Considerations in the use of supercapacitors in combination with batteries in vehicle applications

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Objectives of the Research

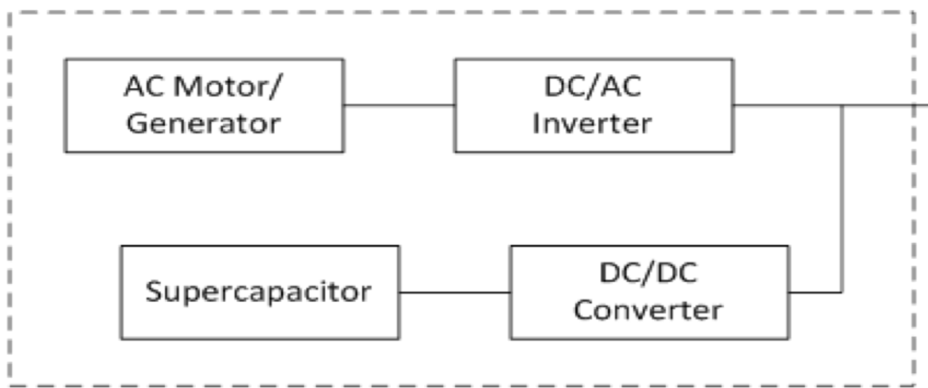
- ❑ Investigate the use of batteries and supercapacitors in PHEVs
- ❑ Select components that are appropriate and optimum
- ❑ Compare the system size and cost with/without supercaps
- ❑ Simulate the PHEVs with supercaps on various driving cycles
- ❑ Highlight the advantages of using supercaps from the battery stress and thermal management points-of-view

Battery requirements in electrified vehicles

- ❑ Meet the power (kW) of the electric motor
- ❑ Accept the regeneration braking energy
- ❑ Provide accessory loads when the vehicle is stopped in a HEV
- ❑ Able to start the engine in a HEV
- ❑ Meet the all-electric range in a PHEV
- ❑ Have long cycle life and reasonable cost

PHEV battery – small, high power, long cycle life, and low cost.

Electric drive with supercapacitors



48V NessCap module (18x3000F)

The optimum duty cycle for the batteries is that they provide the average power and the supercaps meet most of the peak discharge pulses during accelerations and accept the charging pulses during regenerative braking. (in other words, the supercaps load-level the battery).

Key advantages of supercapacitors

- ❑ High power capability permitting energy to be charged/discharged at very high efficiency
- ❑ Very long cycle life for high power, deep discharge cycles
- ❑ Ability to accept very high charge power/high rates
- ❑ Good power capability at low temperatures
- ❑ Minimal thermal management problems

Considerations in selecting a battery for use with supercapacitors

- ❑ Primarily meet the energy storage requirement with much reduced consideration of its power capability
- ❑ Higher energy density, longer cycle life, and lower cost for the same energy storage (kWh)
- ❑ Battery will experience much reduced dynamic high currents which should further increase its cycle life
- ❑ High regeneration braking currents will be accepted by the supercaps and not the battery
- ❑ Greater fraction of total energy stored in the battery can be used in most application than would be the case without supercaps

Do not use the same battery with/without supercaps

Design parameters for the energy storage components in the electric driveline system

Component	Wh/kg	kg/L	$/kWh	$/Wh
Power battery	120	2.2	225	
Energy battery	165	2.2	150	
supercapacitor	9	1.4		2.5

Vehicle design and operation parameters

PHEV range (1)	Wh/mi (2)	battery kWh (3)	Supercapacitor Wh (4)
20 mile	282	7	220
40 mile	282	15	220
60 mile	282	23	220

(1) All-electric range and max. power 120kW; (2) Wh/mi is the average of the value 225 Wh/mi of the FUDS and 340 Wh/mi on the US06; (3) 75% of the energy stored in the battery is used; (4) Energy available from the supercap. to ½ rated voltage

Comparisons of the weight, volume, and costs of the energy storage systems with/without supercapacitors

PHEV range	Power battery kWh	Energy battery kWh	Capac. Wh	weight kg Volume L of battery + capac.	weight kg Vol. L of power battery	Cost ($) battery + capac. (1)	Cost ($) power battery (2)
20 mile	7	7	220	66 kg / 33 L	58 kg / 27 L	$1600	$1575
40 mile	15	15	220	115 kg / 55 L	125 kg / 57 L	$2800	$3375
60 mile	23	23	220	163 kg / 77 L	192 Kg / 87 L	$4000	$5175

(1) The supercapacitor cost was taken as .25 cents per Farad which is $2.5/Wh
(2) The battery costs were $150/kWh for the energy battery and $225/kWh for the power battery

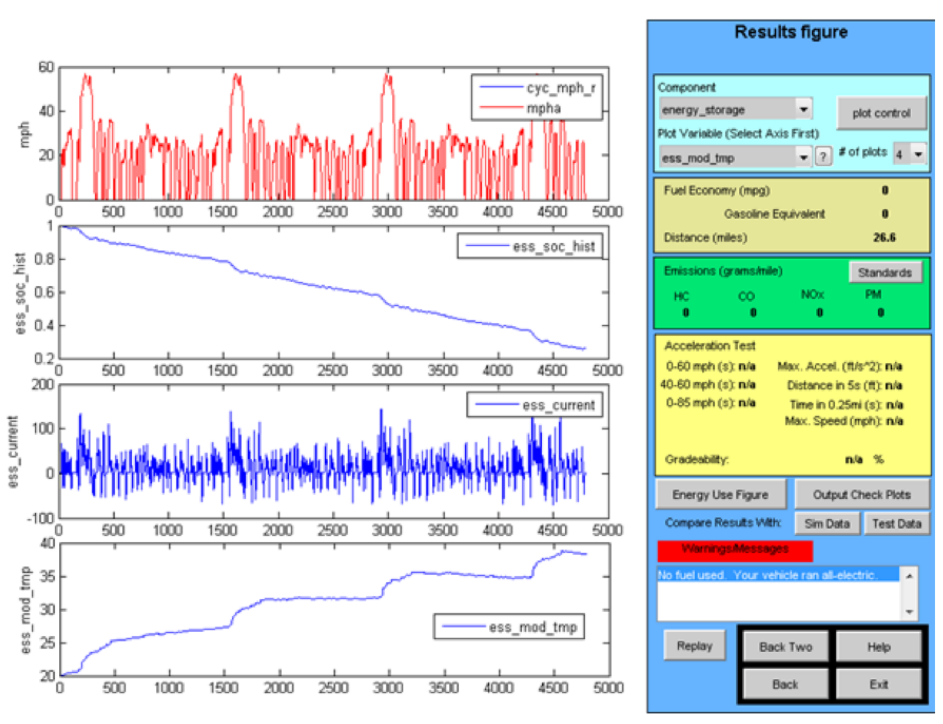
Economic advantage of using supercaps greater with longer all-electric range

Summary of battery/capacitor Advisor simulation results

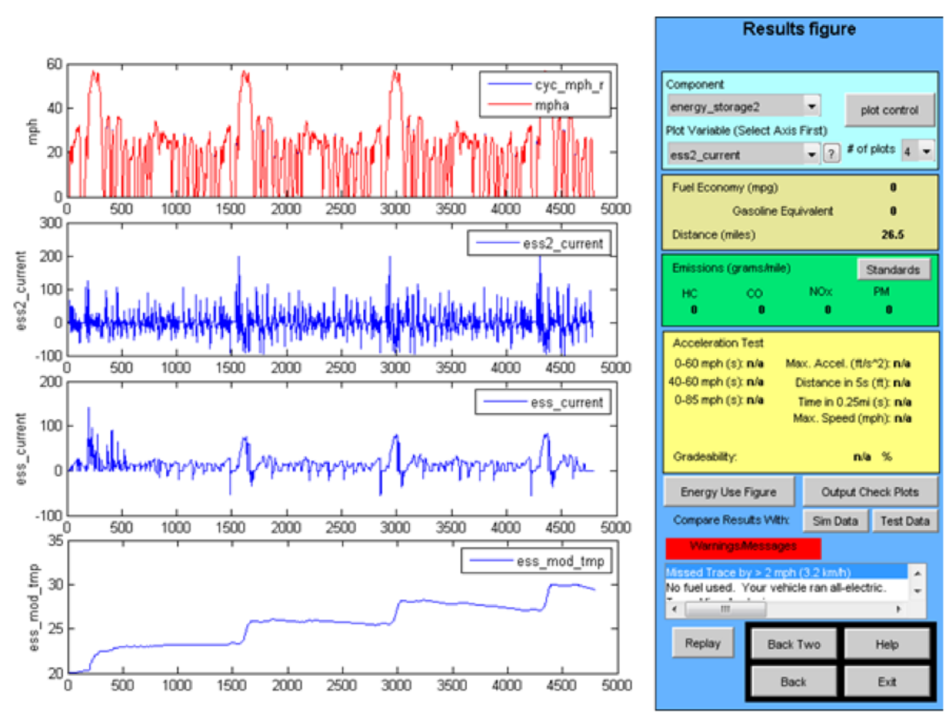
Battery/kg	Drive cycle	Elec. Range mi.	Wh/mi	Battery losses kJ	Battery effic. %	Capac. Losses kJ	Capac. Effic. %	Final temp. C*
Power/ 55	FUDS	26.6	202	455	97			26
kg alone	US06	15.4	337	835	94			43
Energy/	FUDS	26.6	209	1080	94			39
40kg alone	US06	14.9	336	2526	85			80
Energy/ 40kg with Caps.								
24 kg	FUDS	26.5	226	553	95	412	97	30
Skeleton	US06	15.4	343	1438	89	518	94	60
24kg JSR	FUDS	26.5	226	554	95	282	97	30
Micro	US06	15.4	339	1332	89	307	96	60
28 kg	FUDS	26.5	226	650	95	161	99	32
Yunasko	US06	15.4	335	1438	89	121	98	60
20 kg future	FUDS	26.5	226	542	95	203	98	30
hybrid	US06	15.4	337	1328	89	179	98	60

*the initial battery temperature was 20 deg C

40 kg Energy battery w/ and w/o caps, 3.5 FUDS cycles

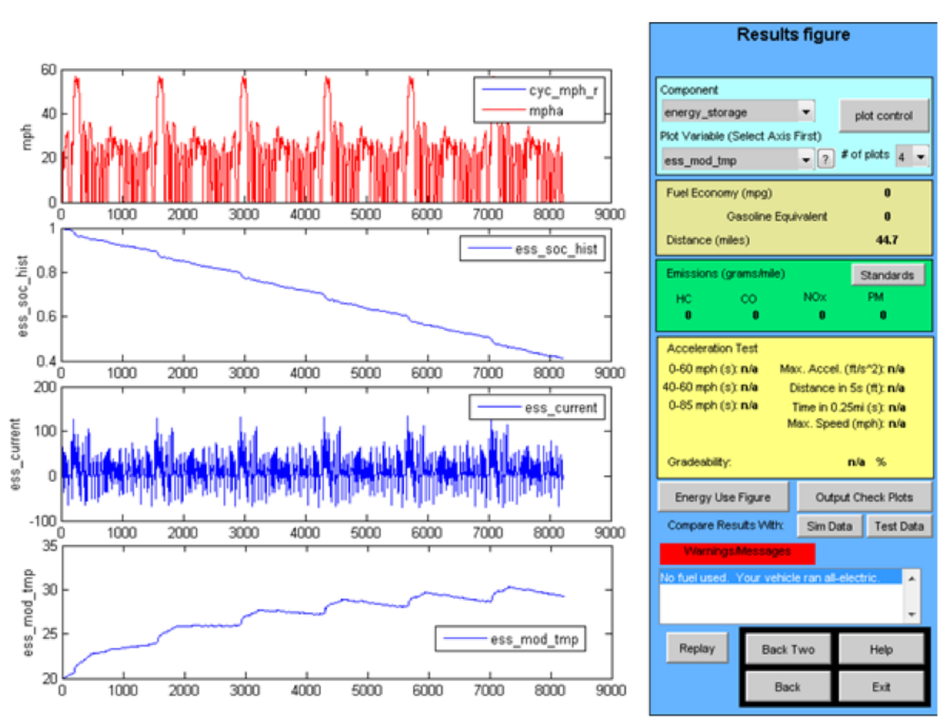


Energy battery alone

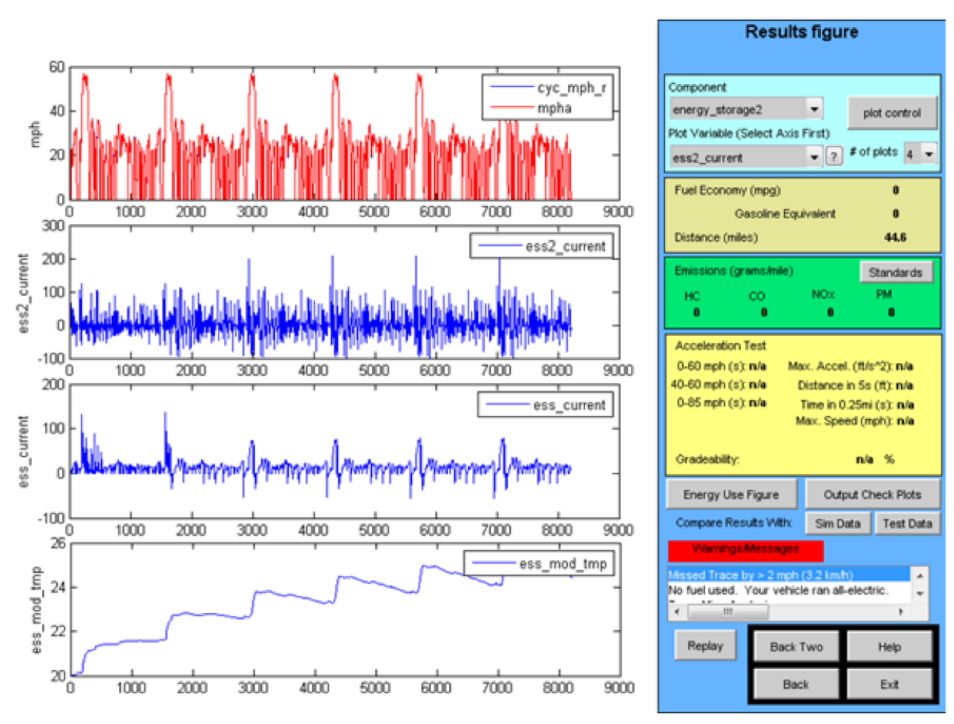


Energy battery with 24 kg Skeleton caps

80 kg Energy battery w/ and w/o caps, 6 FUDS cycles



Energy battery alone



Energy battery with 24 kg Skeleton caps

Conclusions regarding vehicles using supercapacitors

- ❑ Supercapacitors can be used with an energy (EV) battery in a PHEV
- ❑ The supercapacitor reduces the peak currents and stress on the battery by at least a factor of two
- ❑ PHEV applications in mid-size cars will require about 220 Wh of energy storage in the supercap
- ❑ The cost of the supercap/battery system will be attractive due to the lower cost of the energy battery compared to a power battery
- ❑ The cost of supercapacitors will continue to decrease as their volume of production increases. Stop-go hybrids with lead-acid batteries are likely to be the first automotive mass market for supercapacitors.