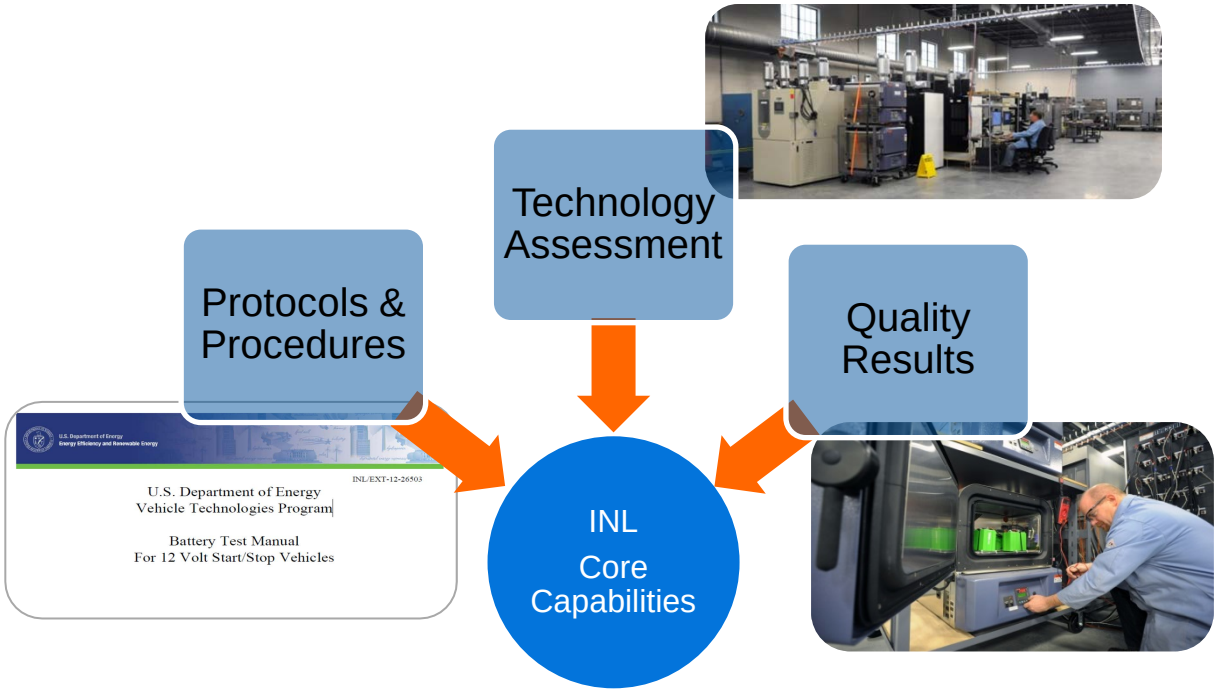
Introduction to Test Protocol and Planning



Jon P. Christophersen

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Test Manuals

- **Recent USABC test manuals:**
  - PHEV, Revision 3
  - 12V S/S, Revision 1
  - EV Manual, Revision 3
- **Revision 3 of the PHEV Manual has undergone extensive revisions.**
  - Technical consistency
  - Procedure/analysis clarification
- **The 12V S/S and EV Manuals are being made consistent with the new PHEV Manual.**

USABC Targets (PHEV)

Characteristics	Units	PHEV-20 Mile	PHEV-40 Mile	xEV-50 Mile
Commercialization Timeframe		2018	2018	2020
All Electric Range (AER)	Miles	20	40	50
Peak Discharge Pulse Power (10 sec)	kW	37	38	110
Peak Discharge Pulse Power (2 sec)	kW	45	46	120
Peak Regen Pulse Power (10 sec)	kW	25	25	65
Available Energy for CD (Charge Depleting) Mode	kWh	5.8	11.6	14.5
Available Energy for CS (Charge Sustaining) Mode	kWh	0.3	0.3	0.3
Minimum Round-trip Energy Efficiency	%	90	90	90
Cold cranking power at -30°C, 2 sec - 3 Pulses	kW	7	7	7
CD Life / Discharge Throughput	Cycles/ MWh	5000/29	5000/58	5000/72.5
CS HEV Cycle Life	Cycles	300,000	300,000	300,000
Calendar Life, 30°C	year	15	15	15

USABC Targets (PHEV)

Characteristics	Units	PHEV-20 Mile	PHEV-40 Mile	xEV-50 Mile
Maximum System Volume	Liter	47	80	100
Maximum Operating Voltage	Vdc	420	420	420
Minimum Operating Voltage	Vdc	150	153	300
Maximum Self-discharge	%/month	<1	<1	<1
System Recharge Rate at 30°C	kW	3.3 (240V/16A)	3.3 (240V/16A)	6.6 (240V/32A)
Maximum Discharge Pulse Current (≤10s)	A	300	300	400
Unassisted Operating Temp Range (10s)	°C	-30 to +52	-30 to +52	-30 to +52
30°-52°	% Power	100	100	100
0°	% Power	50	50	50
-10°	% Power	30	30	30
-20°	% Power	15	15	15
-30°	% Power	10	10	10
Survival Temperature Range	°C	-46 to +66	-46 to +66	-46 to +66
Max System Production Price @ 100k units/yr	$	$2,200	$3,400	$4,250

USABC Targets (12V S/S)

End of Life Characteristics	Units	Target	
		Under hood	Not under hood
Discharge Pulse, 1s	kW	6	
Max discharge current, 0.5s (minimum design)	A	900	
Cold cranking power at -30 °C (three 4.5-s pulses, 10s rests between pulses at min SOC)	kW	6-kW for 0.5s followed by 4 kW for 4s	
Min voltage under cold crank	Vdc	8.0	
Available energy (750W accessory load power)	Wh	360	
Peak Recharge Rate, 10s	kW	2.2	
Sustained Recharge Rate	W	750	
Cycle life, every 10% life RPT with cold crank at min SOC	Engine starts/miles	450k/150k at 45°C	450k/150k at 30°C
Calendar Life at 30°C, 45°C if under hood	Years	15 at 45°C	15 at 30°C
Minimum round trip energy efficiency	%	95	
Maximum allowable self-discharge rate	Wh/day	2	
Peak Operating Voltage, 10s – Max	Vdc	15.0	
Sustained Operating Voltage - Max	Vdc	14.6	
Minimum Operating Voltage under Autostart	Vdc	10.5	

USABC Targets (12V S/S)

End of Life Characteristics	Units	Target	
		Under hood	Not under hood
Operating Temperature Range - to allow 6-kW (1s) pulse	°C	-30 to + 75	-30 to +52
30 °C – 52 °C	Wh	360 (to 75°C)	360
0 °C	Wh	180	
-10 °C	Wh	108	
-20 °C	Wh	54	
-30 °C	Wh	36	
Survival Temperature Range (24 hours)	°C	-46 to +100	-46 to +66
Maximum System Weight	kg	10	
Maximum System Volume	L	7	
Maximum System Selling Price (@250k units/year)	$	$220	$180

USABC Targets (EV)

End of Life Characteristics at 30°C	Units	System Level	Cell Level
Peak Discharge Power Density (30 sec)	W/L	1000	1500
Peak Specific Discharge Power (30 sec)	W/kg	470	700
Peak Specific Regen Power (10 sec)	W/kg	200	300
Available Energy Density @ C/3 Discharge Rate	Wh/L	500	750
Available Specific Energy @ C/3 Discharge Rate	Wh/ kg	235	350
Available Energy @ C/3 Discharge Rate	kWh	45	N/A
Calendar Life	Years	15	15
DST Cycle Life	Cycles	1000	1000
Selling Price @ 100K units	$/kWh	125	100

USABC Targets (EV)

End of Life Characteristics at 30°C	Units	System Level	Cell Level
Operating Environment	°C	-30 to +52	-30 to +52
Normal Recharge Time	Hours	< 7 Hours, J1772	< 7 Hours, J1772
High Rate Charge	Minutes	80% ΔSOC in 15 min	80% ΔSOC in 15 min
Maximum Operating Voltage	V	420	N/A
Minimum Operating Voltage	V	220	N/A
Peak Current (30 sec)	A	400	400
Unassisted Operating at Low Temperature	%	>70% Available Energy @ C/3 Discharge rate at -20°C	>70% Available Energy @ C/3 Discharge rate at -20°C
Survival Temperature Range, 24 hr	°C	-40 to +66	-40 to +66
Maximum Self-Discharge	%/month	< 1	< 1

Voltage Limit Definitions

- **New voltage limits have been defined for each manual.**

$Vmax_{pulse}$ (applies only to short duration pulses) **Fixed**

$Vmax_{100}$ (100% SOC at BOL) **Fixed**

$Vmax_{op}$ (top of operating range at BOL; fixed at BOL) **Fixed**

$Vmin_{op}$ (optional, minimum allowable bottom of operating range) **Typically fixed by developer**

$Vmin_{0}$ (0% SOC at BOL) **Fixed**

$Vmin_{pulse}$ (applies only to short duration pulses) **Fixed**

$Vmin_{Low\ T}$ **Fixed**

*** 12V S/S Definitions**

Battery Size Factor

- **The battery size factor (BSF) is the minimum number of cells required to meet all performance requirements.**
  - The BSF can include series/parallel combinations.
- **PHEV Methodology:**
  - BOL HPPC test assuming 30% CS power margin and 20% CD energy margin.
- **12V S/S Methodology:**
  - BOL HPPC test assuming 30% power margin.
- **EV Methodology:**
  - Scale measured energy from C/3 discharge by the system-level target (45 kWh) and the specified margin.

Test Protocol – Static Capacity

- **Measures device <u>rated</u> capacity based on constant current discharges.**
  - Three consecutive discharge capacities must be stable within ±2% up to a maximum of 10 discharges.
  - Discharge is between $Vmax_{100}$ and $Vmin_0$.
- **The test can be repeated to verify the stability of the <u>operating</u> capacity:**
  - Discharge is between $Vmax_{op}$ and $Vmin_0$.
- **C-rates:**
  - PHEV: C/1 discharge
  - 12V S/S: C/1 discharge
  - EV: C/3 discharge

Test Protocol – Constant Power

- **Measures device energy based on constant power discharges and charges at the designated rates.**
  - PHEV: 10-kW rate
  - 12V S/S: 750-W rate
  - EV: N/A
- **The test is performed over the operating range of the device:**
  - Discharge and charge between $Vmax_{op}$ and $Vmin_0$.
- **The cell- and module-level devices, the constant power discharge is scaled by the BSF.**

Test Protocol – High Rate Charge

- **The High Rate Charge test is only for EV applications.**
- **Verify the ability of the device to restore 80% of the measured operating capacity within 15 minutes.**
  - Charge from $Vmin_0$ to $Vmax_{op}$.
  - Taper at $Vmax_{op}$ to complete the 15-minute charge.
  - Manufacturer provides C-rate (3.2C is the default).

Test Protocol – HPPC

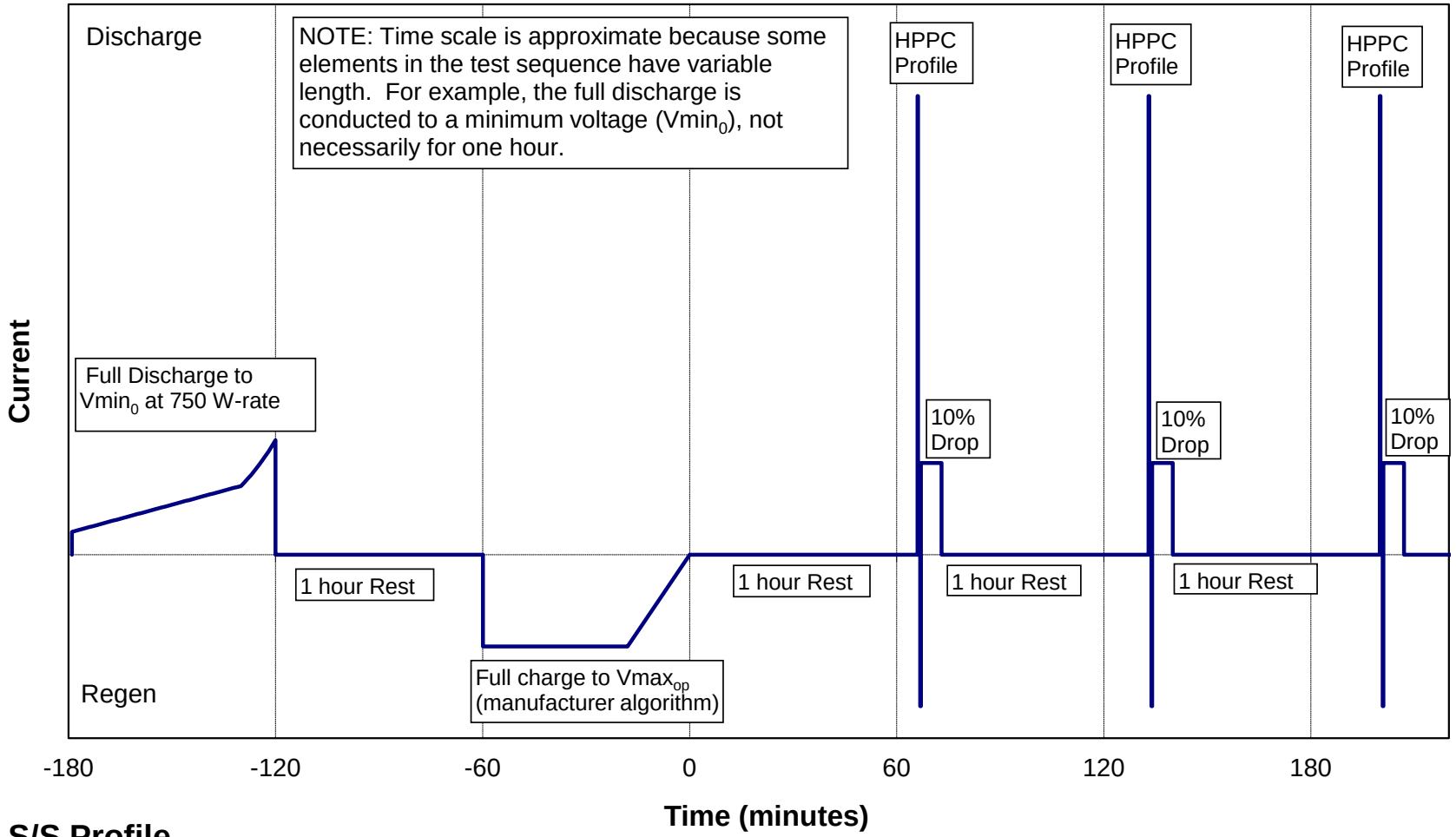
- **The HPPC test is conducted between $Vmax_{op}$ and $Vmin_0$ with a pulse at a "full charge" condition.**

- **Pulse profiles designed based on the USABC target applications**
  - PHEV: 10-s discharge; 40-s rest; 10-s regen
  - 12V S/S: 1-s discharge; 40-s rest; 10-s regen
  - EV: 30-s discharge; 40-s rest; 10-s regen

- **HPPC is preceded by a full discharge at the appropriate rate:**
  - PHEV: 10-kW discharge
  - 12V S/S: 750-W discharge
  - EV: C/3 discharge

Test Protocol – HPPC (cont.)

- **HPPC pulse profile:***



*** 12V S/S Profile**

Test Protocol – HPPC (cont.)

- **The HPPC Verification Test ensures that the target power and energy can be achieved without violating voltage limits.**
  - HPPC test generally yields conservative results.

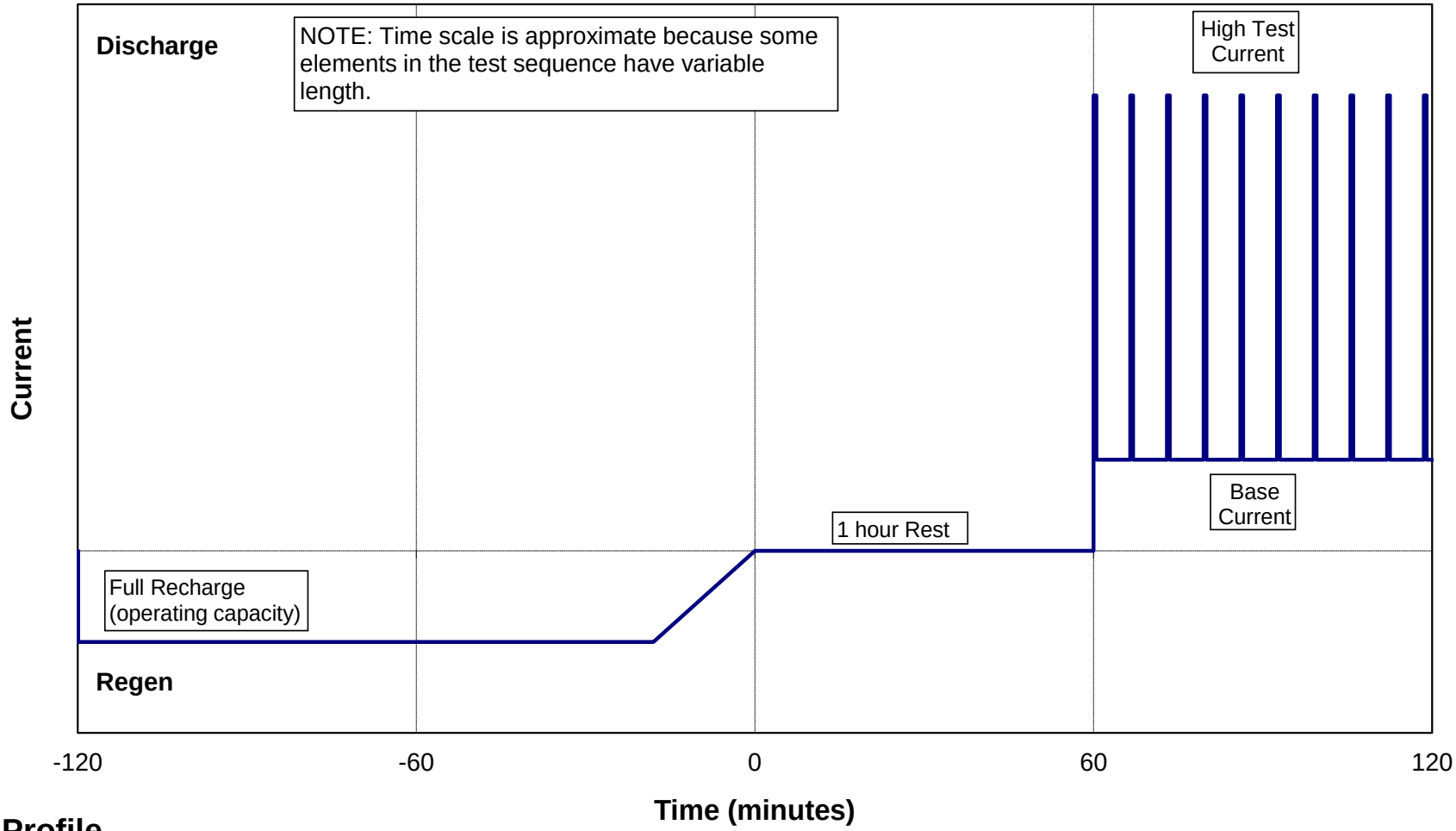
- **Only the EV Manual requires an HPPC Verification test every RPT:**
  - From $Vmax_{op}$, remove the Available Energy at a C/3 rate.
  - Rest for 1 hour at OCV.
  - Perform a 30-s discharge pulse at the appropriate power level.

Test Protocol – Peak Power

- **The Peak Power test is conducted between $Vmax_{op}$ and $Vmin_0$ with a pulse at a "full charge" condition.**
  - This test only applies to EV applications.
- **The Peak Power test profile consists of a base current discharge for each 10% increment and a high test current discharge pulse for 30-s.**
  - No rest steps or regen pulses are included in this test.
- **The high test current should be the maximum current of the device (Imax).**

Test Protocol – Peak Power (cont.)

- **Peak Power pulse profile:***



*** EV Profile**

Test Protocol – Self Discharge

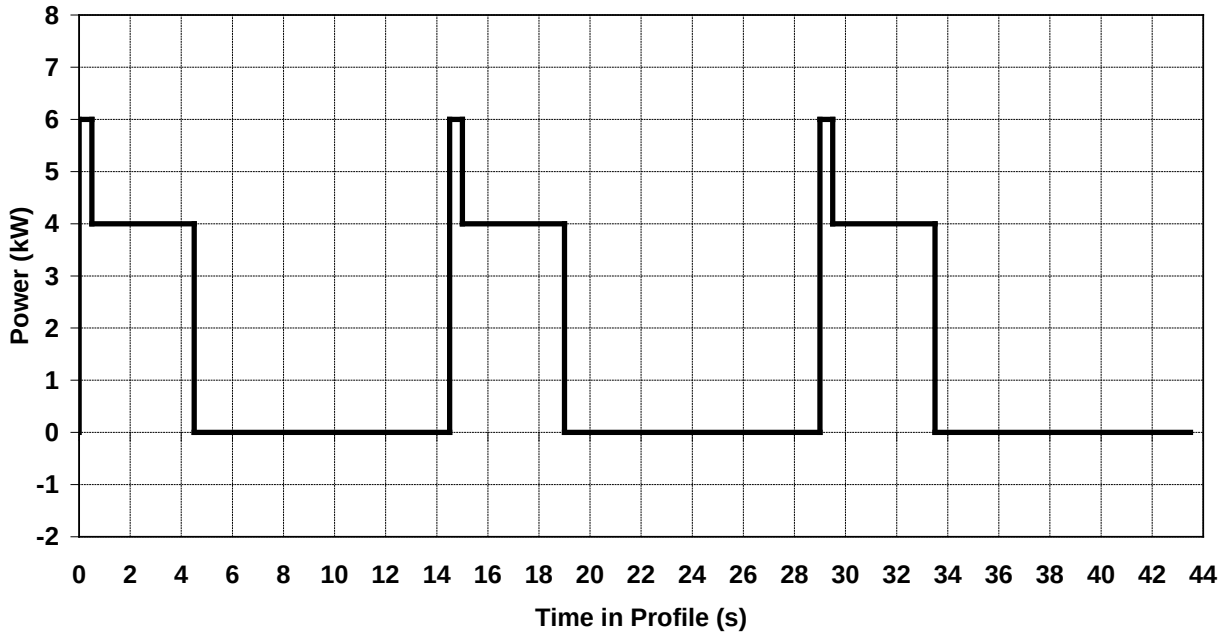
- **Self discharge determines the temporary capacity loss over a pre-determined stand period.**
  - PHEV: 7-day stand
  - 12V S/S: 7-day stand or 30-day stand
  - EV: 30-day stand

- **Self-discharge is performed at various test conditions:**
  - PHEV: Remove CD AE + ½ CS AE at 10-kW rate
  - 12V S/S: Remove 360 Wh at 750-W rate
  - EV: Remove ½ of the AE specified by the manufacturer

- **A constant current/power discharge is performed both before and after the self-discharge test.**

Test Protocol – Cold Crank

- **Cold crank verifies the device's ability to provide sufficient power at -30°C.**
  - PHEV: 2-s, 7 kW power capability
  - 12V S/S: 0.5-s, 6 kW plus 4-s, 4 kW power capability
  - EV: N/A



*** 12V S/S Profile**

Test Protocol – Thermal Performance

- **Thermal performance testing consists of a constant power/current discharge and an HPPC test at various test temperatures.**

- **Test sequence:**
  - 0°C
  - -10°C
  - -20°C if the -10°C test meets the targets
  - -30°C if the -20°C test meets the targets
  - 52°C (75°C for 12V S/S Under Hood applications)

- **All charging is to be performed at reference temperature.**

Test Protocol – Survival Temperature

- **Survival temperature tests verify the capability of the device to endure harsh hot/cold conditions.**

- **Test sequence:**
  - Perform a L-HPPC test at 30°C
  - Discharge to $V_{NOMINAL}$ from $Vmax_{op}$
  - Ramp the temperature to the specified maximum/minimum condition and rest for 4 to 16 hours.
  - Rest for 24 hours
  - Return to 30°C and rest for 4 to 16 hours.
  - Perform a L-HPPC test at 30°C

- **Tests should be conducted at BOL on cells that are not part of the life testing matrix.**

Test Protocol – Life Testing

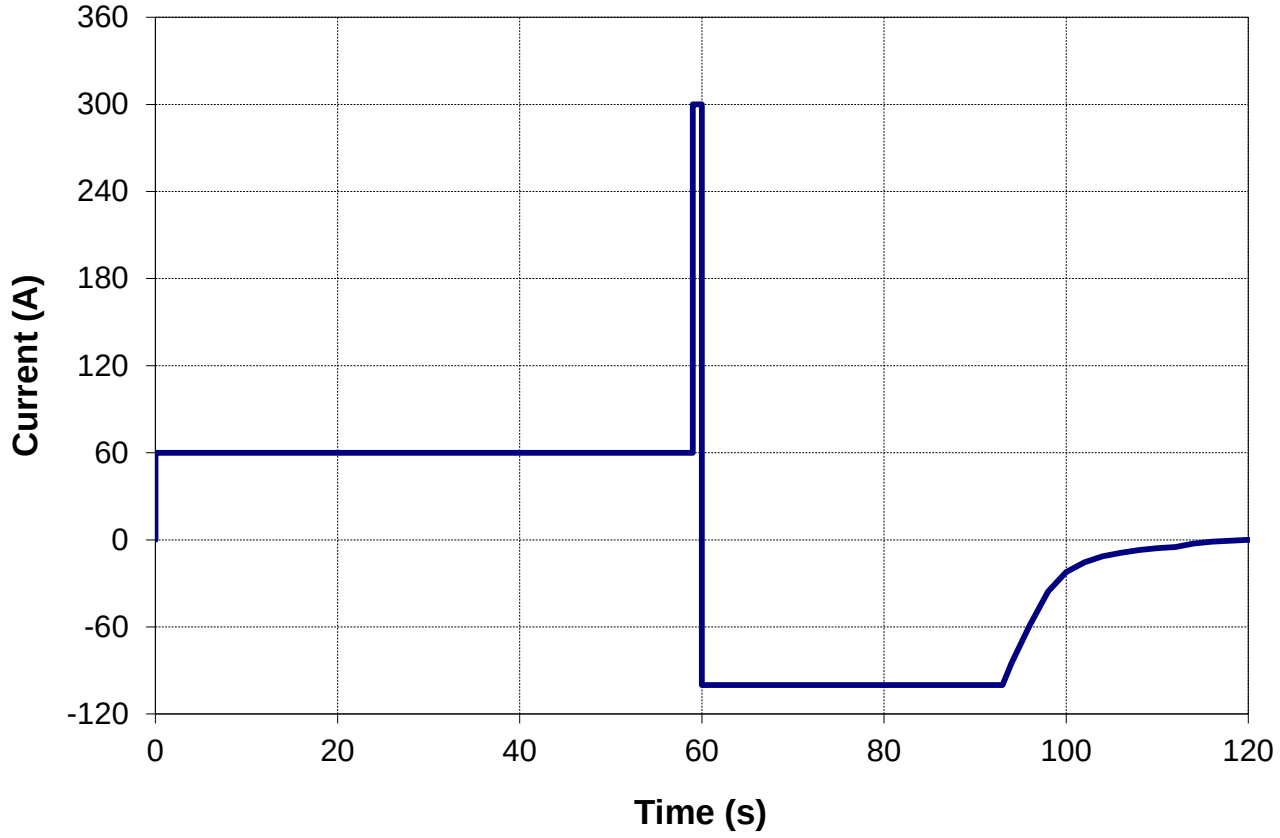
- **Life testing consists of both calendar- and cycle-life aging at reference and elevated temperatures.**

- **Test sequence:**
  - Perform initial reference performance test (RPT0)
  - Fully charge the device to $Vmax_{op}$
  - If necessary, discharge to the specified SOC condition and adjust ambient temperature
  - Conduct the life aging sequence for ~32 days
  - Bring the device back to reference temperature and conduct RPT
  - Repeat last two steps as necessary

- **Energy efficiency and OSPS tests can be performed as necessary to ensure stable cycling.**

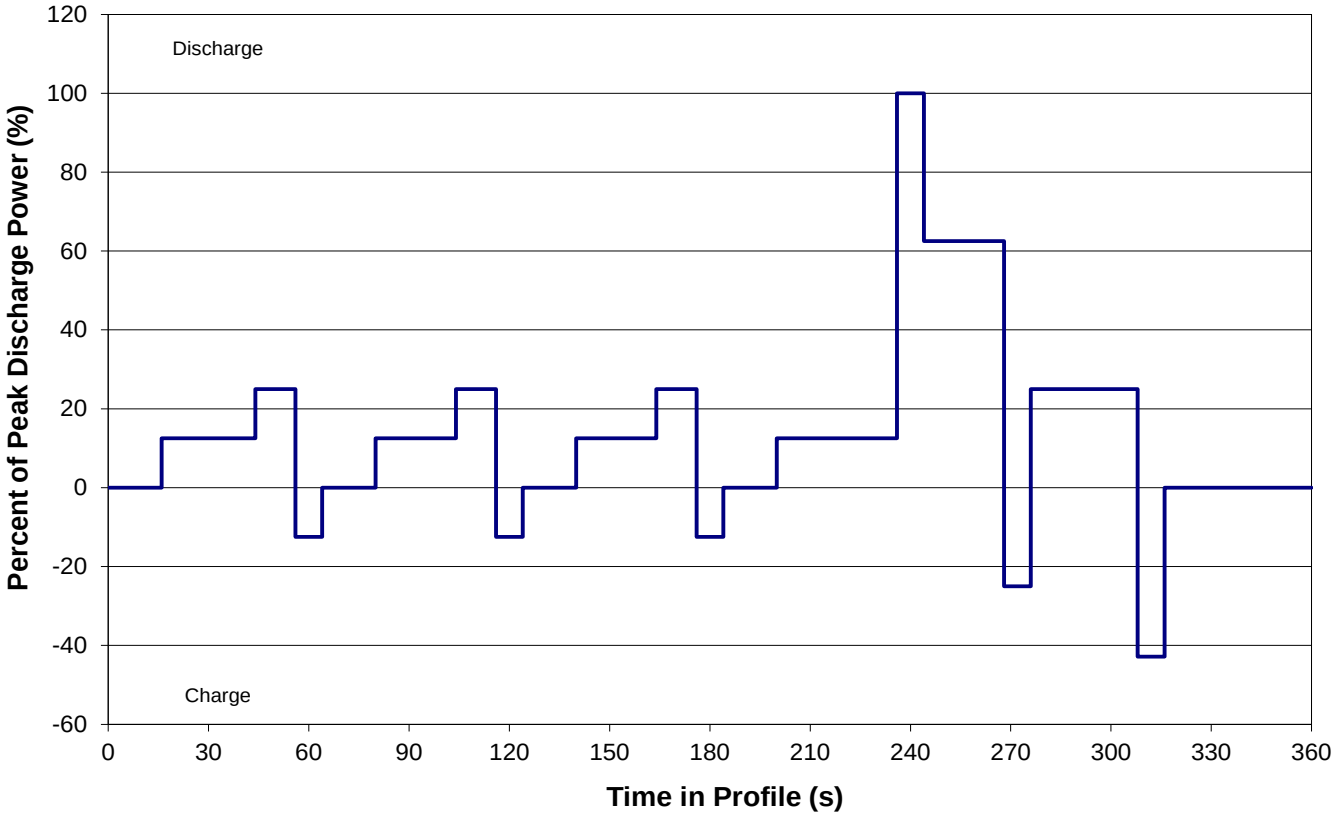
Test Protocol – Cycle-Life (12V S/S)

- **The profile is controlled by the target voltage and the coulombic efficiency will be monitored.**



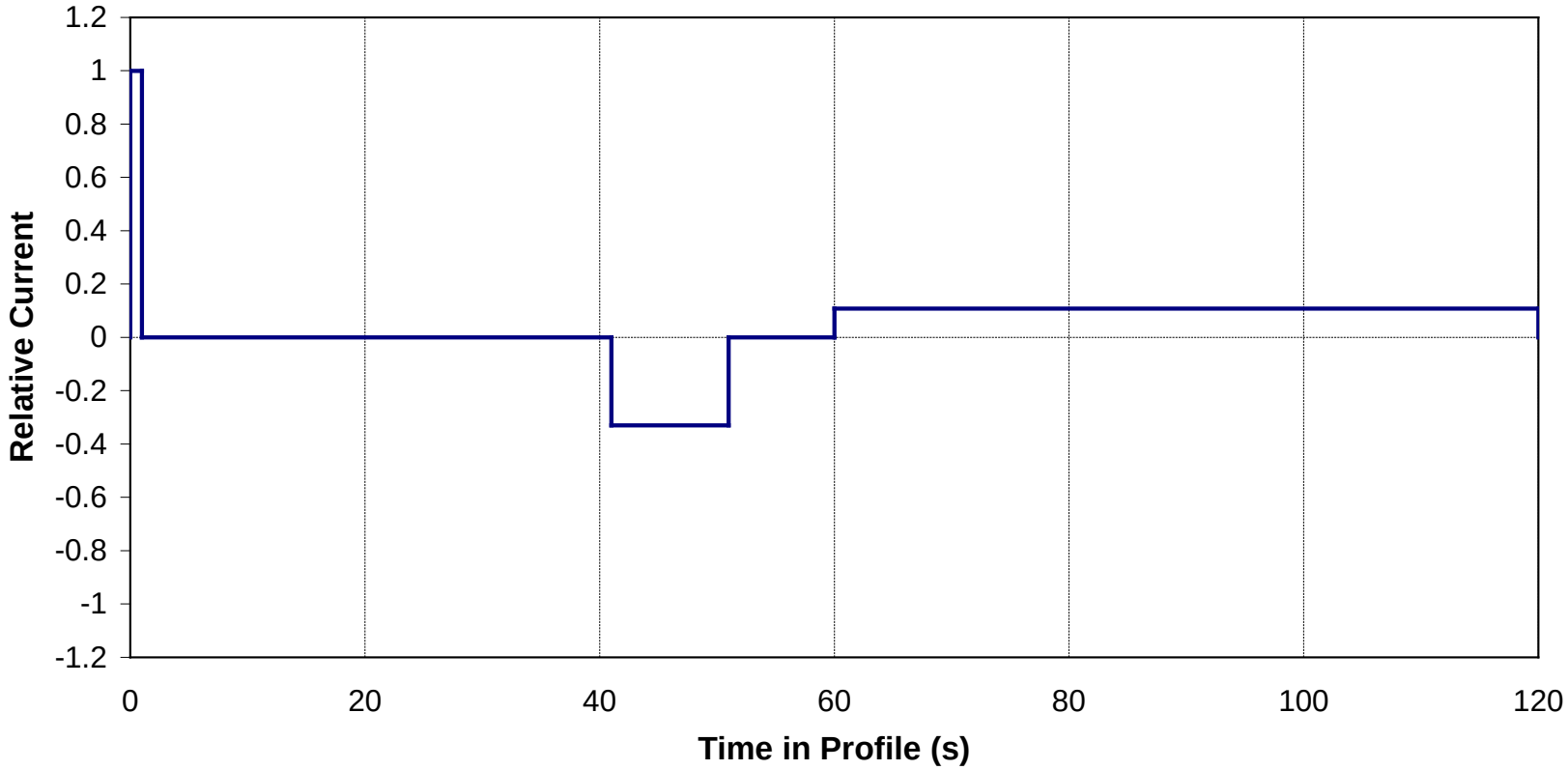
Test Protocol – Cycle-Life (EV)

- **The DST profile is repeated continuously until the net energy removed is equal to the Available Energy target.**



Test Protocol – Calendar-Life (12V S/S)

- **Calendar-life consists of resting at OCV with a pulse profile conducted once every 24 hours.**



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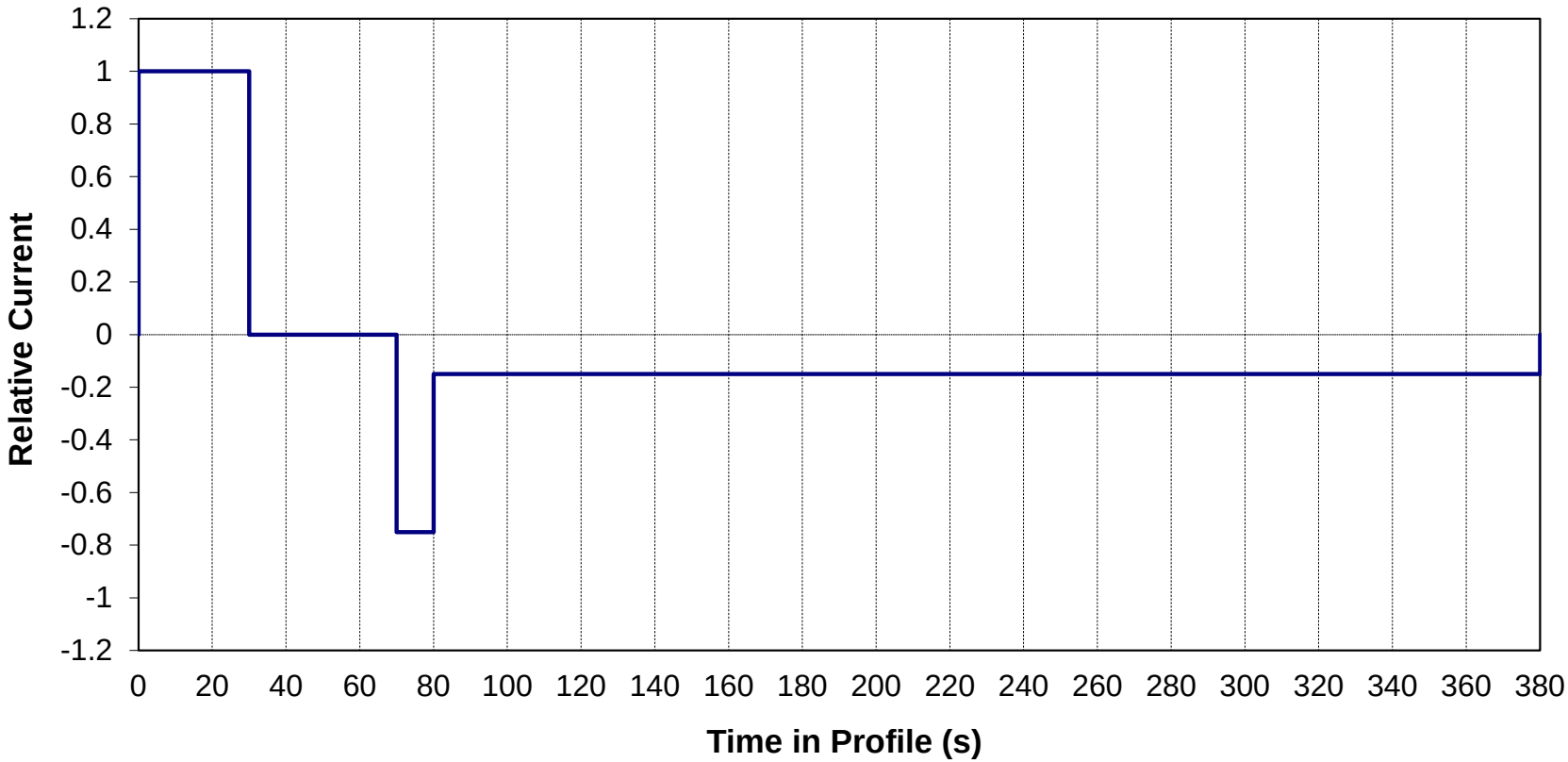

Test Protocol – Reference Performance Test

- **Reference performance tests (RPTs) are conducted every ~32 days at 30°C to gauge degradation rates.**

- **PHEV:**
  - 10kW Constant Power discharge and L-HPPC

- **12V S/S:**
  - 750-W Constant Power discharge and L-HPPC
  - Cold Crank every 10% life (i.e., every other RPT)

- **EV:**
  - C/3 Constant Current discharge and L-HPPC
  - Peak Power
  - HPPC Verification

Test Planning - Matrix

- **Typical device deliverables for performance testing should include at least 15 articles.**
  - A minimum of 3 devices per test condition should be used to ensure statistical relevance.

- **Typical life testing matrix:**
  - (3) devices for cycle-life at reference temperature
  - (9) devices for calendar-life with (3) cells each at reference temperature and elevated temperatures.

- **The remaining (3) cells can be used for extra characterization.**
  - Thermal performance
  - Survival temperature
  - High rate charge

Test Planning - Documentation

- **A formal test plan for each group of devices shall be developed prior to testing.**
  - Test plan must be approved by technical program manager and manufacturer.
- **The test plan should at least include the following:**
  - Device ratings and limitations
  - Safety considerations
  - Specific tests to be performed
- **Special instructions and/or deviations from the standard test protocols must be clearly identified.**

Test Planning - Considerations

- **Temperature control:**
  - Devices should be placed in a thermal chamber to ensure consistent test results.
  - Chambers should be able to at least maintain ±3°C
- **Pressure control:**
  - Pouch or prismatic devices pressure should be specified by the manufacturer.
  - Once fixtured, the device should remain undisturbed.
- **Other considerations:**
  - Testing logistics (setup to teardown) – Mike Evans
  - Channel calibration – Randy Bewley
  - Tester programming – Randy Bewley
  - Safety protocol – Mike Evans

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