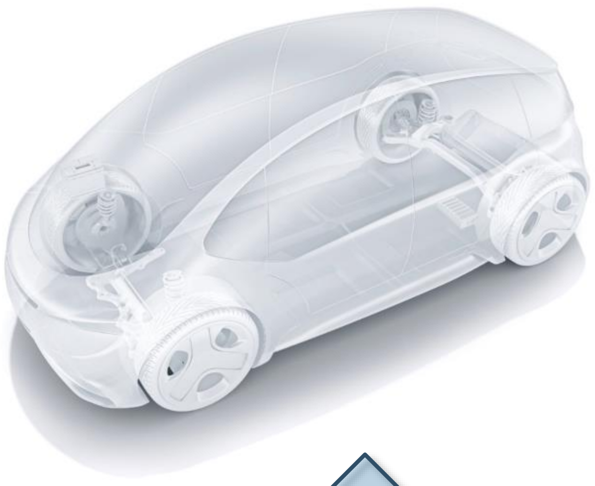
VCU EV FUNCTIONS

VCU Functions
Electric Vehicles

µC Application Software

µC

EV Powertrain	One Pedal Driving	Drive Profiles	Vehicle State Coordination
Safe State Coordination	Safety Monitoring	Range Prediction	Driver Assistance
HV System Coordination	HV / LV Load Management	Thermal Management	Electric Vacuum Pump
Acceleration & Brake Pedal	Vehicle Speed	Gear Lever	12V Battery Sensor



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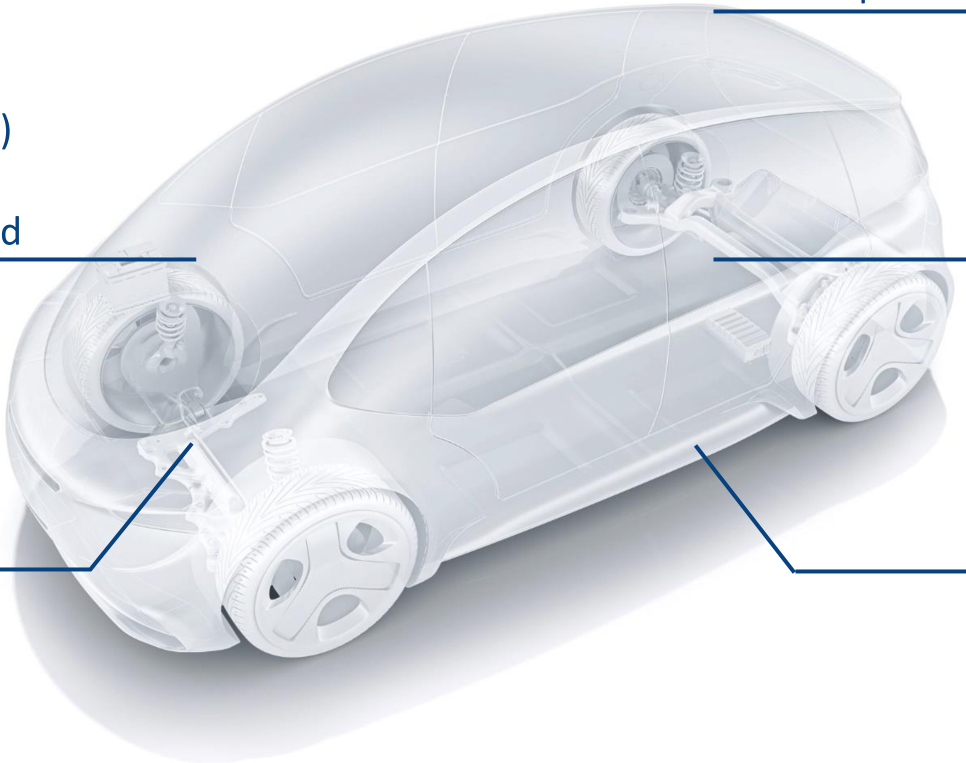
µC - APPLICATION SOFTWARE

VCU EV Functions

Powertrain for Electric Vehicles

Coordination Powertrain
Long-term and short-term limits
Torque Distribution Strategy for 2 E-Machines
Cooperative Regenerative Braking System

Accelerator Pedal Demand
Pedal Interpretation
Drive Mode Selector (PRND)
Propulsion / Recuperation
Coordination Driver Demand



Vehicle State Coordination
Reference Filter
Zero-Crossing-Filter

Drive Program Selection
Creep Control
Cruise Control
Speed Limiter

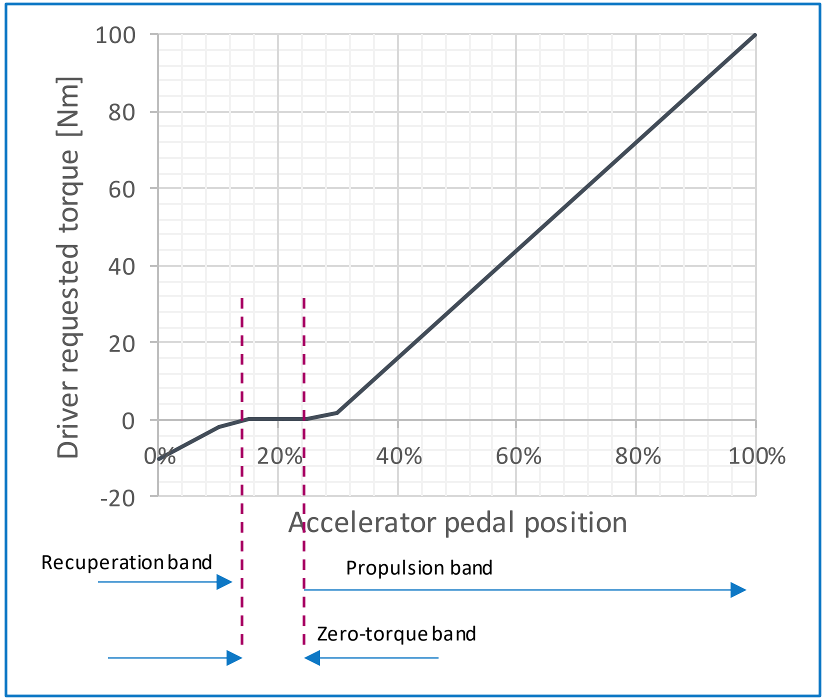
Limp-Home strategy
Vehicle stabilization functions
Quadrant Mapping

VCU EV Functions

Accelerator Pedal Demand

➔ **Signal evaluation and interpretation of accelerator pedal sensors as driver demand**

- Determination of Kick-Down state
- Remove jitter; linearization and filtering of accelerator pedal sensors
- Signal plausibility check
- Three different bands can be calibrated:
  - Recuperation band
  - Zero-torque band
  - Propulsion band



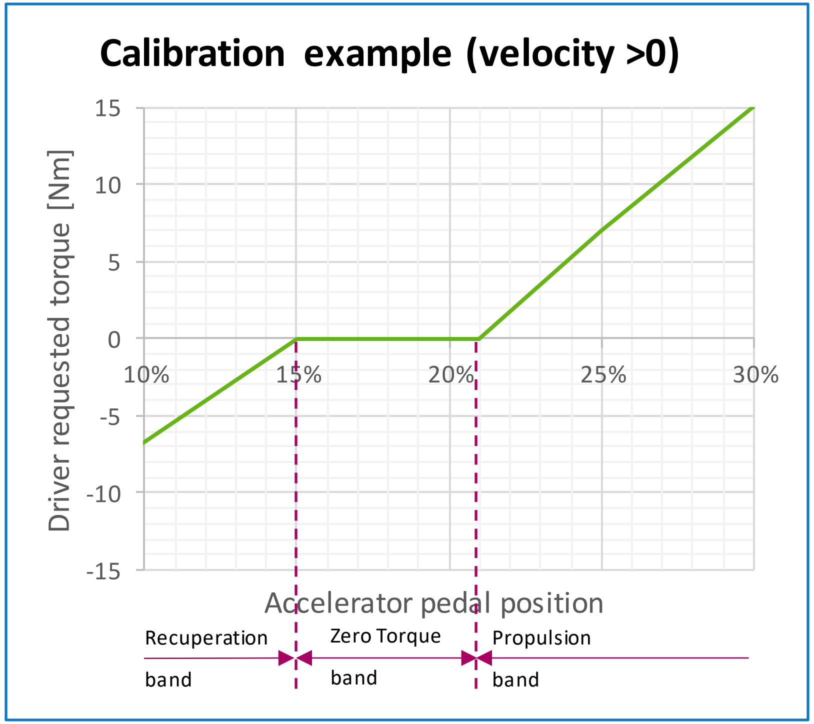
- Non-linear behaviour is supported by adjusting table elements
- Recuperation is supported without using the brake pedal up to a deceleration of 1.3 m/s^2

VCU EV Functions

One Pedal Driving

➔ **Acceleration & braking (incl. up to standstill) controlled only via accelerator pedal**

- Recuperation is supported without using the brake pedal
- Switching on brake lights due to recuperation not necessary (Recuperation limited to a deceleration of 1.3 m/s²)
- different “interpretation bands” could be calibrated
- **recuperation band**
  - driver requested torque is negative
- **zero torque band**
  - driver requested torque is zero (**coasting band**)
- **propulsion band**
  - driver requested torque is positive.



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VCU EV Functions
Customizable Recuperation Levels

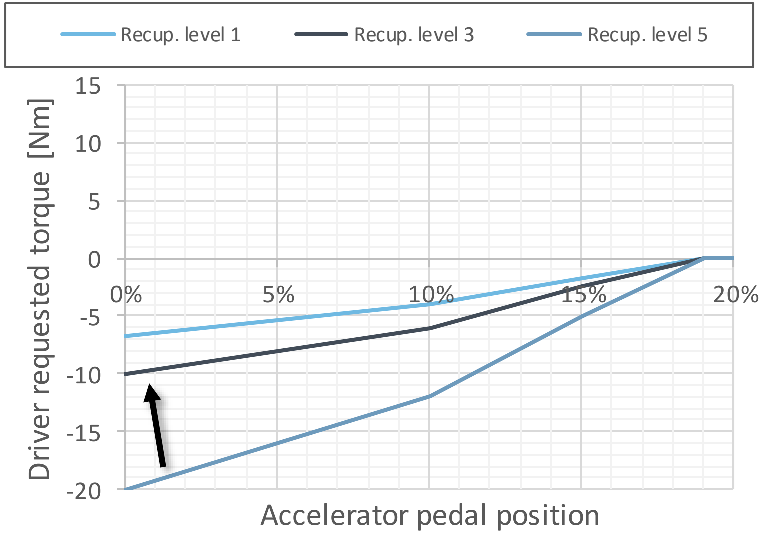
➔ **Configurable recuperation level selected by the driver**

- **Impact of recuperation level:**
  - A multiplier factor is derived from *recuperation level*:

Recuperation level	Multiplier factor
1	≥0
2	0-1
3	0-1
4	0-1
5	≤1

  - If torque request is negative, it will be decreased by the multiplier factor
- **Switch of recuperation level**
  - Switching is always possible

Calibration example



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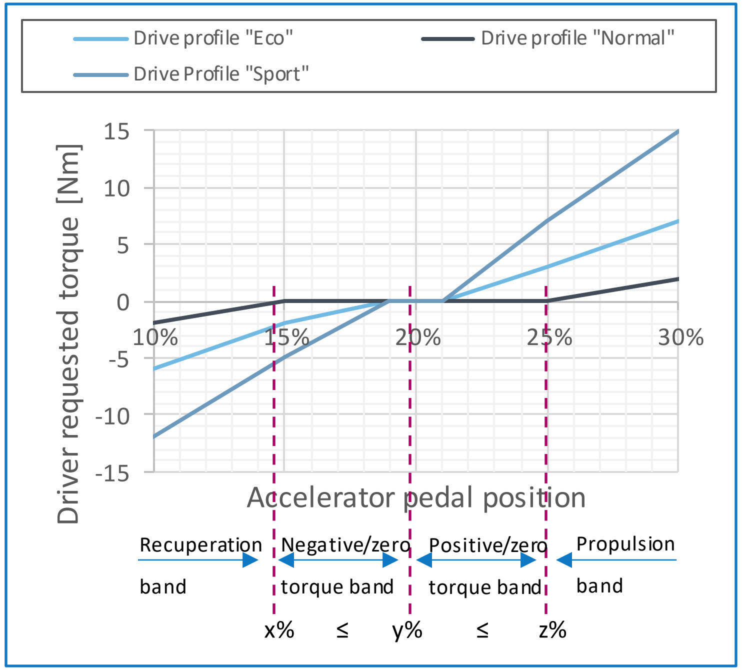
VCU EV Functions

Drive Profiles - Eco, Sport, Normal

➔ **Allow the driver to select between driving profiles e.g. economic or dynamic**

- **Impact of drive profiles:**
  - Accelerator Pedal map
  - **Length of zero-torque dead-band**
  - ASD zero crossing parameter
- **Default drive profile: NORMAL**
- **Switch of drive profile:**
  - **Switching always possible** and desired torque will be ramped up or ramped down from one AccPed map to another
  - Drive profile recommendation (to ECO) at low predicted range
  - **Automatic switch** from "ECO" to "NORMAL" at kick-down of accelerator pedal.
    Automatic switch back if kick down position is left.
    Only supported if default drive profile is NORMAL.



VCU EV Functions
Driver Assistance Functions

- **Speed Limiter**
  - **Maximum vehicle velocity is limited to OEM programmed maximum speed**
  - Driver individual maximum speed (via HMI) on customer request
  - OEM programmed maximum speed cannot be overwhelmed by driver or other assistance functionalities

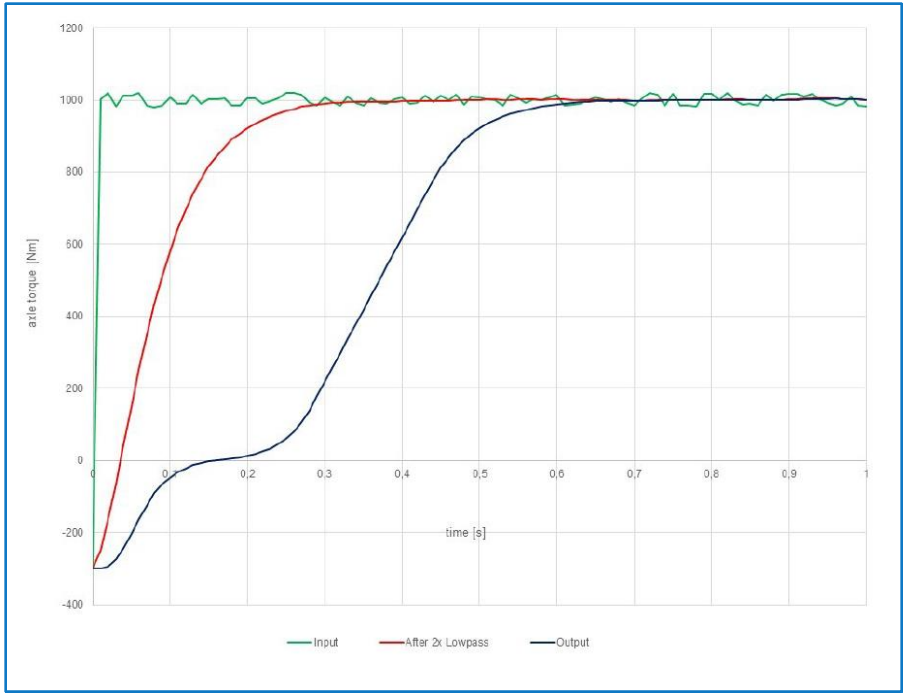
- **Cruise Control**
  - **Cruise Control supported, desired velocity can be set via HMI**
  - Activation and deactivation via HMI is supported
  - Propulsion and recuperation (up to 1.3 m/s^2) is supported

- **Creep Control**
  - **Creep Controller enables drive-off when driver releases brake pedal at low speed**
  - Controller optimizes drive-off automatically for different slopes and vehicle mass
  - Customization of creep controller by driver (activation/deactivation) during parking (P)
  - Interaction with One Pedal Driving:
    - During drive-off: Creep controller is prioritized against One Pedal Driving.
    - Vehicle velocity > Threshold: One Pedal Driving is prioritized against Creep controller
    - Hysteresis between both states, driver's propulsion demand prioritized Creep Controller again.

VCU EV Functions
Driveability- & Anti-Surge-Filtering

➔ **Smoothing torque demand**

- Smoothing of driver demanded torque and
- Smoothing of driving assistance torque demand when required
- Zero-crossing filtering to avoid strokes on drive train
- Provision of parameters for inverter-internal disturbance controller
- Different behavior of zero crossing depending on active drive profile



- Axle-specific zero-crossing filtering is enabled
- Anti “wind-up” in case of drivetrain limitations

VCU EV Functions
Consideration of Component Limitations and CRBS

➔ **Calculate torque demand based on component limitations**

- Determination of **summed vehicle torque limitations** based on battery and inverter potentials
- Determination of **driving axle specific torque limitations** based on battery and individual inverter potentials
- Failure reactions considered in component limitations
- Limp-Home (Torque reduction due to failure management)
- Consideration of performance reduction due to de-rating behavior of HV-components
- Adaption of negative limits in order to ensure fixed distribution of recuperation

- Consider **external demand from cooperative braking system (CRBS)**
- Summation of CRBS demand and accelerator pedal recuperation demand

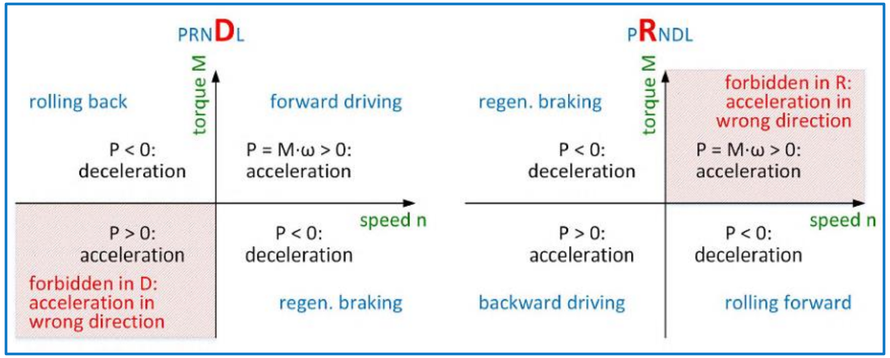
VCU EV Functions

Stability Functions / Coordination Torque Request to Inverter

➔ **Calculate torque request considering driving direction and vehicle stability**

- **Stability Functions**
  - Consider external demand from stabilization torque intervention
  - Axle-specific ESP-interventions can be managed
  - Prioritization of stability interventions against other demands
  - Release of stability interventions by considering ESP-status.

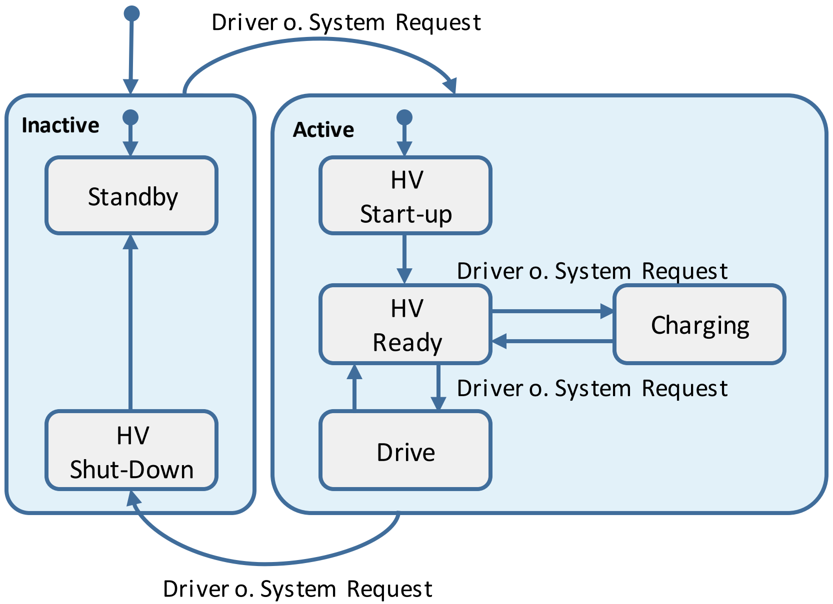
- **Coordination Torque Request to Inverter**
  - Four-Quadrant-Mapping (see example)
  - Individual communication to each e-drive is supported
    - Request offset calibration
    - Standby
    - Torque control



VCU EV Functions

Vehicle State Coordinator / Safe States

- Top Level Control of Vehicle States: **Standby, HV Start-up, HV Ready, Drive, HV Shut-down and Charging**
- Possible **transition conditions** of the states
  - HV Start-up: driver request or charging request or thermal request…
  - Drive: *drive mode* in P / N and powertrain release and brake pressed
  - Inhibit powertrain: vehicle power release withdraw or *driver presence* not detected or plugged charger plug at low velocity …
  - Release Charging: plugged charger plug, vehicle in standstill and fixing brake active
  - HV shut-down: vehicle power release withdraw
- **Safe State Coordination**
  - Inhibit powertrain propulsion
  - Inhibit recuperation
  - Limp Home and vehicle speed limitation
  - High voltage system shutdown
  - Disable ADAS functions
  - Driver alert (show warning to driver)



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VCU EV Functions
Operation of one/two Electrical Drive Units

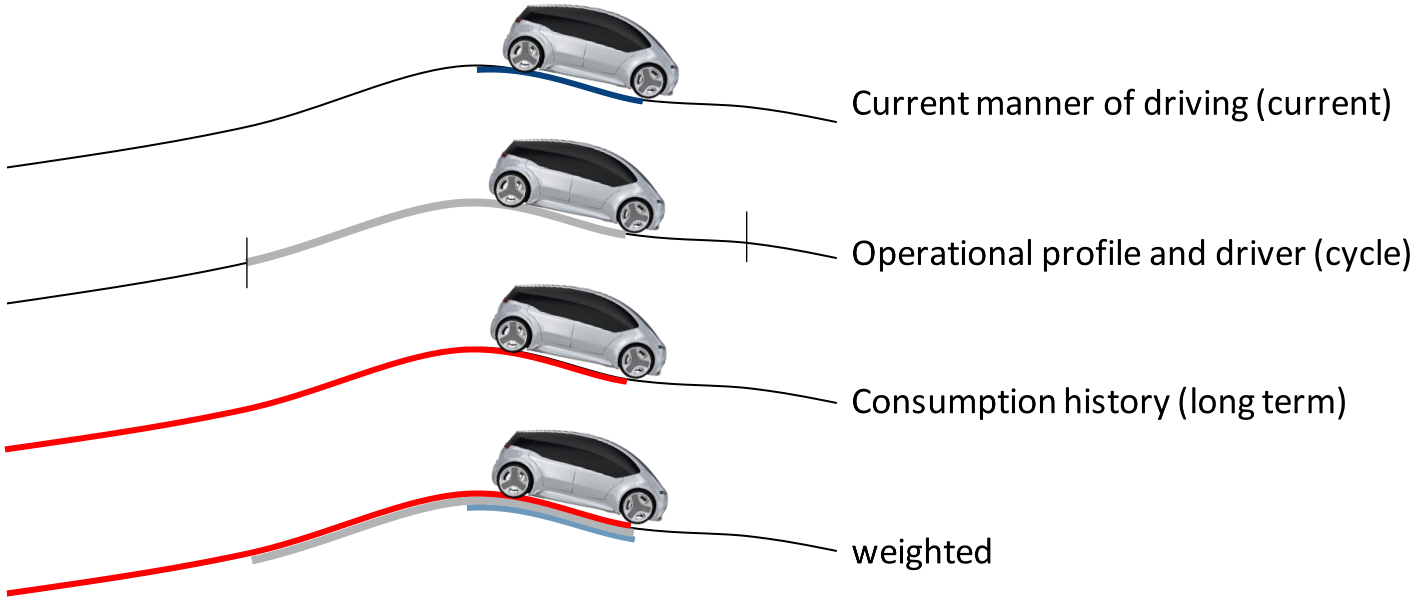
➔ **Calculate torque demand and distribution for two powered axels**

- Enhancement for secondary axle of:
  torque path, vehicle stability functions, torque limitations, zero-crossing filtering, quadrant mapping.
- **Dynamic torque distribution** between front axle and rear axle based on
  - torque demand
  - velocity during propulsion
  - Drive Profile [ECO, Normal] possible
- Gradient limitation of dynamic torque distribution for higher driver demands (due to safety)
- Adaption of torque distribution dependent on component potentials (e.g. e-axle limits)
- Limitation of torque distribution adaption in case component limitations are active
  - No adaption in case of driving stability interventions
- Fixed torque distribution during recuperation (no adaption)
  - Distribution of recuperation torque can be calibrated according to brake distribution of hydraulic brake system

VCU Functions
Range Prediction

➔ **Determine a reliable remaining range prediction**

- The basic range prediction calculates the **predicted range** out of the **available HV battery power** (kWh) and the **past power consumption** (kWh/100km)
- The past power consumption is calculated as weight of long term power consumption (since last reset), the power consumption of the actual driving cycle (since last T15 on) and the current filtered power consumption



VCU Functions
Safety Monitoring

➔ **Provide detection and prevention functions for all safety critical vehicle states**

- Functional Monitoring for an Electric Powertrain
  - **Redundant torque demand calculation**, e.g. driver request and external interventions
  - Monitoring of different operation modes, e.g. no moving while charging or limp home
  - **Redundant signal acquisition of safety critical signals**, e.g. acceleration pedal
  - Creeping monitoring functionality

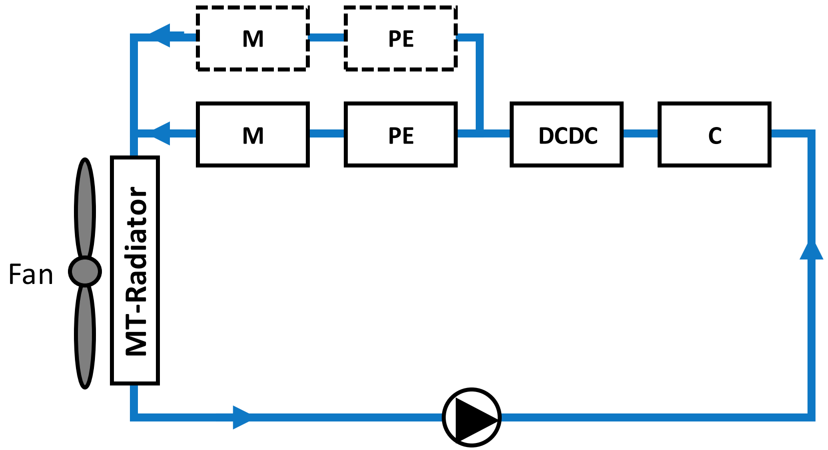
- **Software to avoid relevant Hazards, e.g.:**
  - To prevent **unintended vehicle movement**
  - To prevent **unintended vehicle acceleration**
  - To prevent **unstable vehicle dynamics** due to too high axle propulsion
  - To prevent **unintended vehicle deceleration**
  - To prevent **vehicle movement in the wrong direction**

VCU Functions
Thermal System Control for Battery Electric Vehicles

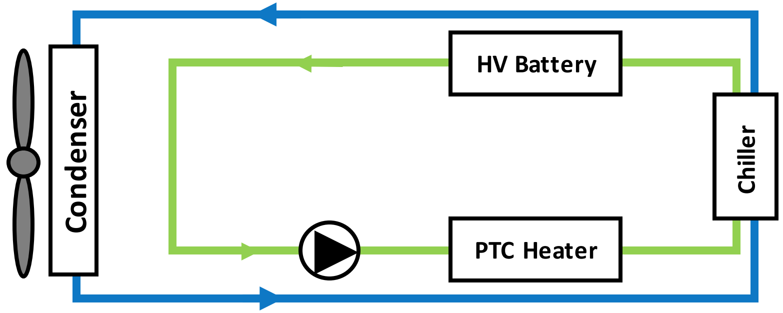
➔ **Control all thermal devices according to cooling and heating requests of active PT components**

- **Medium temperature circuit:** supports **cooling of Inverter, E-Machine, Charger and DCDC**
- Control strategy is based on the temperature difference

- **Low temperature circuit:** supports **cooling and heating of the Battery** (incl. active Battery Temperature Management)
- Interface to the **Cabin Thermal Management**
- Continuously controlled AC compressor with cooling power arbitration between cabin and traction battery

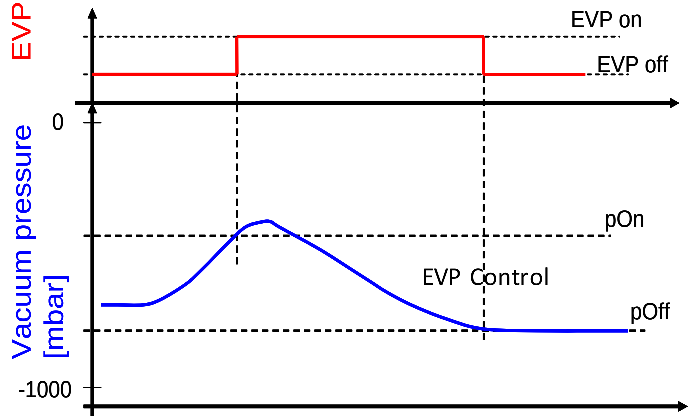


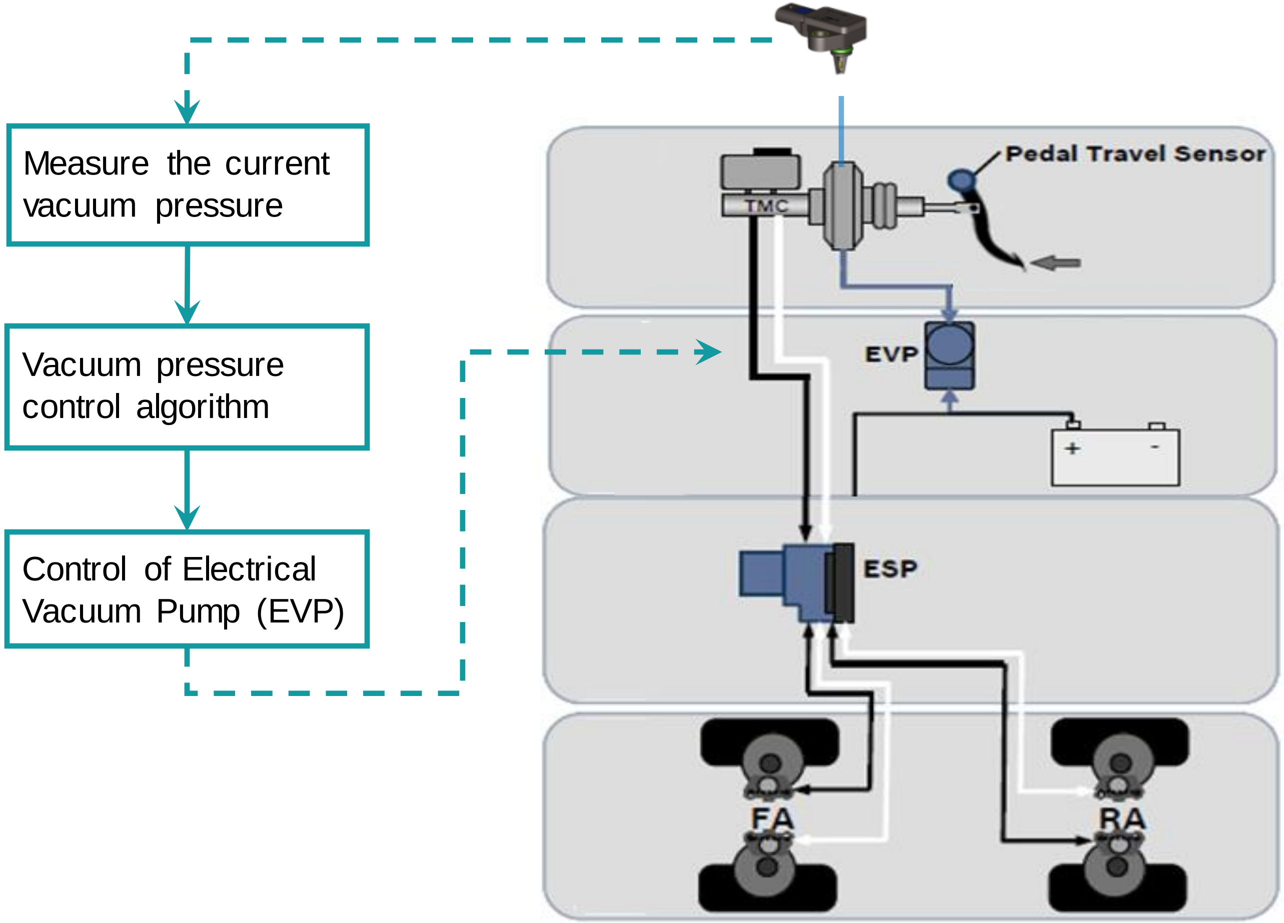
Example for a possible cooling system topology



VCU Functions
Electric Vacuum Pump

➔ **Provide vacuum pressure to support brake booster**





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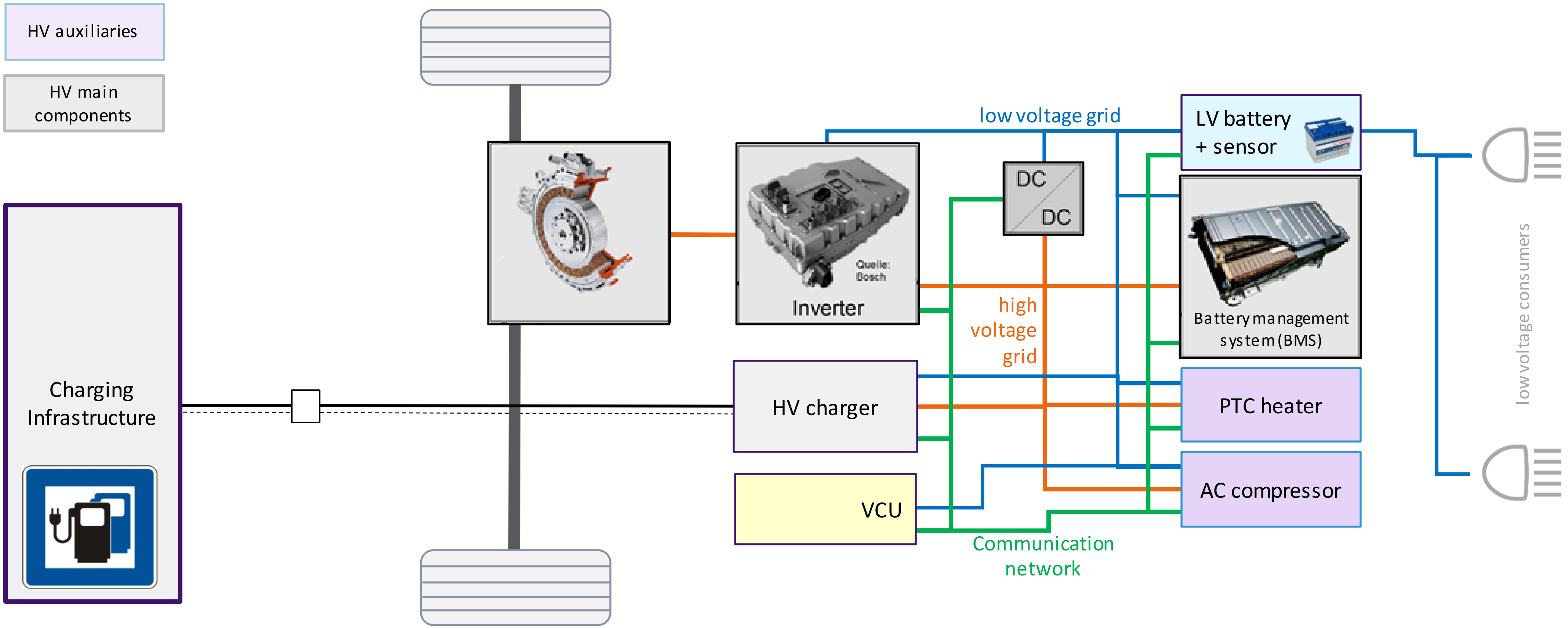
PS-EC Portfolio Information
Vehicle electrical supply system

➔ **Control and distribute electrical power**

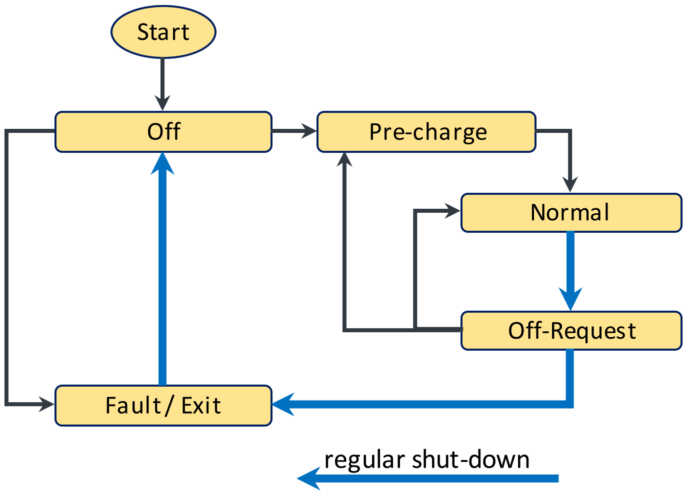


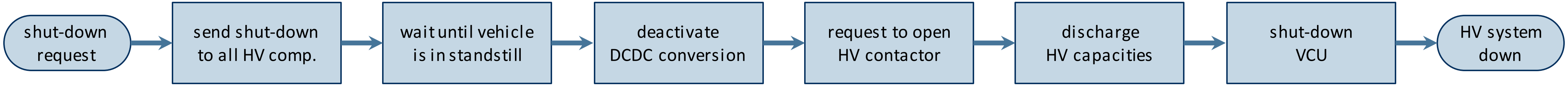
HV - High Voltage (> 60V)   LV - Low Voltage (12V/24V)

VCU-EV Software

Coordination of high voltage system (2/2)

- **HV system shut-down** coordination
  - HV system shut-down depends on vehicle coordinator state and HV shut-down-readiness of the HV components (component current close to zero)
  - Send shut-down command to HV components – HV current set to zero
  - Deactivation of DCDC conversion is delayed until vehicle is in standstill
    Send deactivation demanded to DCDC converter
  - Request to open HV battery contactor to battery management system (BMS)
  - Discharging of capacities in HV grid demanded from inverter,
    to reduce remaining voltage in high voltage grid below 60V
  - Prolongation of vehicle control unit shutdown, until HV system shutdown has finished





BMS – Battery Management System HV - High Voltage (> 60V) LV - Low Voltage (12V/24V)

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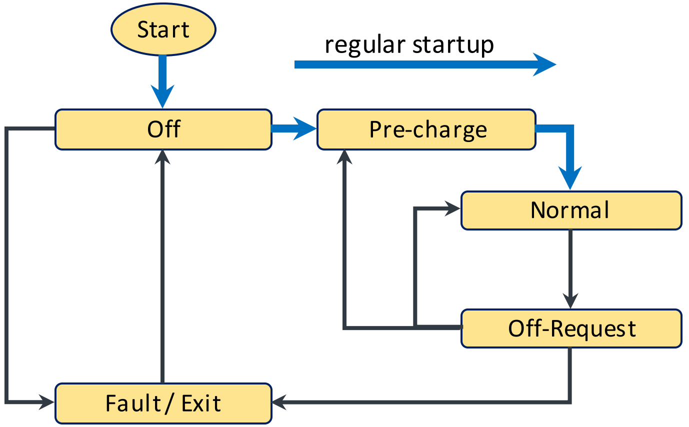
Coordination of high voltage system (1/2)

➔ **Control the state machine of the High Voltage System and coordinate the HV components accordingly**



- Bi-directional CAN communication
  with the control units of the HV components which are coordinated by VCU
- Coordination of
  - main HV system components (BMS, Inverter, DCDC converter) and
  - up to 5 high voltage auxiliary devices (e.g. heater, compressor, ..)

- **HV system start-up** coordination
  - HV system start-up depends on vehicle coordinator state and HV-Readiness of the HV components
  - Pre-charging of capacities in high voltage grid, to prevent electric current peak (requested from battery management system)
  - Send request to BMS to close high HV contactor (i.e. VCU does not directly control the HV contactor)
  - Activation of DCDC conversion demanded from DCDC-converter

BMS – Battery Management System HV - High Voltage (> 60V) LV - Low Voltage (12V/24V)

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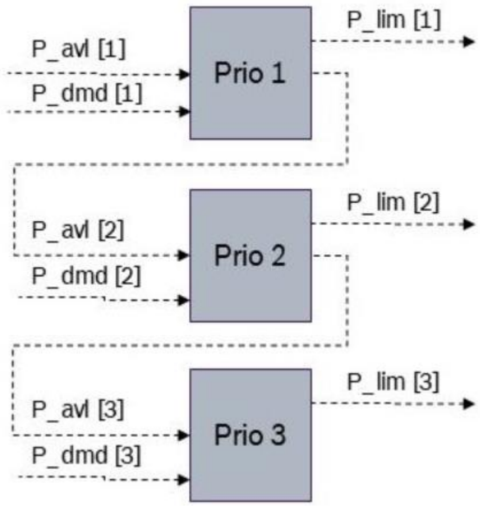
VCU-EV Software

Load management of high voltage system

➔ **Distribute the available power based on component demand and priority**

▶ High voltage load management

- **Demanded power** of HV consumers is **provided as long as sufficient power is available**
- If available power is insufficient, the allocated power of HV consumers* is limited depending on priority.
- Determination of predicted power demand for each HV consumer* (main components and auxiliaries) for power allocation
  → allows buffer capacity for increased power consumption or short term load request
- **Use case dependent** (e.g. driving, charging,..) and prioritized power allocation for HV components*, based on their predicted power demand
- Determination of current power consumption for each HV consumer* (main components and auxiliaries)
- **Predict power limitation** (short-term ~3s / long-term ~10s) for powertrain coordination, based on HV battery power limits and current power consumption of HV auxiliaries.
  Allocated but unused power can be used as buffer for powertrain.



* managed HV components

VCU-EV Software

Diagnosis and limitation of high voltage system

➔ **Detect and react on HV system failures and limits to ensure a safe operation**

- High voltage system failure handling
  - Receive failure information from HV components (e.g. regarding isolation or interlock failures) and trigger appropriate failure reactions (e.g. initiate HV system shut-down)
- High voltage system diagnosis
  - Determination of system voltage limits for HV grid from HV components (e.g. allowed min/max values of Inverter, Charger, ..)
  - Plausibility check of HV grid voltage against HV system limits (minimum, maximum, difference) with appropriate failure reaction
  - Determine the minimum value of HV battery’s state of charge
- Generator power limitation for electric powertrain
  - Predicted a short-term (~3s) and long-term (~10s) power limitation in case of recuperation to ensure a safe operation within the defined battery power limits

BMS – Battery Management System HV - High Voltage (> 60V) LV - Low Voltage (12V/24V)

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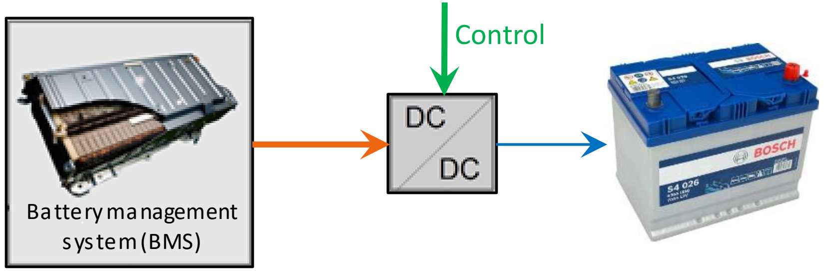
Supply of low voltage system (12V/24V)



➔ **Energy supply for the Low Voltage system by means of energy transfer from HV to LV battery**

- Low voltage battery charging
  - Control of DCDC converter
    - Determination of DCDC converter set-point voltage, based on temperature of LV battery
    - Limited dynamic for voltage set-point control to prevent noticeable dynamic effects
- Low voltage components supply
  - Support of Bosch's intelligent LV battery sensor
    - Communication with Bosch's intelligent LV battery sensor
    - Capture of LV battery properties (Voltage, Temperature, ..)

- Low voltage load management not implemented
  - Power consumption of different LV consumers not controlled or coordinated

HV - High Voltage (> 60V) LV - Low Voltage (12V/24V)

VEHICLE SENSORS

CONNECTED TO VCU

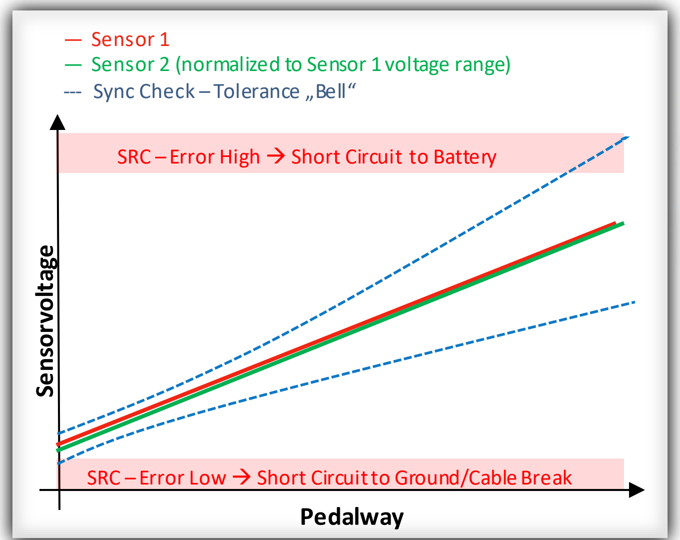
VCU Functions
Accelerator pedal position

Function overview

Signal evaluation and interpretation of accelerator pedal sensors as driver demand.

Detailed feature

- Remove jitter; linearization and filtering
- Provision of the kick-down status
- Error reaction and Limp mode



Signal plausibility check

- Signal Range Check (SRC)
- Synchronization-Check
- Brake over Acceleration(BOA)

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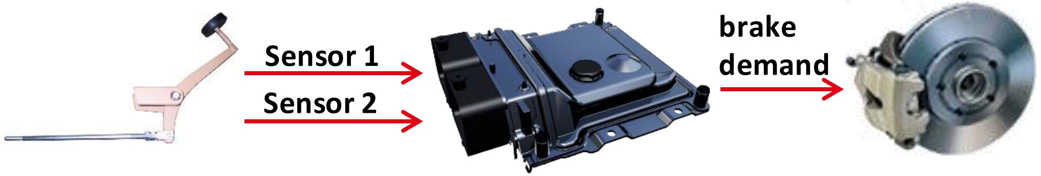
VCU Functions
Brake pedal evaluation

<u>Function overview</u>

- Evaluates the sensors in the brake pedal
- Zero Pedal Position Learning
- Calculation of the brake pedal status
- Brake pedal way sensor for Recuperation

Diagnose for brake

- Physical Range Check
- Brake Pressure Plausibility Check
- Brake Status Plausibility Check
- Brake Switch Stuck diagnosis



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VCU Functions
Vehicle speed evaluation

<u>Function overview</u>

Possible sensor-interfaces

- PWM-sensor
- CAN-sensor (ESP)
- E-Machine speed (electric vehicles) up to 4 EM

Dual signal source concept

- a main and a redundant signal source are defined
- In case of an error in one signal the system switch to the second signal

Plausibility check of vehicle speed

- Physical range check
- Power Plausibility check

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VCU Functions
Drive program selection

<u>Function overview</u>

- Evaluation of the drive program switch and recuperation switch
- calculate the recuperation factor requested by the driver
- possible signal sources:
  - DIO / ADC / CAN (ECO)
- Definition of the default value after power-on

Plausibility checks:

- If a switch is pressed longer than a certain time the drive mode change is not accepted
- If two switches are pressed simultaneously both are ignored and the previous status is retained.

VCU Functions
12V battery sensor

<u>Function Overview</u>

<u>ADC sensor:</u>

monitor the 12 V battery status.

- Measurement of Battery voltage with two sensors
- Diagnoses of power supply cut off at initialization
- Diagnosis of permanent power supply for VCU

<u>Electronic battery sensor (EBS)</u>:

- Evaluation of sensor values voltage, temperature, and current from EBS
- Error reporting from EBS to VCU