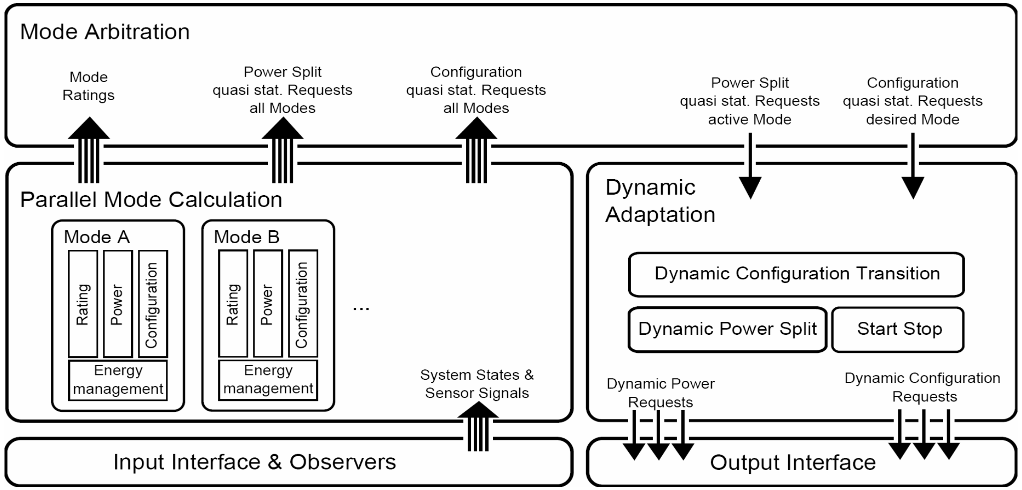
Software structure – Overview

virtual vehicle



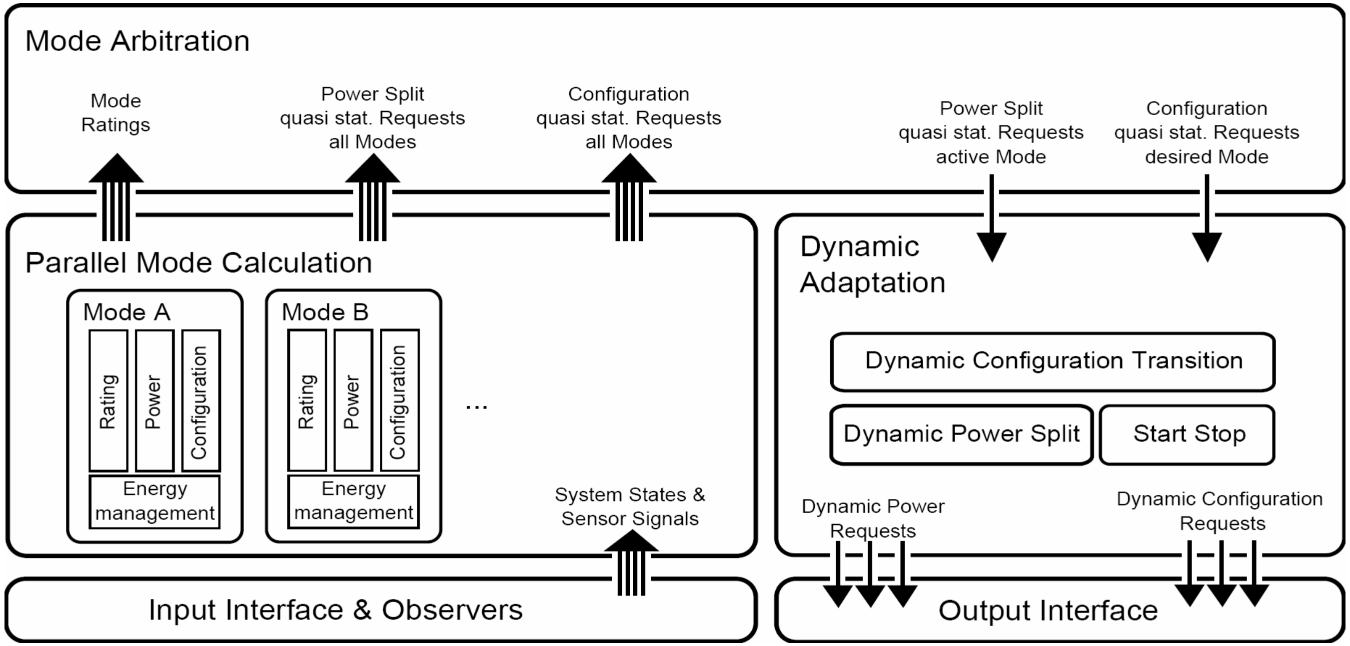
virtual vehicle

- Input Interface & Observers
  - Data collection
  - Data generation

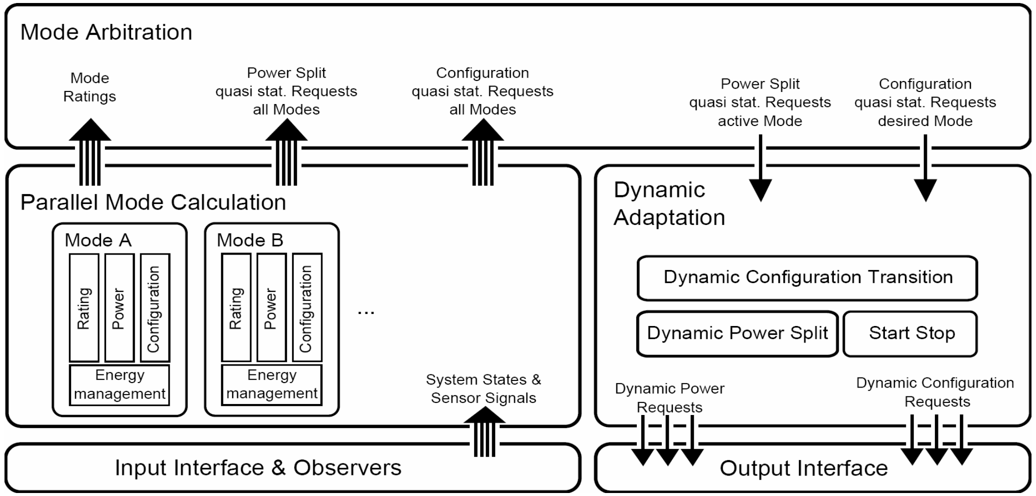


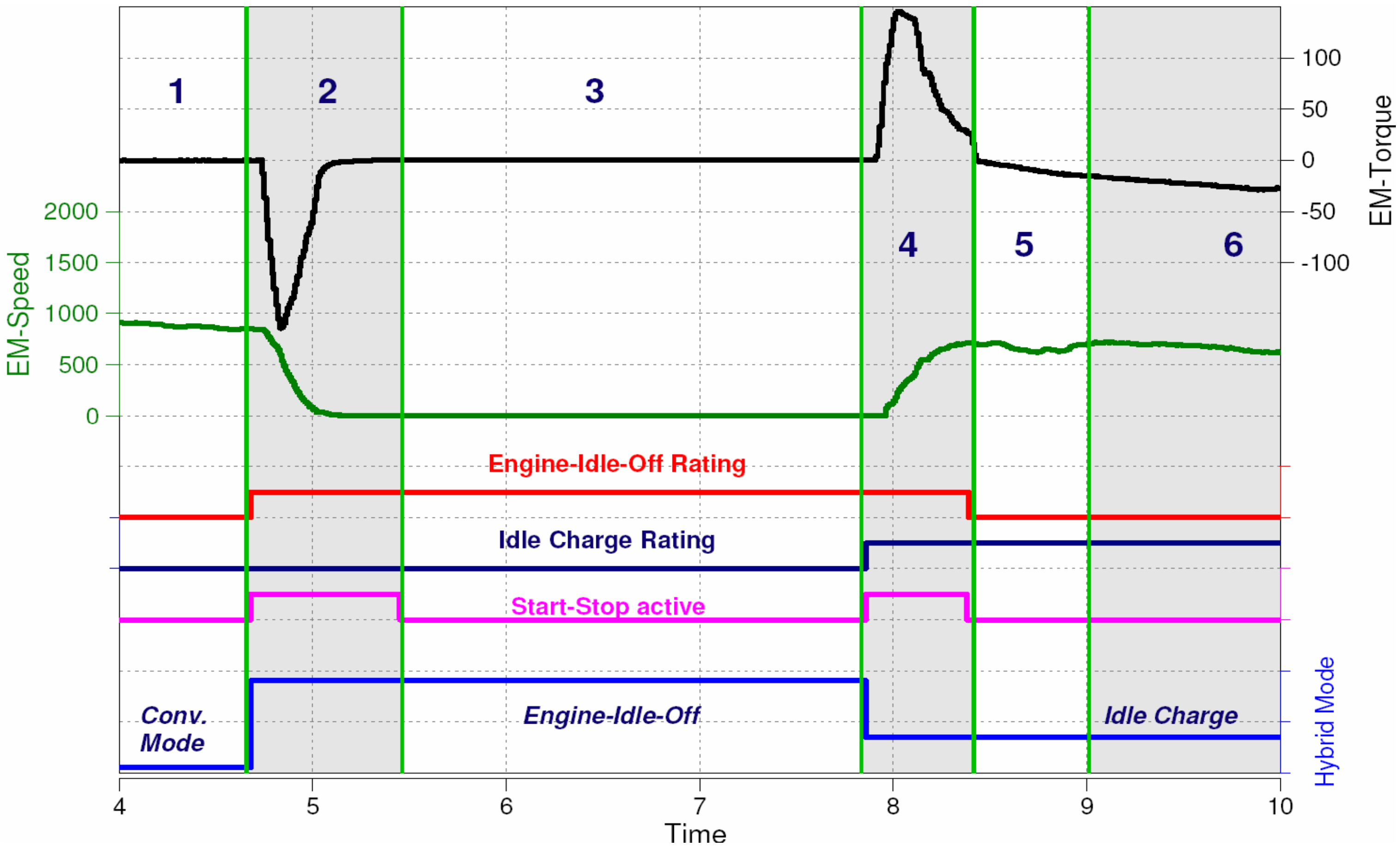
- Parallel Mode Calculation
  - Energy management
    - Ranges of available energy/capacity
    - Power capability of storage unit(s)
  - Calculation of quasi-stationary power requests (e.g. torque, speed)
  - Calculation of drive train configuration requests
  - Mode rating calculation
  - Calculations are considering
    - Driver demands
    - State of vehicle components
    - Current, past and future driving situations

- Mode Arbitration
  - Mode selection based on mode ratings
  - Pre-defined mode prioritization (optional)
  - Request selection process
    1. Best possible mode defines operation mode configuration requests
    2. Actual mode defines the fast quantities requests

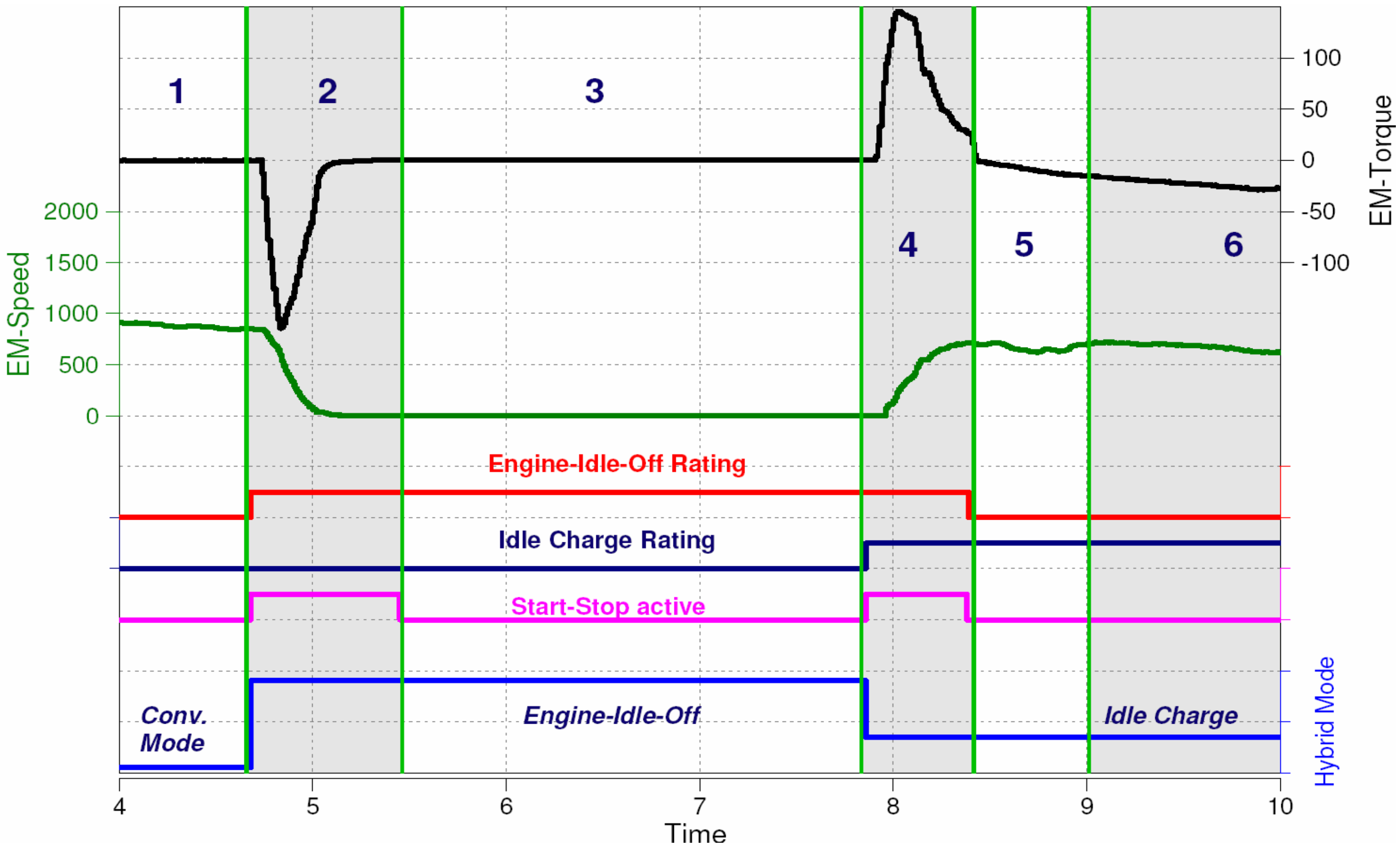


- Dynamic Adaptation
  - Handles transitions between modes
  - Coordination of drive train transitions
    - Clutch activation/deactivation
    - Gear shift
    - Starting/stopping the internal combustion engine
  - Torque/speed request transitions
    - Dynamic request limitation (NVH requirements)
    - Engine – E-Motor speed synchronization
- Output Interface





- Phase 1: Conventional operation mode
  - Combustion engine is running in idle mode
- Phase 2: Mode transition - Engine on → Engine off
- Phase 3: Engine-idle-off mode
  - Combustion engine is stopped
  - Board net supply from battery system



- Phase 4: Mode transition – Engine off → Engine on
- Phase 5: Mode transition – Smooth torque transition
- Phase 6: Idle charge mode
  - Combustion engine is running in idle mode
  - Board net power supply from e-motor
  - Battery charge power from e-motor

- **Scalable function framework**
  - Covers a wide range of hybrid vehicle topologies
  - Various applications (engineering targets)
- **Concept allows implementation of different control strategies**
  - Optimal, sub-optimal and heuristic
  - Prototype and series software
- **Reusability of software code**
- **Well structured architecture enables seamless calibration and documentation process**
- **Easy mode set configuration and mode adjustments (without influencing other modes)**
- **Supports hybrid vehicle variant management**

Thank you for your attention!

Questions?

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