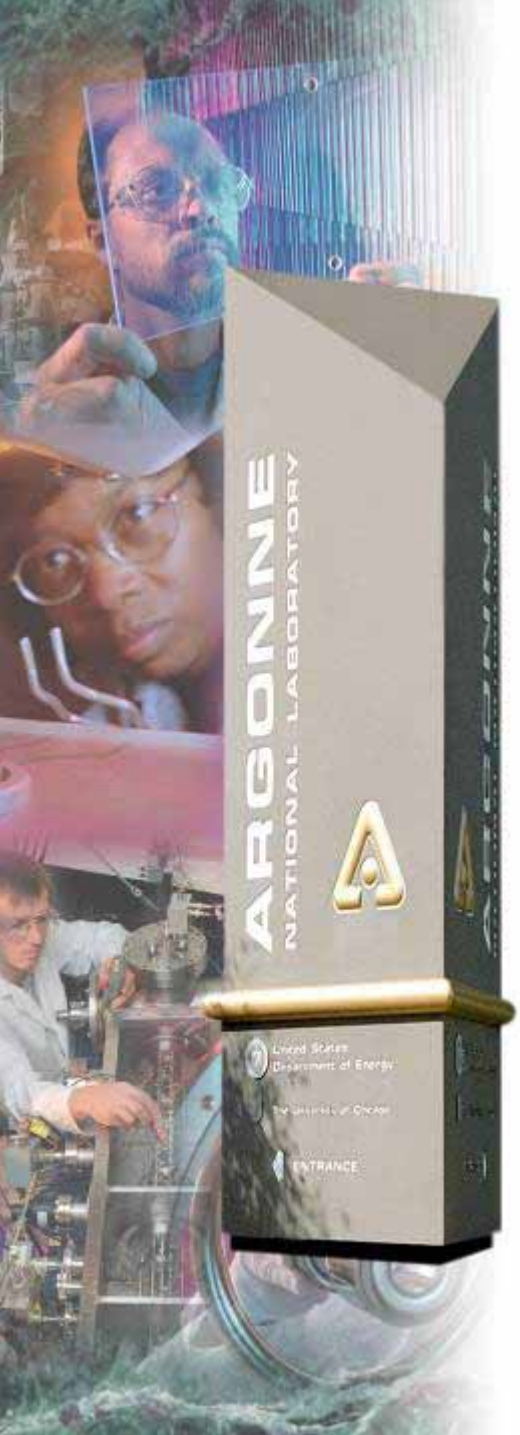

Dual Source Energy Storage Potential for Fuel Cell Vehicle Applications

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Office of Science
U.S. Department of Energy

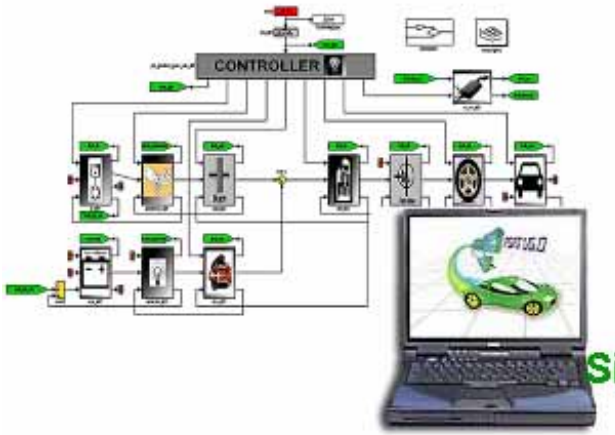
Lead Acid Best Fits with Ultracapacitor

Battery

Ultra-capacitor

	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	-30 to 80
Number of cycles	~300	~1500	~1500	~500000

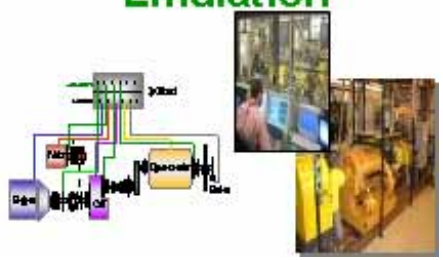
Modeling, Test and Validation Are Integrated



Simulation

Validation

Emulation



From Modeling to HIL

Ultracapacitor Model Development

DC/DC Converter Needs

Control Strategy

Simulation Results

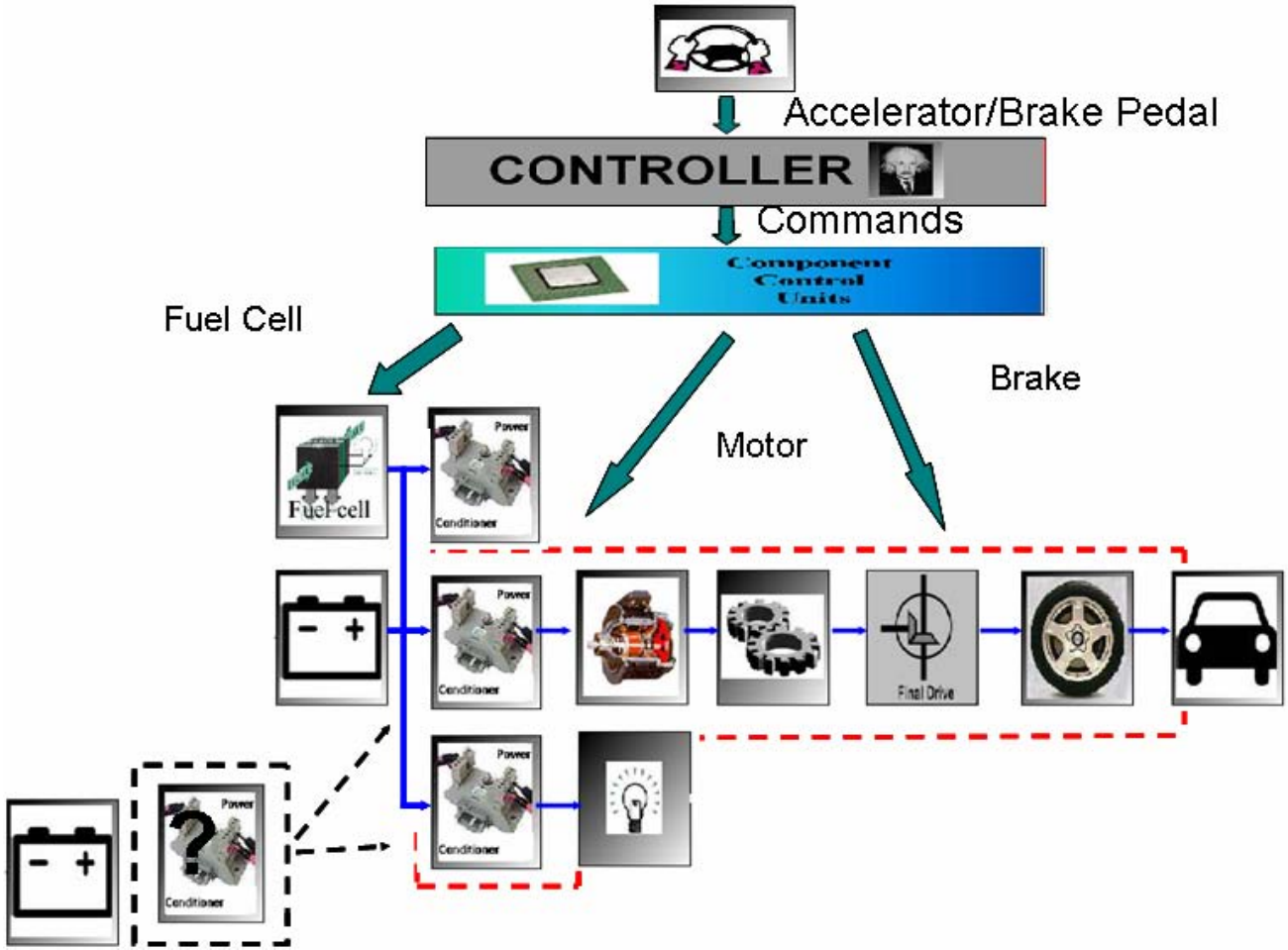
Hardware Development

Tests

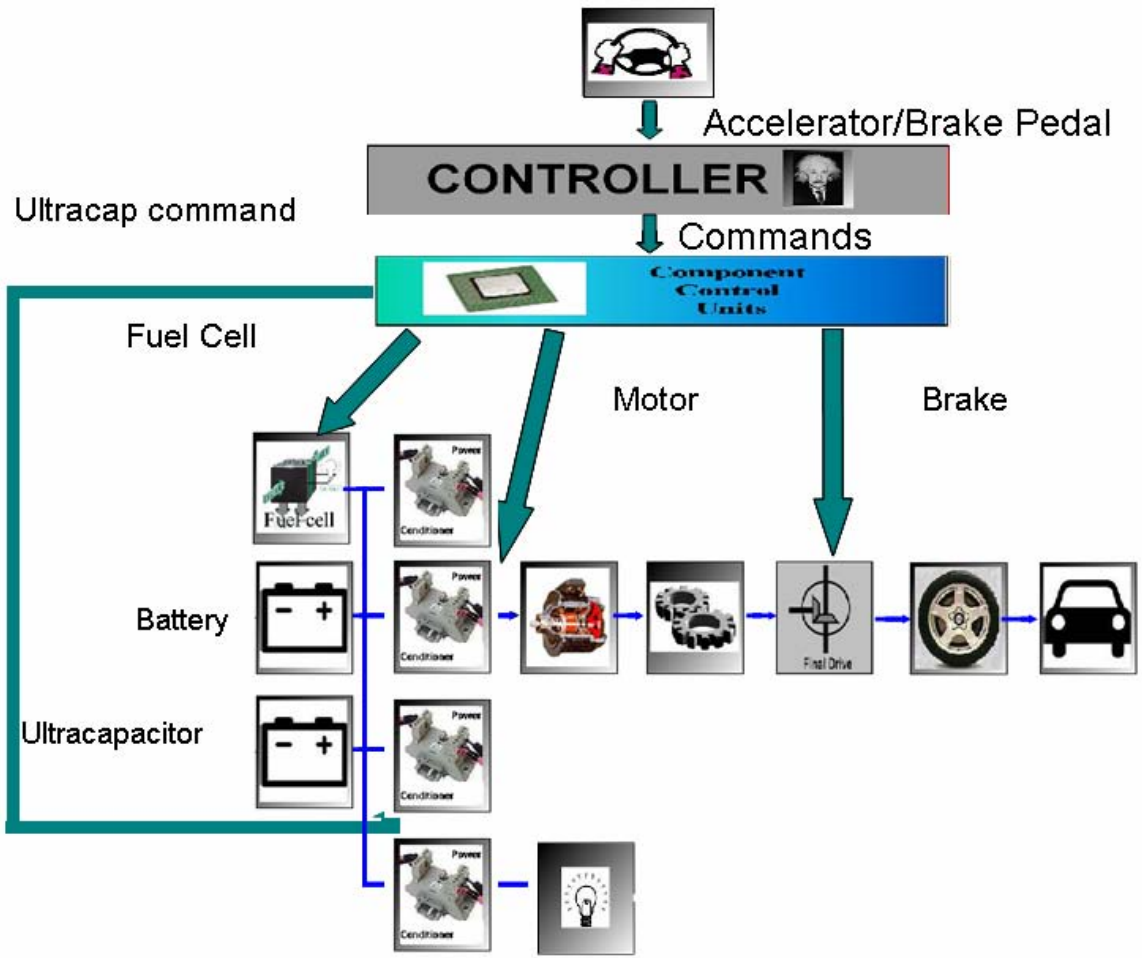
Results Analysis

Control Strategy Integration in PSAT-PRO

More Realistic Powertrain

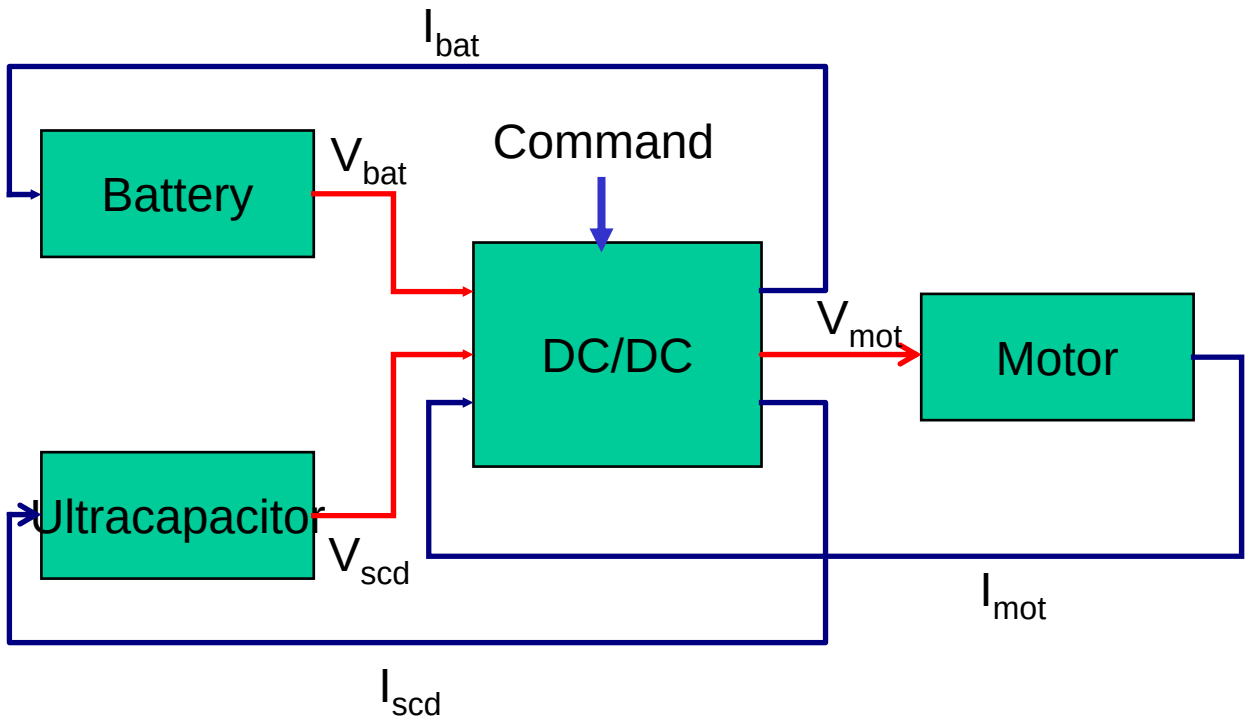


Two Energy Storage Systems Combined

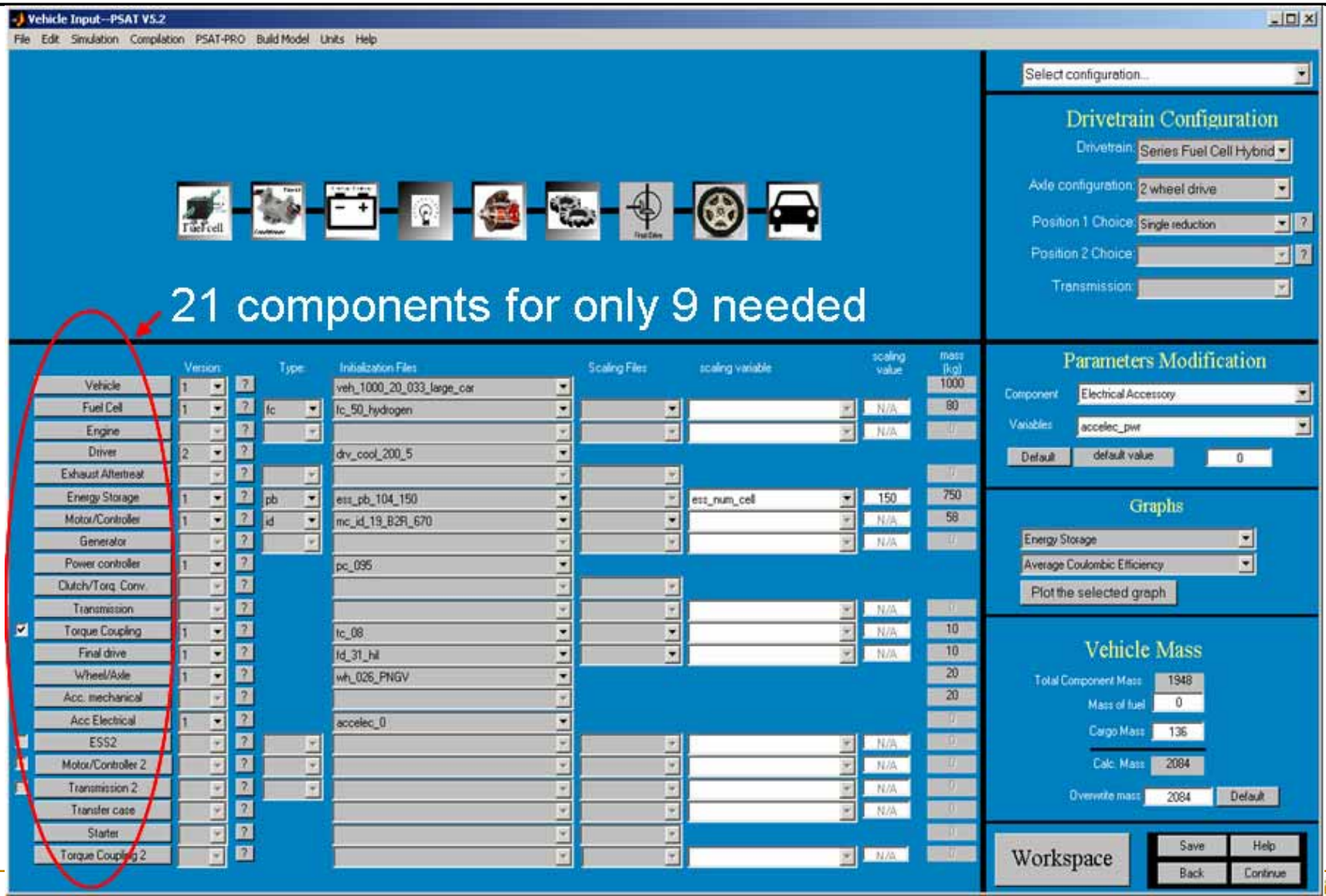


DC/DC Model

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

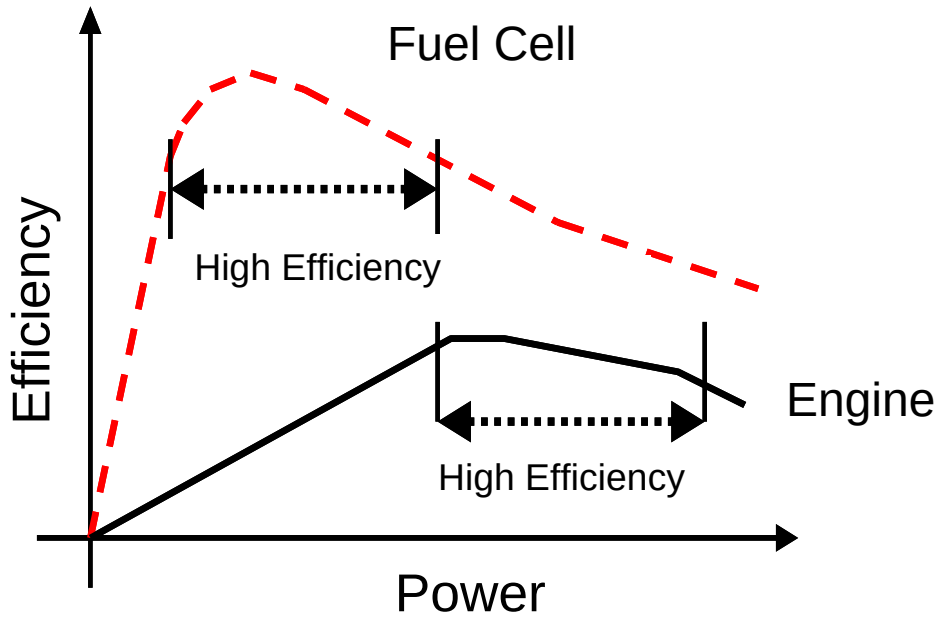


GUI Modification Needed



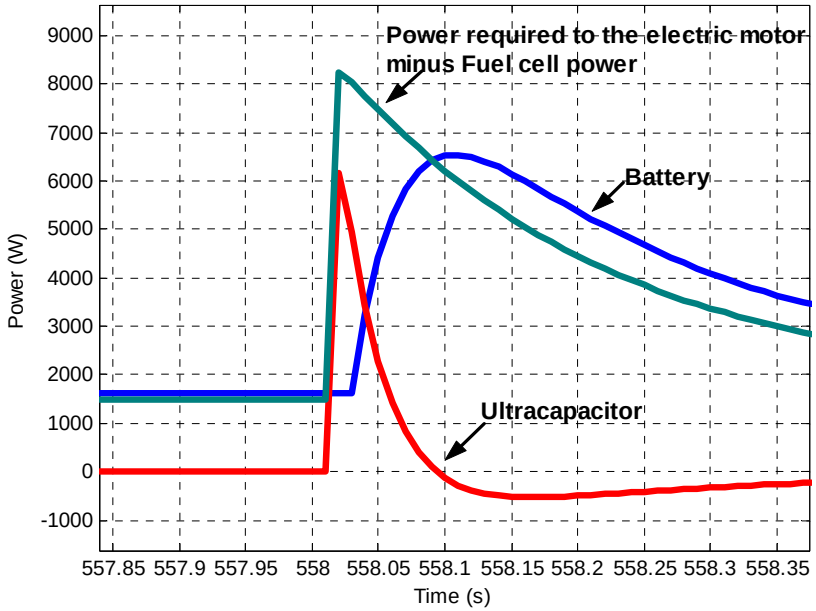
GUI Modification Needed

Fuel Cell Used as the Primary Energy Source



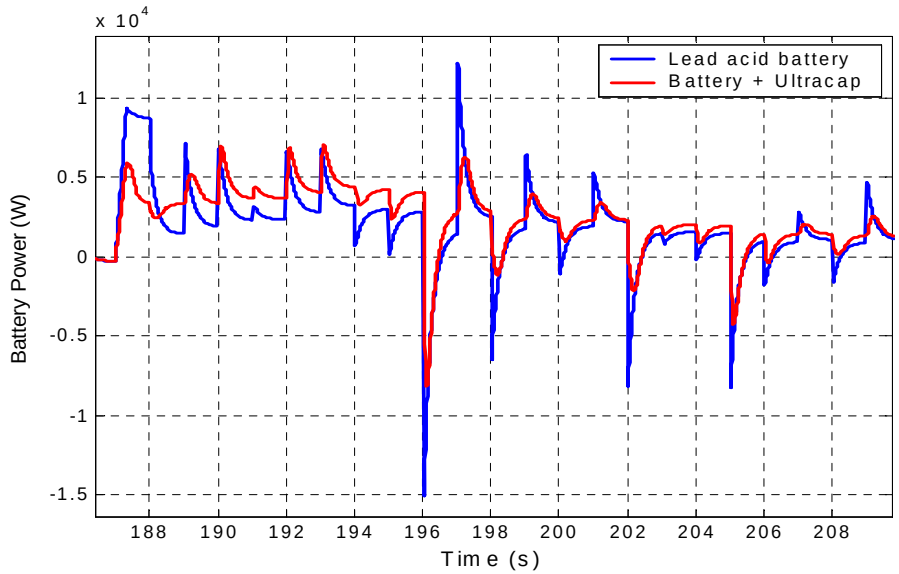
- Energy Storage
  - Store energy during deceleration events
  - Help propulsion during low power demand phases as well as high transients

Ultracapacitors Help Smooth Battery Power

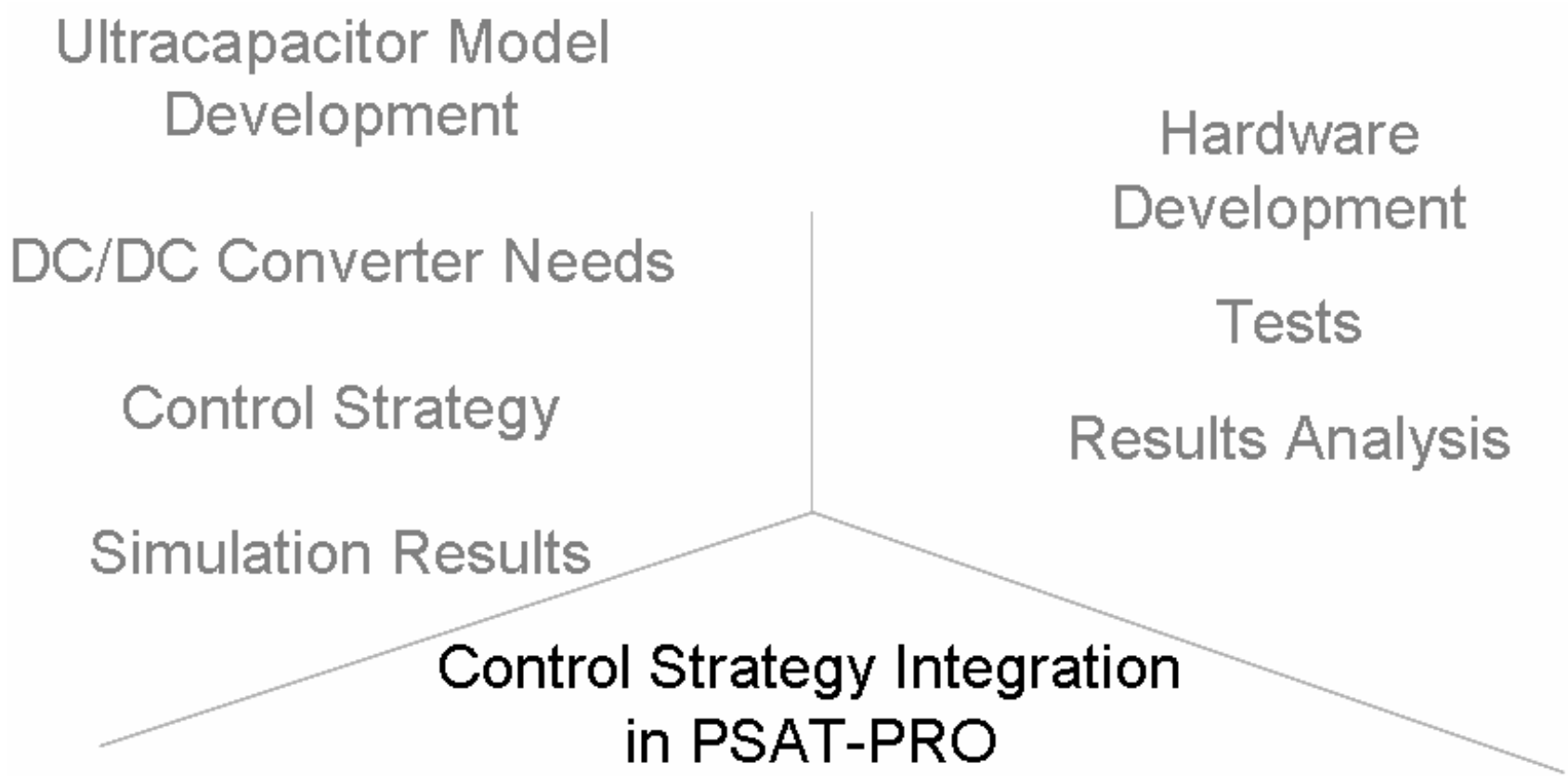


Ultracapacitors help reduce battery spikes

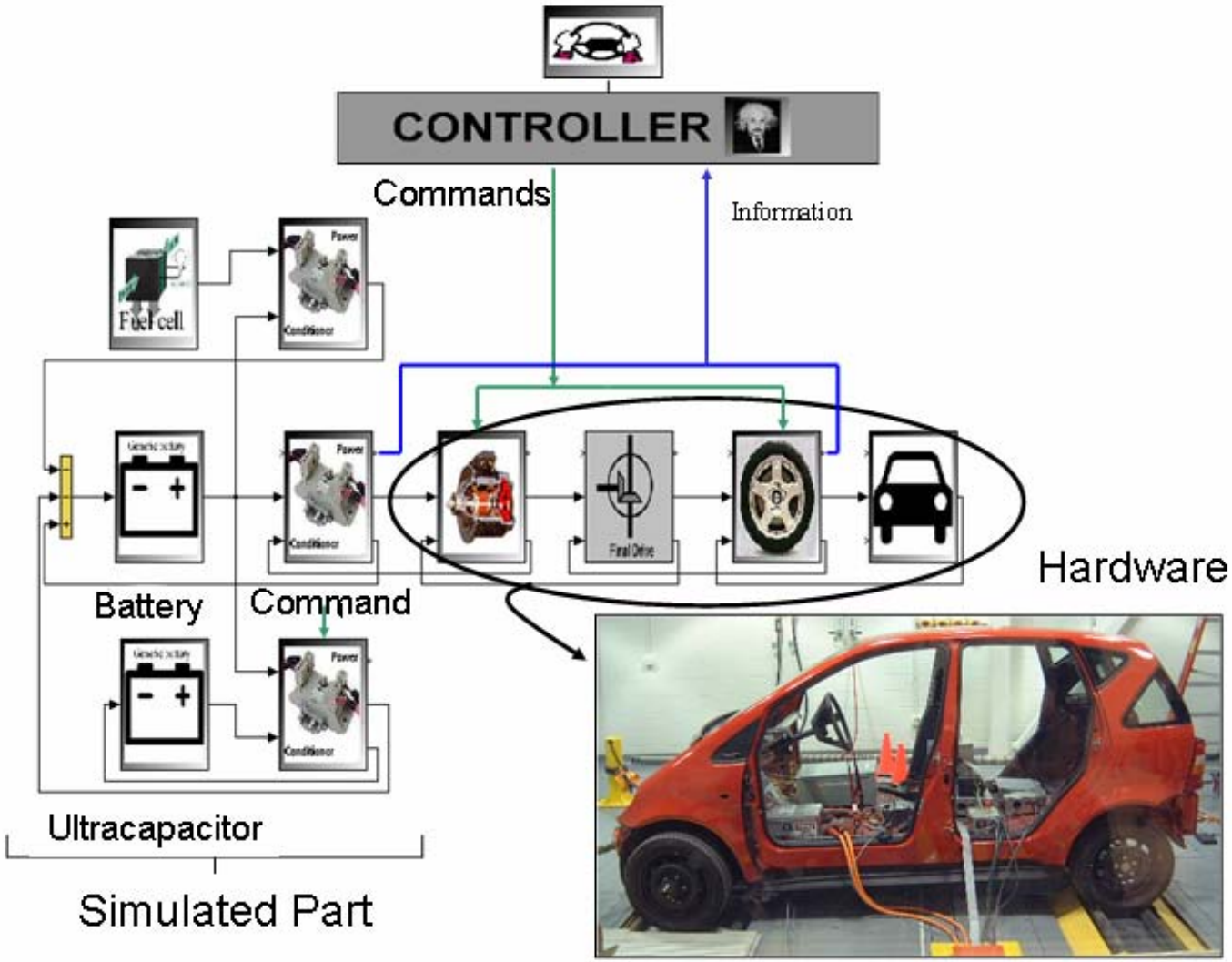
Ultracapacitors help during high transients.



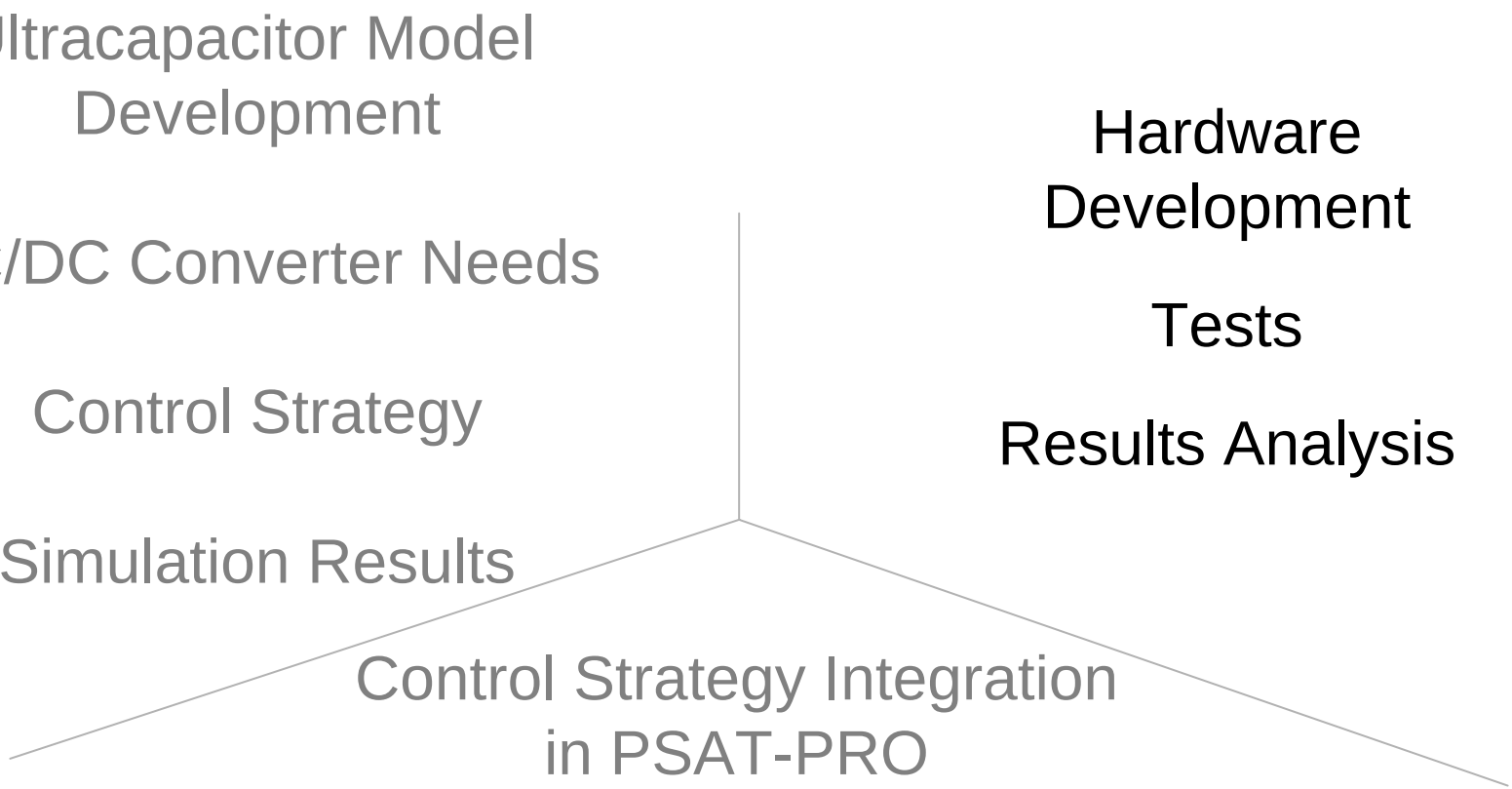
From Modeling to HIL



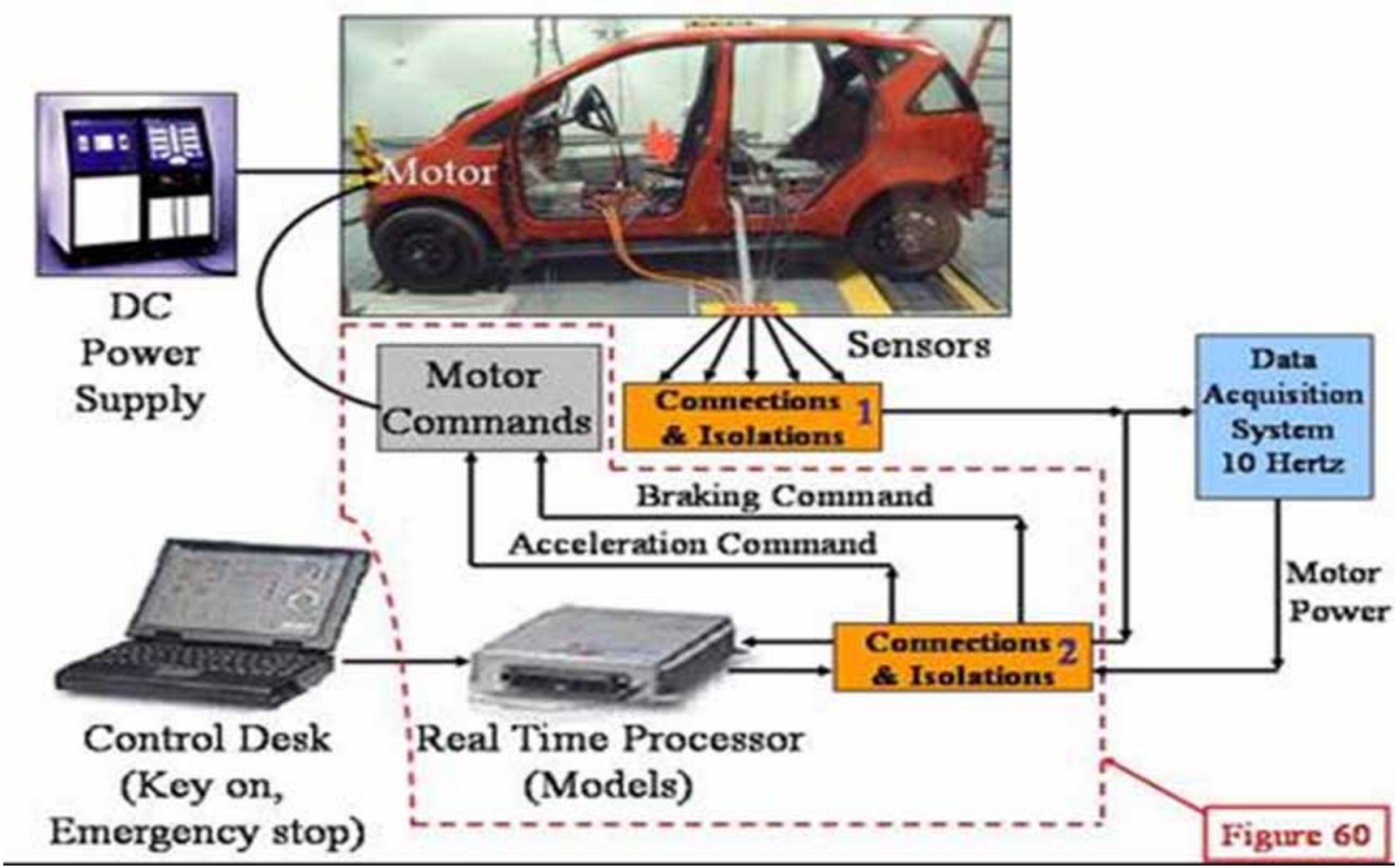
Hardware in the Loop (HIL)



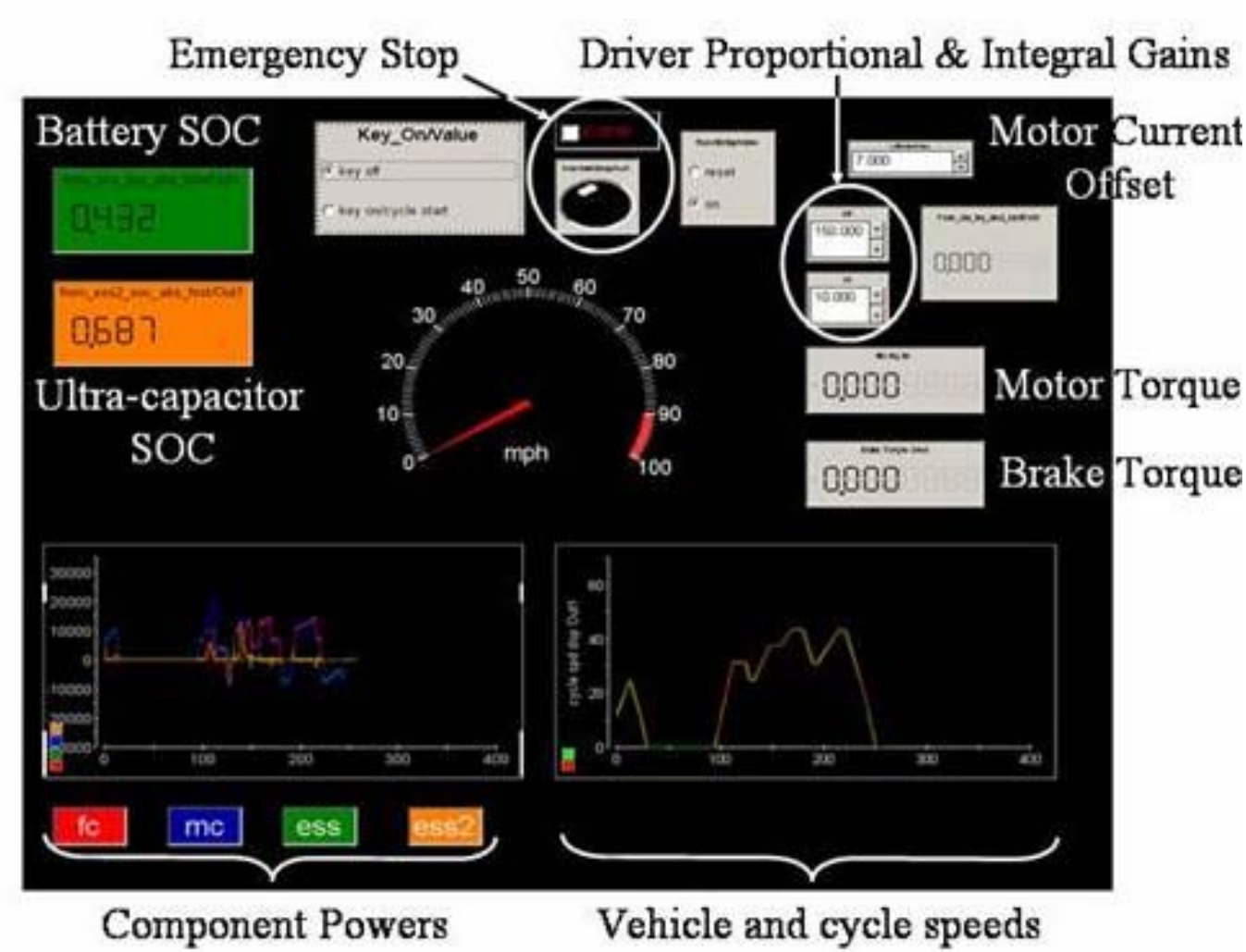
From Modeling to HIL



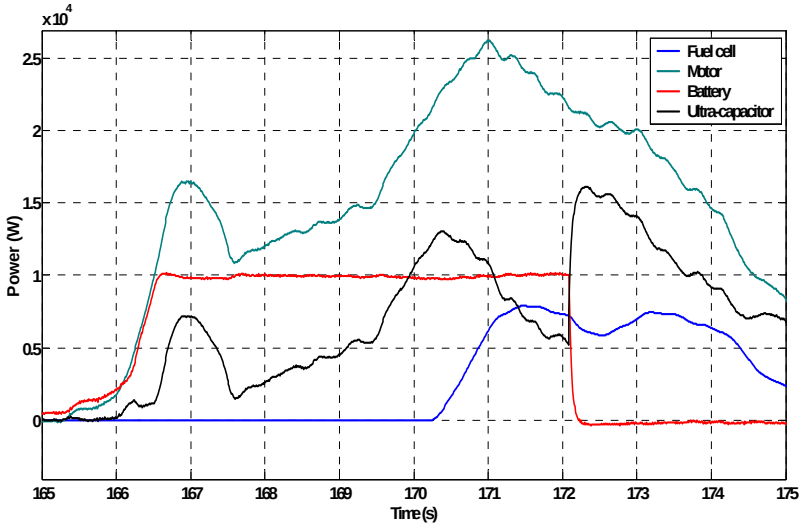
Hardware & Software Connections



Control Desk Interface



Test Results



Low SOC Battery:

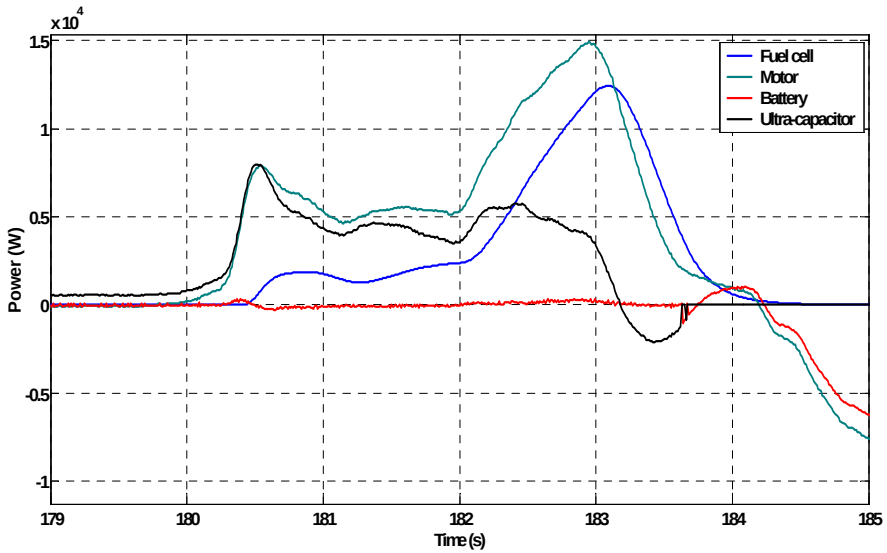
During acceleration, ultracapacitors provide
what the fuel cell can't

During deceleration, the battery is charged

High SOC Battery:

Provides maximum power (10 kW),

Ultracapacitor provides or absorb 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**