System simulation of HEV/EV

Lucas Kostetzer

ESSS Brazil & CADFEM Germany
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Design questions for HEV’s

- Energy management in HEV
  - Energy source switching
  - Engine to shut off rather than idle
  - Recapturing a portion of normally wasted braking energy
  - Engine downsizing
Motivation: System Simulation

- Automotive and especially HEV/EV systems consist of a variety of components. Each component may influence the behavior of another component.
Vehicle simulation @ System level

- Longitudinal dynamics
- Performance
  - Acceleration 0-100km/hr
- Fuel Consumption
- Hybrid/Electric
  - Electric machine sizing
  - Control
  - Power electronics
  - Battery
- Sizing engine effects
  - ……
Vehicle modeling concepts

- **Backward**
  - Easy and faster implementation
  - Evaluation of the requirements
    - Torque, Power
  - Fuel consumption evaluation

- **Forward**
  - Physical based modeling is possible
  - Information “flow” closer to reality
  - More effort for implementation
  - Performance evaluation
Vehicle propulsion HEV/EV project

- Energy consumption in standard drive cycles
  - FTP75, EUDC, ...
  - Fuel consumption and SOC calculation
  - Energy management strategy
  - Architecture evaluations
    - P-HEV, S-HEV

- Sizing for performance of EV
  - Electric motor sizing
  - Battery sizing
  - Function of:
    - Acceleration
    - Maximum speed

First part

Second part
focus of the present work
Vehicle modeling concepts

Backward Model

Forward Model

Driver

Speed_request

Torque

Speed_real

Speed_request
EV – forward model
Inertia force – VHDL-AMS

ENTITY mass_tr IS
GENERIC(
v0 : VELOCITY := 0.0);
PORT(
  QUANTITY m : MASS := 1.0;
  TERMINAL tr1 : TRANSLATIONAL_V);
END ENTITY mass_tr;

ARCHITECTURE behav OF mass_tr IS
QUANTITY v ACROSS f THROUGH tr1 TO translational_v_ref;
QUANTITY acc : ACCELERATION;
BEGIN
  IF (domain = quiescent_domain) USE
    v == v0;
  ELSE
    v'dot == acc;
  END USE;
  f == m*acc;
END ARCHITECTURE behav;

Across: velocity
Through: Force
Aerodynamic force – VHDL-AMS

Entity AeroDrag is
generic (Cd : real := 0.45 ;
         Af : real := 1.70 ;
         Rho : real := 1.259 ) ;
port (terminal MTV : TRANSLATIONAL_V) ;
end entity AeroDrag ;

architecture simple of AeroDrag is
quantity vel across F_ad through MTV to
TRANSLATIONAL_V_REF ;
Begin
F_ad == 0.5*rho*CD*Af*vel**2.0;
end architecture simple ;

“Through” to a reference is lost
“Through” from a reference is source
Electric motor – simplified model – VHDL-AMS Lib

- Torque source component

- Torque is function:
  - Axle rotational speed
  - Maximum torque curve
  - Control Signal
    - 0 to 1
      - Zero torque up to maximum torque

Across: rotational velocity

Through: Torque

Data table with max torque

FIRST modeling level:
- No power electronics
- No electrical
- Only power values
Local controller + battery – Power level

- Input from driver
  - Throttle signal: 0 to 1
  - Brake signal (regen. Brk)

- Check power available from battery
  - Power request, available

- Control signal
  - Based on available power from battery
  - Signal from 0 to 1 to set the motor torque
Performance study

- Electric motor sizing
- Battery discharge power selection
Results – transient simulation

- Drives is with full throttle since $t_0$

- Each motor/battery is one simulation case

Parametric study:
- $EM\_size\_factor = 0.5$ to $4$
- $BAT\_factor = 10$ to $40$

- Limiting conditions (power/torque) and resistance forces will give the dynamics behavior

Max speed

Time from 0 to 60km/hr
Maximum velocity

- EM_size_factor has no big effect after a limit
  - It means a system limited by the discharge battery power

- Using a bigger motor it will not help if the battery does not deliver enough power

- For the nominal value (EM_size_factor=1) battery power higher than 20kW is not necessary (2)
Acceleration 0-60km/hr

- Battery discharge power has a non-linear influence (1)
  - Kind of saturation

- Acceleration is limited by motor power in lower rotational speeds (2)
  - Extra battery power does not help

- A compromise must be found
  - Motor size
  - Battery requirement

Engineers can now decide based on performance simulations
What can be done next

- Investigate more design variations
  - Gear ratios
  - Include weight effect into parameterization

- Going deeper into electrical drive train
  - Power electronics
  - Electric motor
  - Battery models
Summary

- System level simulation for vehicle propulsion
- HEV/EV applications
  - Energy consumption
  - Performance tests
- Components sizing, design aided by system simulation
  - Reach specific performance requirements
- For the studied EV a balance must be found between electric motor and battery pack size