Working Paper No. **HDH-12-03e**
(12th HDH meeting, 15 January 2013)

GRPE-HDH Research Project

12th meeting of the GRPE informal group on heavy duty hybrids (HDH)

Report of the Institutes on validation test program 1

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Content

- Scope and framework conditions of validation test program 1
- Summary of working tasks 1 at validation test program 1
- Drive cycle and test methodology investigations
- Summary of working tasks 2 at validation test program 1
- Restructuring of Simulink models
- Signal list and naming convention

Heavy Duty Hybrid HILS

Developing the methodology for certifying Heavy Duty Hybrids based on HILS

HILS Model verification

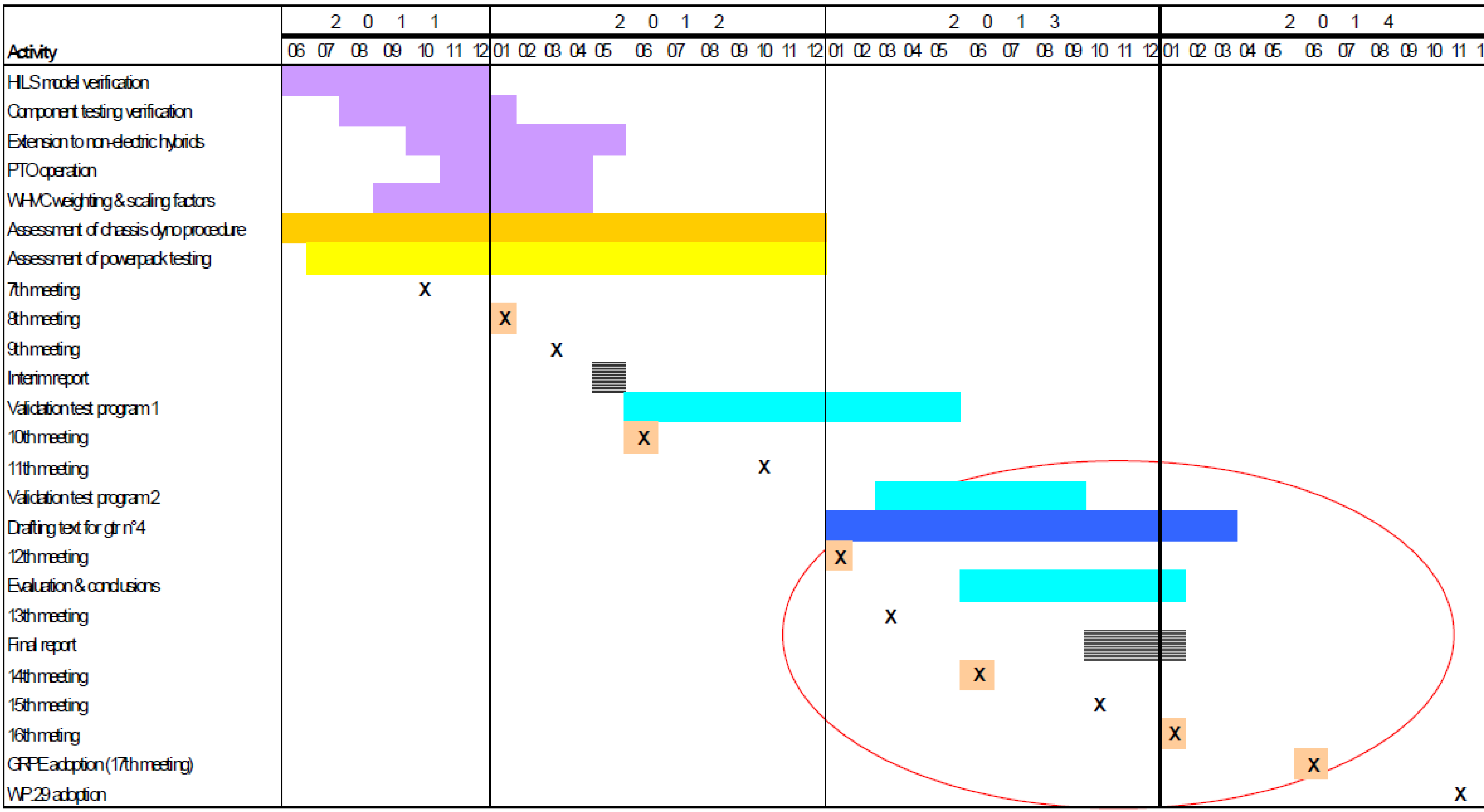
Validation test program 1

Validation test program 2

Achievements within the project due to date

- The first part of the HDH work program (research program) has been successfully finished
- Validation test program 1 on the basis of a real heavy duty hybrid software based simulation was agreed; OICA has taken over the budget for task 1, EC is sponsoring tasks 2 and 3.
- The three HDH test cycle options are investigated in validation test program 1
- Further consideration of JASIC alternative proposal will be done by Japan
- Vehicle manufacturers are asked to submit vehicles for validation test program 2

Project planning



Validation test program 1 overview

Task 1) Adaptation of the Japanese HILS Simulator for serial hybrid

- Task 1.1) and 1.2) serial hybrid model with different driver models are completed
- Task 1.3) modelling non-electric components is finalized, overall model-implementation deferred with regard to validation phase 2
- Task 1.4) Meetings with Daimler, Volvo and Scania took place
- Task 1.5) Currently different planetary gearbox models available
- Task 1.6) Thermal models to be completed/validated within 2 weeks
- Task 1.7) SILS model test runs performed with one serial powerpack and different vehicles (mass, tires, drivetrain gear ratios)

			Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
	1	SILS for serial hybrid												
✓	1.1	Set up a serial HDH as SILS												
✓	1.2	Adapt driver model												
✓	1.3	Library for non electric components												
O	1.4	Meetings with OEM's and stakeholders												
✓	1.5	Library for new power pack components												
O	1.6	Thermal models												
✓	1.7	Simulation runs and validation												

Validation test program 1 overview

Task 1.4) Meetings with OEM's (Daimler, Volvo, Scania)

- Most important insights
  - Vehicle speed and mass/inertia will be needed for ECU logics (gear shifting,..)
    - When considered, pure vehicle independent approach not feasible
  - Avoid having multiple ECUs at HILS (effort, costs, complexity)
    - One representative hardware ECU (hybrid ECU, free to choose by manufacturer?)
    - Interface model with remaining ECU functions (SILS)
    - Pure SILS solution would be preferred (HILS or SILS selectable?)
  - Specification of needed interface signals difficult because lack of practical experience and information on Simulink models
    - Latest GRPE-HDH models should be available for manufacturers

Validation test program 1 overview

Task 1.5) Library for new powerpack components

- Most commonly used components should be already available

- Different planetary gearbox models available in library
  - Without component inertias and gearing losses
  - With inertias but without consideration of gearing losses
  - For consideration of gearing losses
    - Efficiency input parameters have to be specified
      - As there is currently no urgent need, manpower is used for drive cycle & testing method investigations
  - All available gearbox models validated with other software tools (GT-Suite)

- As soon as vehicles for validation phase 2 are identified, component list will be checked for missing parts

Validation test program 1 overview

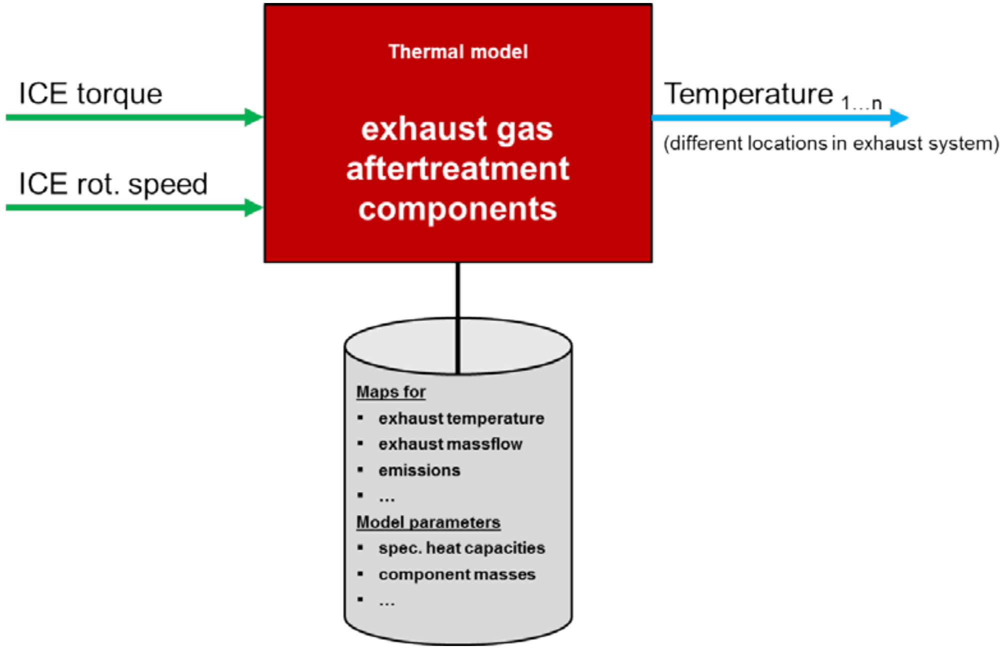
Task 1.6) Thermal models

- **Extend the GTR-HILS Simulator with thermal models for exhaust gas aftertreatment system, coolant, lube oil, battery and electric motor**
  - In previous project phase it was decided that HDH will have to undergo a cold start test (+20°C) similar to the conventional ICEs
  - HDH ECUs will need plausible information on the temperature levels of all relevant components to select the correct operation strategies
  - Simple thermal models with generic input parameters are being developed / adapted and integrated into the HILS simulator

Validation test program 1 overview

Task 1.6) Thermal models

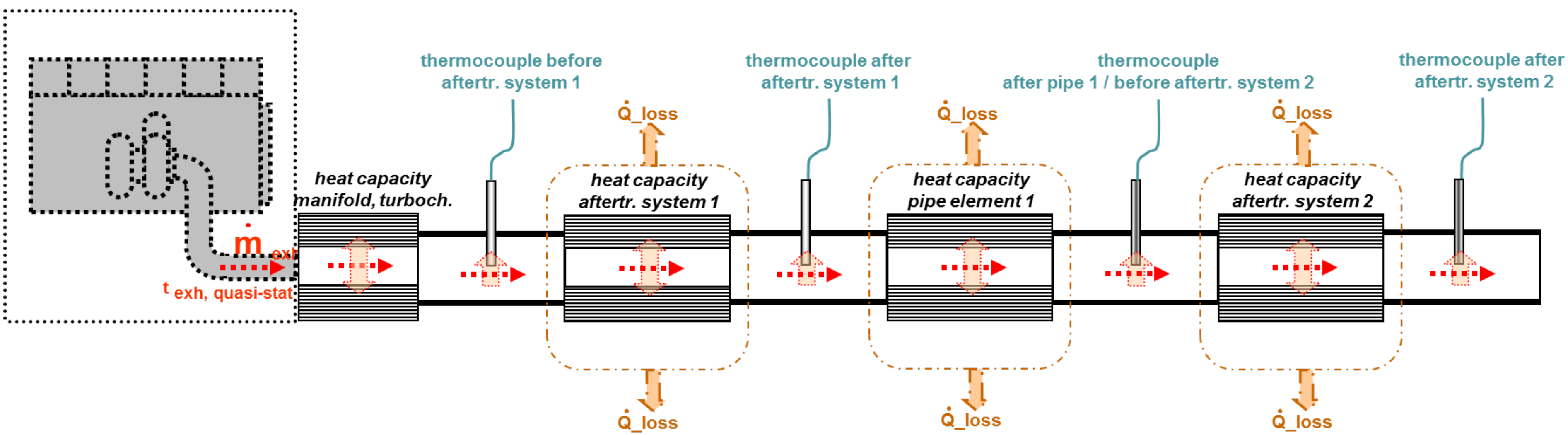
- **Thermal models for exhaust gas aftertreatment components**
  - implemented in Simulink
  - validation with existing measurement data finished
  - ready to be linked to the main Simulink model



Validation test program 1 overview

Task 1.6) Thermal models

- **Thermal models for exhaust gas aftertreatment components**
  - modular approach (combinations of 2 elements)
  - system of pipe elements and aftertreatment catalysts can be modeled
  - gas and surface temperatures at each element are provided



Validation test program 1 overview

Task 1.6) Thermal models

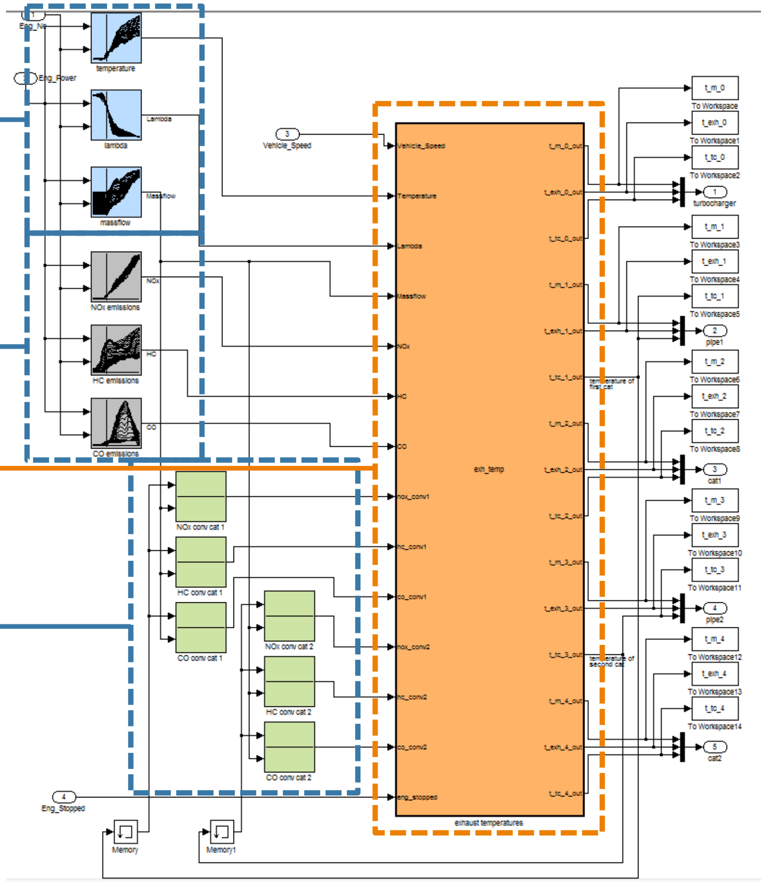
- **Thermal models for exhaust gas aftertreatment components – basic model structure**

maps for temperature exh. out, lambda, massflow

maps for emissions

Calculations in MATLAB code

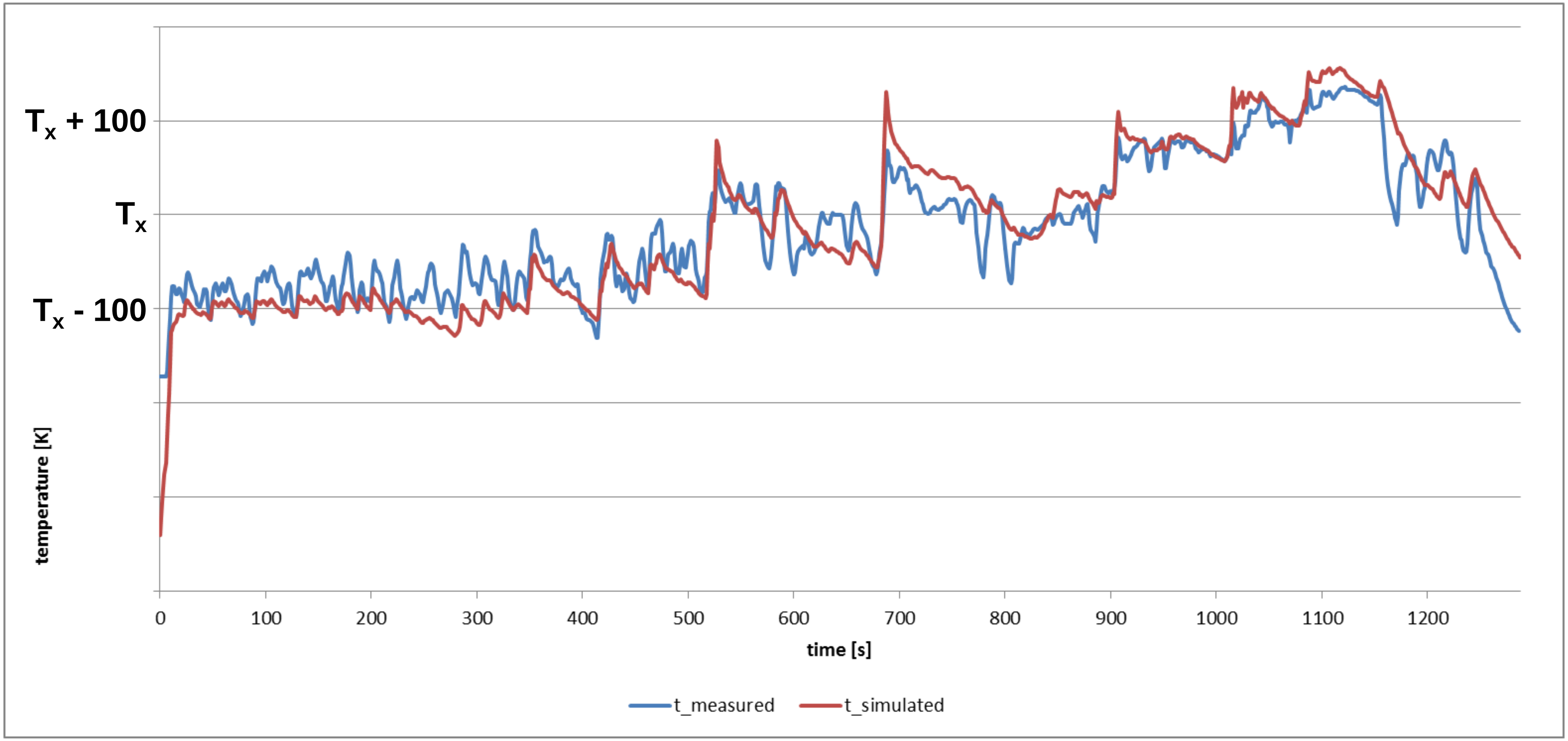
maps for conversion rates of catalyst



Validation test program 1 overview

Task 1.6) Thermal models

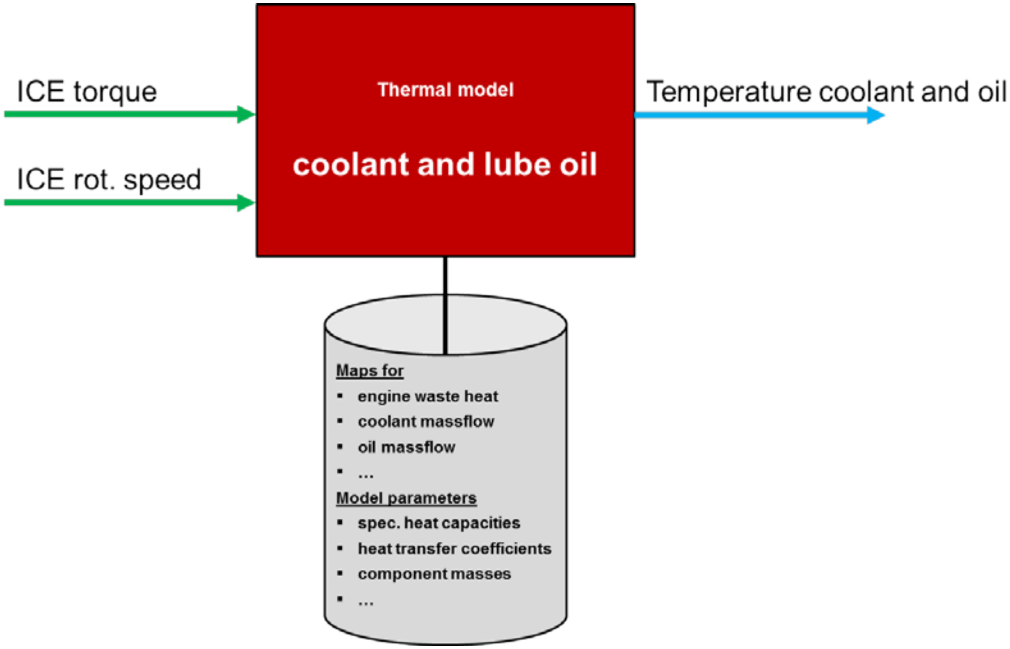
- **Thermal models for exhaust gas aftertreatment components – simulation vs. measurement at specific location**



Validation test program 1 overview

Task 1.6) Thermal models

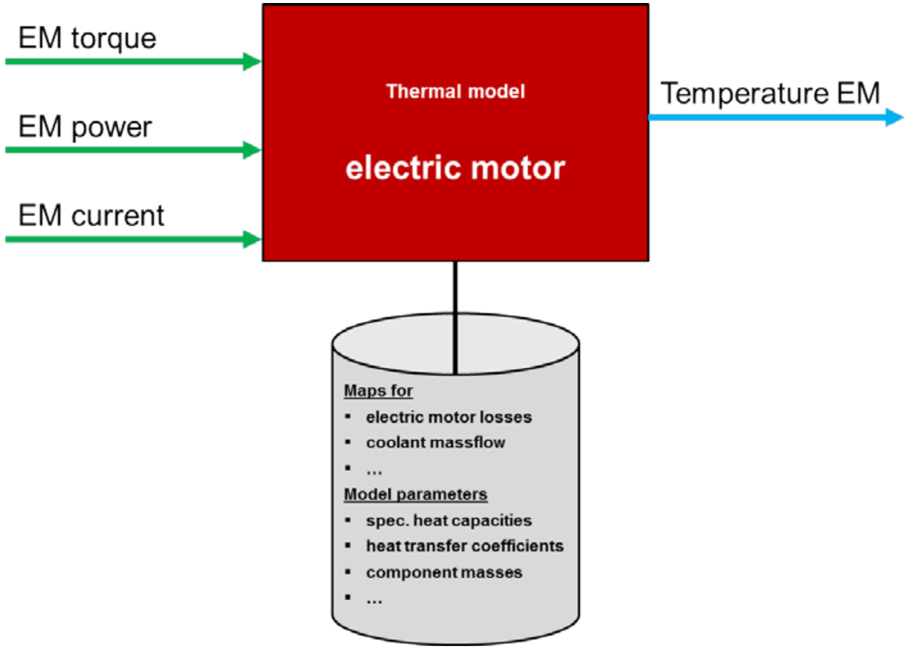
- **Thermal model for coolant and lube oil**
  - complex model implemented in Simulink
  - measurements on engine testbed for parameterization of model completed
  - adaption of existing model finished within next week
  - parameterization and validation with measurement data until end of January

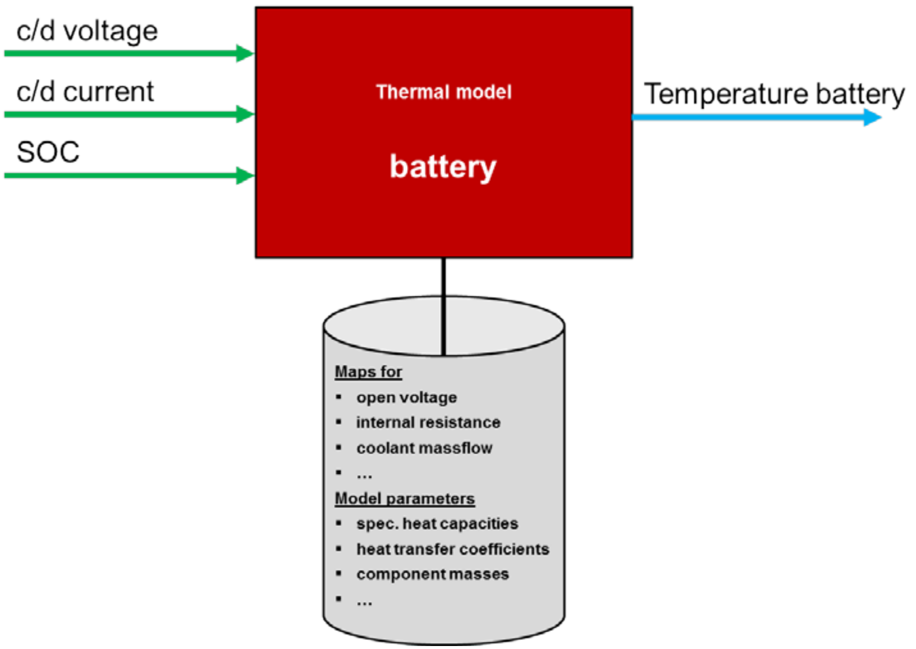


Validation test program 1 overview

Task 1.6) Thermal models

- **Thermal models for battery and electric motor**
  - development in cooperation with *Institute of Electrical Measurement and Measurement Signal Processing* at TUG
  - development finished within next week
  - model validation until end of January



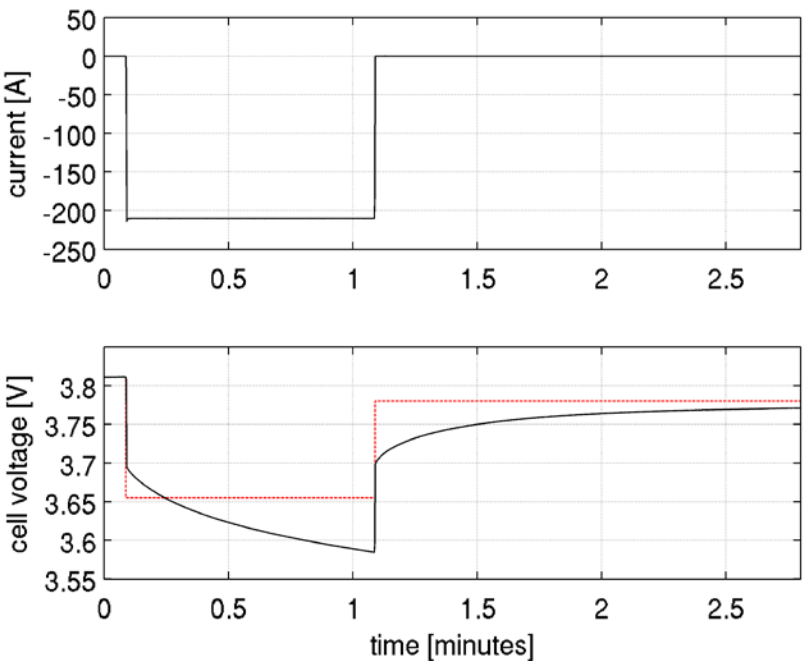


Validation test program 1 overview

Task 1.6) Thermal models

- **Thermal model for battery**
  - Time dependence of current / voltage behavior is required for a better estimation of the power loss
  - Parameterization: measurements based on method defined in Kokujikan No. 281

    > only different data analysis

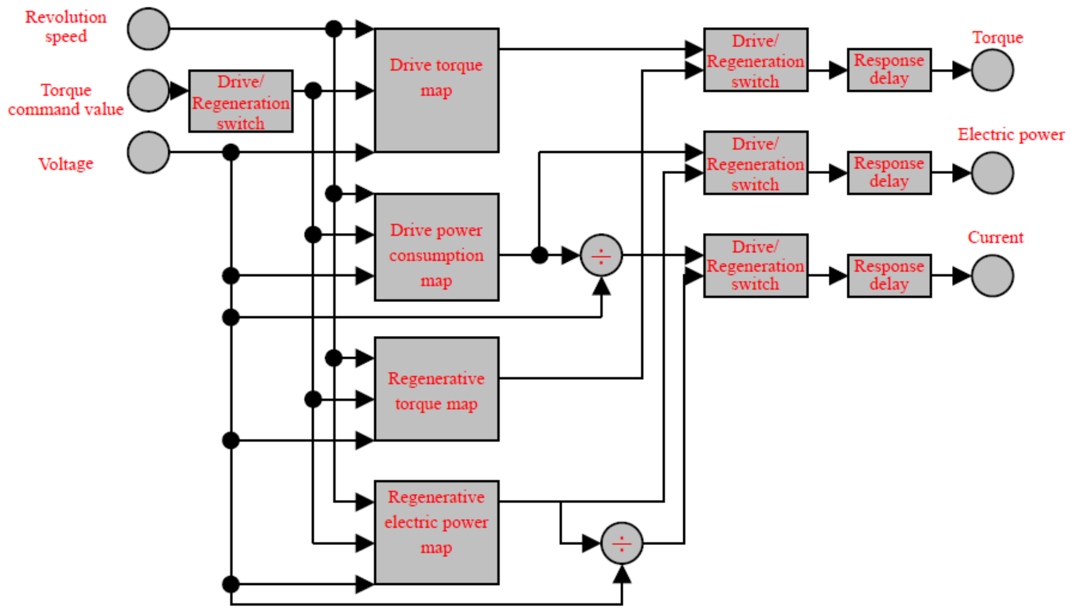


- No time dependent model as shown in Kokujikan No. 281
- Time dependent model

Validation test program 1 overview

Task 1.6) Thermal models

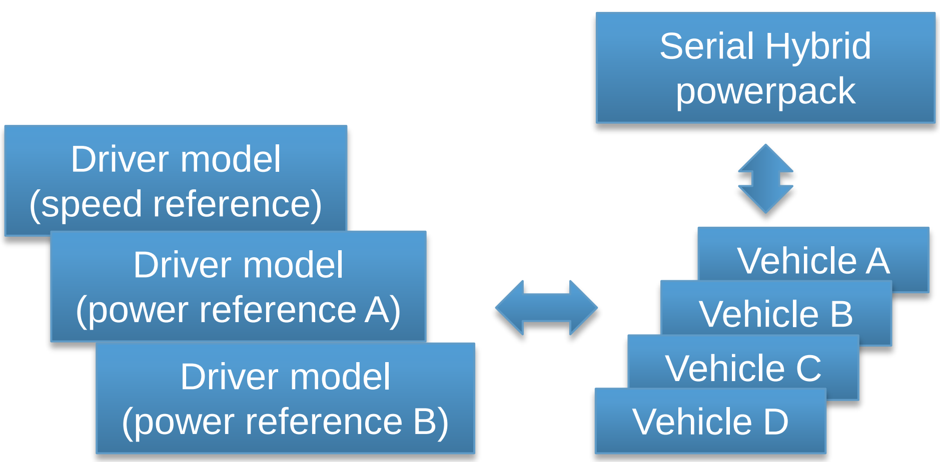
- **Thermal model for electric motor**
  - based on electric motor model from Kokujikan No. 281
  - mechanical losses represent thermal energy input for electric motor
  - temperatures of electric motor (and cooling fluid) are calculated
  - generic parameterization of cooling system (powerpack testing)

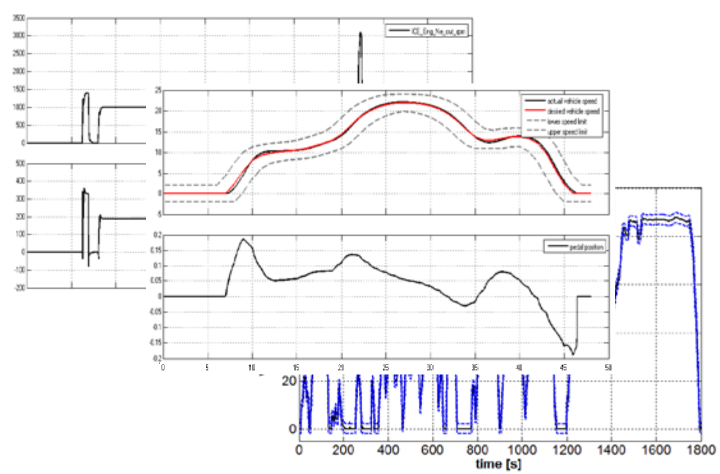


Validation test program 1 overview

Task 1.7) Serial hybrid SILS model test runs

- Test runs performed with
  - Generic serial hybrid powerpack data and
    - Different driver models (one speed and two power demand drivers)
    - Different vehicles (mass, tires, drivetrain gear ratios)
    - But without thermal models, as they are just „add ons“ they should not influence the model behaviour when implemented

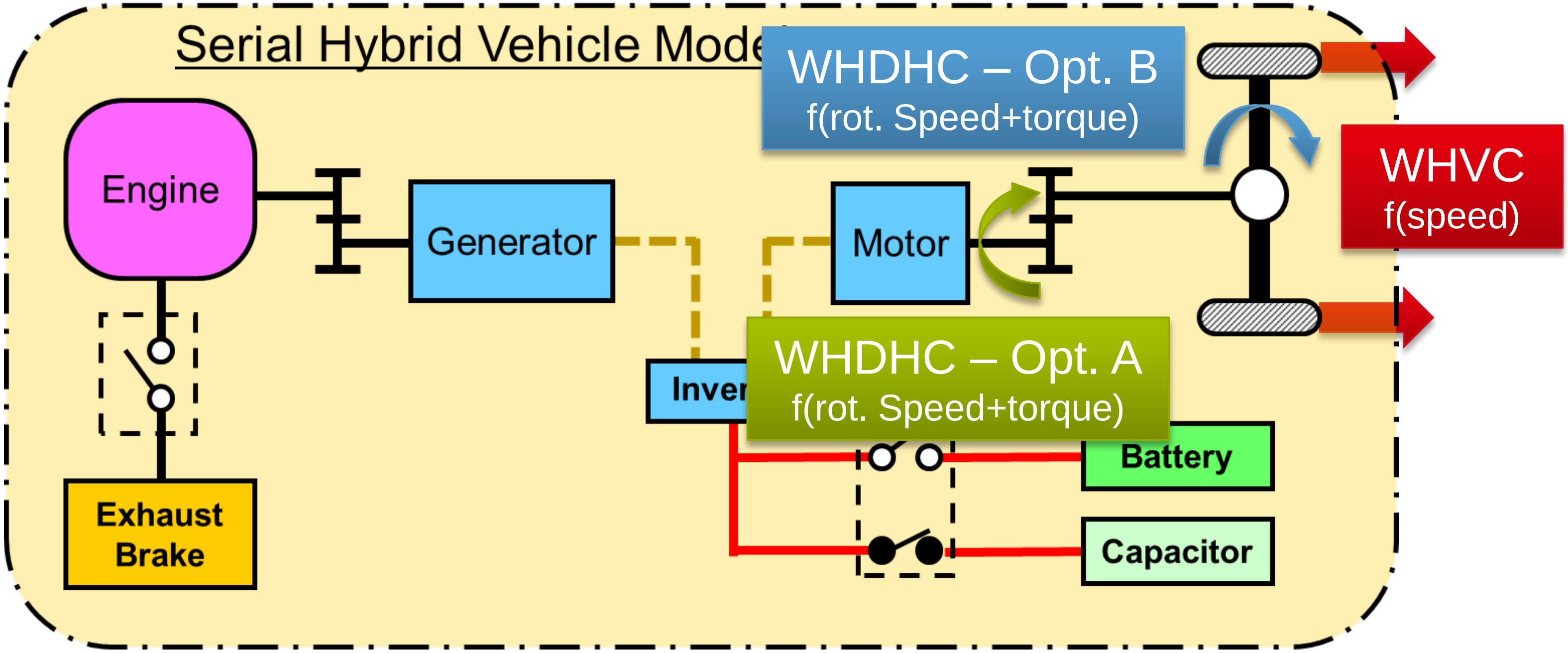




Validation test program 1 overview

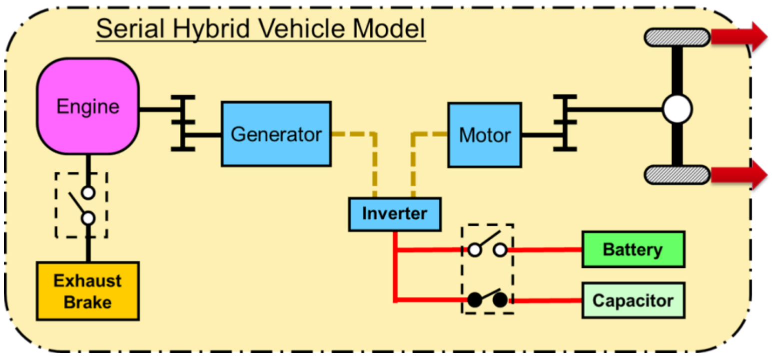
Task 1.7) Serial hybrid SILS model test runs

- Different driver models includes
  - Driving cycles at different vehicle interfaces

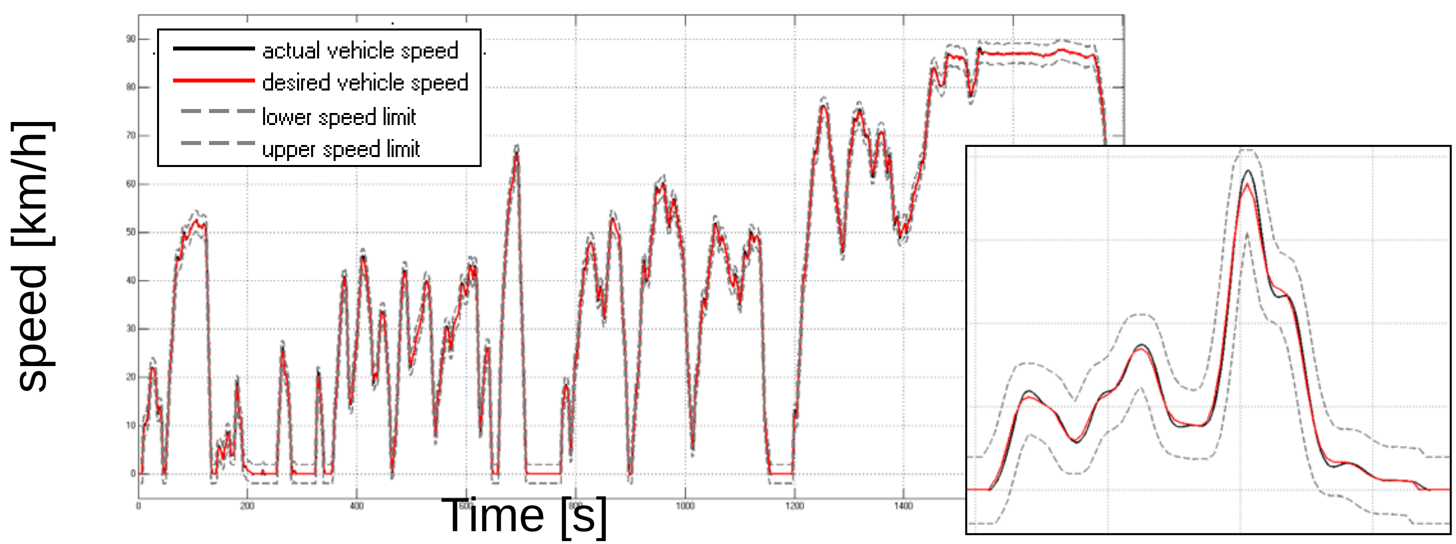


WHVC Driver

Vehicle speed reference cycle

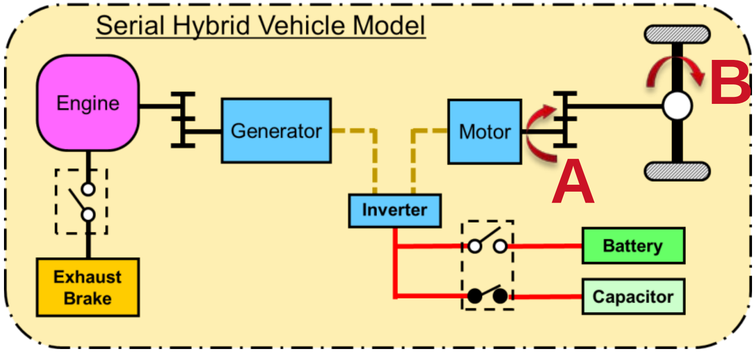


- Test vehicle
  - 12 tons serial hybrid
  - 172 kW el. motor
- WHVC speed trace can be followed within the tolerances (+/-2 km/h, 1 sec)

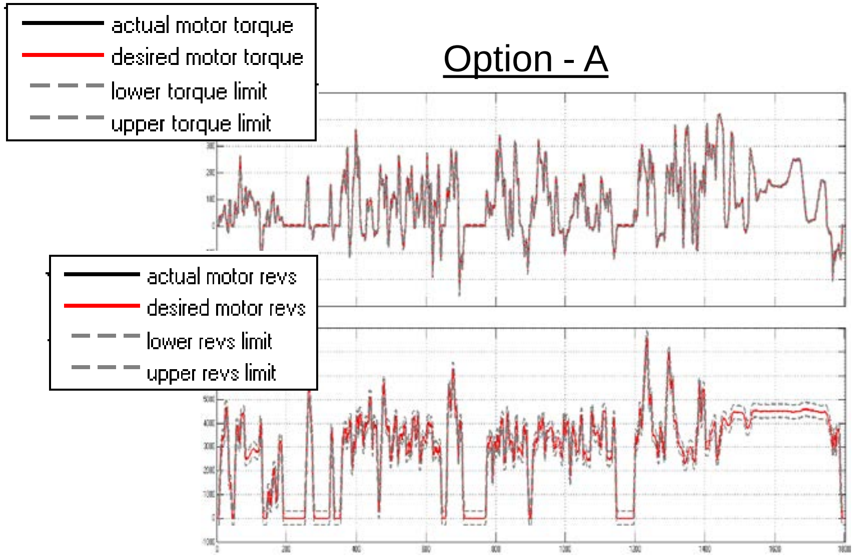


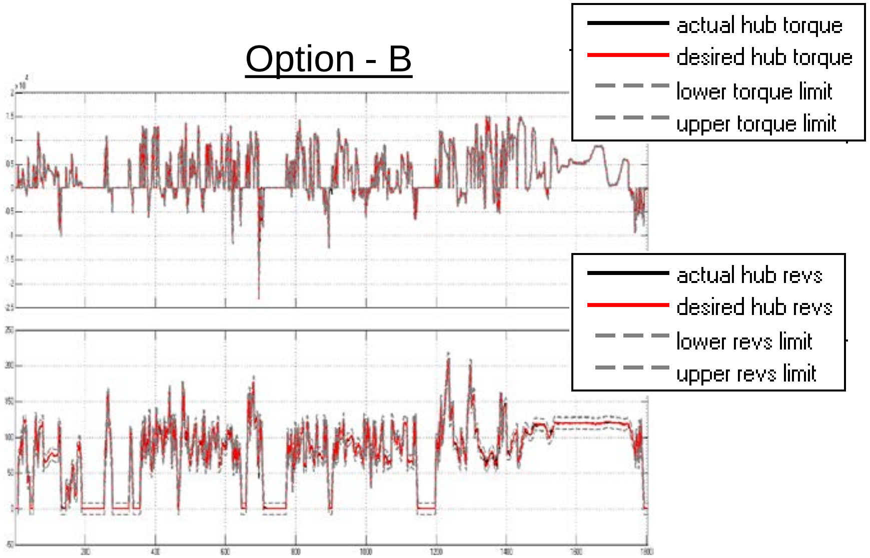
WHDHC Driver

Torque / rot. speed reference cycle



- Test vehicle
  - 12 tons serial hybrid
  - Same powerpack / same drivetrain as before
- HILS model also able to follow torque / rot. speed input cycles (WHTC, WHDHC,..)





Drive cycle investigations

(continuing work from previous research phase)

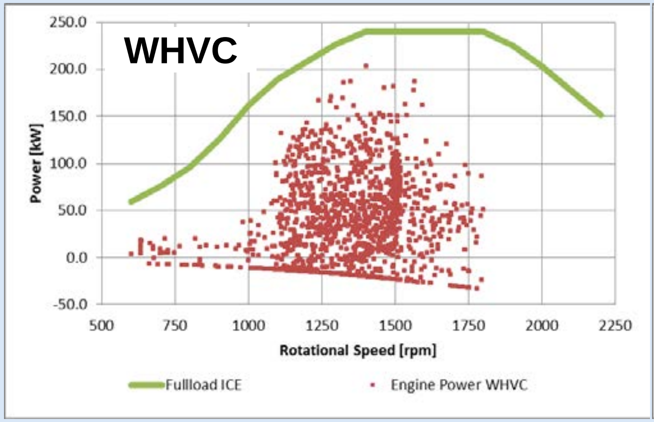
Starting point

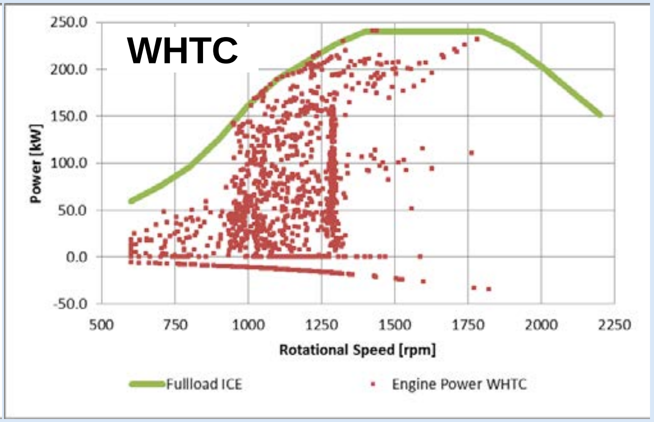
- Japanes HiLS approch based on a speed cycle (like WHVC)
- Conventional engine certification based on engine cycle (WHTC)

Fair comparison of conv. HD and HDH

- WHVC vs. WHTC for conventional ICE engines
- HILS with WHVC not compareable with conventional vehicles >> unrealistic engine operating points (no full load)

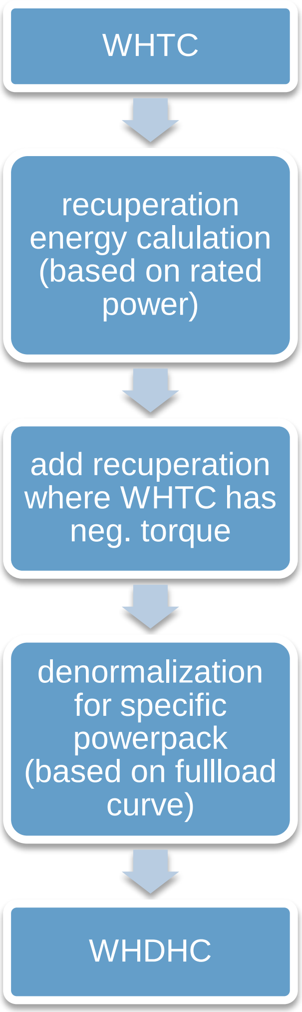
Comparison of engine loadpoints for a conventional HD vehicle (14 ton / 240 kW)





Drive cycle investigations

With a 12 ton serial hybrid vehicle



- To compare WHVC and WHDHC (WHTC for HDH)

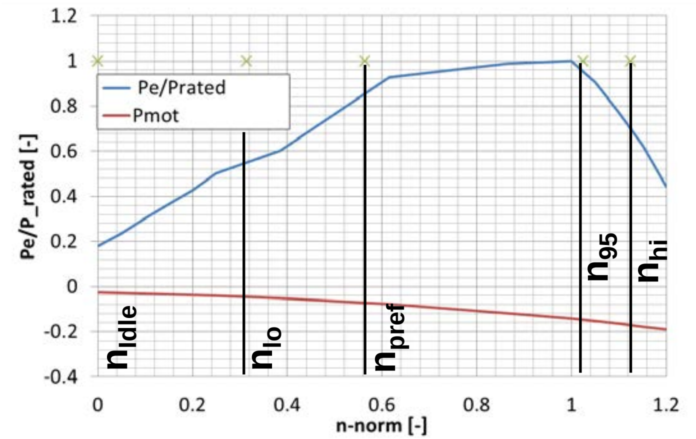
  >>> calculate WHDHC for specific powerpack (depending on fulload curve)
  - Reference engine at serial hybrid: el. Motor
    - For legislation: new methods to define powerpack fullload curve have to be developed

      for investigation: existing methods are sufficient
    - For legislation: norm/denormalization of powerpack fullload has to be developed

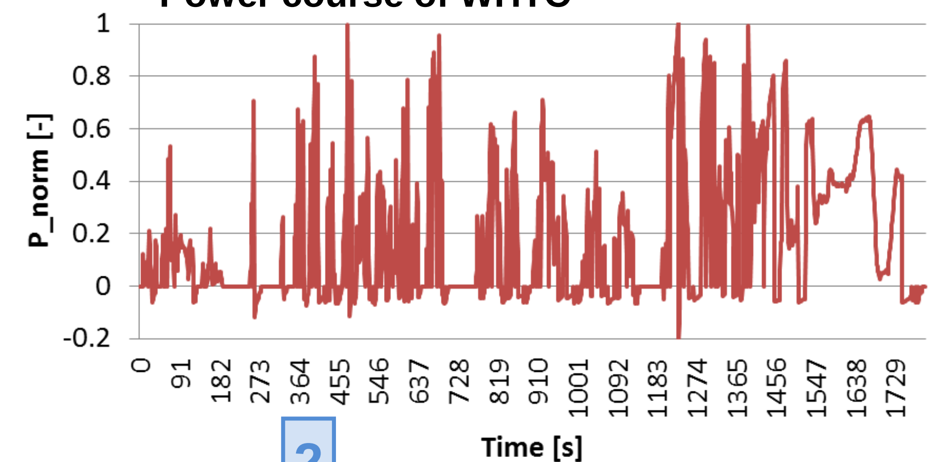
      for investigation: existing methods are sufficient
  - WHTC only includes neg. power down to engine motoring curve

    >>> available recuperation energy has to be added (related to powerpack full-load curve)
- Run HILS model with different cycles and compare drive motor operation pattern and delivered work

Drive cycle investigations – *Generation of WHDHC*



1

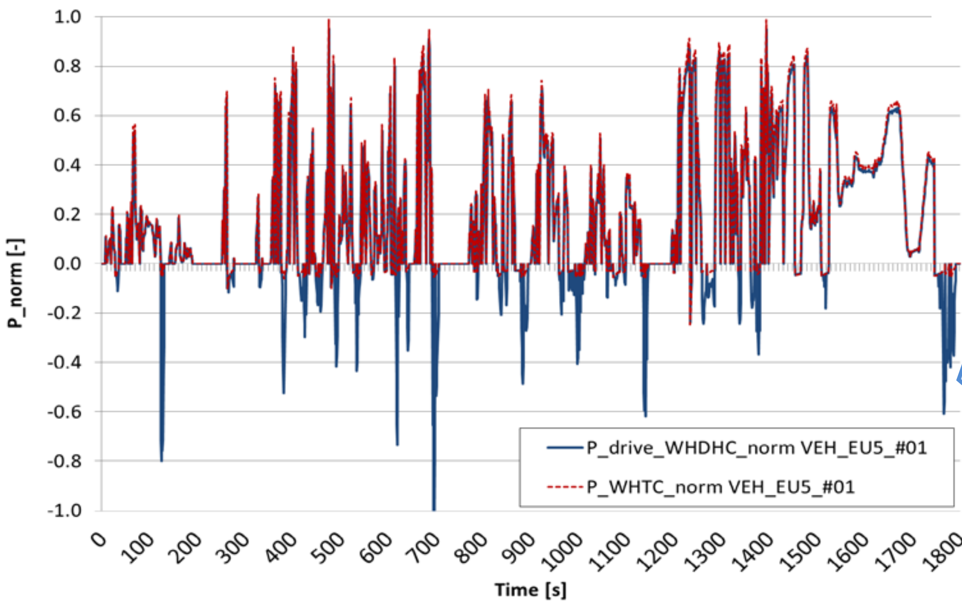


2

WHTC = effective engine power
\+ losses in drive train
\- power mechanical brakes

Power course at wheel hub
(=P_{drive_WHDHC})

3



4

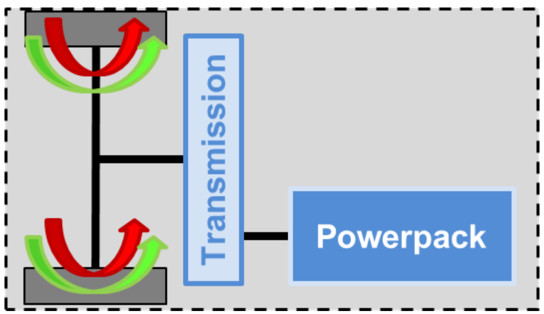
WHDHC as input for HILS

Drive cycle investigations – *Different options*

speed cycle

speed: WHVC

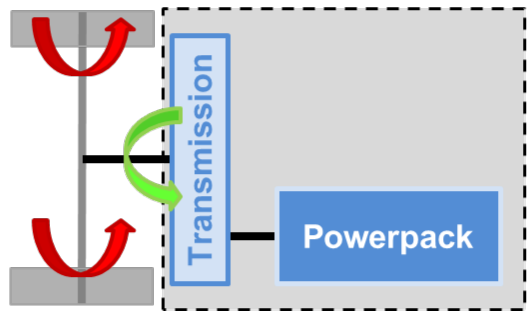
power: WHVC (driving resistances)



wheelhub cycle

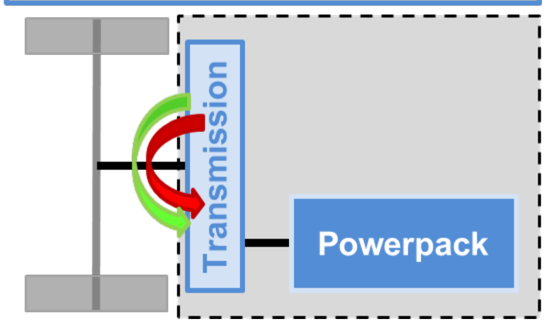
speed: WHVC

power: WHTC



speed: WHTC

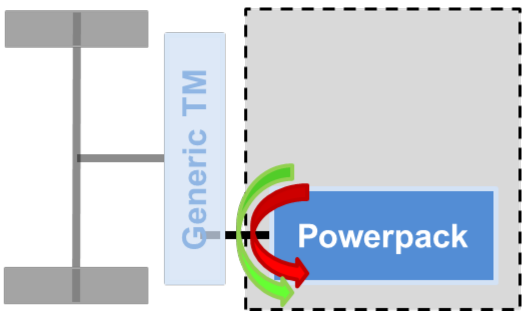
power: WHTC

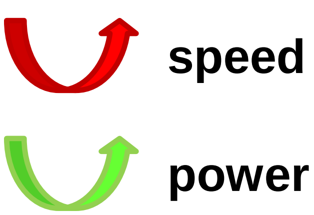


powerpack cycle

speed: WHTC

power: WHTC

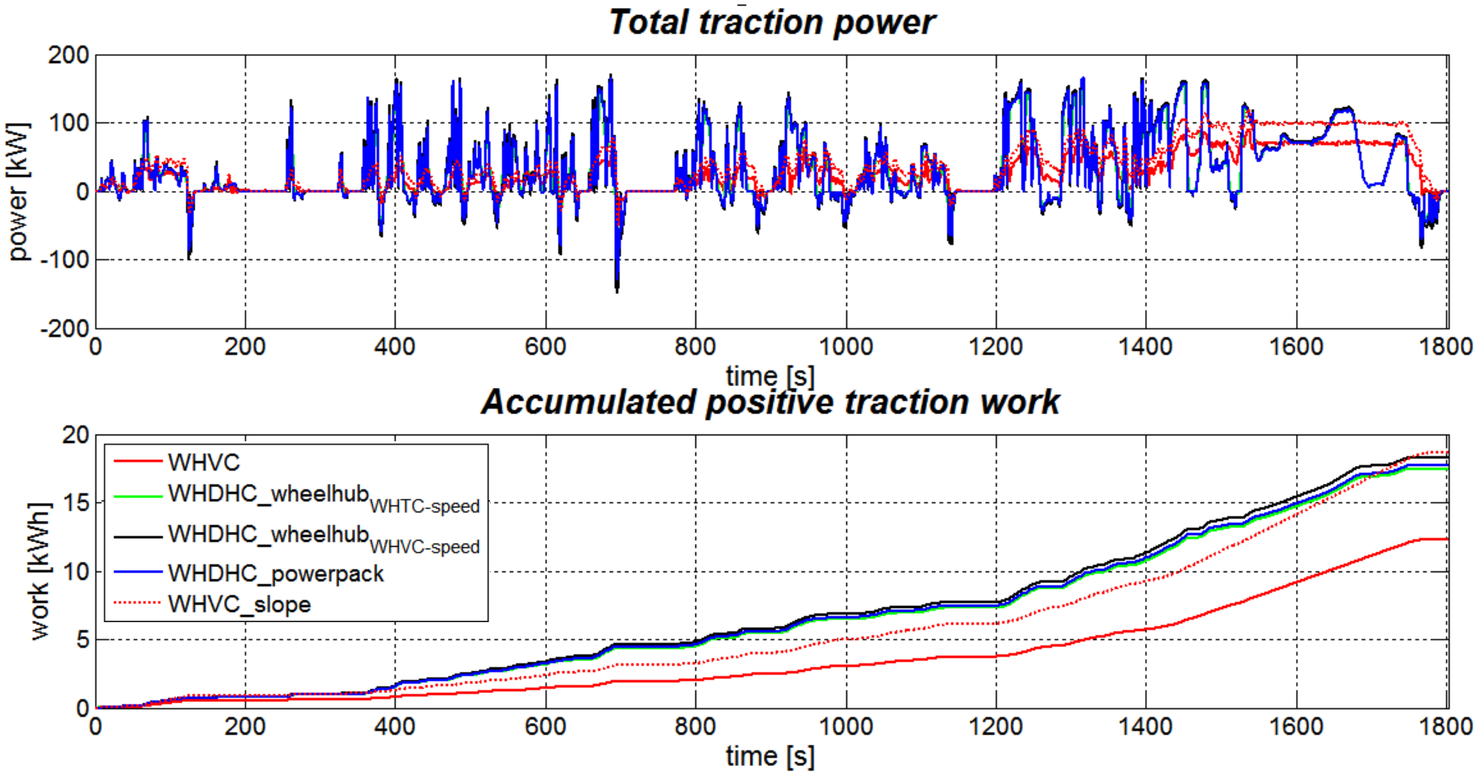




Drive cycle investigations

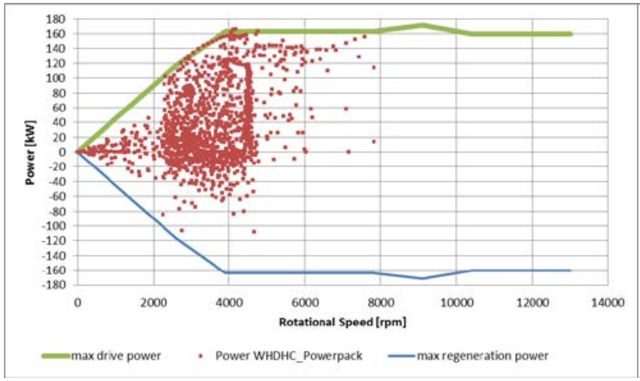
With a 12 ton serial hybrid vehicle

- To compare conventional and hybrid vehicles
  - Accumulated work for vehicle traction must be equal!

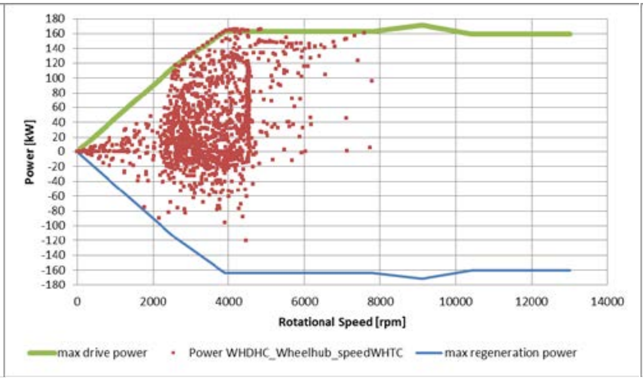


Drive cycle investigations

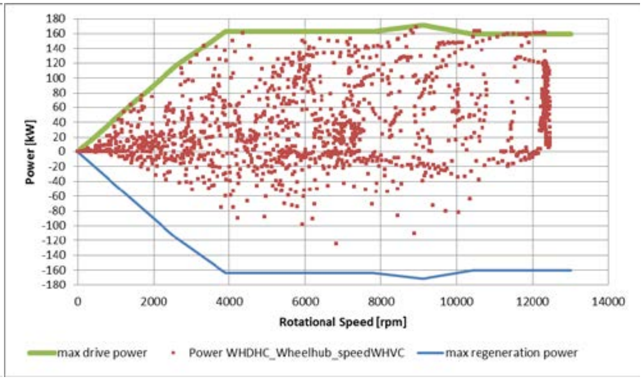
With a 12 ton serial hybrid vehicle



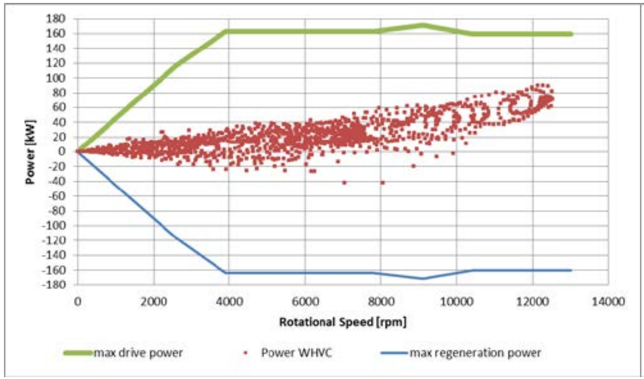
Powerpack



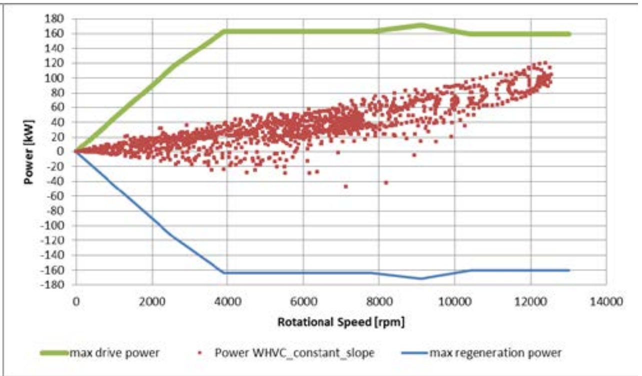
Wheelhub (speed from WHTC)



Wheelhub (speed from WHVC)



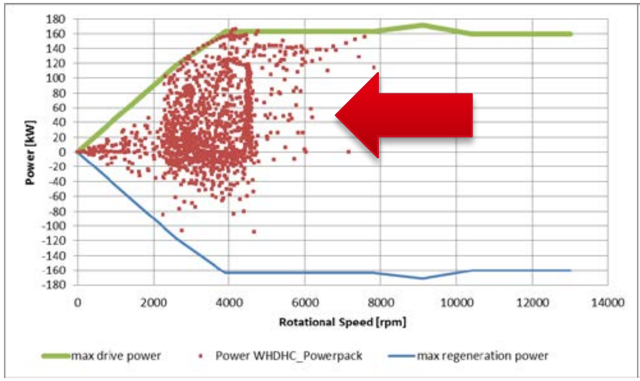
WHVC



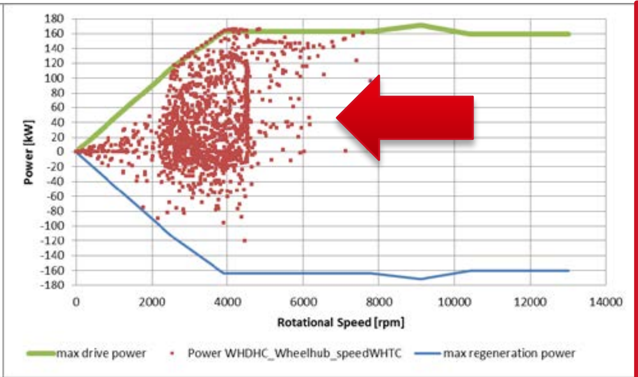
WHVC (with constant slope)

Drive cycle investigations

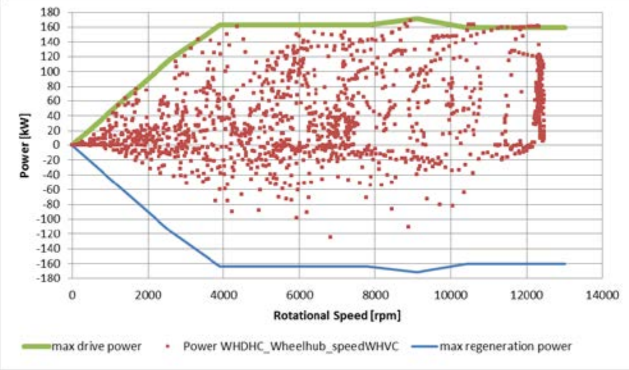
With a 12 ton serial hybrid vehicle



Powerpack



Wheelhub (speed from WHTC)



Wheelhub (speed from WHVC)

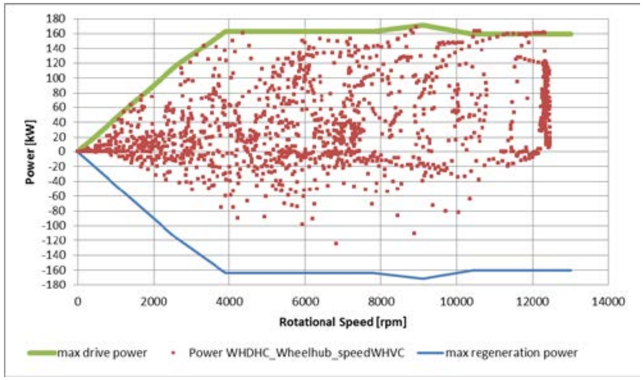
- WHVC does not cover whole powerpack operating range
- Chart nr. 1 and nr. 2 should be similar to nr. 3
  - Due to WHTC rot. speed denormalization method (developed for ICE) shift to lower speeds when denormalizing an el. motor
  - WHTC speeds are highly fluctuating (include shift pattern)
- Potential test method -> Wheelhub with speed from WHVC

Drive cycle investigations

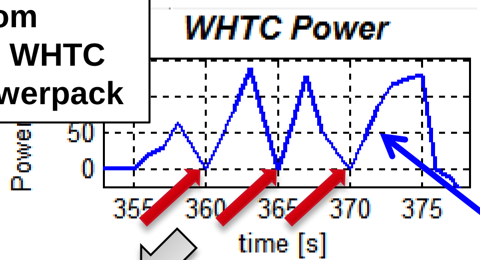
With a 12 ton serial hybrid vehicle

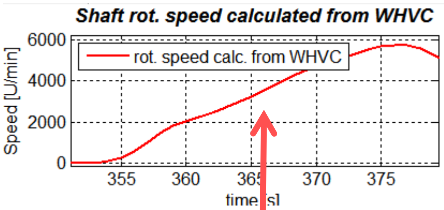
- <u>Potential test methodology</u>

  Wheelhub (speed from WHVC)



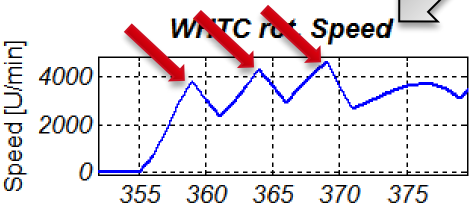
Power from denormalized WHTC for specific powerpack

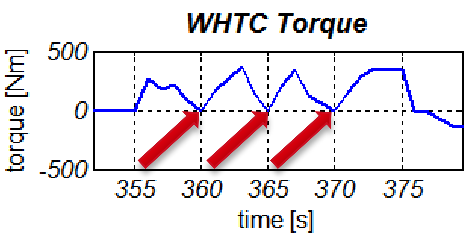




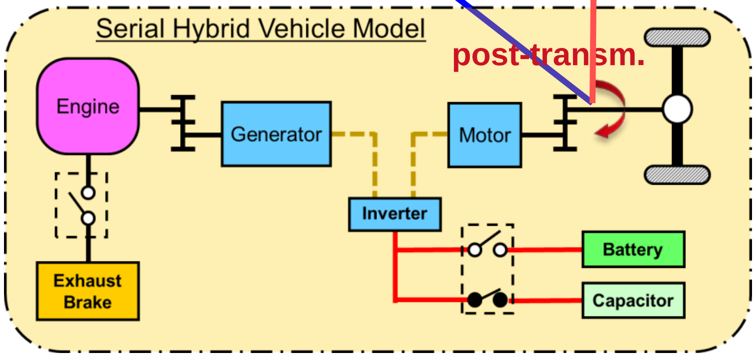
WHDHC (rot. speed + torque)

Rot. speed calculated from WHVC and tire radius / differential gear ratios





Excerpt of WHTC torque pattern (torque gaps caused by gearshifting)



<u>**Identified problem:**</u>

High fluctuating power curve leads to high fluctuating torque curve -> ECU errors at jap. HILS test (ref. to Ottawa)

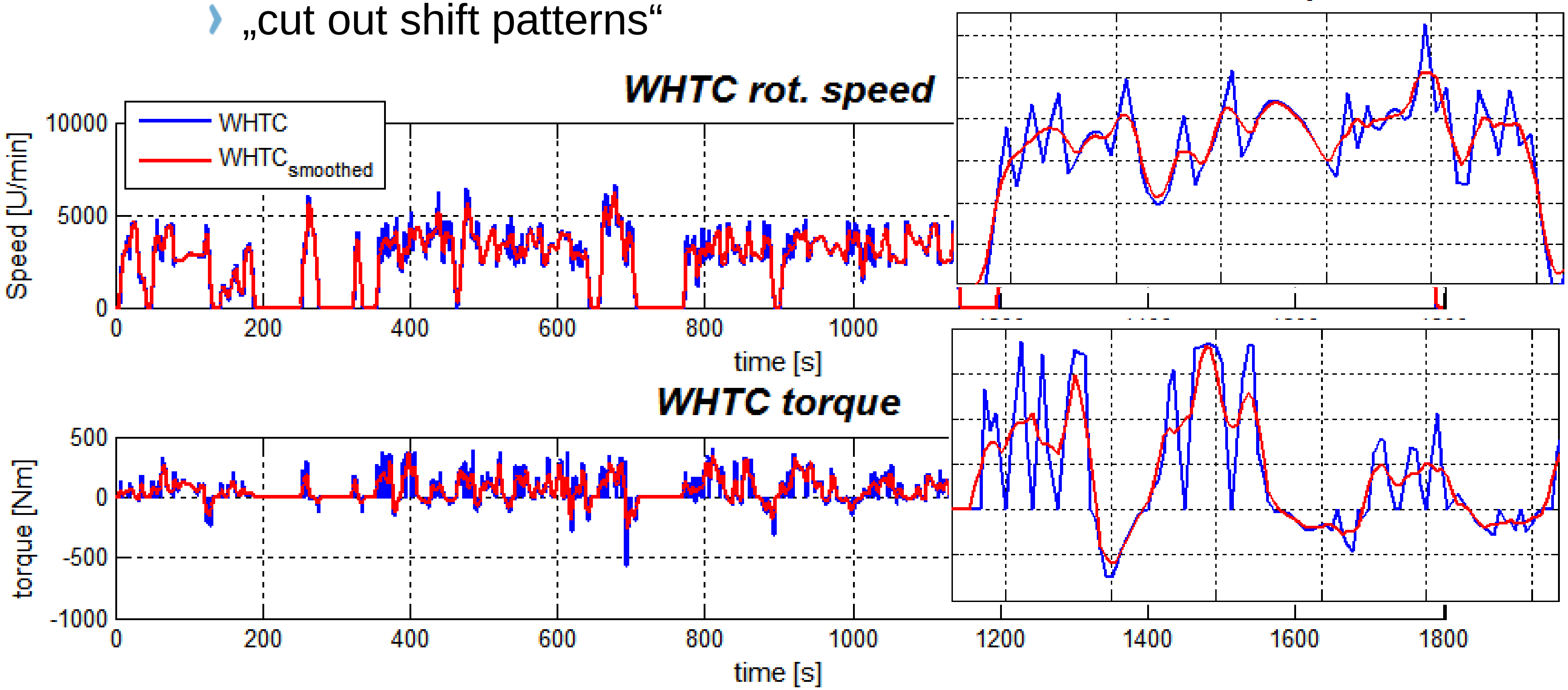
<u>**Possibilities:**</u>

curve smoothing

Drive cycle investigations

Smoothing of WHTC curves

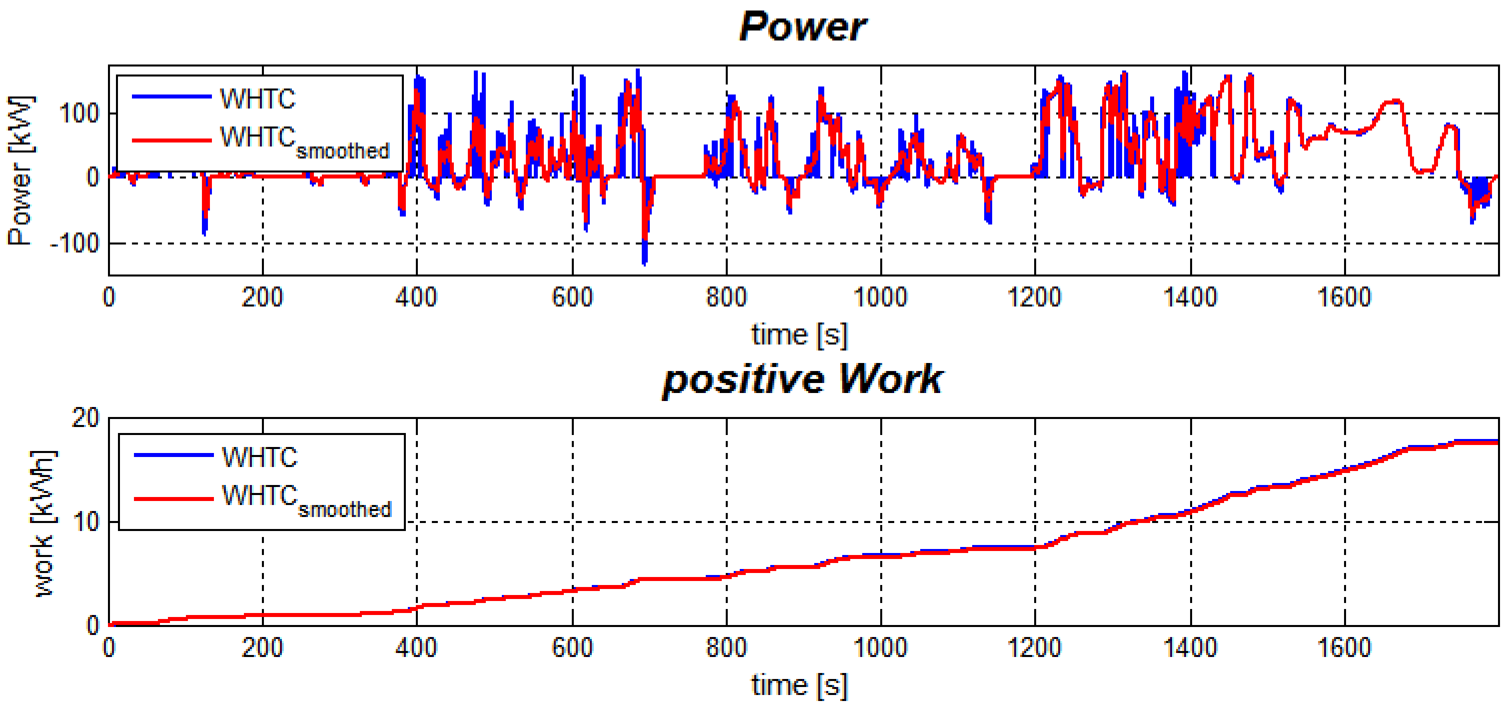
- Need to get a smooth Power curve
- Torque and speed have to be smoothed
  - „cut out shift patterns“



Drive cycle investigations

Smoothing of WHTC curves

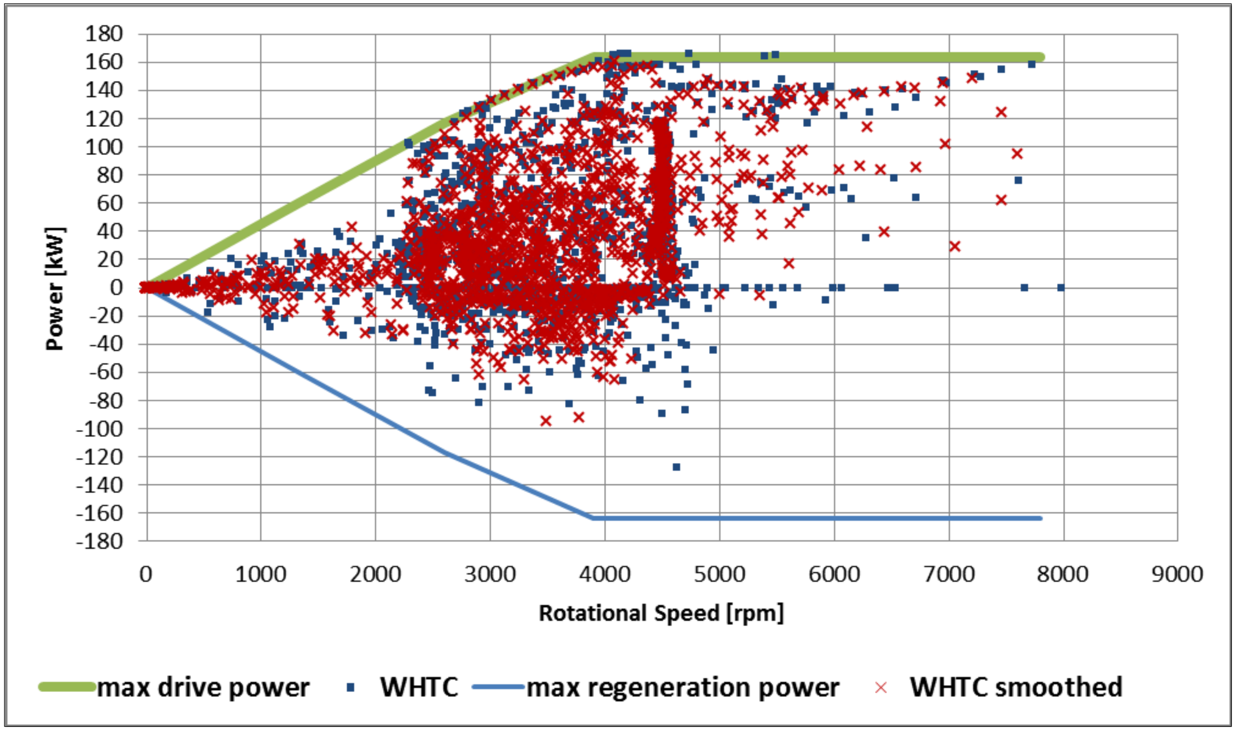
- After smoothing, nearly same positive work (0.8% deviation)
- Power pattern slightly modified –> less full power peaks
  - Influence on emissions should be investigated (mild parallel hybrids)



Drive cycle investigations

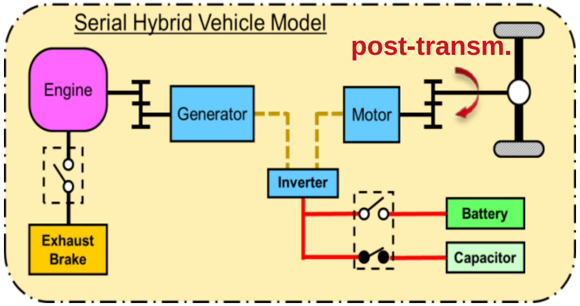
Smoothing of WHTC curves

- Excample of operation point distirbution (WHTC vs. smoothed WHTC)
- Smoothing has no tremendous negative effect on distribution



Drive cycle investigations

Smoothing of WHTC curves

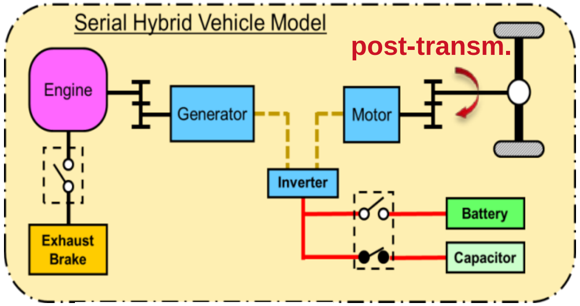


- *Wheelhub approach (speed from WHVC)*
  - Produce a „less fluctuating“ power curve
  - Get a „ less fluctuating“ rot. speed curve calculated from WHVC
  - A „ less fluctuating“ torque curve can be calculated

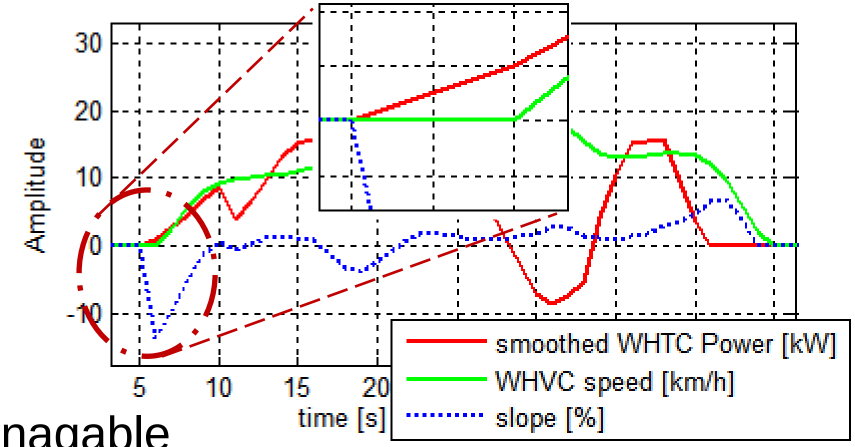
- Advantages of method
  - Conventional and hybrid vehicles would be compareable
  - Whole powerpack operation range will be tested
  - ***(under investigation)*** due to less fluctuating speed and torque
    - Method can be tested at Japanese HILS test bed (convert load torque into road slopes)

Drive cycle investigations

Smoothing of WHTC curves



- *Wheelhub approach (speed from WHVC)*
  - Still high road slopes due to areas of clutch actuation in WHTC -> missmatch between power and speed curve
  - Improve smoothing methods
  - If problems with slopes not managable
    - No explicit need to be drivable on chassis dyno, only on HILS test bed
    - Model validation run could be performed with a cycle which produces similar powerpack operating points



Validation test program 1 overview

Task 2) Adaptation of the Japanese HILS Simulator for parallel hybrid

- 2.1 Meetings with OEM's and stakeholders
- 2.2 Set up a data bus system in the model to allow various combinations of engines, gear boxes and storage systems
- 2.3 Adapt the Software to simulate a parallel HDH
- 2.4 Simulation runs and validation of basic functions, including the functions from task 1

			Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
	2	Adaptation of SILS for parallel HDH												
O	2.1	Meetings with OEMs and stakeholders												
O	2.2	Set up a data bus system in the model												
✓	2.3	Adapt the Software to parallel HDH												
O	2.4	Simulation runs and validation												
	3	Procedure and Manual writing/reporting												
	3.1	Report on test procedure, user manual												
	3.2	Provide the interface system for real ECUs												
	3.3	Adaptations and improvements of methods												

Task 2.1)

- Deliverables

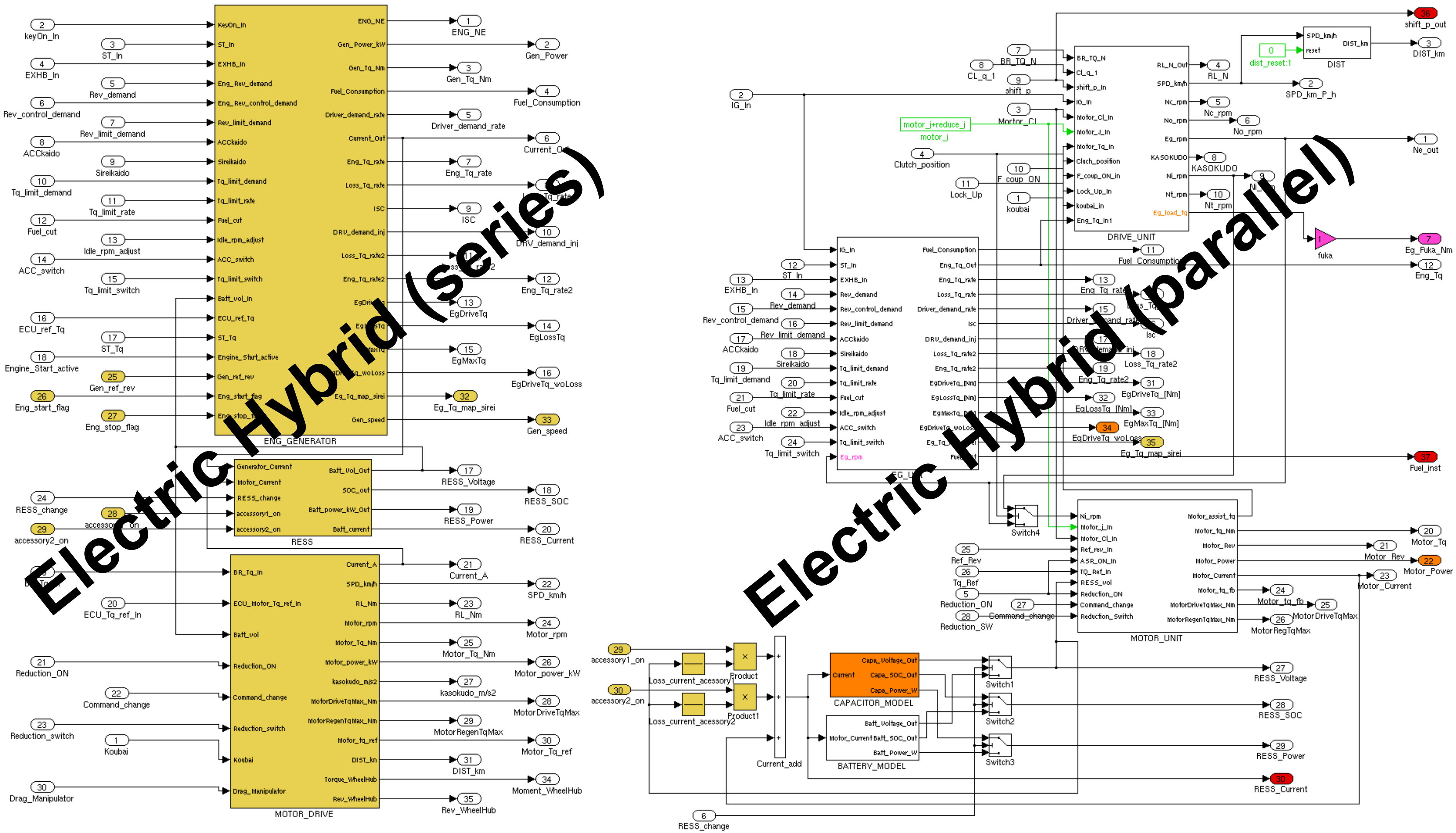
- **Meetings with OEM's and stakeholders**
  - See Task 1.4

Task 2.2)

- Deliverables

- **Set up a data bus system in the model to allow various combinations of engines, gear boxes and storage systems**

  - Difficult in the current model to setup a data bus system
    - Components are represented in different ways in the two vehicle models
    - Components are lumped in different ways
  - There is a need to restructure the models

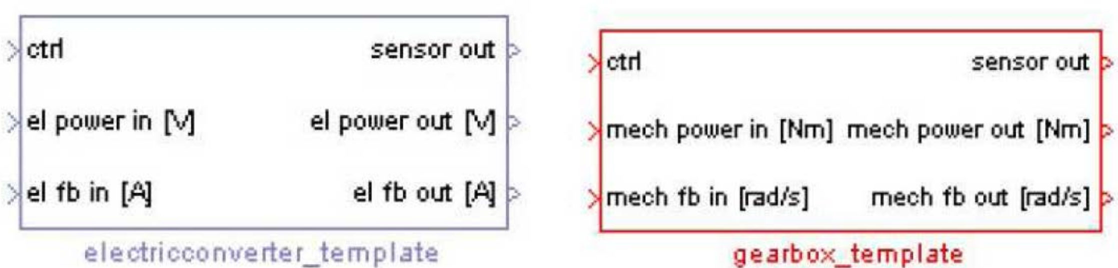

Electric Hybrid (series)
Electric Hybrid (parallel)
ENG_GENERATOR
RESS
MOTOR_DRIVE
DRIVE_UNIT
MOTOR_UNIT
CAPACITOR_MODEL
BATTERY_MODEL

Task 2.2)* Restructuring of Models

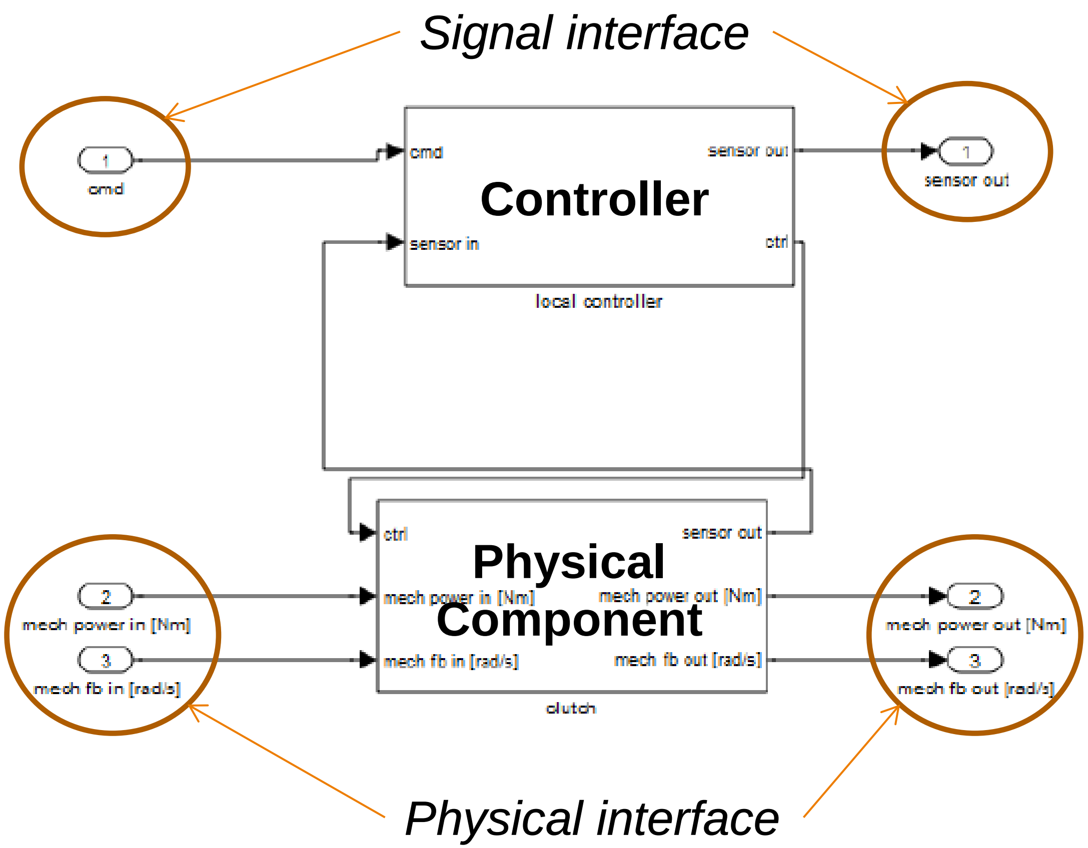
- Two types of interfaces are needed:
  - The *physical interface* is related to how different components are connected together physically

	Electrical	Mechanical (rotational, translational)	Chemical	Fluid
Flow	Voltage [V]	Torque [Nm], Force [N]	Spec. energy [J/kg]	Pressure [Pa]
Effort	Current [A]	Speed [rad/s], Velocity [m/s]	Mass flow [kg/s]	Flow [m^3/s]

  - The *signal interface* is related to control/sensor signals (needed for ECU)

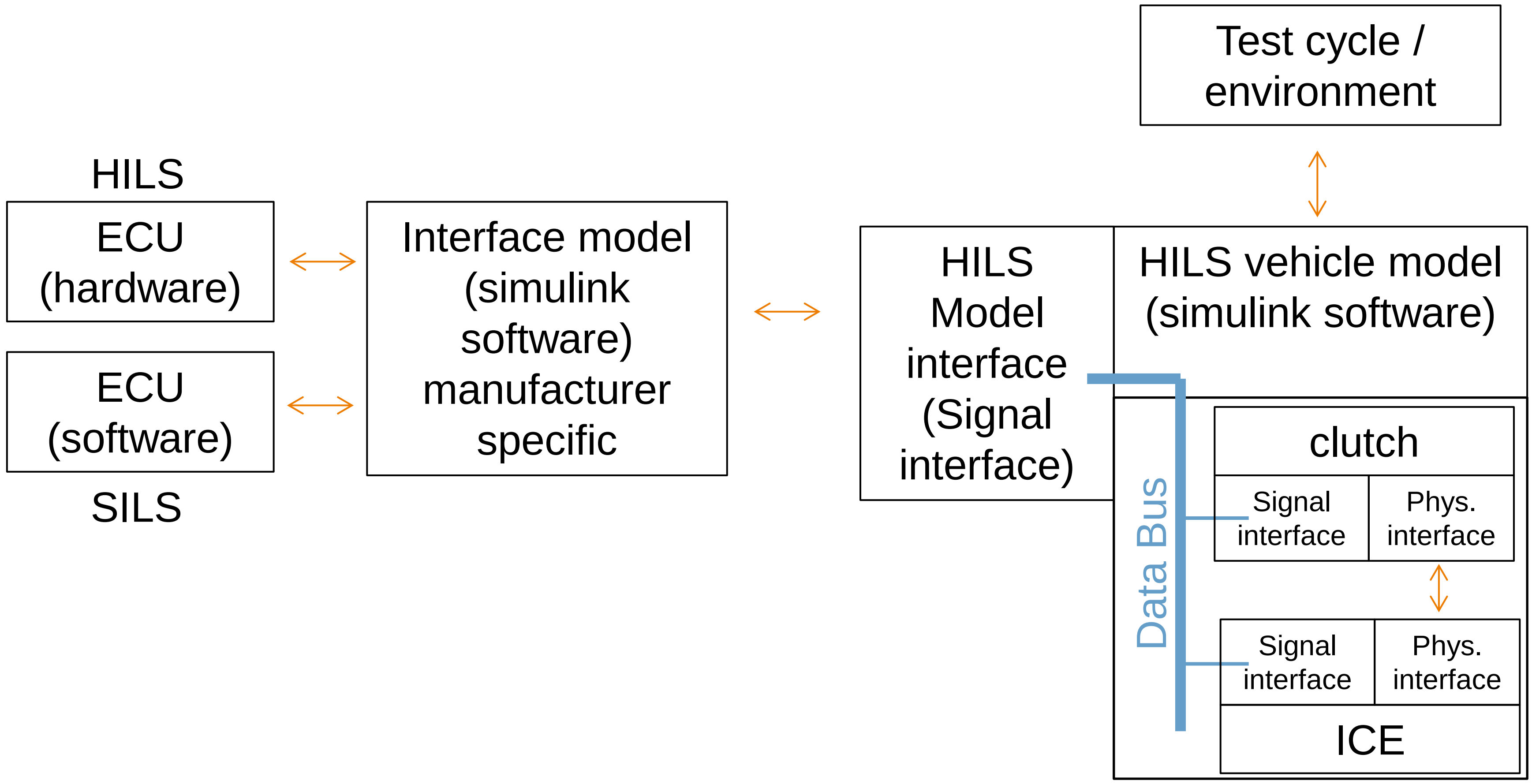


Task 2.2)* Restructuring of Models

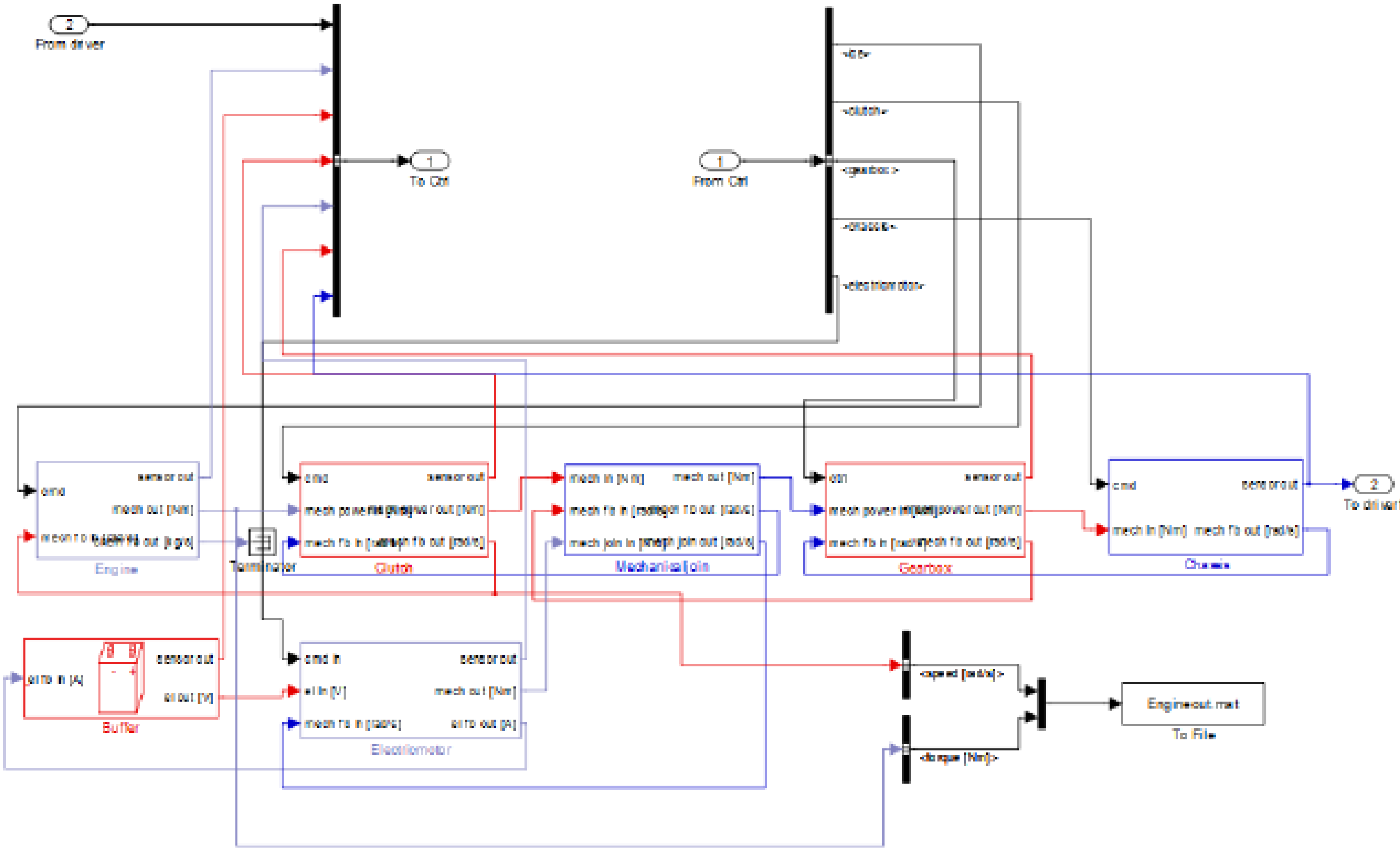


A port based approach: This structure is similar as the simulation models in for example Autonomi, Dymola (Powertrain library), CAPSim, VSIM, TruckSim

Task 2.2)* Restructuring of Models



Task 2.2)* Restructuring of Models



Task 2.2)

- Discussion point

- **Set up a data bus system in the model to allow various combinations of engines, gear boxes and storage systems**
  - Bring up the question (“who is the owner of the model in the end”)
    - Who is responsible for structure, who for components; are these different persons/Authorities?
  - Manufacturers should be able to bring in their own submodels, we can only provide a minimum of signals that are needed

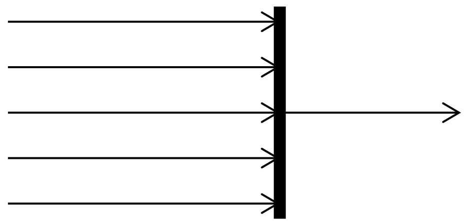
Task 2.2)* Restructuring of Models

- In the GTR:
  - the physical interface can be specified (fixed)
  - a minimum set of control/sensor signal can be specified*

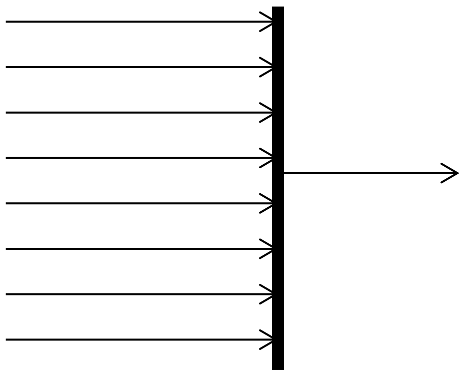
*) If other signals are needed or more complex models are needed (no change of physical interface) it is possible for OEMs to include those without effecting the model structure

Task 2.2)* Restructuring of Models

- Signal naming must be defined
  - Proposal: Use ideas and specifications from AUTOSAR
- Signals can be lumped together in a databus
  - Flexible structure
  - Easy to new add signals



Standard signal interface



Extended signal interface

Task 2.3)

- Deliverables

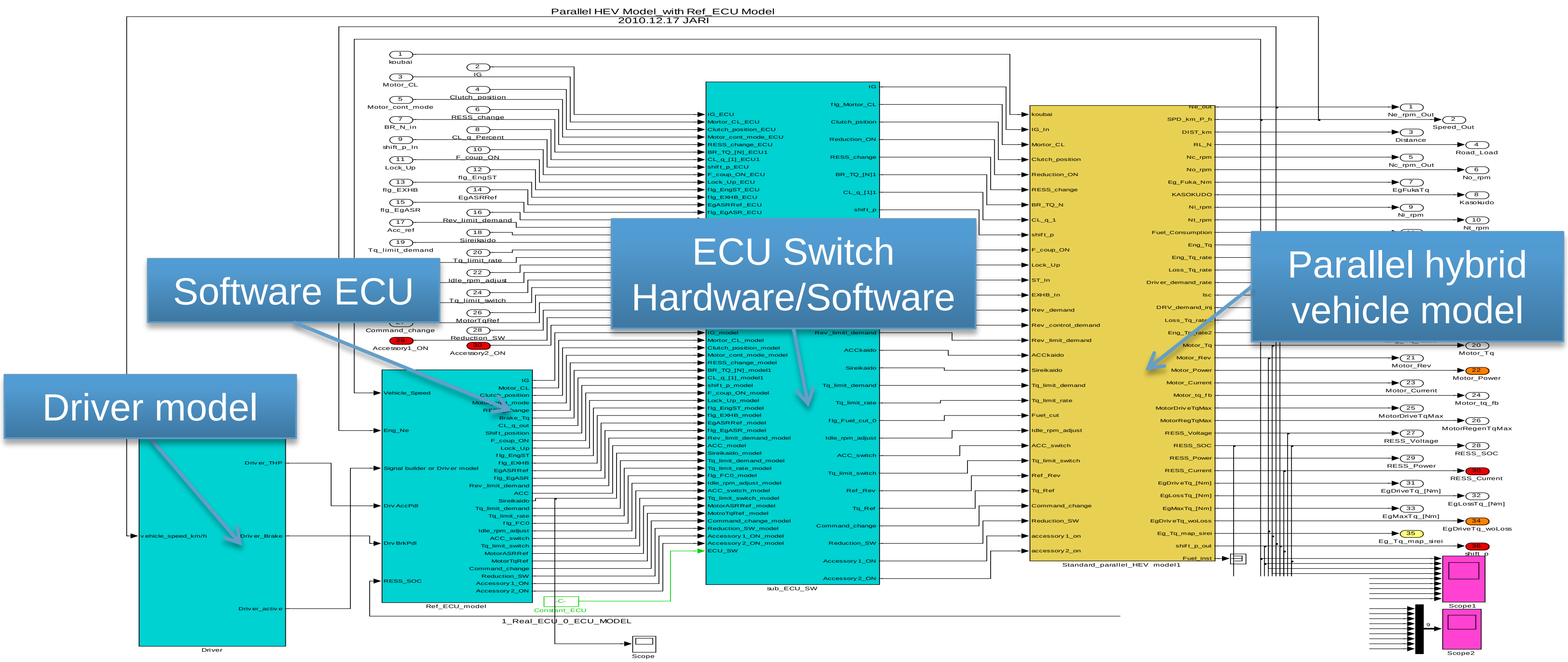
- **Adapt the Software to simulate a parallel HDH**
  - Basic parallel hybrid model was provided by JARI
  - ECU control strategy was added

    The control strategy is to use the electric machine below a certain speed and the combustion engine above that. If energy level stored in the accumulator is lower than a certain value, the electric machine is used as generator and is then driven either by the engine or purely by the kinetic energy of the vehicle. The electric machine is used for braking the vehicle when possible, if the brake torque is not enough then the mechanical brakes are used as well. The electric machine is also used for power assist when the desired torque, interpreted from the accelerator pedal position, is larger than the combustion engine can deliver.
  - Driver model running the model, from **Task 1.1 and 1.2**

Task 2.3)

Set up a serial HDH in the simulator with the ECU as software in the loop

- Basic parallel hybrid model was provided by JARI
- ECU functions were added



Task 2.4)

- Deliverables

- **Simulation runs and validation of basic functions, including the functions from task 1**
  - The same simulations runs from task 1.7 can be performed for task 2.4

THANK YOU FOR YOUR ATTENTION!

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