Analysis of hybrid hydraulic vehicles and comparison with hybrid electric vehicles using batteries or super capacitors

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Introduction

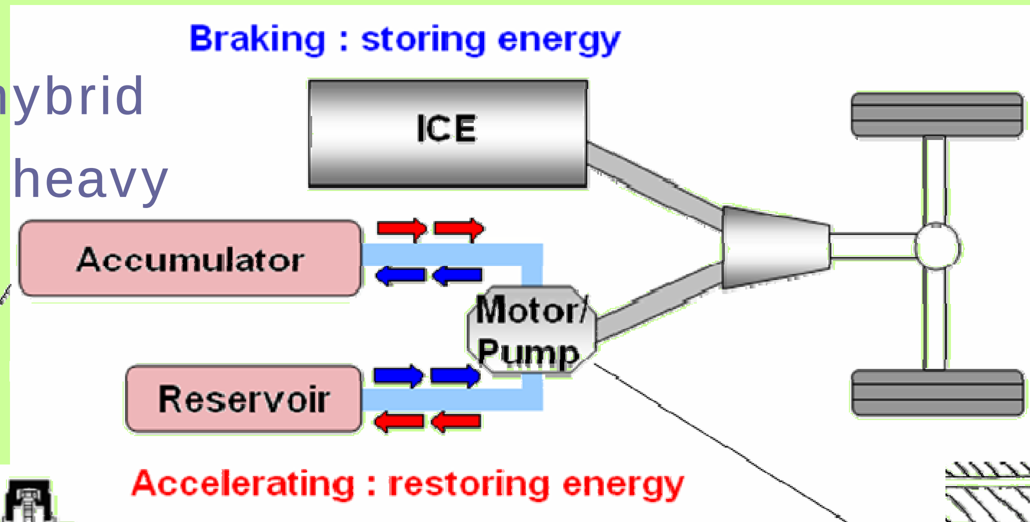
- Great efforts to reduce CO_2 emissions from the transportation sector
- Research for alternative propulsion systems to conventional vehicles using internal combustion engine
- The hybrid electric vehicle (HEV) generally considered as a short term solution
- Another interesting solution that can rise soon is the hybrid hydraulic vehicle (HHV)

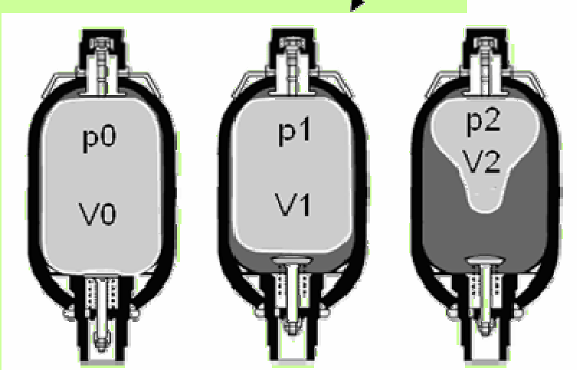
Introduction

- Hydraulic hybrid vehicle

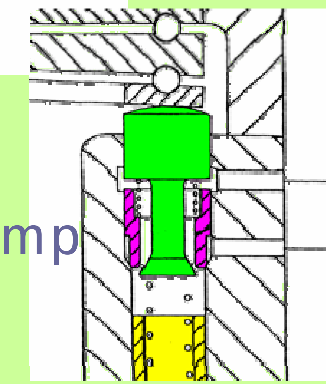
  -Parallel mild hybrid

  -Interesting in heavy urban vehicle





-New hydraulic reversible motor/pump working with non lubricating fluids



Objectives

- Simulation and comparison of different solutions adapted to urban buses
  - A conventional internal combustion diesel engine that will serve as a reference configuration
  - A mild HEV using batteries as energy storage system
  - A mild HEV using super capacitors as energy storage system
  - A HHV based on a reversible hydraulic motor pump and hydraulic accumulators
- Modeling and simulation of the vehicles with the software ADVISOR

Objectives

- Calculation of the fuel consumption of the buses on three drive cycles
- Estimation of the development and fabrication cost of the three hybrid systems
- Comparison of the cost of one solution with the annual savings that it allows and calculation of the payoff period

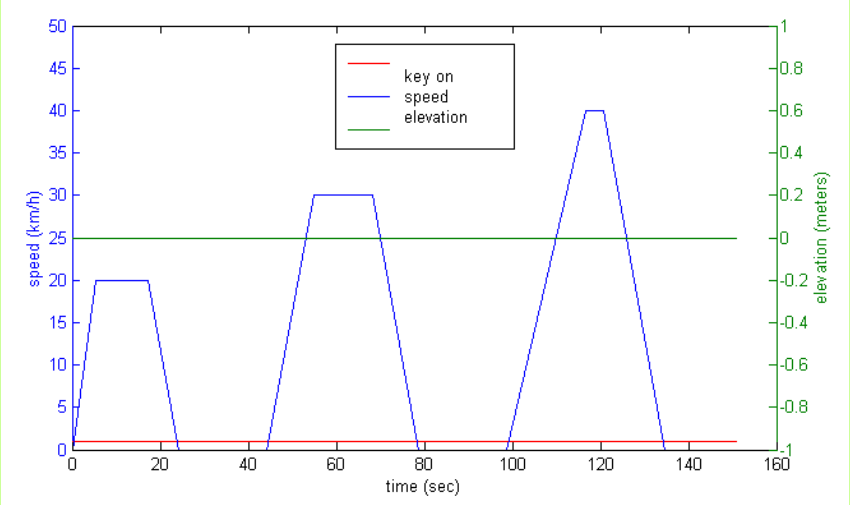
Simulation tools

- ADVISOR is a software code, developed in the MATLAB/Simulink environment, allowing to tailor quickly vehicle models (conventional or hybrid electric) and to simulate their fuel consumption and performance on given drive cycles

- ADVISOR includes a "SOC correction" option, which constrain to the state of charge (SOC) at the end of the cycle to be equal to the SOC at the beginning of the cycle within a given tolerance chosen by the user

SORT drive cycle

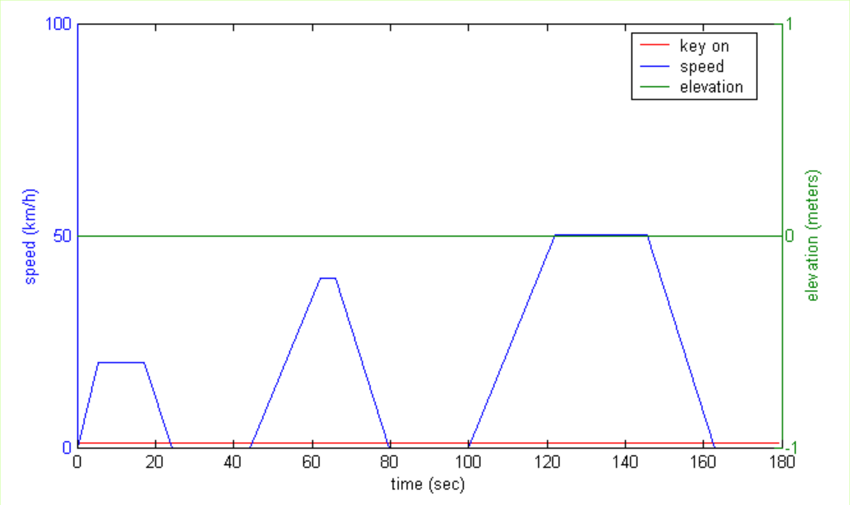
- The buses are simulated on the three SORT (standardized on-road test) drive cycles developed by the UITP (International association of public transport)



Heavy urban SORT drive cycle

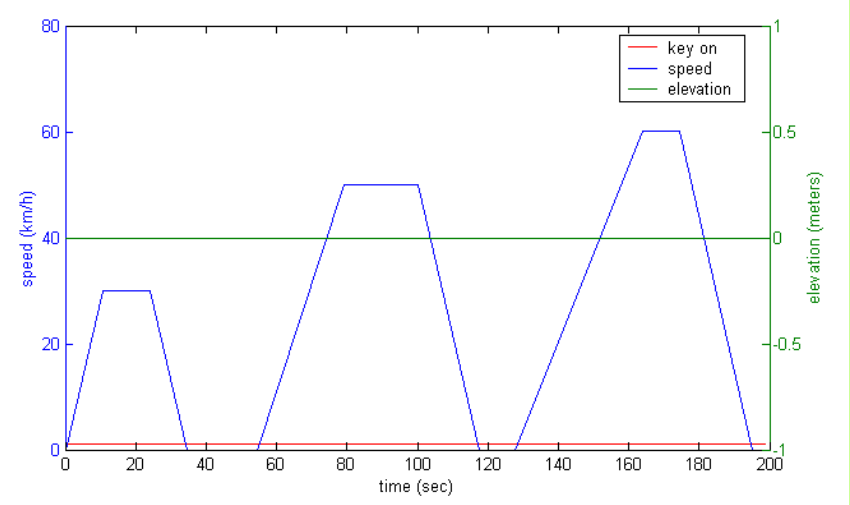
Commercial speed = 12 kph

SORT drive cycle



Easy urban SORT drive cycle

Commercial speed = 17 kph



Suburban SORT drive cycle

Commercial speed = 27 kph

Vehicles design and modeling

- Conventional bus based on Vanhool A300 bus
- Hybrid buses designed to have equivalent or even better performance (max speed, gradeability and acceleration) than reference bus
- Hybrid ratios and size of the storage systems chosen to give the smallest fuel consumption (parametric studies)

Conventional bus

Diesel engine	Power	205 kW
	Max Efficiency	44 %
Aerodynamics	S	7.24 m²
	Cx	0.79
Tires	Rolling resistance	0.00938
	Rolling Radius	0.5 m
Vehicle	Curb weight	11280 kg

HEV bus with batteries

Diesel engine	Power	150 kW
	Max efficiency	44 %
AC induction motor	Power	39 kW
	Max efficiency	92 %
NIMH batteries	Voltage	574 V
	Energy	26.25 kWh
Vehicle	Curb weight	11663 kg

HEV with super capacitors

Diesel engine	Power	160 kW
	Max efficiency	44 %
AC induction motor	Power	64 kW
	Max efficiency	92 %
Maxwell BMOD0018	Voltage	390 V
	Available energy	0.564 kWh
Vehicle	Curb weight	11542 kg

Hybrid hydraulic bus

Diesel engine	Power	160 kW
	Max efficiency	44 %
Reversible motor/pump	Power	64 kW
	Max efficiency	92 %
Accumulator +reservoir	Max pressure	345 bar
	Energy	0.771 kWh
Vehicle	Curb weight	12318 kg

Results

- Methodology
  - Consumption calculated for each bus configuration
  - Calculation of the fuel savings compared to the reference bus
  - Estimation of the hybrid system costs (literature)
  - Calculation of the annual economy (brake maintenance and fuel savings) on the basis of a annual traveled distance of 45000 km
  - Calculation of the annual cost of the storage system
  - Estimation of the payback period

Fuel savings

	ICE	HEV Bat.	HEV SC.	HHV
Consumption SORT 1 (l/100km)	64.1	48.6	54.7	53.1
Saving SORT 1 (%)	-	-24.2	-14.7	-17.2
Consumption SORT 2 (l/100km)	52.6	42.1	43.0	43.9
Saving SORT 2 (%)	-	-20	-18.3	-16.5
Consumption SORT 3 (l/100km)	46.9	36.2	37.5	40.4
Saving SORT 3 (%)	-	-22.8	-20.0	-13.9

Payback HEV with batteries

Hybrid system cost (€)	+27760		
Energy storage cost (€/year)	+2617		
Brake economy (€/year)	-850		
Fuel economy (€/year)	-7631	-5169	-5268
Economy (€/year)	-5864	-3402	-3501
Payoff period (years)	4.7	8.2	7.9
	Sort 1	Sort 2	Sort 3

Payback HEV with super capacitors

Hybrid system cost (€)	+18273		
Energy storage cost(€/year)	0		
Brake economy (€/year)	-850		
Fuel economy (€/year)	-4628	-4726	-4628
Economy (€/year)	-5478	-5576	-5478
Payoff period (years)	3.3	3.3	3.3
	Sort 1	Sort 2	Sort 3

Payback HHV

Hybrid system cost (€)	+20113		
Energy storage cost(€/year)	0		
Brake economy (€/year)	-850		
Fuel economy (€/year)	-5415	-4283	-3200
Economy (€/year)	-6265	-5133	-4050
Payoff period (years)	3.2	3.9	5
	Sort 1	Sort 2	Sort 3

Conclusion

- All the three hybrid solutions are environmentally friendly and economically attractive
- HEV with batteries is the best in terms of CO_2 reduction but it is penalized by the cost of the batteries
- HEV with super capacitors offers a short payoff period in every driving conditions
- HHV has also a good payoff period in particular in heavy urban traffic

Thank you for your attention