

Dual Source Energy Storage Potential for Fuel Cell Vehicle Applications

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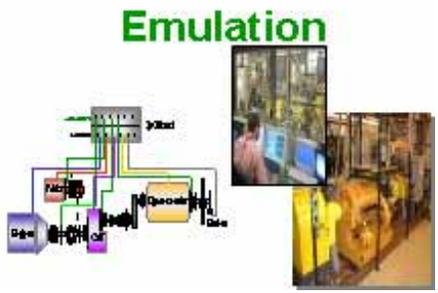
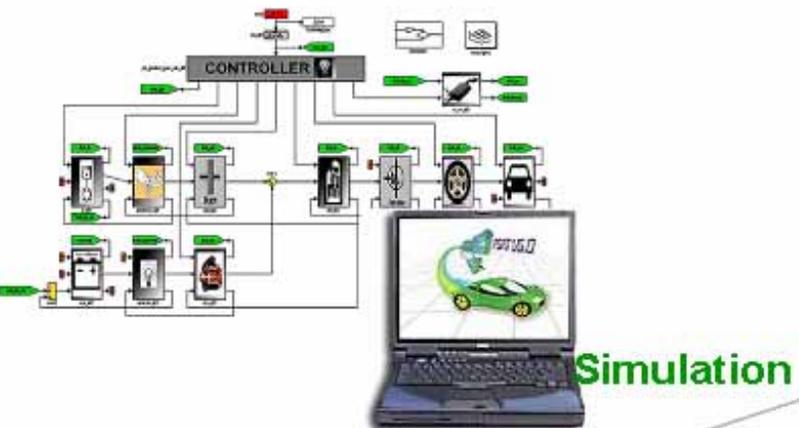


Lead Acid Best Fits with Ultracapacitor



	Lead Acid	NiMH	Li-ion	Ultracapacitors
Nominal Voltage (V)	2.0	1.3	3.8	
Max voltage (charge) (V)	2.7	1.7	4.0	3.0
Max Voltage (discharge) (V)	1.5	0.8	2.7	0
Specific Energy (Wh/kg)	30	70	70 to 120	4
Specific Power (W/kg)	<400	<900	<1500	9000
Temperature (C)	-30 to 60	-25 to 55	-25 to 45	20 to 80
Number of cycles	~300	~1500	~1500	~500000

Modeling, Test and Validation Are Integrated



From Modeling to HIL

Ultracapacitor Model
Development

DC/DC Converter Needs

Control Strategy

Simulation Results

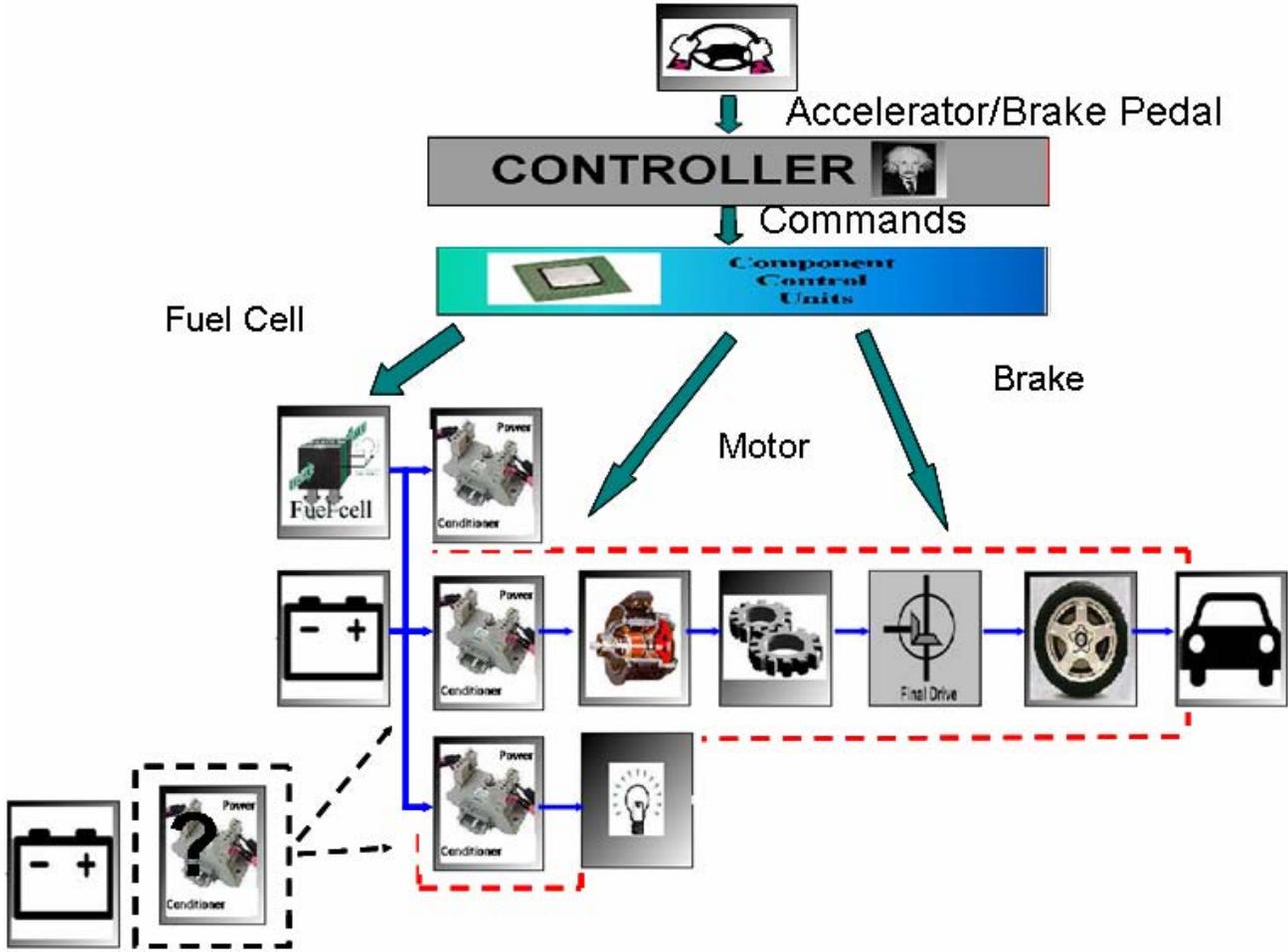
Hardware
Development

Tests

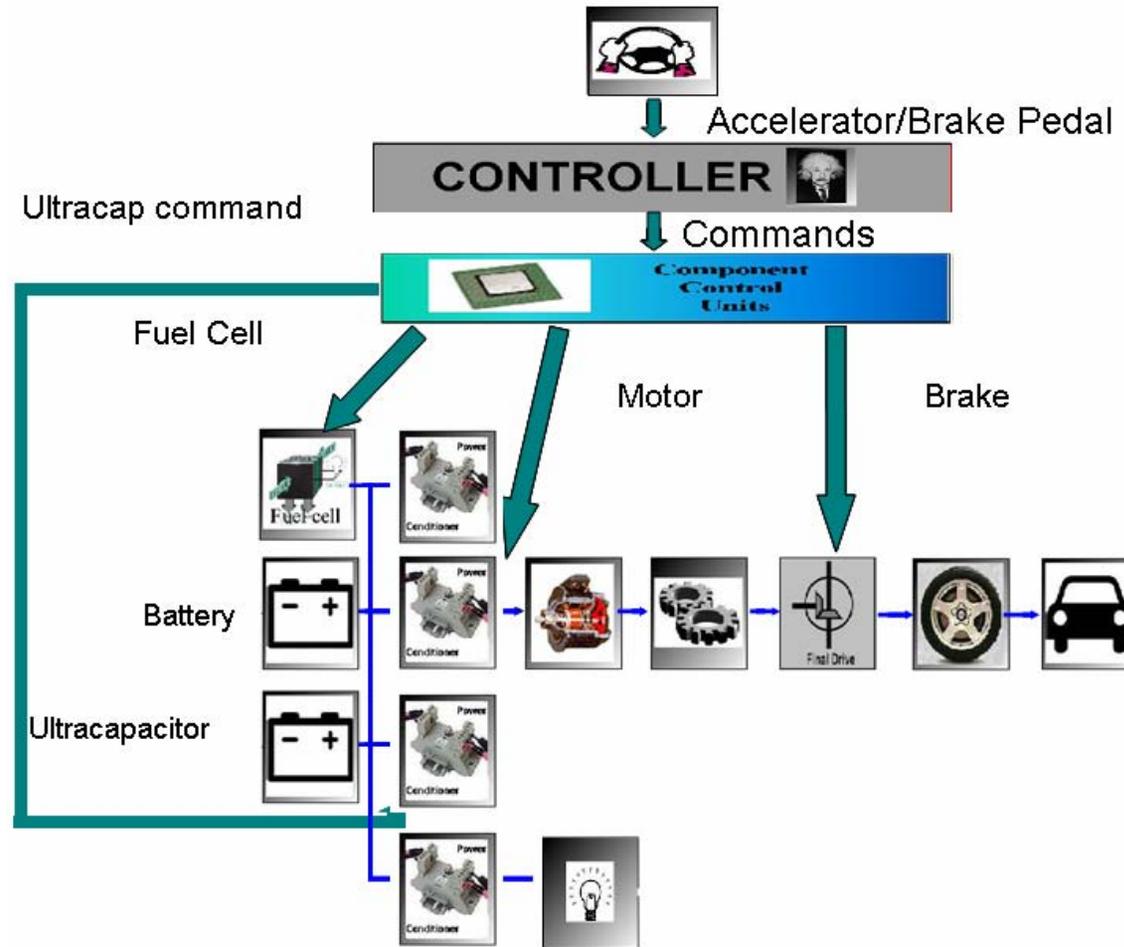
Results Analysis

Control Strategy Integration
in PSAT-PRO

More Realistic Powertrain

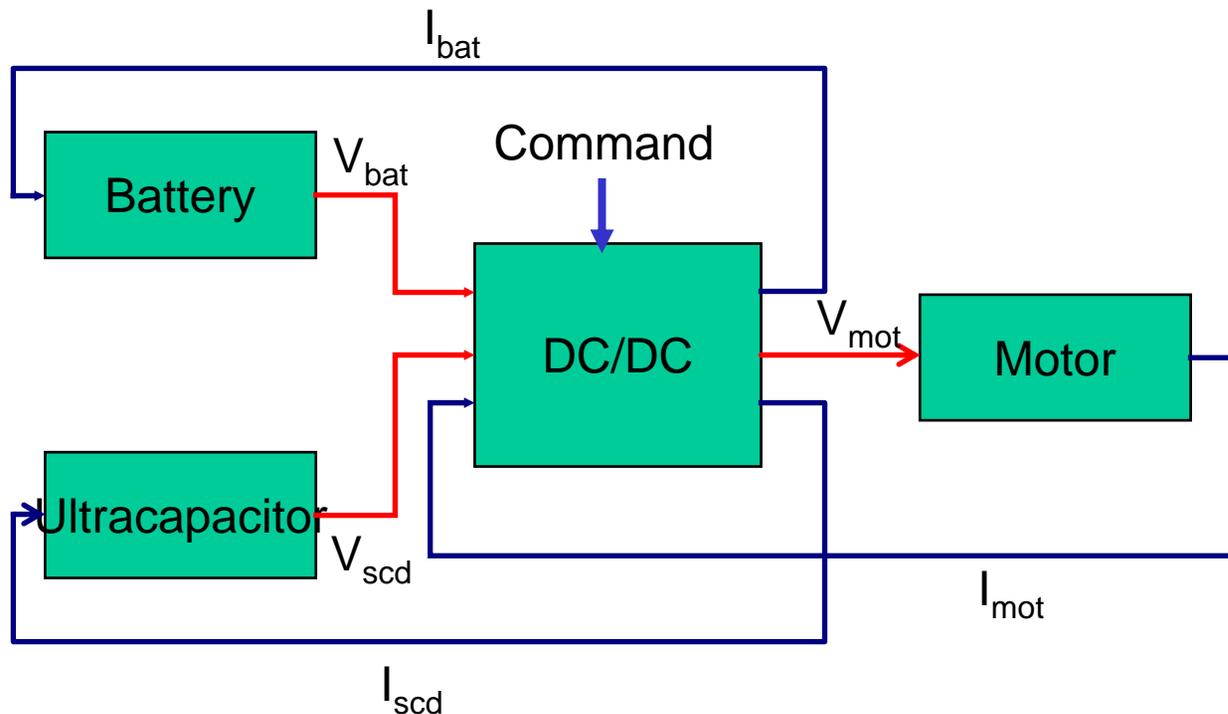


Two Energy Storage Systems Combined



DC/DC Model

- Constant voltage in output
- More realistic powertrain : - Efficiency different of 1
- 12 V electrical accessories
- Split power between battery and ultracapacitor



GUI Modification Needed

Vehicle Input--PSAT V5.2

File Edit Simulation Compilation PSAT-PRO Build Model Units Help

Select configuration...

Drivetrain Configuration

Drivetrain: Series Fuel Cell Hybrid

Axle configuration: 2 wheel drive

Position 1 Choice: Single reduction

Position 2 Choice:

Transmission:

Parameters Modification

Component: Electrical Accessory

Variables: accelec_pw

Default default value 0

Graphs

Energy Storage

Average Coulombic Efficiency

Plot the selected graph

Vehicle Mass

Total Component Mass: 1948

Mass of fuel: 0

Cargo Mass: 136

Calc. Mass: 2084

Overwrite mass: 2084 Default

Workspace Save Help Back Continue

21 components for only 9 needed

	Version	Type	Initialization Files	Scaling Files	scaling variable	scaling value	mass (kg)
Vehicle	1		veh_1000_20_033_large_car				1000
Fuel Cell	1	fc	fc_50_hydrogen			N/A	80
Engine						N/A	0
Driver	2		drv_cool_200_5				
Exhaust Aftertreat							0
Energy Storage	1	pb	ess_pb_104_150		ess_num_cell	150	750
Motor/Controller	1	id	mc_id_19_B2F1_670			N/A	58
Generator						N/A	0
Power controller	1		pc_095				
Dutch/Torq. Conv.							
Transmission						N/A	0
Torque Coupling	1		tc_08			N/A	10
Final drive	1		fd_31_hl			N/A	10
Wheel/Axle	1		wh_026_PNGV				20
Acc. mechanical							20
Acc. Electrical	1		accelec_0				0
ESS2						N/A	0
Motor/Controller 2						N/A	0
Transmission 2						N/A	0
Transfer case						N/A	0
Starter							0
Torque Coupling 2						N/A	0

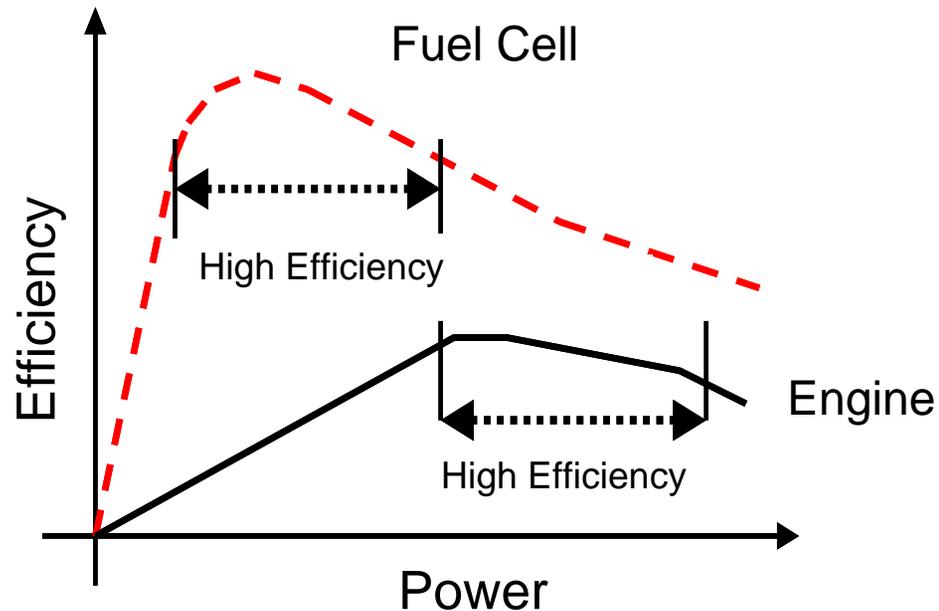
GUI Modification Needed

The screenshot displays the PSAT V5.1 Beta1 software interface. The main window is titled "Vehicle Input - PSAT V5.1 Beta1" and contains a central workspace with a hierarchical diagram of vehicle components. To the right, there are several configuration panels: "Drivetrain Configuration" with dropdowns for Drivetrain (Series Fuel Cell Hybrs), Axle configuration (2 wheel drive), Position 1 Choice (Single reduction), Position 2 Choice, Transmission, and Energy storages (2); "MC_options" with checkboxes for Power Converter (mc) and Torque coupling (mc); "Parameters Modification" with dropdowns for Component (Electrical Accessory) and Variables (acceler_per); "Graphs" with a dropdown for Energy Storage and Average Coulombic Efficiency; and "Vehicle Mass" with input fields for Total Component Mass (1142), Mass of fuel (0), Cargo Mass (136), Calc. Mass (1276.1), and Override mass (1360). At the bottom right, there is a "Workspace" section with buttons for Save, Help, Back, and Continue.

Component	Version	Type	Initialization file	Scaling file	Scaling variables	value	Mass (kg)
Driver	2		drv_ultracap_h4				0
Energy Storage	1	pb	ess_pb_12_150		ess_run_cell	55	43.3
Power Converter 4	1		pc_1_350				
Motor Controller	1	pm	mc_pm_init4	mc_s	mc_eff_max_des	0.94	102.5
Fuel Cell	1	fc	fc_50_hydrogen	fc_hyd_s	fc_eff_max_des	0.5952	11.2
Power Converter 2	2		pc_037				30
Torque Coupling	1		tc_1	tc_s	tc_eff_max_des	1	10
Final Drive	1		fd_454_init4	fd_s	fd_eff_max_des	0.9	0
Wheel/Gate	1		wg_020				20
Vehicle	1		veh_600_172_030_civic				800
Energy Storage2	5	ul	ess_ultracap		ess2_run_cell	29	0.8
Power Converter 3	2		pc_1				
Power Controller	1		pc_1_12				
Acc Electrical	1		acceler_600				0

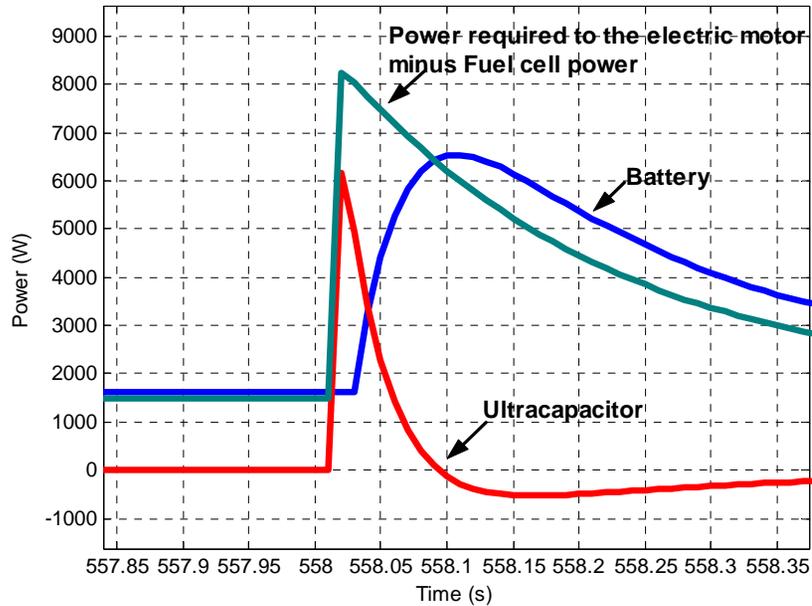


Fuel Cell Used as the Primary Energy Source



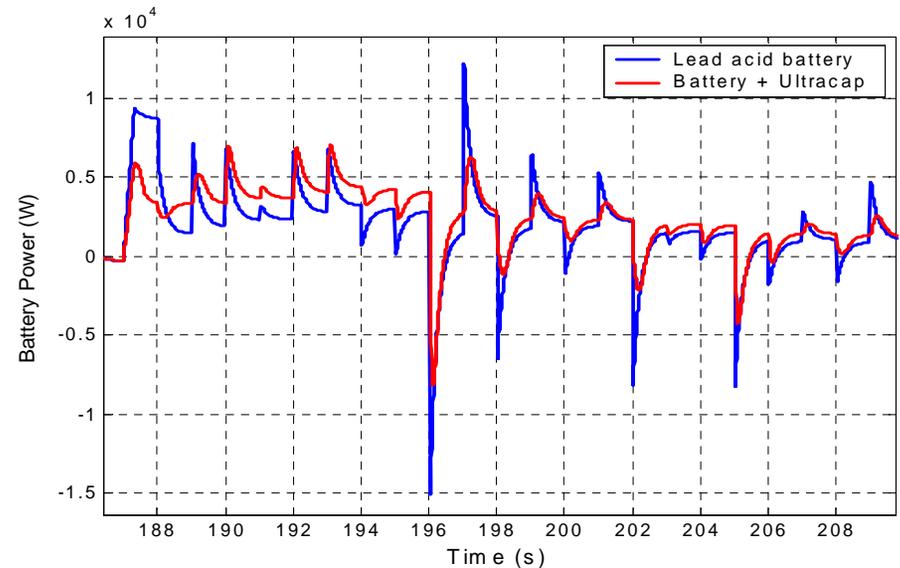
- Energy Storage
 - Store energy during deceleration events
 - Help propulsion during low power demand phases as well as high transients

Ultracapacitors Help Smooth Battery Power

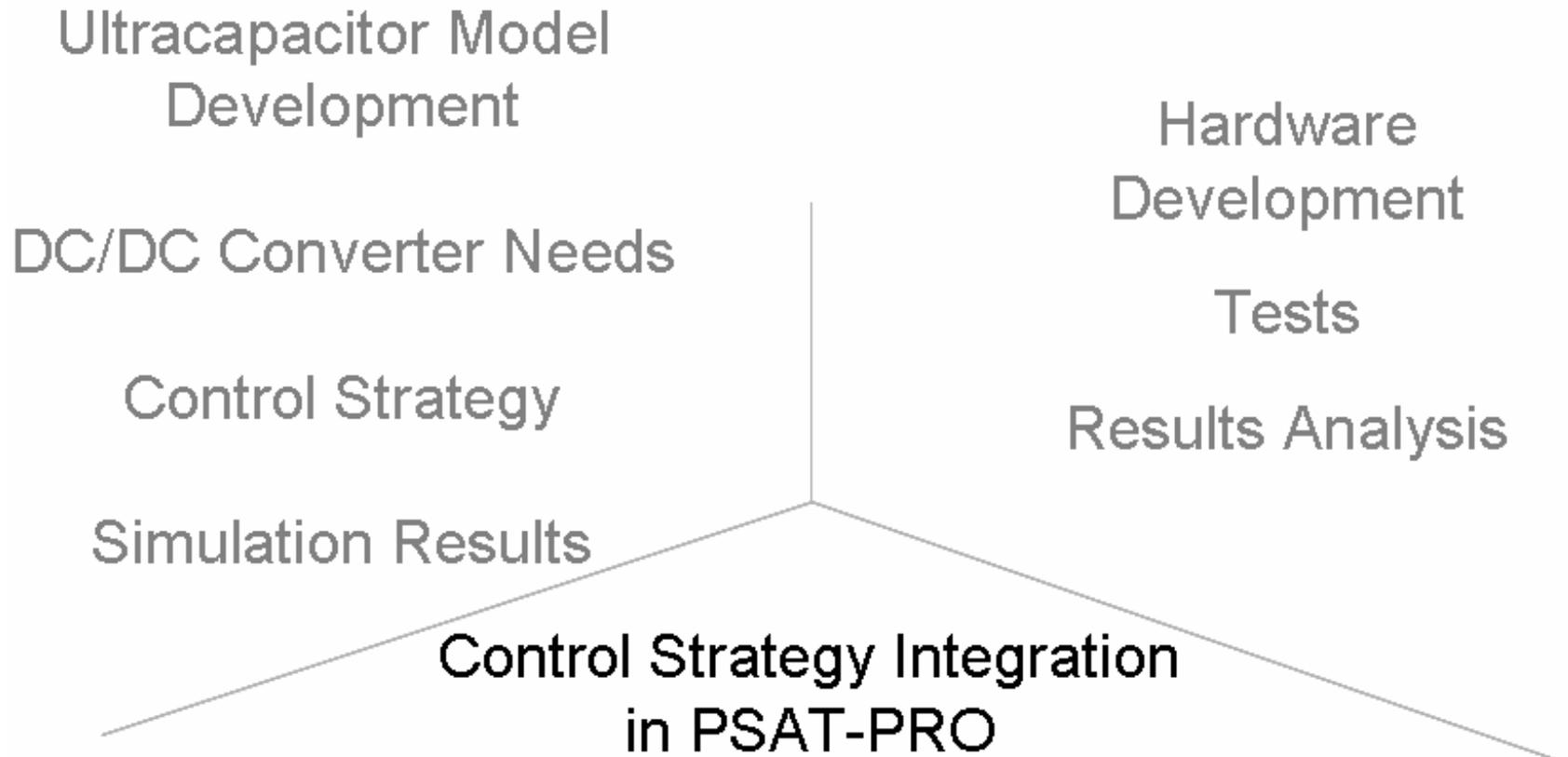


Ultracapacitors help reduce battery spikes

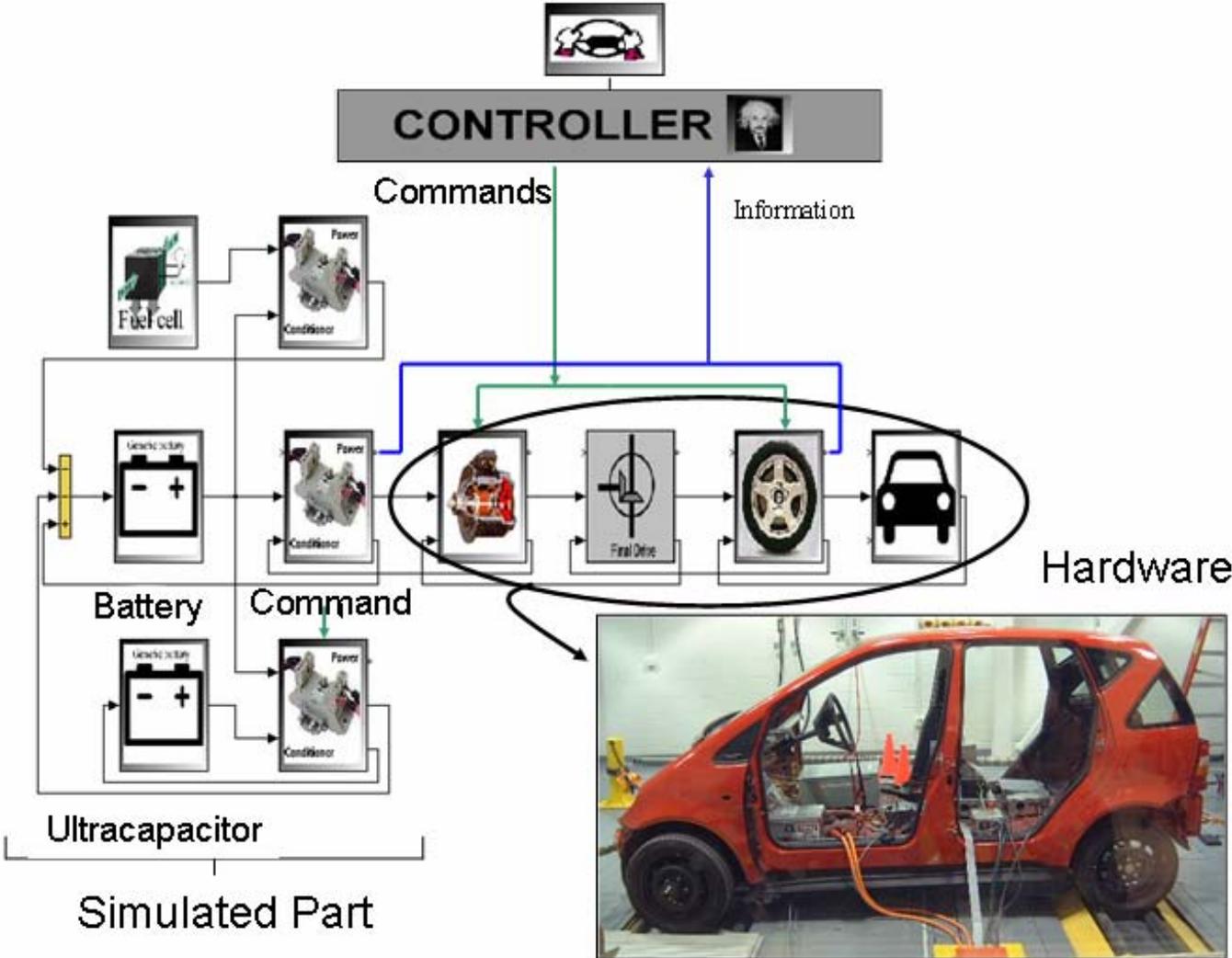
Ultracapacitors help during high transients.



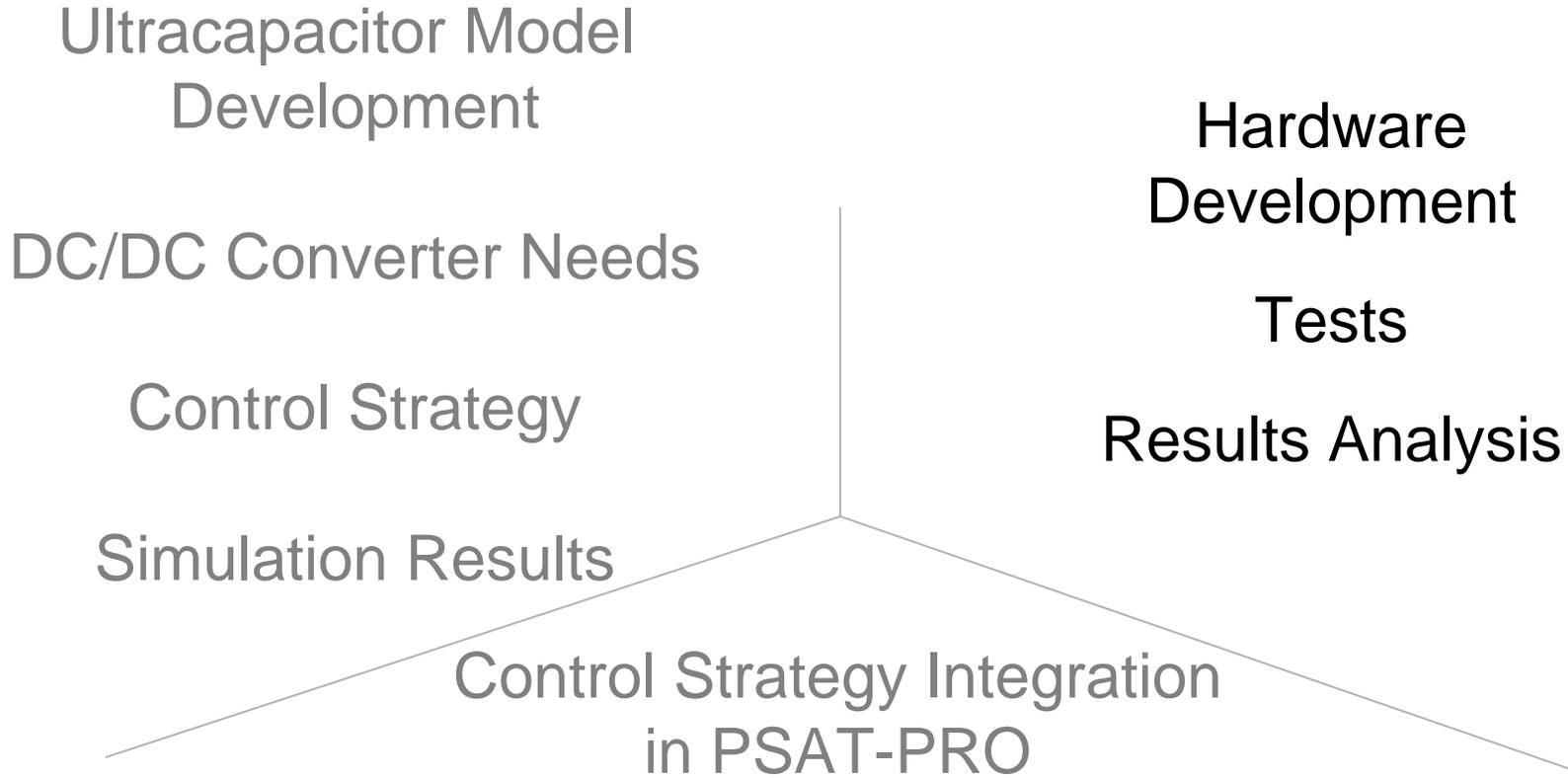
From Modeling to HIL



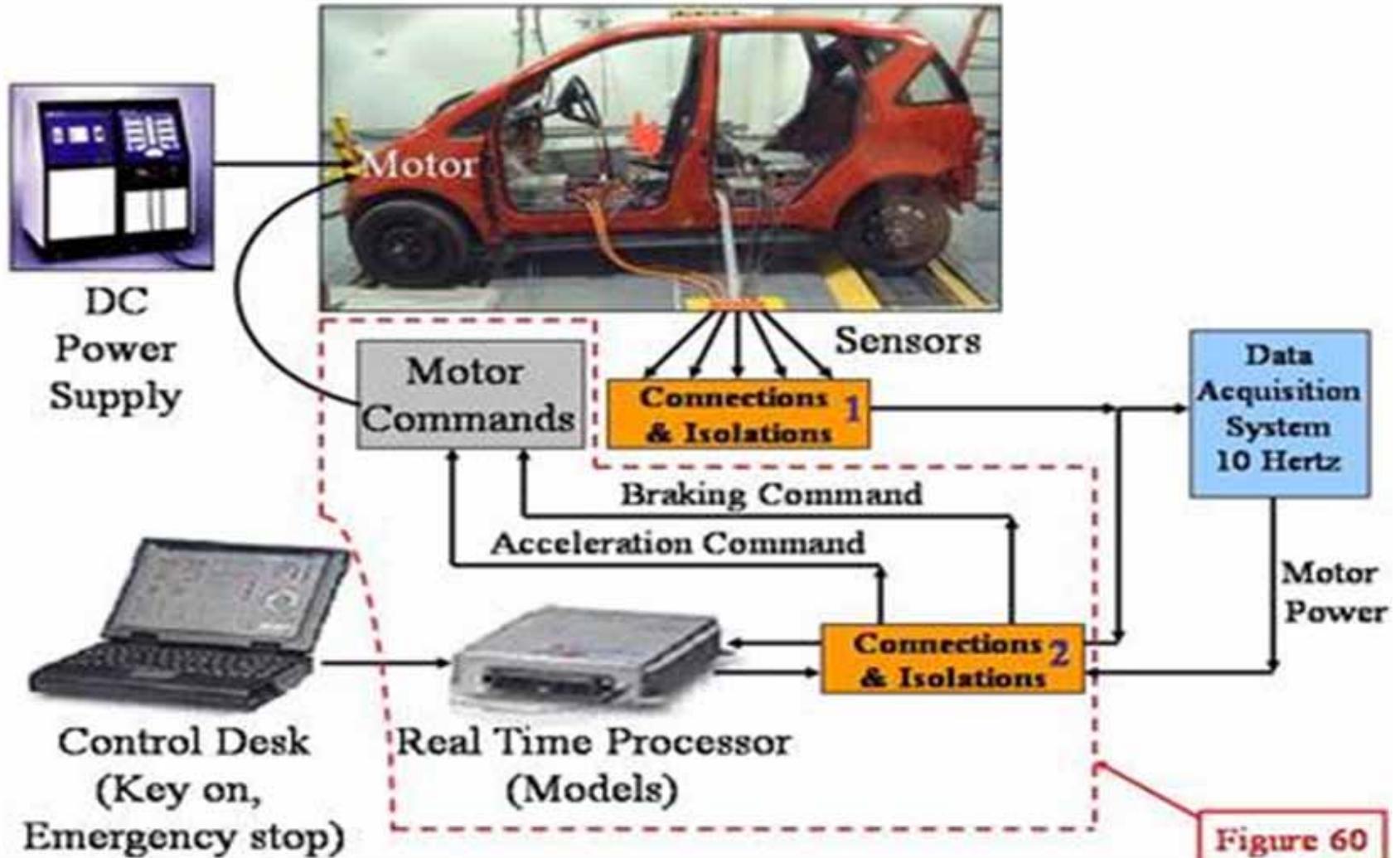
Hardware in the Loop (HIL)



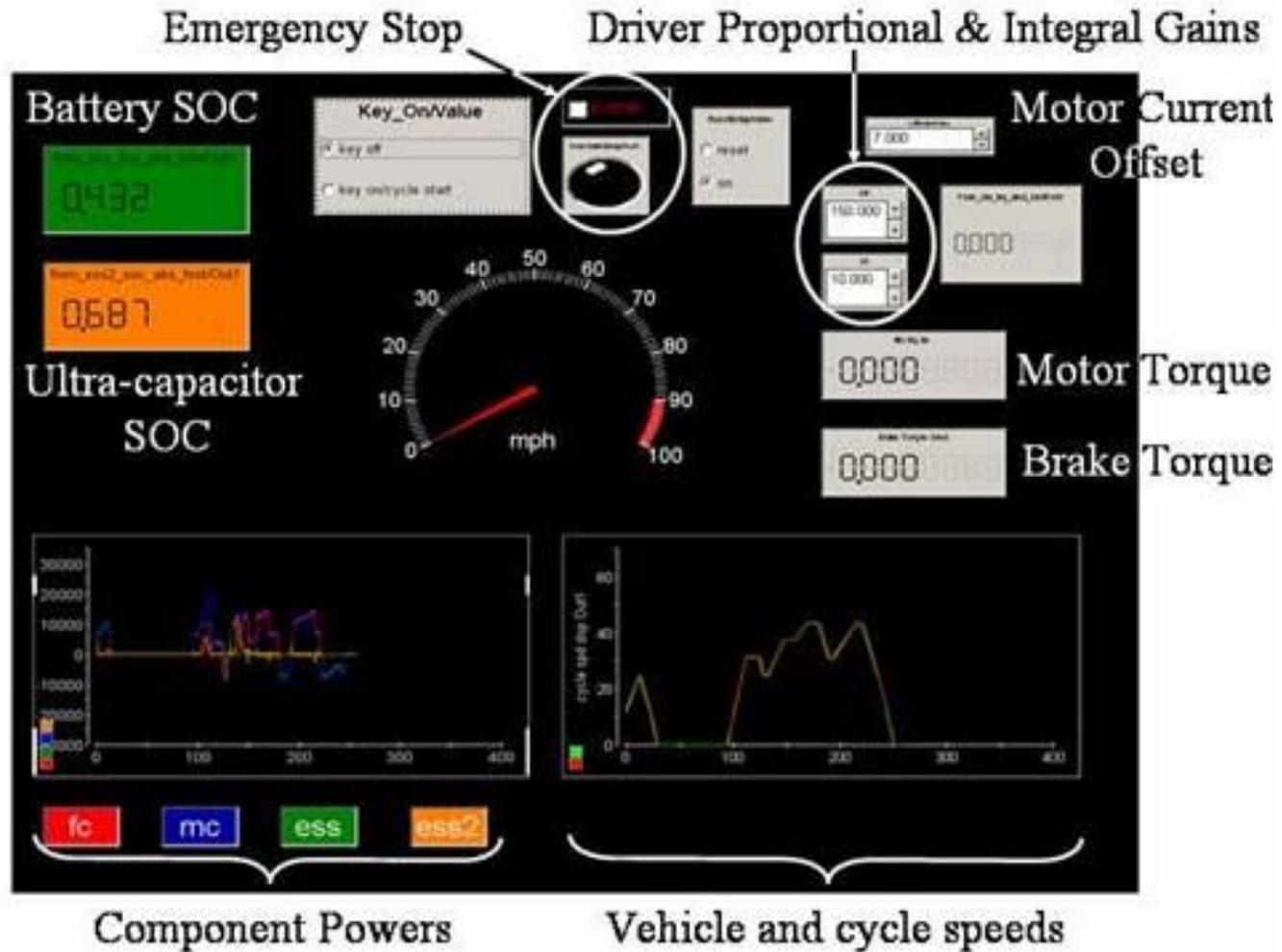
From Modeling to HIL



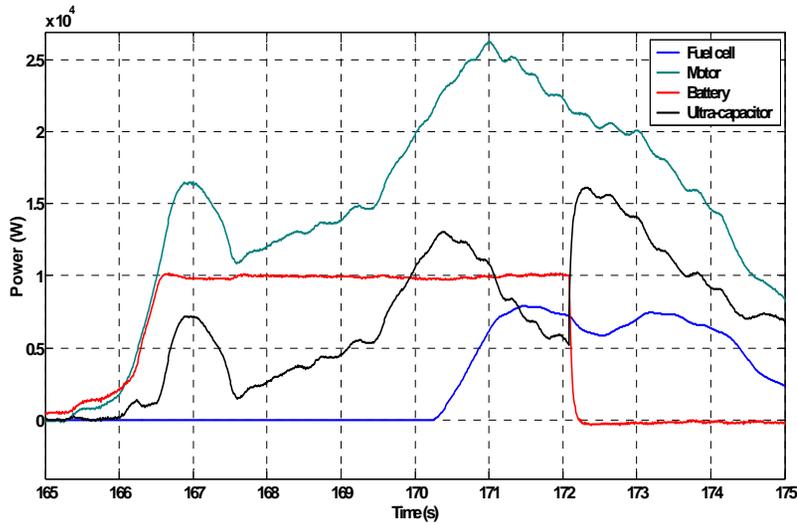
Hardware & Software Connections



Control Desk Interface



Test Results



Low SOC Battery:

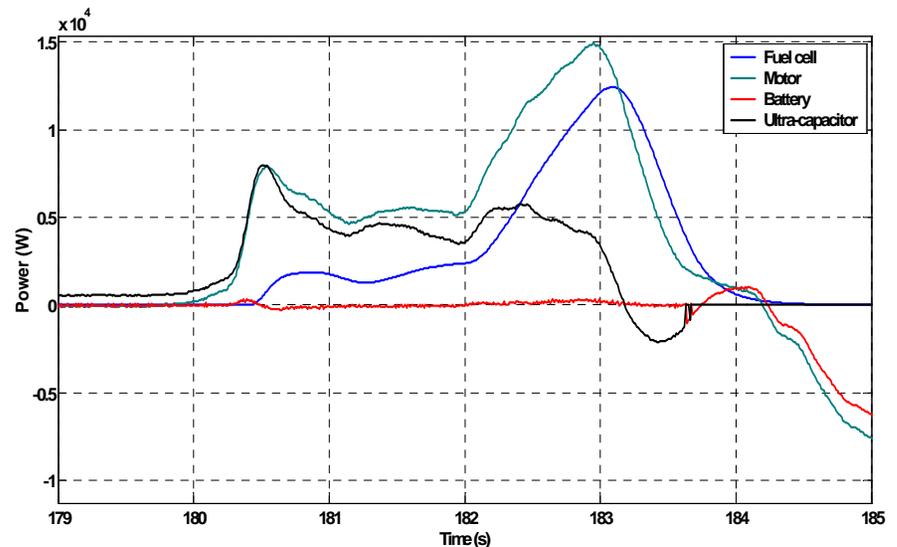
During acceleration, ultracapacitors provide what the fuel cell can't

During deceleration, the battery is charged

High SOC Battery:

Provides maximum power (10 kW),

Ultracapacitor provides or absorbs transients power



Conclusion

- **Dual energy storage configurations have been integrated into PSAT including**
 - Component models
 - DC/DC models
 - Control strategies
- **DOE report has been completed**