Working Paper No. **HDH-07-06**
(7th HDH meeting, 12 to 14 October 2011)

RESEARCH PROGRAM ON AN EMISSIONS TEST PROCEDURE FOR HEAVY DUTY HYBRIDS (HDH)

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

Jonas Fredriksson
Department of Signals and Systems
Chalmers University of Technology
Gothenburg, Sweden

Content

- Introduction
- Work package 3-1
  - Background
  - Method/Analysis
  - Results
- Work package 3-2
  - Background
  - Method/Analysis
  - Results
- Summary

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

3. Extension of HILS to non-electrical hybrids, which are currently not covered by Kokujikan No.281.

To May 2012 the following WP is to be carried out.

- Overview of possible other types of hybrids of interests and issues for HILS testing will be investigated. Information gathering. Proposal of which non-electric hybrids to include in the HILS method.
- Evaluate, using software models and simulation the possibilities of using HILS for assessment of quality factors of these hybrids.

Tasks and timeplan

	Work task description	***Period (Start-end)***
WP 3	Extension to non-electrical hybrids	
WT 3.1	Technology overview and selection of scope	06/2011-10/2011
WT 3.2	Development of HIL elements (models) for non-electrical hybrids	10/2011-01/2012
WT 3.3	Test methods for input data to non-electrical component models	01/2012-02/2012
WT 3.4	Definition of control signals	01/2012-02/2012
WT 3.5	Alignment with HILS for HEV and verification	03/2012-04/2012

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

WP 3-1: Technology overview and selection of scope

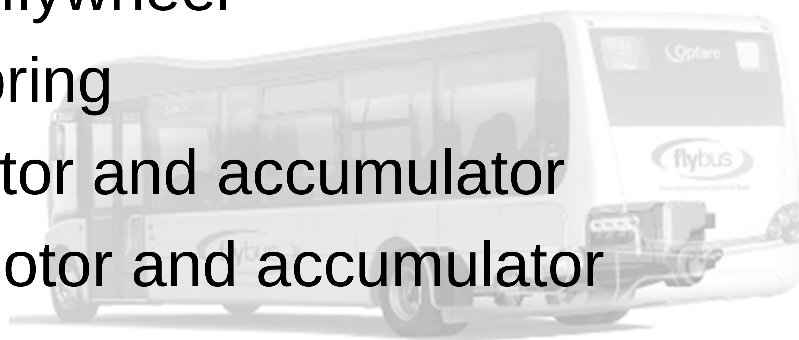
- Detailed analysis on what non-electric hybrid systems/components to be included in the HILS method. Review of non-electric hybrid topologies proposed in the literature, by OEMs and others. Review of non-electric components, such as flywheels, accumulators etc, used in non-electric powertrains proposed in the literature, by OEM and others. Together with OEMs and other partners decide which topologies that should be covered. Meetings with OEMs, will be co-planned with TU Graz and TU Wien in relation to WP 1-4 (TU Graz and TU Wien offer).

- The preliminary result is a list of non-electric powertrain topologies and a list of components that needs to be modeled.

Hybrid Powertrain Principles

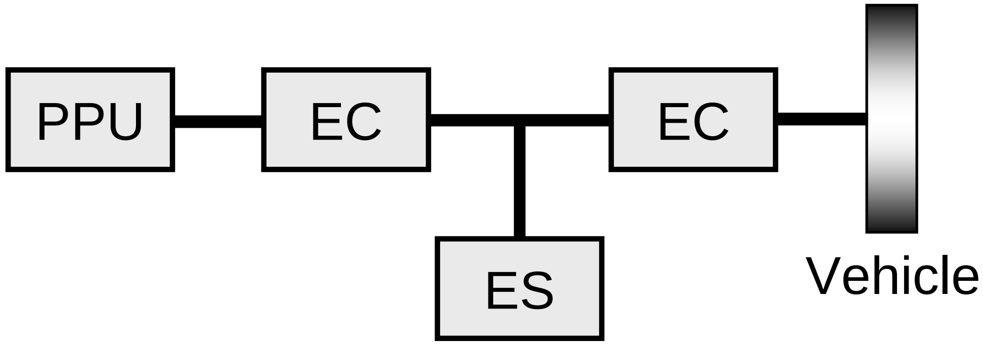
Energy storage and converter

- Electrochemical, generator/motor and battery
- Electrostatic, generator/motor and supercapacitor
- Electromagnetic, generator/motor and superconductor coil
- Kinetic, CVT and flywheel
- Kinetic, motor/generator and flywheel
- Potential, CVT and torsion spring
- Potential, hydraulic pump/motor and accumulator
- Potential, pneumatic pump/motor and accumulator



Hybrid Powertrain Topologies

Series topology:



PPU: Primary Power Unit

EC: Energy Converter

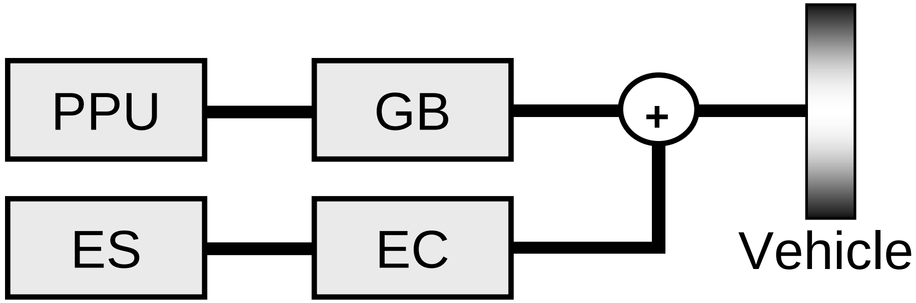
ES: Energy Storage

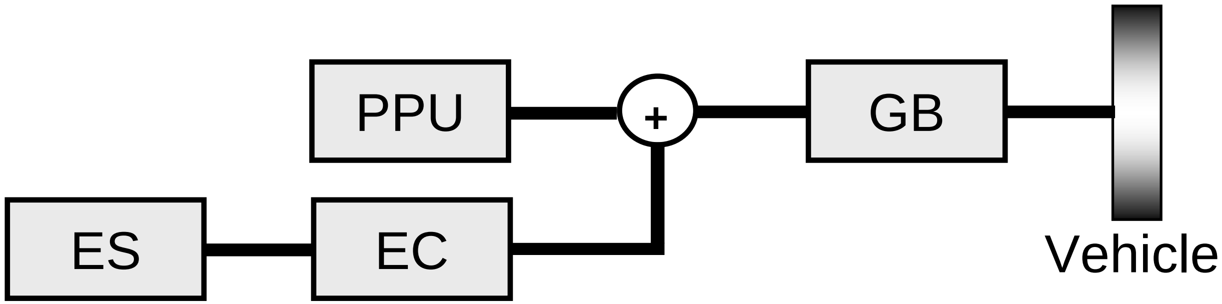
FW: Flywheel

GB: Gearbox

Hybrid Powertrain Topologies

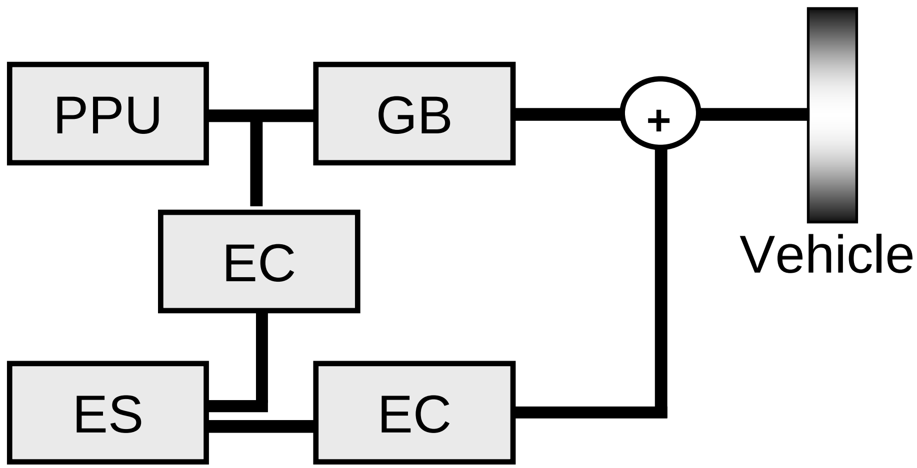
Parallel powertrain:



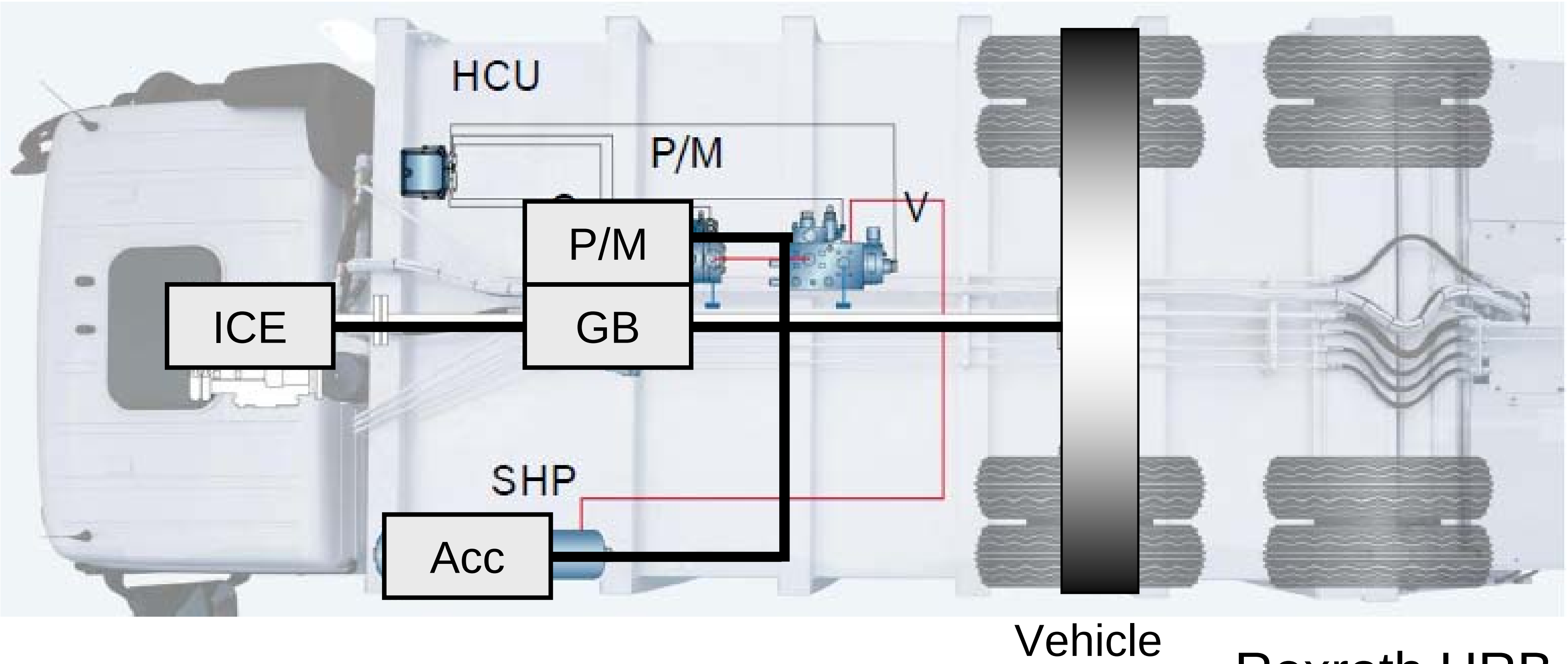


Hybrid Powertrain Topologies

Split (series-parallel) powertrain:



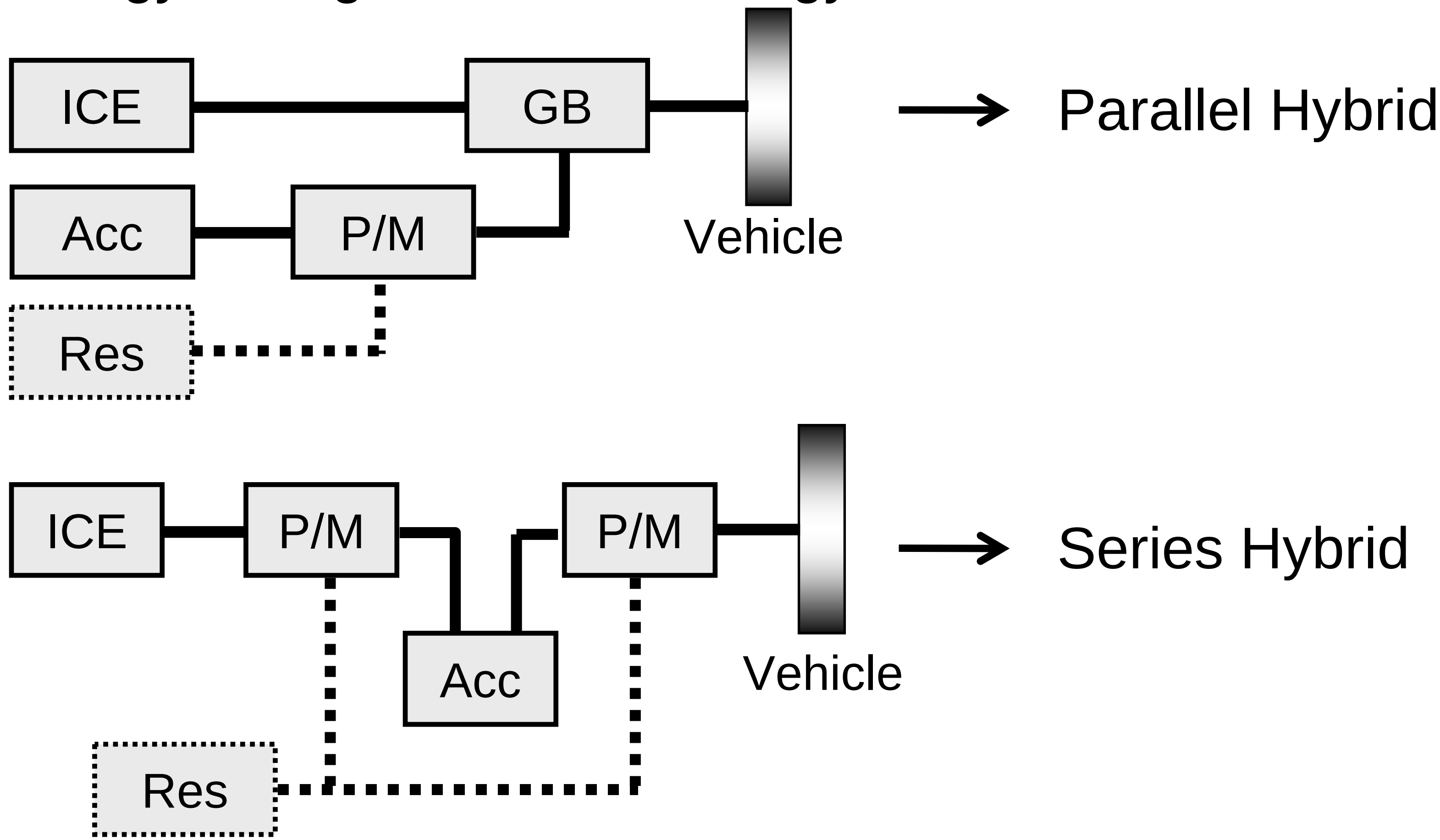
Hydraulic pump/motor and accumulator



Rexroth HRB

Hydraulic pump/motor and accumulator

- Energy storage: Potential energy

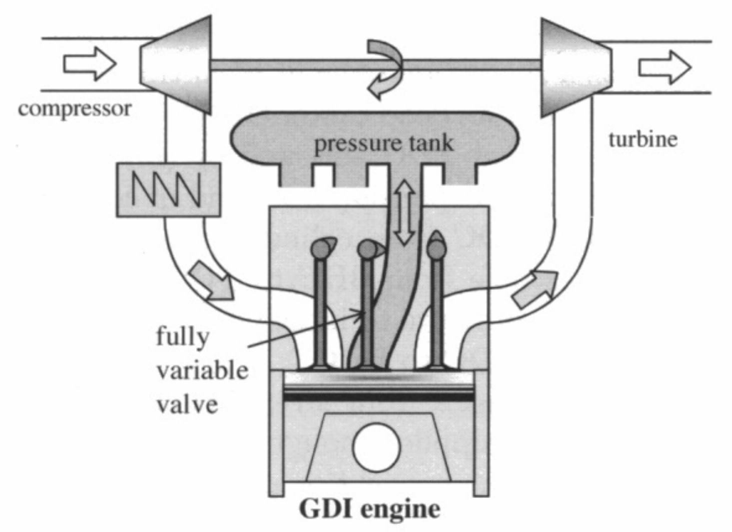


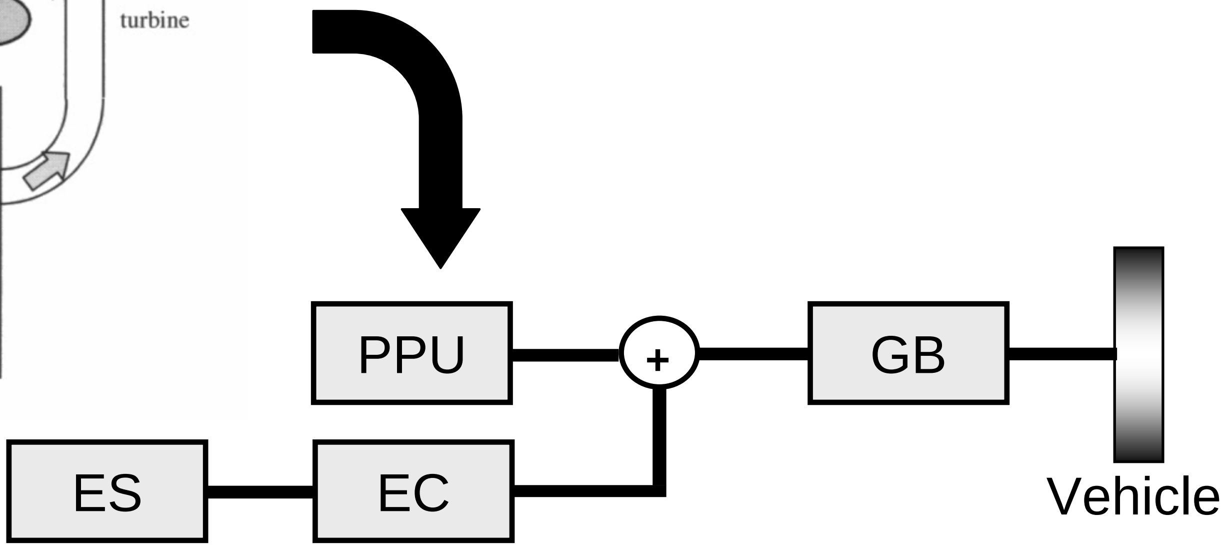
Hydraulic pump/motor and accumulator

- Ford F150 and F350 Hydraulic Hybrid (Parallel)
- Eaton, Hydraulic Launch Assist (Parallel and Series)
- NRG Dynamix (Parallel and Series)
- Innas, Netherlands, (Series)
- Parker, Runwise system, (Parallel and Series)
- Bosch Rexroth, HRB (Parallel and series)
- Poclain Hydraulics, ADDIDRIVE Assist (Series, addon to non-driven wheels)

Pneumatic pump/motor and accumulator

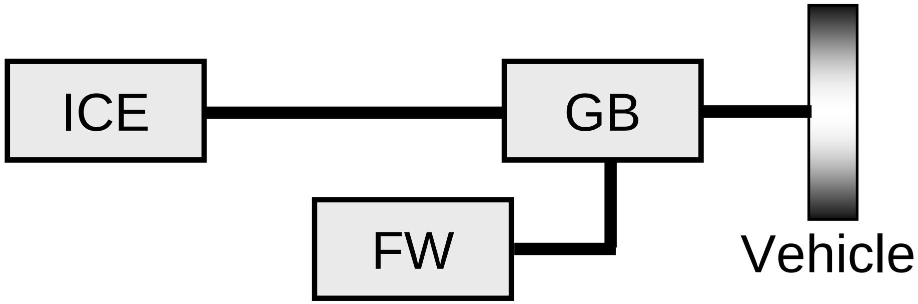
- Enery storage: Potential energy
  - Principle could be similar as for hydraulic hybrids
- Alternative: Hybrid engine concept:

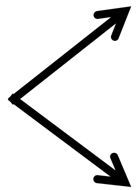




CVT and flywheel

- Energy Storage: Kinetic energy

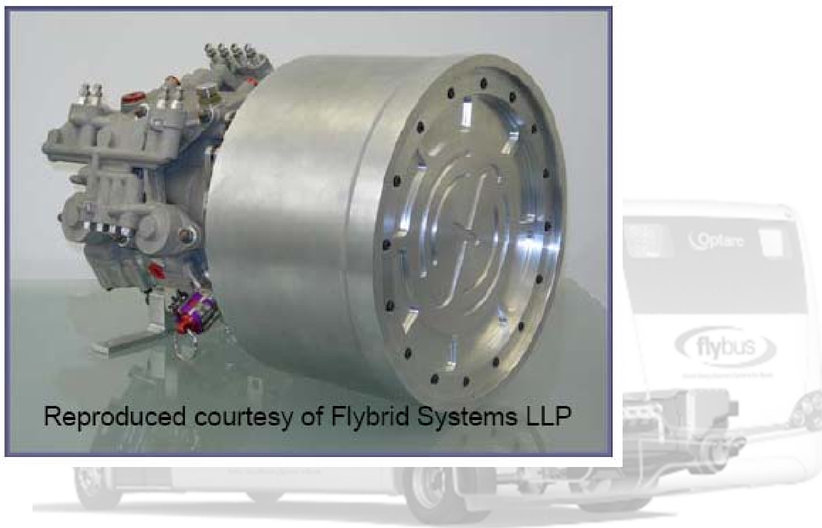




Parallel Hybrid

Series Hybrid

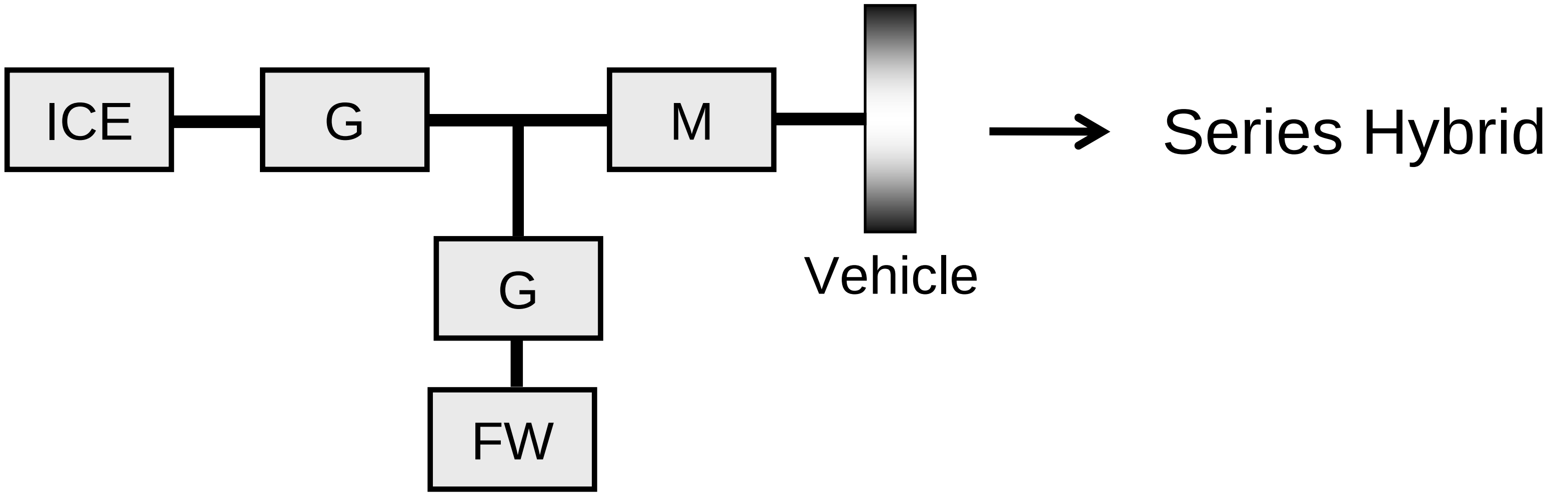
- Examples:
  - Formula 1
  - Flybrid
  - Torotrack for city bus



Reproduced courtesy of Flybrid Systems LLP

Motor/generator and flywheel

- Energy storage: Kinetic energy



- Examples:
  - PhD thesis from Uppsala University

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

WP 3-1: Technology overview and selection of scope

- Detailed analysis on what non-electric hybrid systems/components to be included in the HILS method. Review of non-electric hybrid topologies proposed in the literature, by OEMs and others. Review of non-electric components, such as flywheels, accumulators etc, used in non-electric powertrains proposed in the literature, by OEM and others. Together with OEMs and other partners decide which topologies that should be covered. Meetings with OEMs, will be co-planned with TU Graz and TU Wien in relation to WP 1-4 (TU Graz and TU Wien offer).

- The preliminary result is a list of non-electric powertrain topologies and a list of components that needs to be modeled.

Results

- Non-electric hybrid powertrain topologies (concepts) fits well into the same categories as for electric hybrid powertrains

- Non-electric hybrid powertrains can be divided into:
  - Series powertrain topologies
  - Parallel powertrain topologies
  - (Split powertrain topologies)

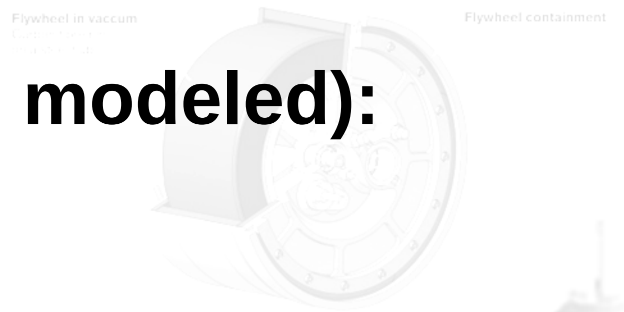
Interesting non-electric powertrain concepts:

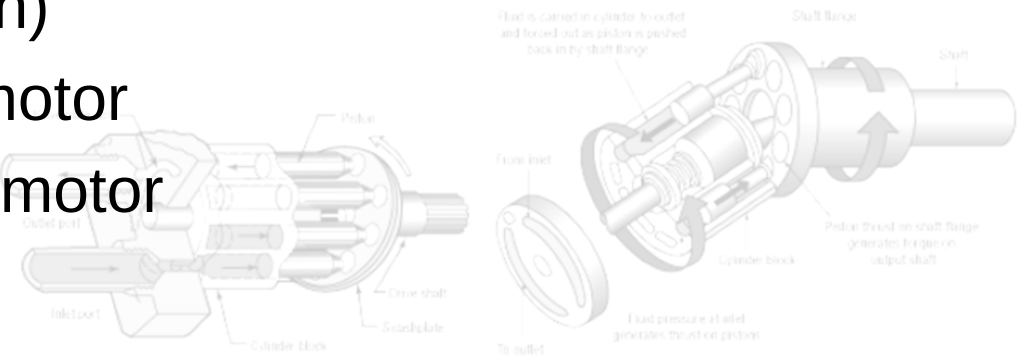
- Proposal:
  - CVT and flywheel
  - Motor/generator and flywheel
  - Hydraulic or (pneumatic) pump/motor and accumulator

Results

Component list (to be modeled):

- Energy storages:
  - Flywheel
  - Hydraulic accumulators
  - Pneumatic accumulators
- Energy converters
  - CVT (transmission)
  - Hydraulic pump/motor
  - Pneumatic pump/motor





(a) Swash-plate type, inline axial-piston type (b) Bent-axis type, axial-piston type

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

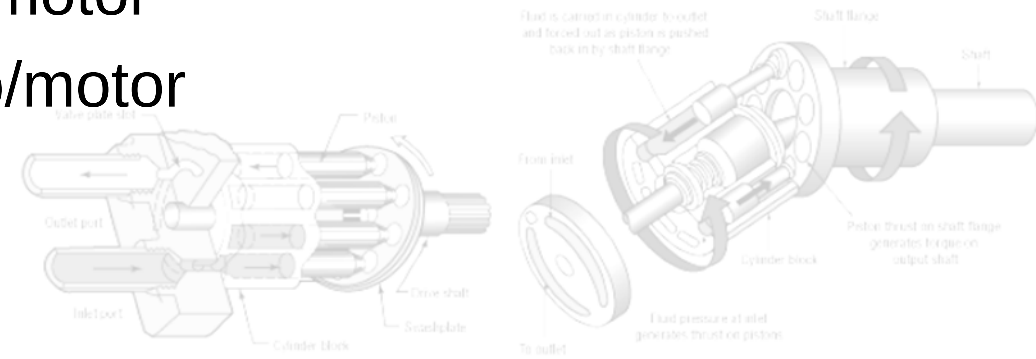
WP 3-2: Development of HIL elements for non-electrical hybrid systems/components

- Based on the list of topologies and components in WP 3-1, develop simple, representative mathematical models of the different powertrain components, such as actuators and energy buffers. The models will be implemented in a simulation software. All models will be documented.

- The result is a set of simulation models of non-electric powertrain components, which are suitable to use in a HILS setup.

Components

- Energy storages:
  - Flywheel
  - Hydraulic accumulators
  - Pneumatic accumulators
- Energy converters
  - CVT (transmission)
  - Hydraulic pump/motor
  - Pneumatic pump/motor



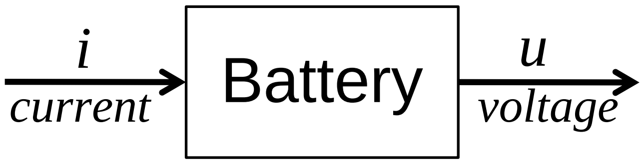
(a) Swash-plate type, inline axial-piston type (b) Bent-axis type, axial-piston type

Energy storages

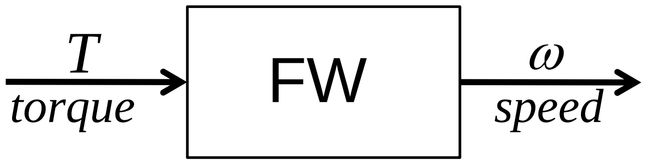
- Flywheel
- Accumulators

Flywheel

Electric battery:



Flywheel:



State-of-Charge

$$C\frac{dSOC}{dt} = -i$$

$$J\frac{d\omega}{dt} = -T - T_{loss}(\omega)$$

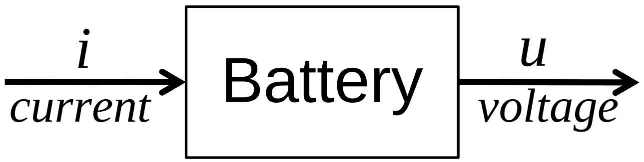
losses

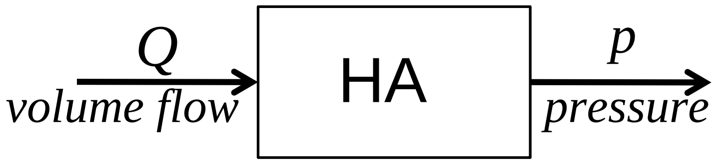
$$u = u_{OCV}(SOC) - Ri$$

$T_{loss}(\omega)$ - Lookup table

Accumulator

Electric battery:





State-of-Charge

$$C\frac{dSOC}{dt} = -i \qquad \frac{dV_g}{dt} = Q \quad \text{(mass balance)}$$

losses

$$u = u_{OCV}(SOC) - Ri$$

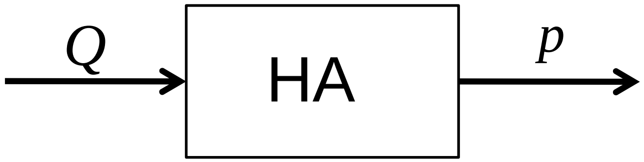
Temperature

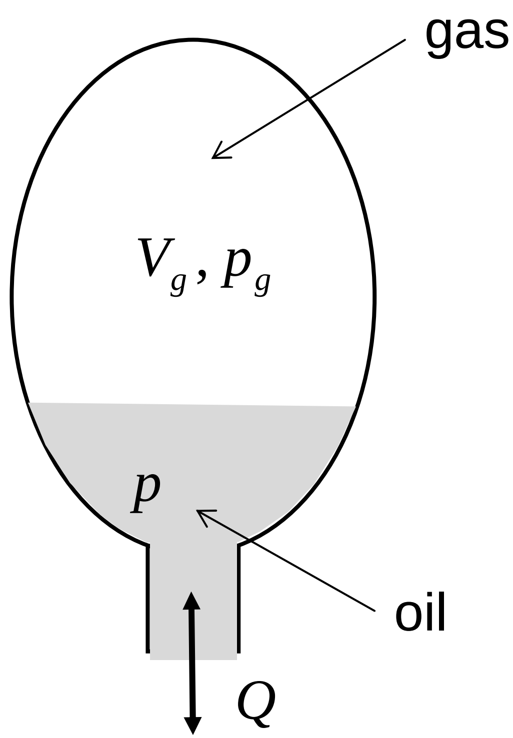
$$p_g = \frac{m_g R_g \vartheta_g(t)}{V_g(t)} \quad \text{(ideal gas law)}$$

$$m_g c_v \frac{d\vartheta_g}{dt} = -\frac{m_g R_g \vartheta_g(t)}{V_g(t)} Q - hA_w(\vartheta_g - \vartheta_w)$$

(energy balance)

Accumulators





State-of-Charge

Mass balance: $$\frac{dV_g}{dt} = Q$$

Temperature

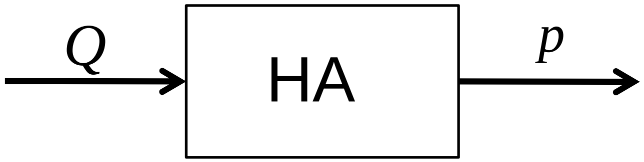
Ideal gas law: $$p_g = \frac{m_g R_g \vartheta_g(t)}{V_g(t)}$$

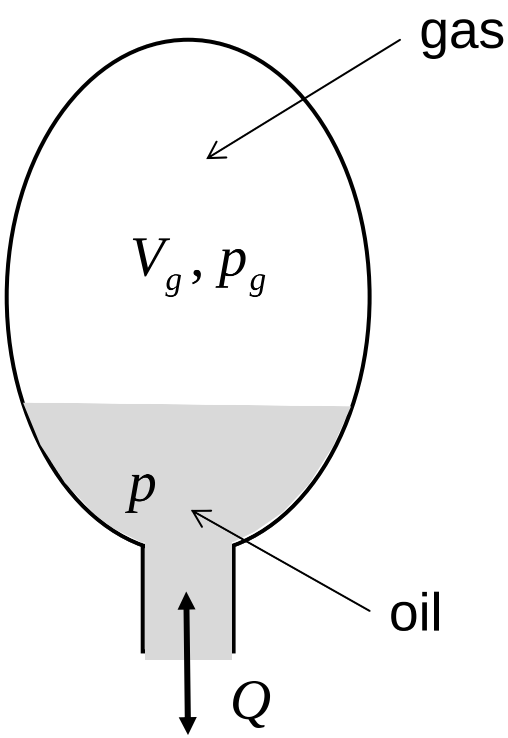
Assumption ([1]): $p \approx p_g$

Energy balance: $$m_g c_v \frac{d\vartheta_g}{dt} = -\frac{m_g R_g \vartheta_g(t)}{V_g(t)} Q - hA_w(\vartheta_g - \vartheta_w)$$

[1] Guzzella and Sciarretta, Vehicle Propulsion Systems, Springer, 2007

Accumulators





State-of-Charge

Mass balance: $$\frac{dV_g}{dt} = Q$$

Temperature

Ideal gas law: $$p_g = \frac{m_g R_g \vartheta_g(t)}{V_g(t)}$$

Assumption ([1]): $p \approx p_g$

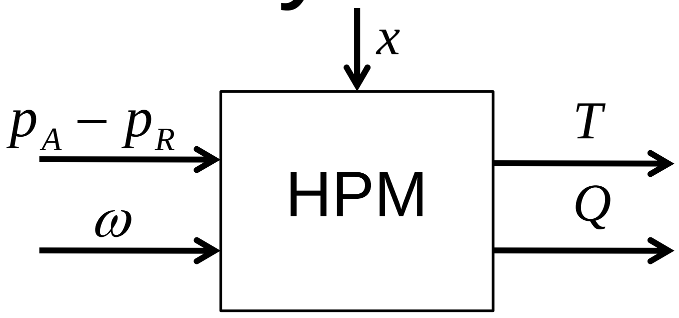
Energy balance: $$m_g c_v \frac{d\vartheta_g}{dt} = -\frac{m_g R_g \vartheta_g(t)}{V_g(t)} Q - hA_w(\vartheta_g - \vartheta_w)$$

[1] Guzzella and Sciarretta, Vehicle Propulsion Systems, Springer, 2007

Energy converters

- Hydraulic pump/motor
- (CVT)

Hydraulic Pump/Motor



	Pump:	Motor:
Volumetric flow rate:	$Q = \eta_v x D \omega$	$Q = x D \omega / \eta_v$
Torque:	$T = \eta_t x D (p_A - p_R)$	$T = x D (p_A - p_R) / \eta_t$

Efficiencies:

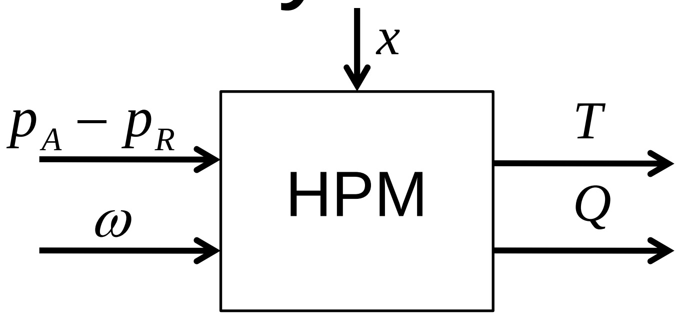
$$\eta_v = 1 - \frac{C_s}{xS} - \frac{p_A - p_R}{\beta} - \frac{C_{st}}{x\sigma}$$

laminar loss; compressibility loss; turbulent loss

$$\eta_t = 1 - \frac{C_s S}{x} - \frac{C_f}{x} - C_h x^2 \sigma^2$$

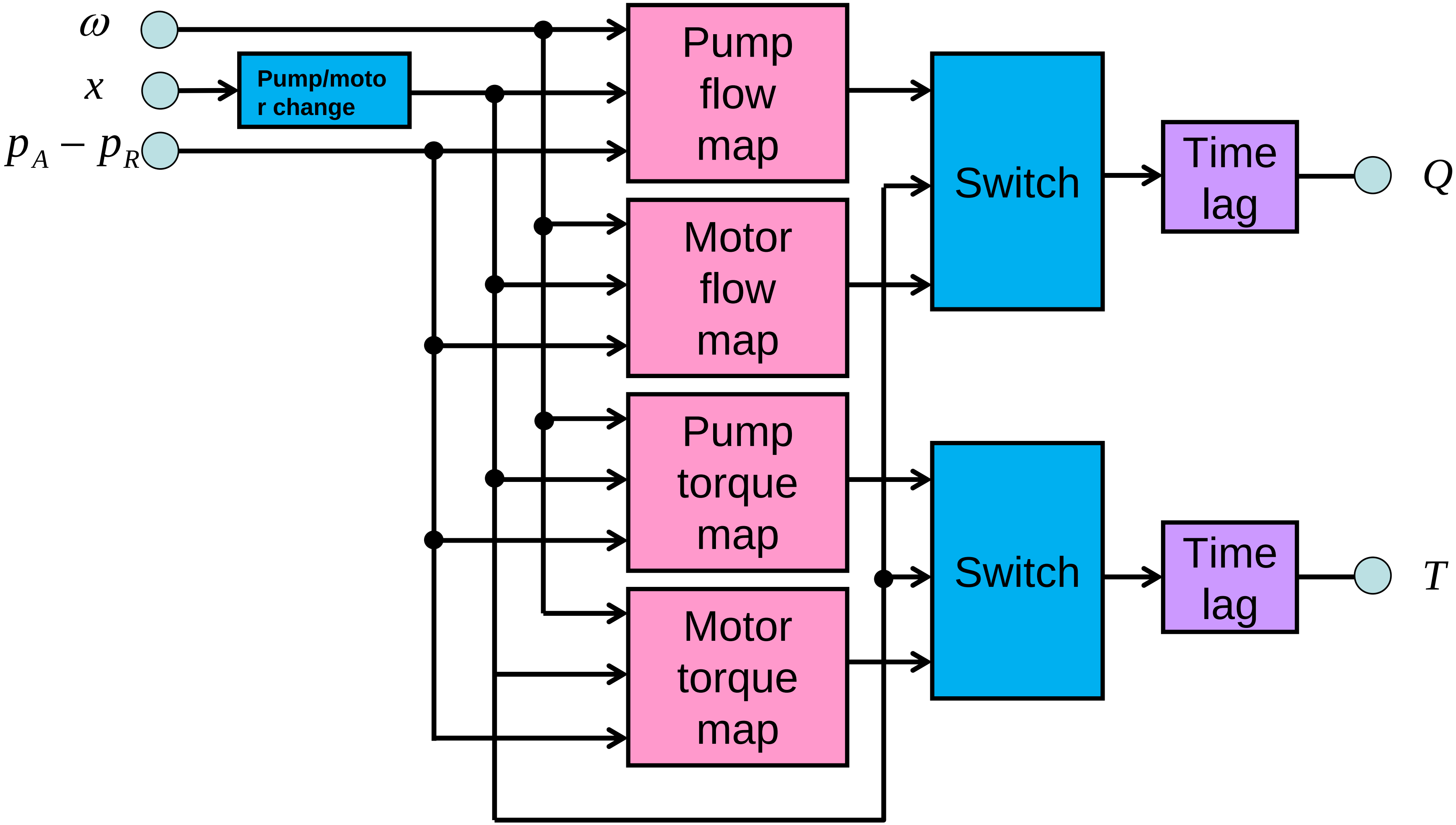
viscous loss; friction loss; hydrodynamic loss

Hydraulic Pump/Motor



	Pump:	Motor:
Volumetric flow rate:	$Q = \eta_v x D \omega$	$Q = x D \omega / \eta_v$
Torque:	$T = \eta_t x D (p_A - p_R)$	$T = x D (p_A - p_R) / \eta_t$
Efficiencies:	$\eta_v = f(x, p_A - p_R, \omega)$	$\eta_t = f(x, p_A - p_R, \omega)$

Pump/motor Vs ...



… Vs Electric Motor Model

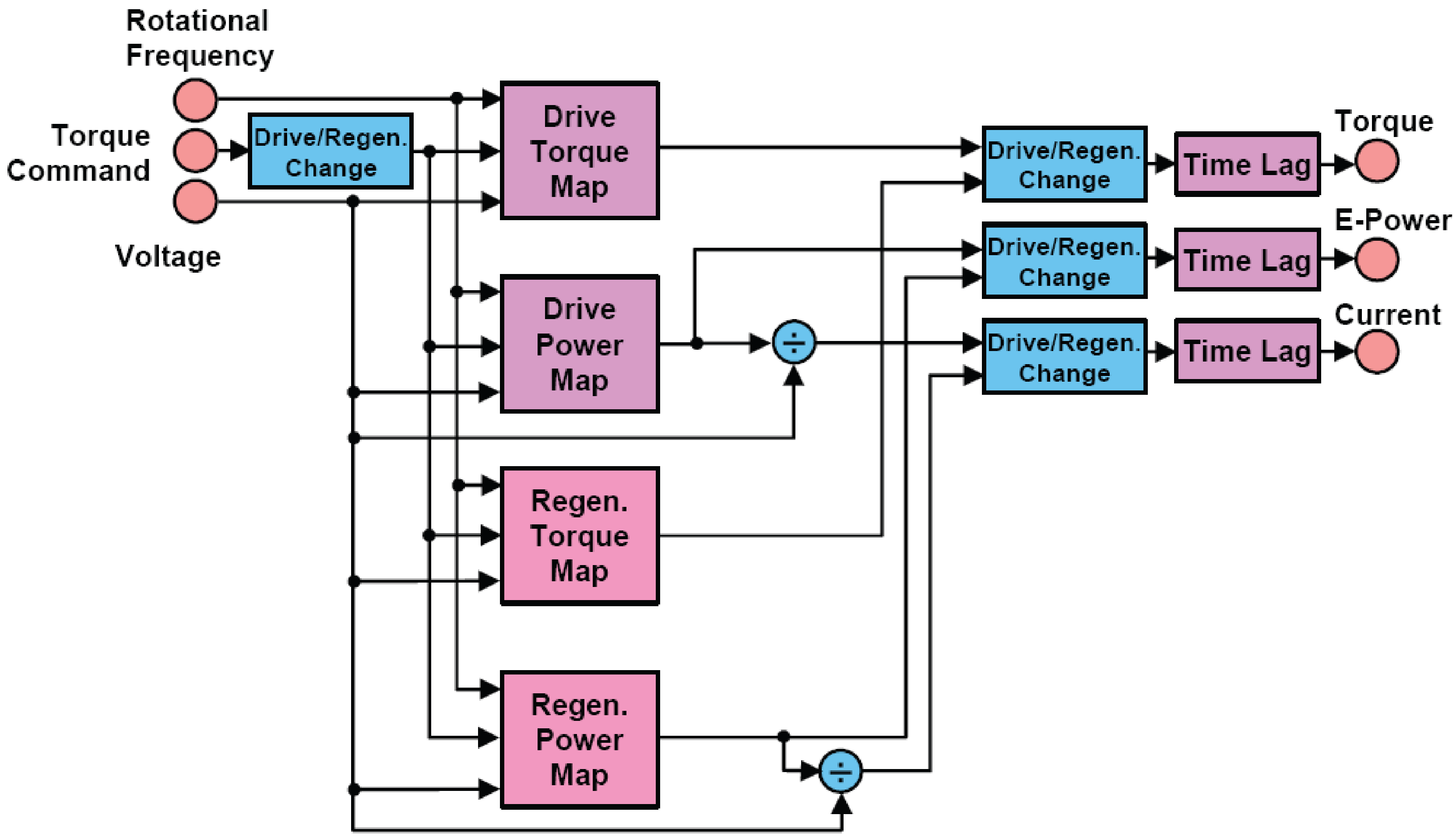


Fig. 3 Conceptual Diagram of Electric Motor Model

Development of Emissions and CO2 Test Procedure for Heavy Duty Hybrid Vehicles

WP 3-2: Development of HIL elements for non-electrical hybrid systems/components

- Based on the list of topologies and components in WP 3-1, develop simple, representative mathematical models of the different powertrain components, such as actuators and energy buffers. The models will be implemented in a simulation software. All models will be documented.

- The result is a set of simulation models of non-electric powertrain components, which are suitable to use in a HILS setup.

Results

- Mathematical models for
  - Flywheel
  - Accumulator
  - Pump/Motor

Summary

- WP 3-1:
  - Non-electric hybrid powertrain topologies (concepts) fits well into the same categories as for electric hybrid powertrains

→ HILS should be possible for non-electric HDHs

- WP 3-2:
  - Mathematical Models for
    - Flywheel
    - Accumulator
    - Pump/Motor

→ Similar model structures as proposed in Kokujikan No. 281

Next...

- CVT model
- Implementation
  - MATLAB/Simulink?
- Verification
  - Data???
- System modelling
  - Incorporate into the Japanese open-source model
  - Controller design

CHALMERS
UNIVERSITY OF TECHNOLOGY

Thanks for your attention!

Contact information

Jonas Fredriksson
Department of Signals and Systems
Chalmers University of Technology

jonas.fredriksson@chalmers.se
+46-31-772 1359