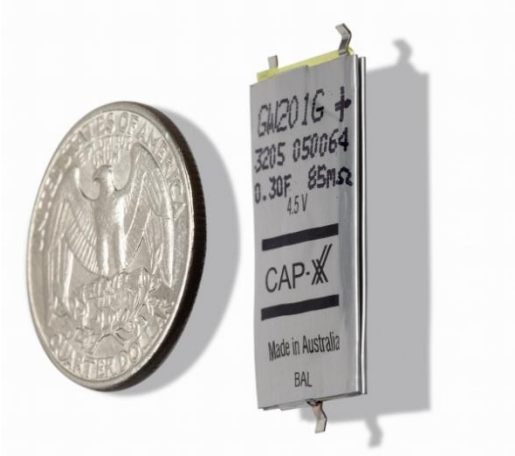
CAP-XX



Supercapacitors for Automotive & Other Vehicle Applications

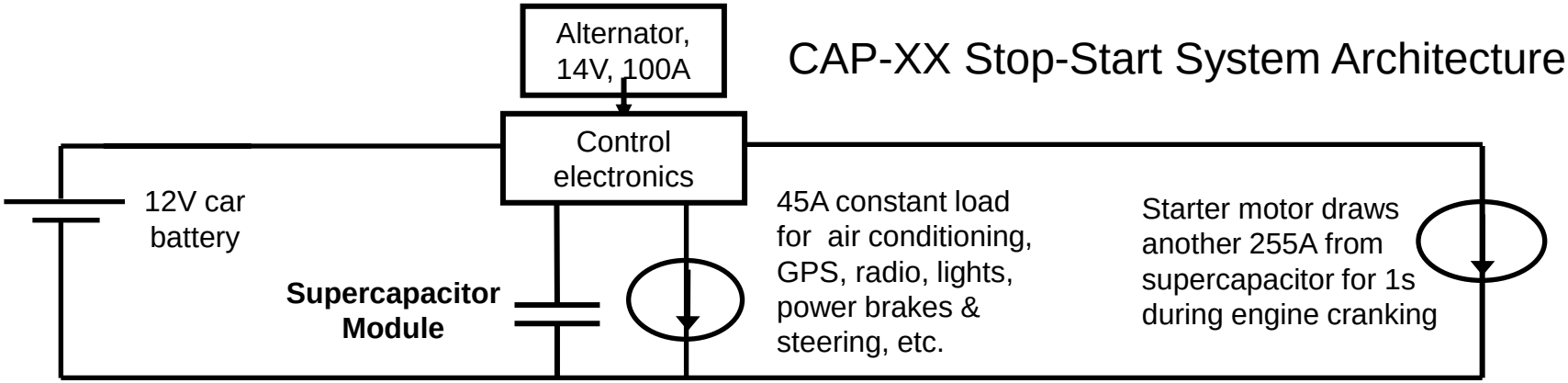
March 2012

Automotive applications for Supercapacitors

- Auto batteries have limitations in terms of life, power delivery and environmental range
- Supercapacitors resolve the limitations of Lead-Acid & Lithium-ion batteries, delivering far superior electrical performance in applications such as:
  - ✓ Warm cranking for fuel efficient Stop-Start systems
  - ✓ Cold cranking support to extend battery life
  - ✓ Regenerative energy capture during braking/coasting
  - ✓ Distributed power systems to reduce wiring loom size/weight/cost
  - ✓ Drive-train support in Hybrid Electric and Electric Vehicles
  - ✓ Drive train support in Fuel Cell/Hydrogen-powered Vehicles
  - ✓ Drive train support in Electric Buses, Trucks, Bikes, etc.

Everybody is talking about HEV and EV, but the largest and closest opportunity is in Stop-Start Systems

Market #1: Stop-Start Systems



CAP-XX Stop-Start System Architecture

- Stop-Start systems deliver 5-15+% savings in fuel and vehicle emissions…
  …but require the engine to be started many more times over it's life
- Batteries can't deliver the 300A+ to start the engine this frequently…
  … or start it at all in very low temperatures
- A supercapacitor module can resolve these problems – starting the engine 100s of times more frequently, even a low temperatures, extending battery life
- The cost of a 14V, 6 cell supercapacitor module would be ~US$60
- Testing is ongoing and suggests greatly improved life for lead-acid batteries

Batteries alone cannot satisfy the requirements of Stop-Start

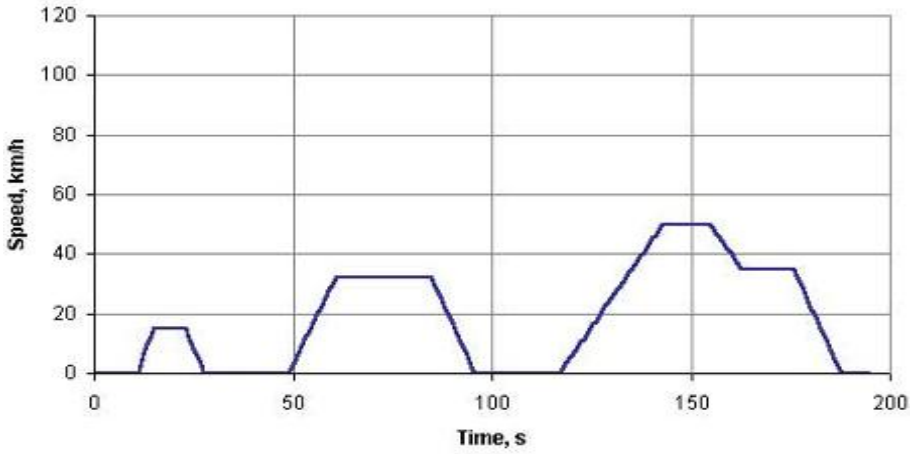
Stop-Start Test Results

- CAP-XX Stop-Start test lab is running 2 different test cycles
- In both tests, effective battery life is defined as battery voltage falling below 10V during a start cycle (at this voltage, the operation of on-board electrical and electronic systems will be compromised)

1. **New European Drive Cycle (NEDC) at 23ºC:**
   - Stop-Start supercapacitor module is about the size of 6 DVD cases, and is rated at 150F at 14V, with an ESR of 4.5mΩ
   - **Battery alone - Failed after 44,000 starts**
   - **Battery + Supercapacitor – Ran for 120,000 starts**
   - The minimum battery voltage for the Battery + Supercapacitor test rig remained well above 10V during starting for more than 110,000 starts, and was only 400mV lower than when the test commenced
2. **Mazda Battery Charge Acceptance Test at 23ºC:**
   - **Battery alone - Failed after 981 starts**
   - **Battery + Supercapacitor - Ran for 9,553 starts**

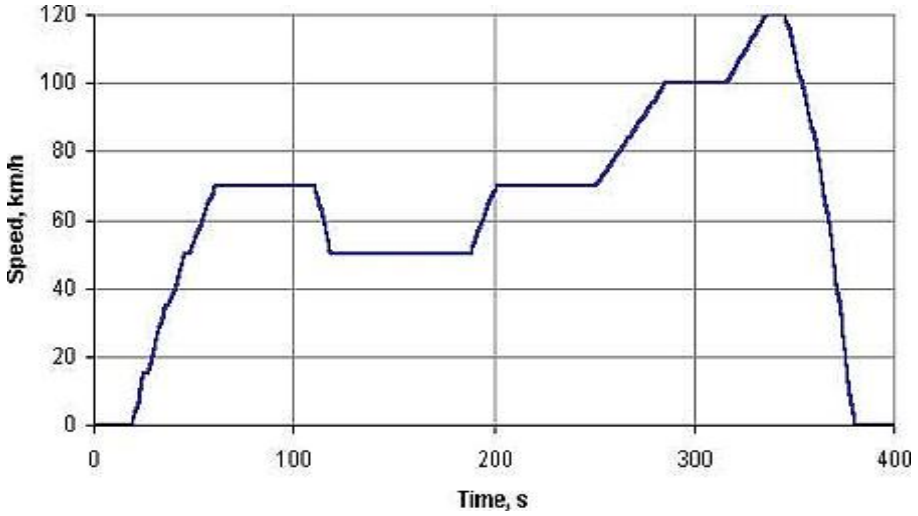
New European Drive Cycle: A Standard Automotive Test

Repeat this urban cycle 4 times ...

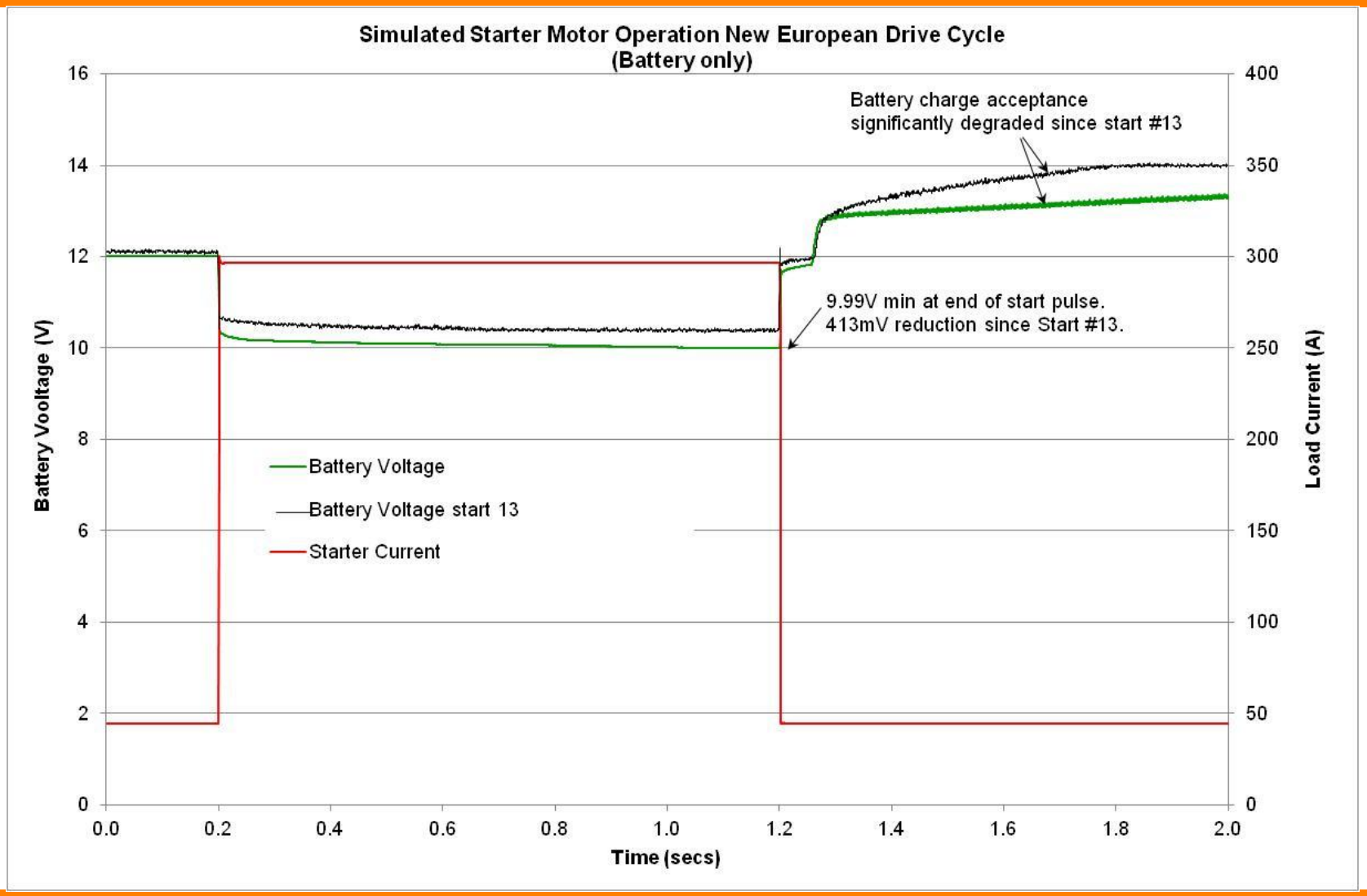


... then do this highway cycle once.

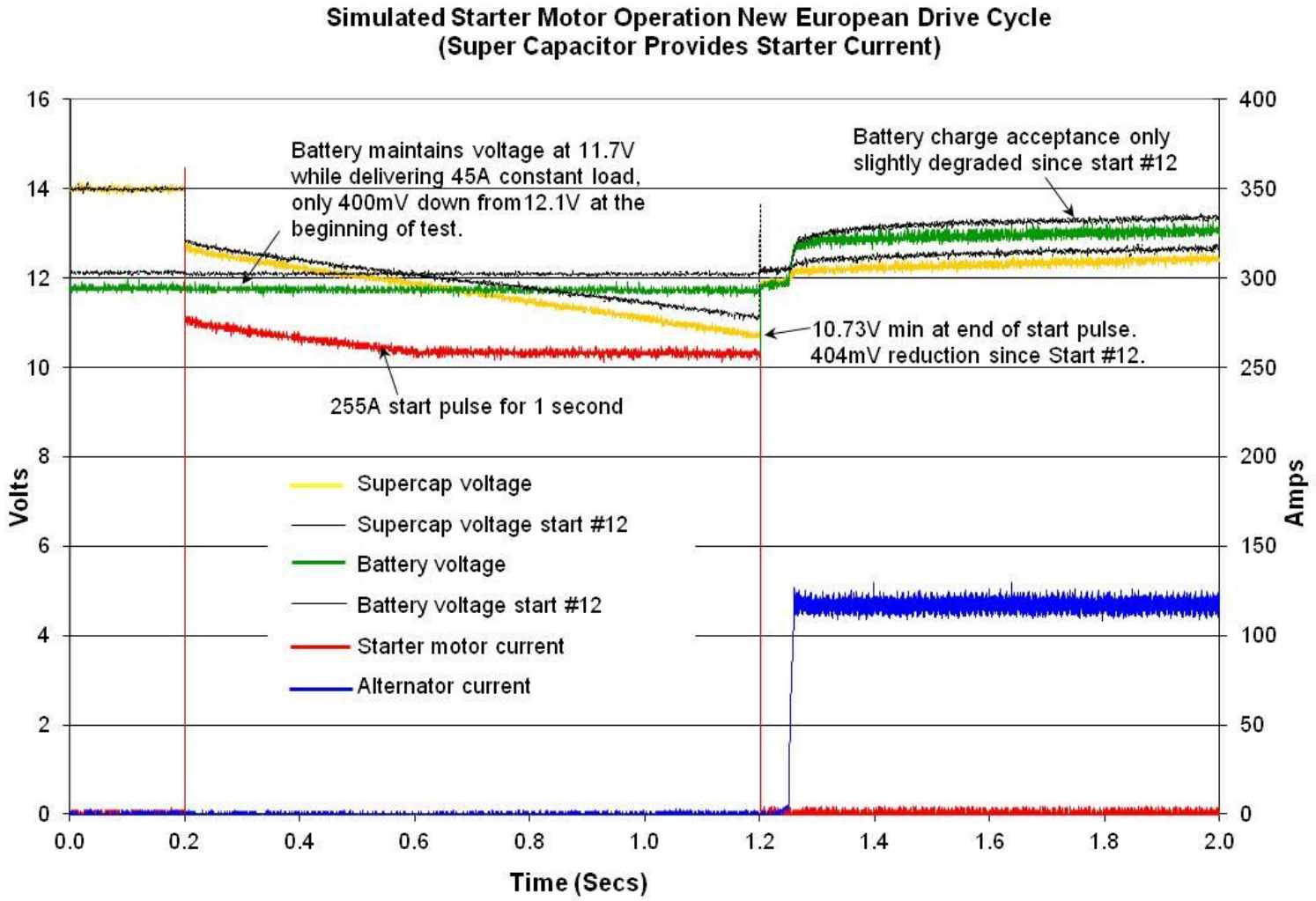
Repeat until battery voltage <7.2V (total failure) or <10V (functional failure)



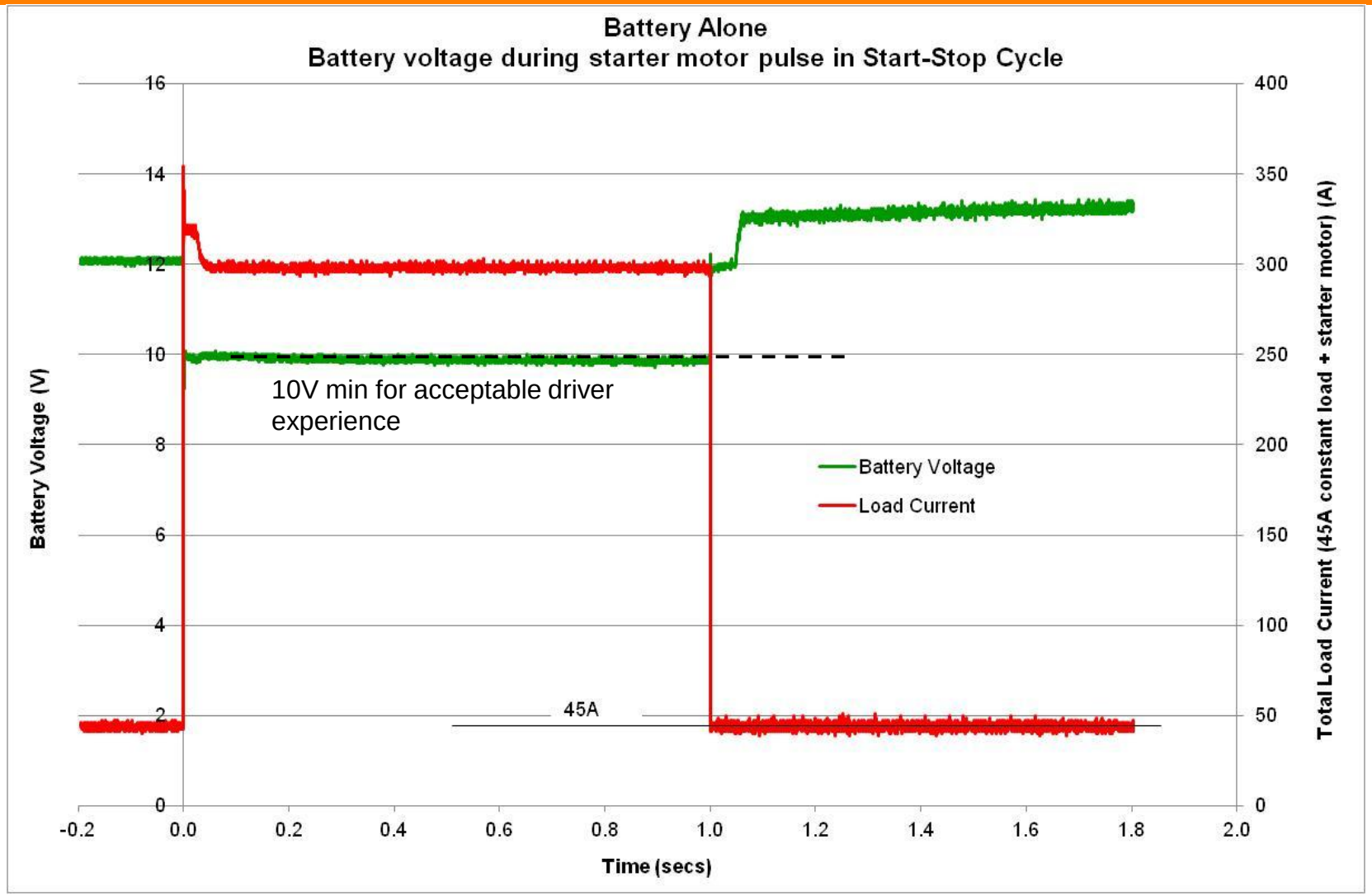
New European Drive Cycle: Battery alone; 44,000 starts



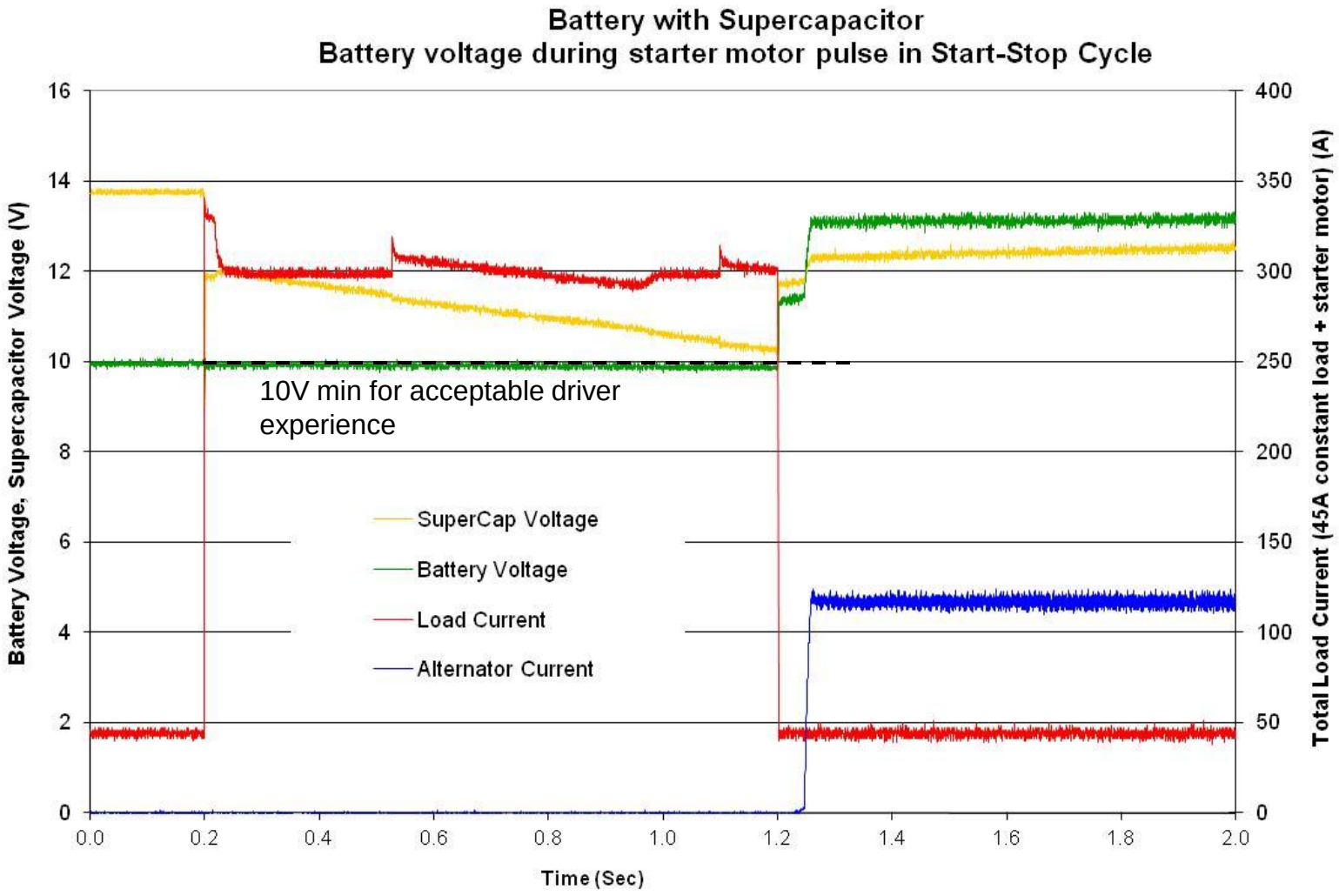
New European Drive Cycle: Battery + Supercapacitor; 110,000 starts



Mazda drive cycle: Battery alone; 981 starts



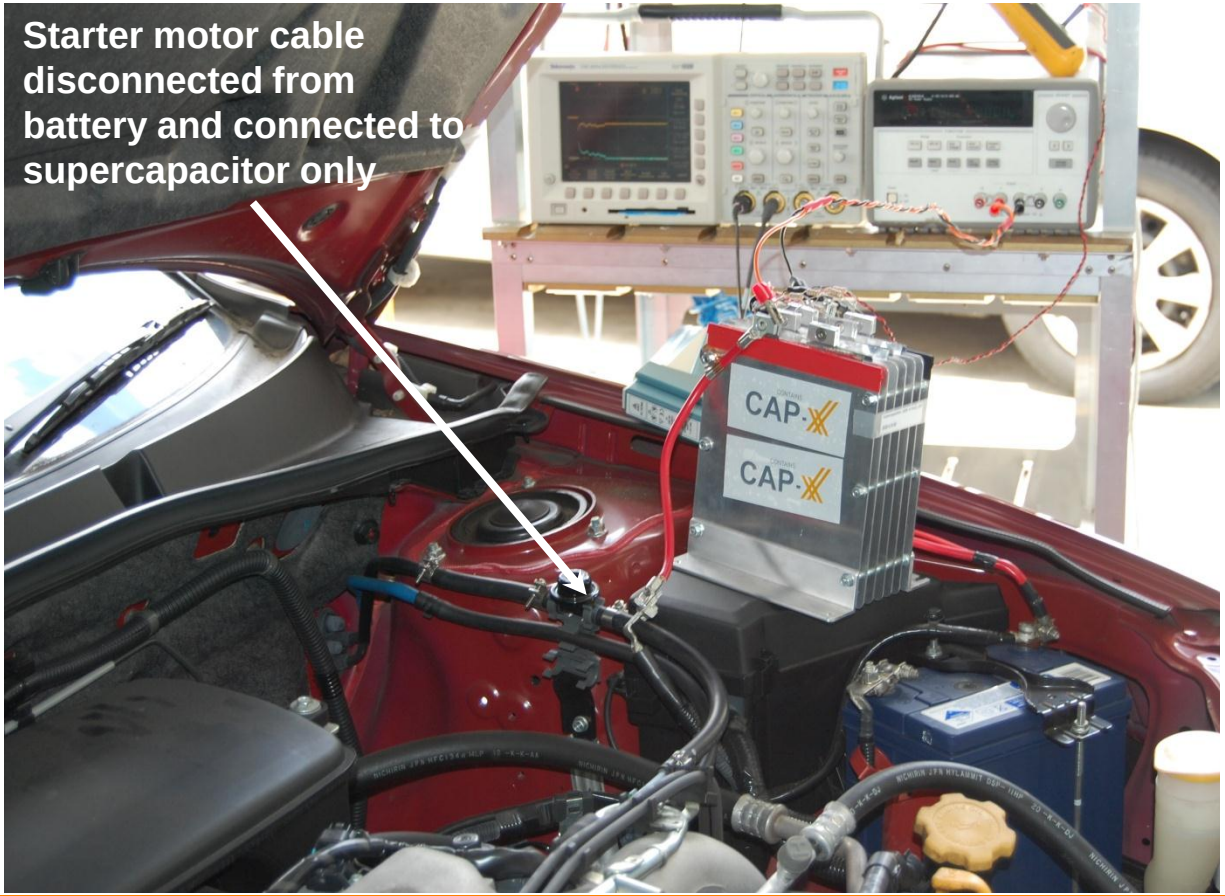
Mazda drive cycle: Battery + Supercapacitor; 9,553 starts



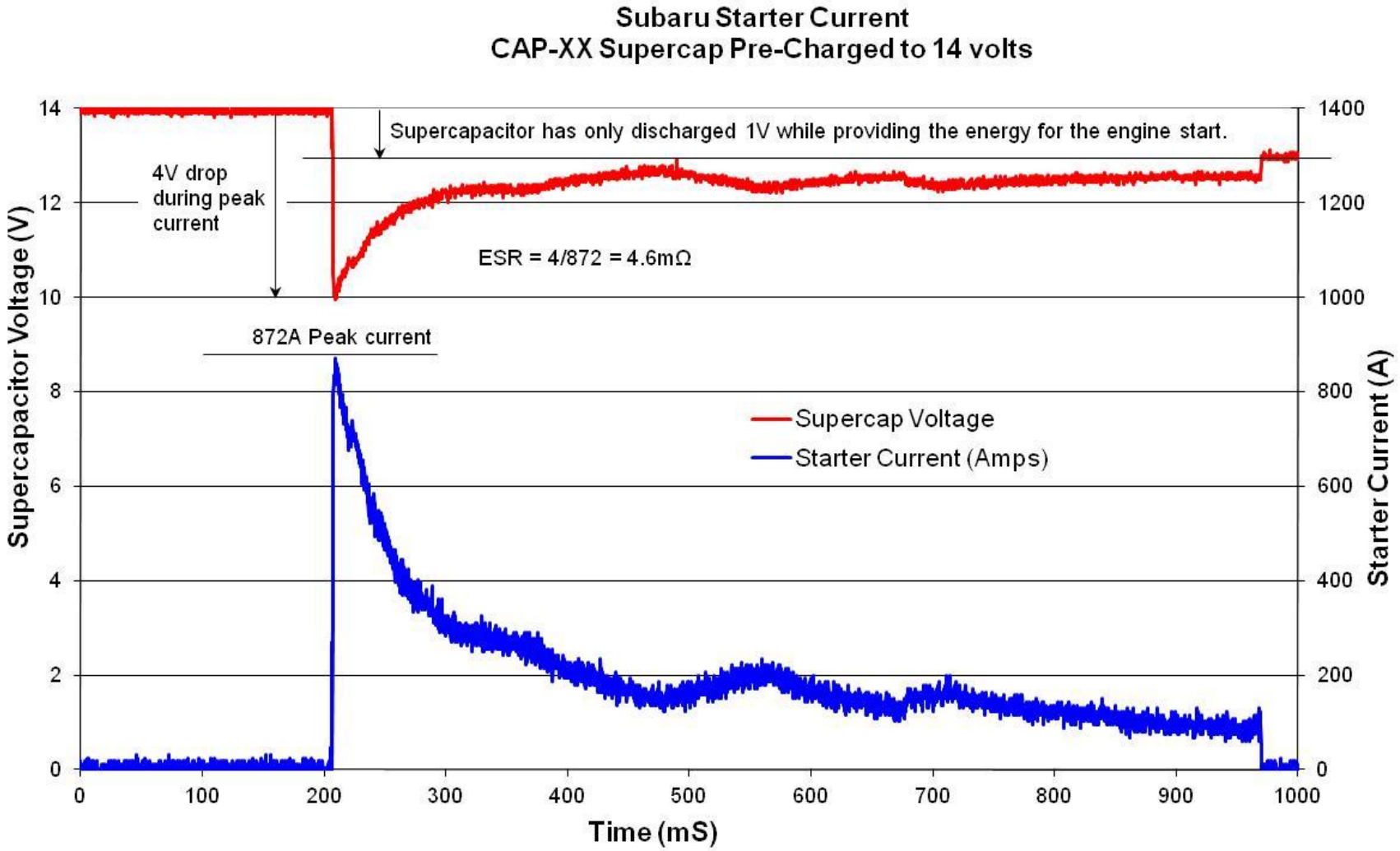
Market #2: Cold Cranking
Starting a Car with a Supercapacitor

1. Pre-charge the supercapacitor module to 14V
2. Connect the vehicle starter motor +ve cable to the supercapacitor module
3. Start engine from the supercapacitor

- The supercapacitor module has no external energy source
- Engine was started 7 times before the supercapacitor needed a recharge
- Peak current was 872A
- This same supercapacitor had already completed over 17,000 starts in the Mazda Stop-Start Battery Test



Starting a car with a Supercapacitor: Current & Voltage profile



Case Study 1

A 20,000kg bus travelling at 50 km/h and stopping in 10 secs:

1. Kinetic Energy of the bus = 1929 kJoules
   This is the maximum amount of energy that can be recovered during regenerative braking at 100% efficiency
2. Average Power generated during braking = 193 kWatts
3. At 400V Charging Voltage, Charging Current = 482 Amps

- This charging current is too large for a battery to accept, but not for a supercapacitor
- A CAP-XX Supercapacitor Module rated at 42F at 400V (286 x 3000F cells) would support this application

Case Study 2

A 1,000kg car travelling at 50 km/h and stopping in 10 secs:

1. Kinetic Energy of the vehicle = 96.45kJoules
   This is the maximum amount of energy that can be recovered during regenerative braking at 100% efficiency
2. Average Power generated during braking = 9.64 kWatts
3. At 14V Charging Voltage, Charging Current = 689 Amps

- This charging current is too large for a battery to accept, but not for a supercapacitor
- The CAP-XX Stop-Start Supercapacitor Module, rated at 150F at 14V (6x 900F cells), would be ideal

Market #4: HEV & EV Drivetrain

- Hybrid electric vehicles, with smaller battery packs, need supercapacitors as a power buffer
- In some cases, the batteries can be eliminated altogether:
  - Supercapacitors recapture brake energy
  - Return it as a power boost for acceleration
  - Allows a much smaller engine, substantial fuel savings, and
  - No need for drivetrain batteries
- Electric vehicles, with much larger battery packs, still need supercapacitors as a power buffer to:
  - Recapture brake energy (utilising charge currents that the battery can't handle)
  - Provide power for acceleration that the battery can't provide
  - Provide secure power for brakes, steering and other critical functions in case of battery failure

HEV/EV Drivetrain Solutions: The CAP-XX Advantage

- Existing supercapacitor modules for automotive use need lots of cells to provide sufficient energy, power and voltage
- CAP-XX is now developing Hybrid Supercapacitors with superior energy density and higher cell voltage
  - 2x the energy density means smaller, lower cost cells
  - 20% increase in cell voltage means fewer cells/module
  - Yielding >50% savings in cost, weight, size and volume of the module
  - And longer life than any competing battery
- Our Applications Engineering team can assist with Stop-Start Control Module and Supercapacitor Module designs

Market #5: Fuel Cell Vehicles

- Fuel cells are the only solution to long range zero emission driving. The energy density of the H_2 fuel is similar to petrol
- Filling a tank takes minutes (vs hours for battery charging)

BUT:

- Fuel cells respond poorly to rapid changes in power demand (such as acceleration from standstill)
- Fuel cells respond poorly in very cold temperatures

Supercapacitors overcome these problems…

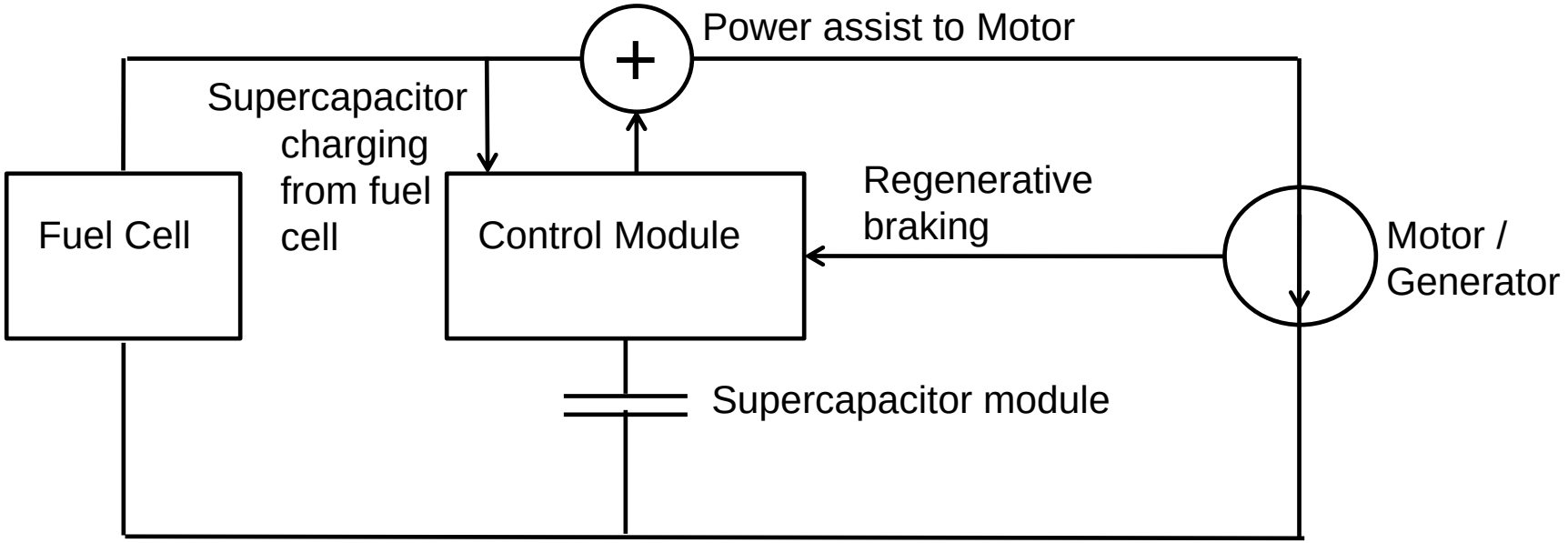
- By acting as a power buffer between the fuel cell and engine
- By delivering high power even at sub-zero temperatures

… and extend driving range

- By capturing energy during braking and coasting

Fuel Cell Vehicle: Supercapacitor-enabled Solution

CAP-XX Fuel Cell System Architecture



The CAP-XX Advantage

- Lead-Acid and Lithium-ion batteries have limitations in life, power delivery and low temperature performance which impact their utility in Automotive applications
- CAP-XX supercapacitors have superior power density for high current, low energy applications
- For high energy applications, CAP-XX's new hybrid supercapacitors will offer double the energy density, halving the cost, weight and size/volume of the module
- CAP-XX has a very strong Applications Engineering team to assist customers with the design of Automotive Control Modules and Supercapacitor Modules

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