Vehicle Propulsion Systems
Lecture 4

Hybrid Powertrains, Part 1 – Topologies and Operating Principles

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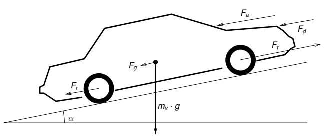
Outline

The Vehicle Motion Equation

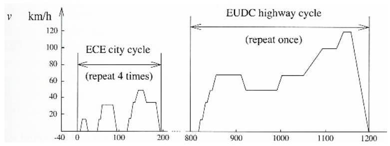
Newtons second law for a vehicle

$$m_v \frac{d}{dt} v(t) = F_t(t) - (F_a(t) + F_r(t) + F_g(t) + F_d(t))$$



- F_t – tractive force
- F_a – aerodynamic drag force
- F_r – rolling resistance force
- F_g – gravitational force
- F_d – disturbance force

Energy consumption for cycles



Numerical values for MVEG-95, ECE, EUDC

$$\text{air drag} = \frac{1}{x_{tot}} \sum_{i \in trac} \bar{v}_i^3 \, h = \{319, 82.9, 455\}$$

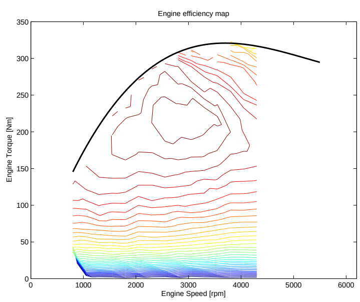
$$\text{rolling resistance} = \frac{1}{x_{tot}} \sum_{i \in trac} \bar{v}_i \, h = \{.856, 0.81, 0.88\}$$

$$\text{kinetic energy} = \frac{1}{x_{tot}} \sum_{i \in trac} \bar{a}_i \, \bar{v}_i \, h = \{0.101, 0.126, 0.086\}$$

$$\bar{E}_{\text{MVEG-95}} \approx A_f \, c_d \, 1.9 \cdot 10^4 + m_v \, c_r \, 8.4 \cdot 10^2 + m_v \, 10 \qquad kJ/100km$$

Engine Efficiency Maps

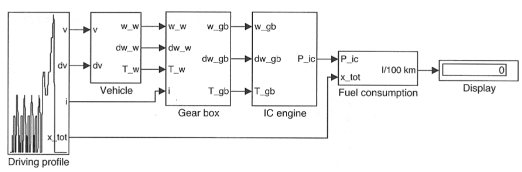
Measured engine efficiency map – Used very often



–Willans line approximation.

Model implemented in QSS

Conventional powertrain.



Efficient computations are important
–For example if we want to do optimization and sensitivity studies.

Outline

Definition

What characterizes a Hybrid-Electric Vehicle

- Energy carrier is a fossil-fuel.
- Presence of an electrochemical or electrostatic energy storage system.

Potential for Energy Savings

Benefits of Hybrid-Electric Vehicles

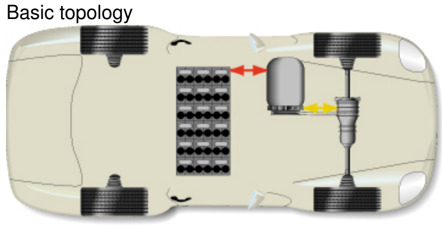
- Downsize engine while maintaining maximum power requirement
- Recover energy during deceleration (recuperation)
- Optimize energy distribution between prime movers
- Eliminate idle fuel consumption by turning off the engine (stop-and-go)
- Eliminate the clutching losses by engaging the engine only when the speeds match

Possible improvements are counteracted by a 10-30% increase in weight.

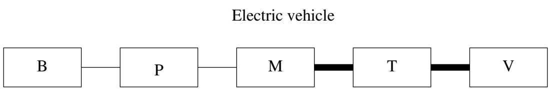
Outline

Electric Vehicles

- Basic topology



- Sketch of the paths



Electric Vehicles

- Contain basic elements of HEV.
- Not "interesting", for optimization. –No in-depth coverage in the course.
- Interesting from the design point of view.
- Drawbacks compared to a conventional vehicle
  - Not autonomous
  - Refueling time
  - Low range/weight
- ⇒ Niche vehicles
- Plug-in EV:s are hot in media
- Development of plug-less vehicles –Inductive charging
- Range extenders (transition to series hybrid)

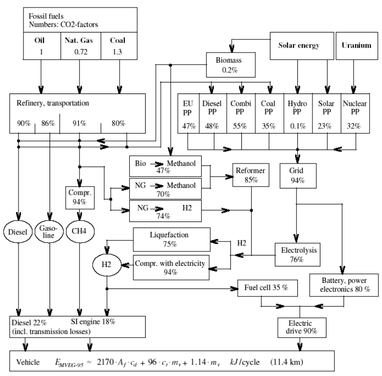
Electric Vehicles – Niche

- Applications requiring zero-emissions.
  - Indoor vehicles, mines ...
  - In-city distribution vehicles
  - Zero emission vehicle requirements
- Other niched vehicles

Lightning

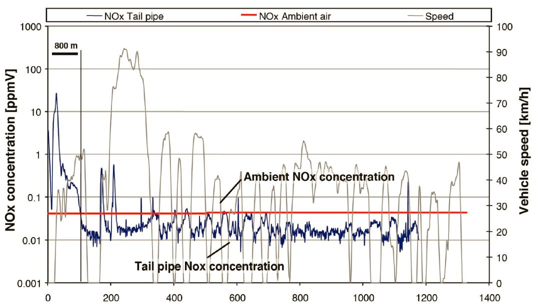
Tesla Roadster

Are Electric Vehicles = Zero Emissions ?



Zero Emissions – Is it the Limit?

Measured emissions – Diesel car



Basic configurations

Basic classification of hybrids

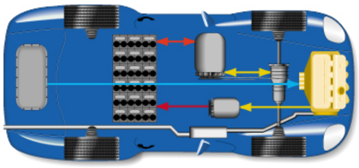
- Series hybrid
- Parallel hybrid
- Series-parallel or combined hybrid

There are additional types that can not be classified into these three basic types

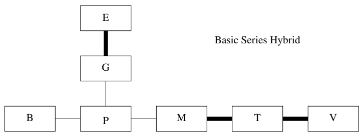
- Complex hybrid (sometimes)

Outline

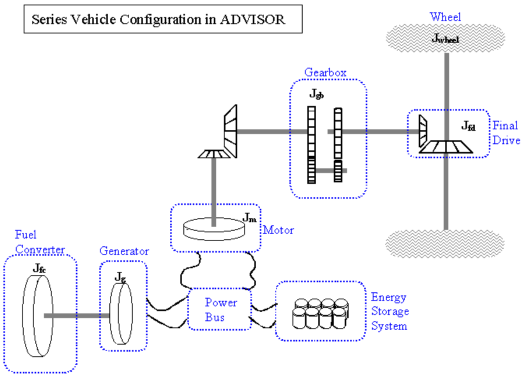
Series Hybrid – Topology



Sketch of the topology



Series Hybrid

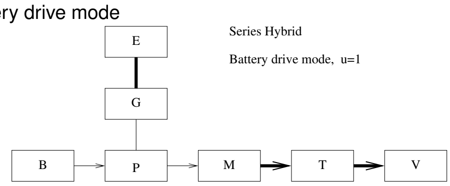


Series Hybrid – Modes and Power Flows

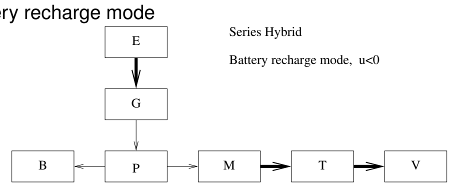
The different modes for a series hybrid

$$u \approx P_{batt}/P_{vehicle}$$

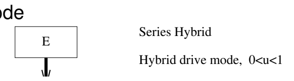
Battery drive mode



Battery recharge mode

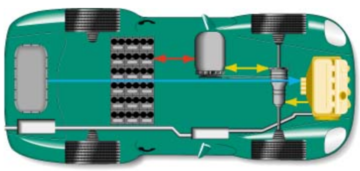


Hybrid drive mode

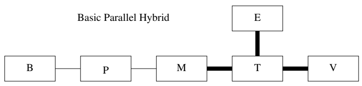


Outline

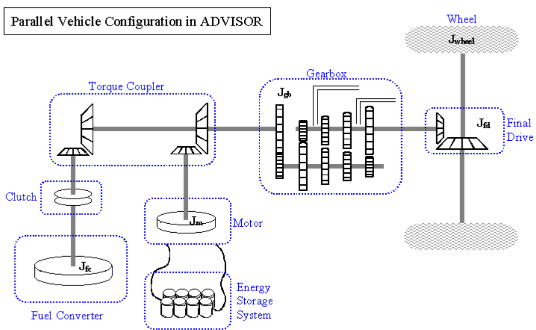
Parallel Hybrid – Topology



Sketch of the topology



Parallel Hybrid – Topology

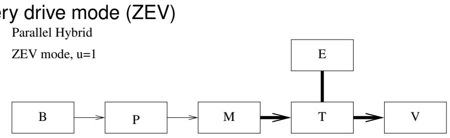


Parallel Hybrid – Modes and Power Flows

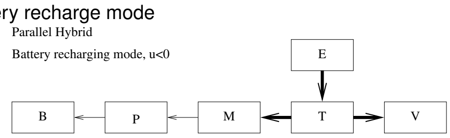
The different modes for a parallel hybrid

$$u \approx P_{batt}/P_{vehicle}$$

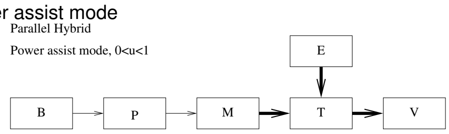
Battery drive mode (ZEV)



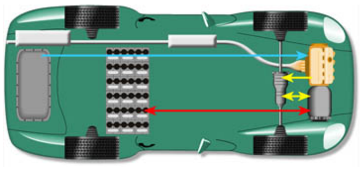
Battery recharge mode



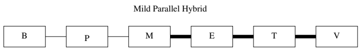
Power assist mode



Mild Parallel Hybrid – Topology

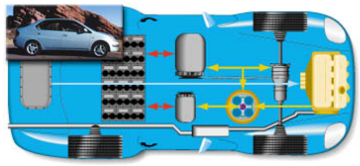


Sketch of the topology

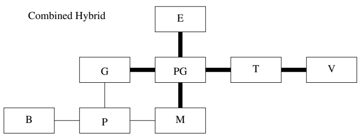


Outline

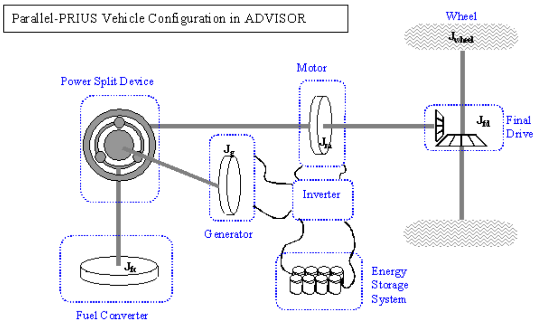
Combined Hybrid – Topology



Sketch of the topology



Combined Hybrid – Topology

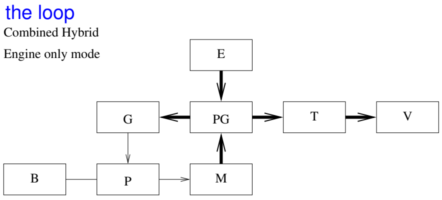


Combined Hybrid with PGS – Modes and Power Flows

The different modes for a combined hybrid

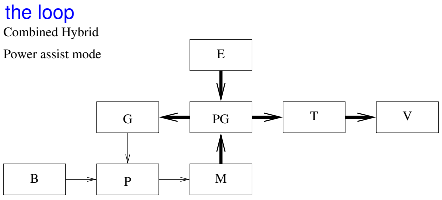
Conventional vehicle

–Note the loop



Power assist mode

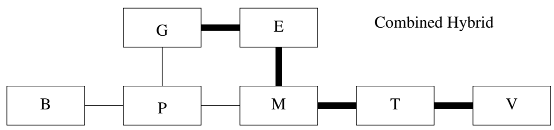
–Note the loop



Battery drive mode (ZEV)

Combined Hybrid

Combined Hybrid Without Planetary Gear



Outline

Implemented concepts

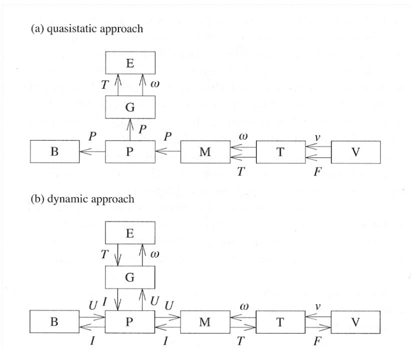
- Passenger cars
  - Parallel hybrids
  - Combined hybrids
  - Very few series hybrids (range extenders to EV).
- Trucks and busses
  - Series hybrids
  - Parallel hybrids
  - Combined hybrids
- Diesel trains
  – Series configuration but no storage

Degree of Hybridization

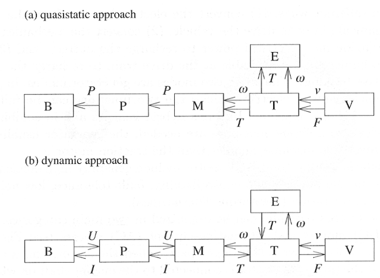
- Degree of hybridization
  –The ratio between electric motor power and engine power.
- Implemented hybrid concepts in cars
  Degree of hybridization varying between 15–55%
- True mild hybrid concepts
  Degree of hybridization varying 2–15%

Outline

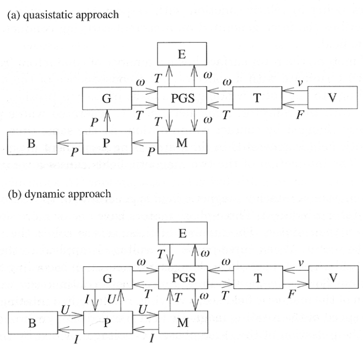
Causality – Series Hybrid



Causality – Parallel Hybrid



Causality – Combined Hybrid with PGS



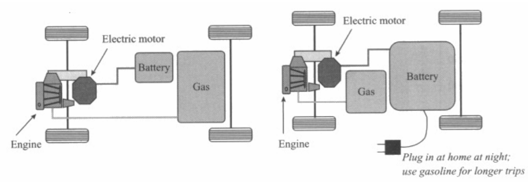
State Of Charge – SOC

- Charge condition for the battery.
- Full range SOC $\in$ 0–100%.
- Used range SOC $\in$ 50–70%.
- Generally difficult problem
  Models that include aging are not (yet) good enough.

Charge Sustaining Strategy

Charge Sustaining Strategies

- Basic control problem for a hybrid
  SOC after a driving mission is the same as it was in the beginning
  –Advisor simulation
- Plug-in hybrids
  Not charge sustaining



(a) Charge sustaining, or H0, hybrid architecture (b) Plug-in hybrid with electric range capability.

Summary of different hybrid concepts

Feature	Conv.	Mild	Full	Plug-in
Shut of engine at stop-lights and stop-go traffic	(x)	X	X	X
Regenerative braking and operates above 42 V		X	X	X
Electric motor to assist a conventional engine		X	X	X
Can drive at times using only the electric motor			X	X
Recharges batteries using the wall plug with at least 32 km range on electricity				X

’08 List of Hybrid Passenger Cars (Incomplete)

- Chevrolet Silverado Hybrid Truck, Chevrolet Tahoe Hybrid
- Daihatsu Highjet
- Ford Escape, Ford Mercury Mariner Hybrid
- GMC Sierra Hybrid Truck, GMC Yukon Hybrid
- Highlander Hybrid
- Honda Accord Hybrid, Honda Civic Hybrid, Honda Insight Hybrid
- Landrover Hybrid
- Lexus GS450h, Lexus RX 400h
- Nissan Altima
- Porsche Cayenne Hybrid
- Saturn VUE Greenline Hybrid
- Suzuki Twin
- Toyota Alphard Hybrid, Toyota Camry, Toyota Estima Hybrid, Toyota Prius
- Twike