Vehicle Propulsion Systems
Lecture 4

Hybrid Powertrains
Part 2 Component Modeling

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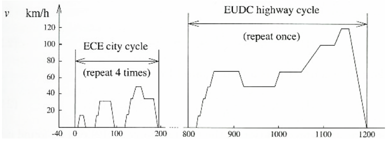
Outline

- Repetition
- Electric motors, Generators
- Batteries, Super Capacitors
- Power Links
- Torque Couplers
- Power Split Devices

Energy consumption for cycles



Numerical values for MVEG-95, ECE, EUDC

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

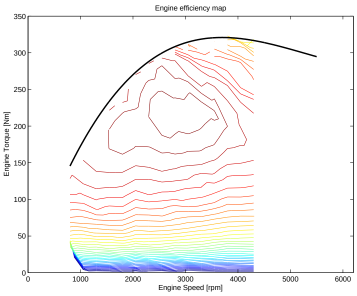
$$\text{rolling resistance} = \frac{1}{x_{tot}} \sum_{i \in trac} \bar{v}_i\, h = \{.856, 0.81, 0.88\}$$

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

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

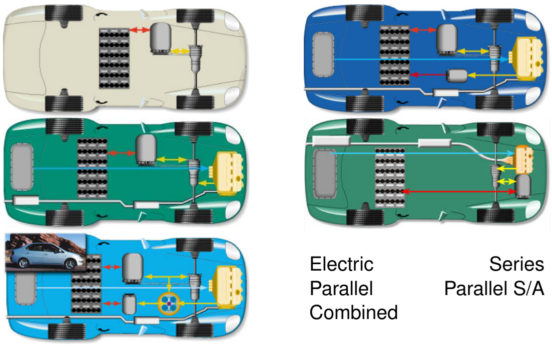
Engine Efficiency Maps

Measured engine efficiency map – Used very often



–Willans line approximation.

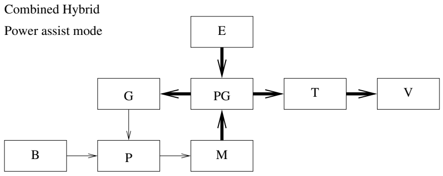
Hybrid concepts



Electric Series
Parallel Parallel S/A
Combined

Hybrid operating modes

Example: Combined hybrid in power assist mode.



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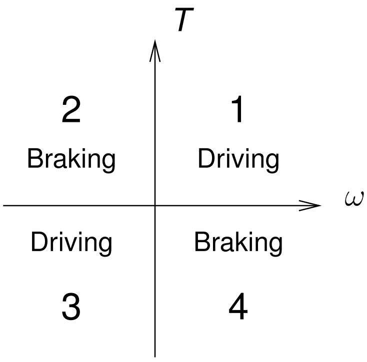
Electric Motors – Classification

Electric motors are often classified into four groups
(there are other classifications)

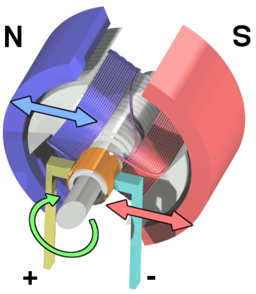
- DC-Machines
- Synchronous machines (sometimes including brushless DC-motor)
- Asynchronous machines
- Reluctance machines

There are also other devices:
Stepper motors (Digitally controlled Synchronous Machine), Ultrasonic motors.

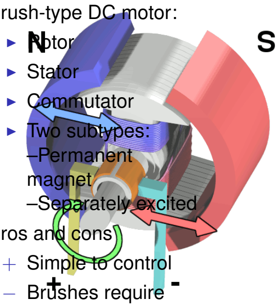
The 4 Quadrants



Brushed DC-Machine



Wikipedia picture



Brush-type DC motor:

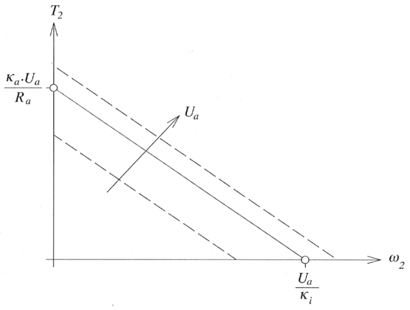
- Rotor
- Stator
- Commutator
- Two subtypes:
  –Permanent magnet
  –Separately excited

Pros and cons

- + Simple to control
- – Brushes require maintenance

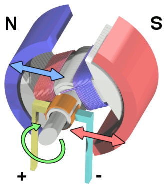
DC-motor torque characteristics

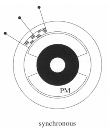
Characteristics of a separately excited DC-motor



Brushless DC-Motor

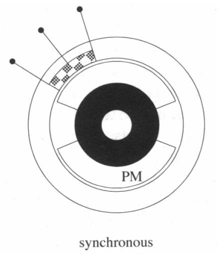
- Solves DC commutator and brushes problem
  - Replace electromagnet in rotor with permanent magnet.
  - Rotate field in stator.
- DC-motor is misleading
  - DC source as input
  - Electronically controlled commutation system AC
- Linear relations between
  - current and torque
  - voltage and rpm





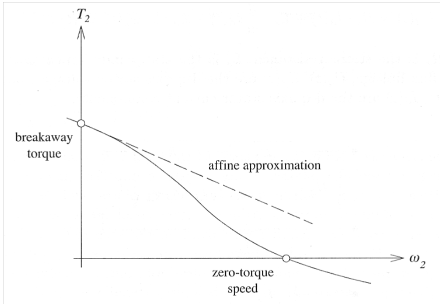
Synchronous AC machines

- AC machine
- Rotor follows the rotation of the magnetic field
- Has often *permanent magnets* in rotor
  –This is the same as the brushless DC motor.



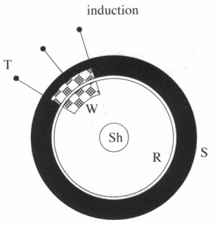
Torque Characteristics

Brushless DC



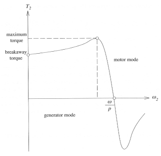
Asynchronous AC machines – Induction motors

- Stator has a rotating magnetic fiels
- Rotor has a set of windings, *squirrel cage*
  –See separate animation.
- Electric field induces a current in the windings
- Torque production depends on slip.



Torque Characteristics

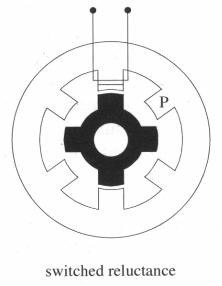
–Induction AC motor



Reluctance machines

Reluctance = Magnetic resistance.

- Synchronous machine
- Rotating field
- Magnetic material in the rotor
- Rotor tries to minimize the reluctance



Motor – Modeling

Quasistatic (equations are general)

- Power relationships:
  –input power $P_1(t)$
  –delivered power $P_2(t) = T_2(t)\,\omega_2(t)$
- Efficiency usage

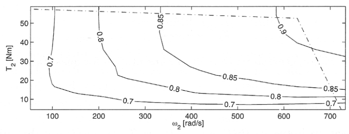
$$P_1(t) = P_2(t)/\eta_m(\omega_2(t), T_2), \qquad P_2(t) > 0$$

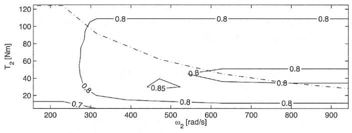
$$P_1(t) = P_2(t) \cdot \eta_m(\omega_2(t), -T_2), \qquad P_2(t) < 0$$

- Description of the efficiency in look-up tables
- Willans line to capture low power performance

First quadrant maps for η_m – AC machines

PM Synchronous





Induction motor, Asynchronous AC

Extending the Maps for η_m

- Traditional first quadrant drive is normally well documented
  –Supplier information for $\eta_m(\cdots)$
- Electric motor drive

$$P_2(t) = \eta_m(\omega_2(t), T_2) \cdot P_1(t), \qquad P_2(t) > 0$$

- Electric generator load

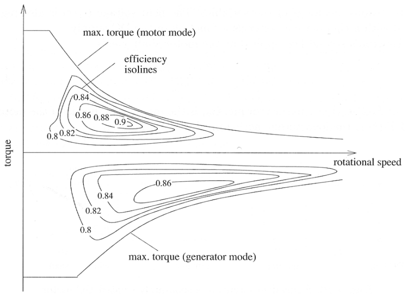
$$P_1(t) = \eta_g(\omega_2(t), T_2) \cdot P_2(t), \qquad P_2(t) < 0$$

- How to determine η_g?
- Method 1: Mirror the efficiency map

$$\eta_m(\omega_2(t), -T_2) = \eta_g(\omega_2(t), T_2)$$

- Method 2: Calculate the power losses and mirror them
- Method 3: Willans approach

Two Quadrant Maps for η_m



Mirroring efficiency is not always sufficient.

Motor – Modeling

- More advanced models
  - Use component knowledge: Inductance, resistance
  - Build physical models
- Dynamic models are developed in the book.

Electrical Machines in Hybrids

Machines encountered

- Separately excited DC
- Permanent magnet synchronous DC
- Induction motors
- (Switched reluctance machines)
  –Considered to be interesting

AC motors (compared to DC motors)

Less expensive but more sophisticated control electronics, gives higher overall cost.
Higher power density, higher efficiency.

AC motors (permanent magnet vs induction motors)

Averaged values from Advisor database.

	Efficiency	Power density
permanent magnet	92.5 %	0.66 kW/kg
induction motors	90.5 %	0.76 kW/kg

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Torque Couplers

Power Split Devices

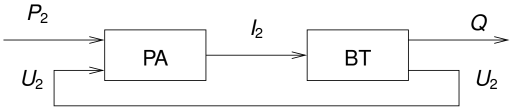
Batteries

- Energy storage devices – Energy density important
- Performance – Power density important
- Durability

Battery type	Energy Wh/kg	Power W/kg	cycles
Lead-acid	40	180	600
Nickel-cadmium	50	120	1500
Nickel-metal hydride	70	200	1000
Lithium-ion	130	430	1200

Modeling in QSS Framework

- Causality for Battery models in QSS.



- Models have two components
  - The first component is

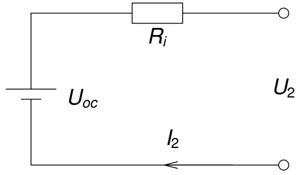
$$I_2 = \frac{P_2}{U_2}$$

  - The other, the relation between voltage and terminal current SOC

$$U_2 = f(SOC, I_2, \dots)$$

Standard model

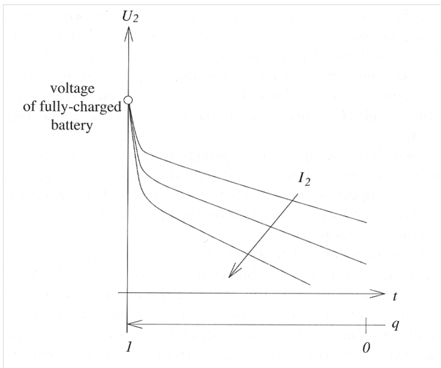
Simple model for the battery
–Open circuit voltage U_{oc}



Output voltage

$$U_2 = U_{oc} - R_i\, I_2$$

Voltage and SOC



Battery – Efficiency definition

- Efficiency definition is problematic
  - Not an energy converter
  - Energy storage
  - Peukert test
    –Constant current during charge and discharge.
  - Ragone test
    –Constant power during charge and discharge.
- Efficiency will depend on the cycle.

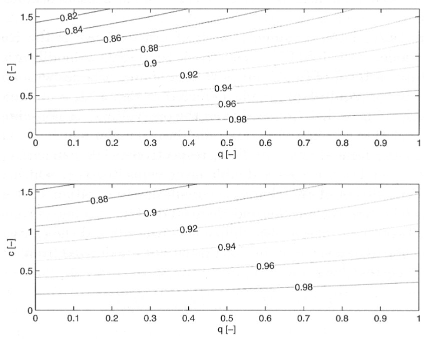
$$E_d = \int_0^{t_f} P_2(t)dt = /\text{Peukert test...}/ = t_f(U_{oc} - R_i \cdot I_2) \cdot I_2$$

$$|E_c| = \int_0^{t_f} |P_2(t)|dt = /\text{Peukert test...}/ = t_f(U_{oc} + R_i \cdot |I_2|) \cdot |I_2|$$

$$\eta_b = \frac{E_d}{E_c}$$

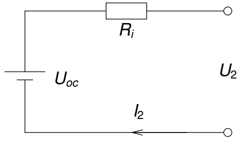
- Can also define an instantaneous efficiency.

Efficiency definition – Instantaneous



Supercapacitors

- Supercapacitors and ultracapacitors
- High power density
  –Used as short time scale energy buffer.
  –Load leveling to the battery.
- Very similar to battery in modeling
  Exchange the battery for a capacitor in the circuit below.



- Efficiency definitions
  Peukert and Ragone

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Power Links

- Electrical glue components
    - DC-DC converters
    - DC-AC converter
- Account for power losses

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Torque couplers

- Components that are included to:
    - Glue for mechanical systems acting on the same shaft
- Can include:
    - Gears in the coupling equation
    - Sub models for friction losses
- Basic equations
  –Angular velocities
  –Torque (from a power balance, including losses)

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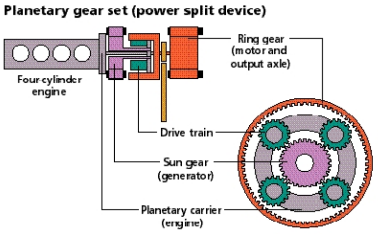
Power Split Devices

- Manage power splits between different components
- Important component for achieving flexibility
- Modeling approach: Speed relations with torque from power balance.



Can add more planetary gears