



California Energy Commission Vehicle-to-grid Testing and Demo with DoD

Joint Service Power Expo

Dan Markiewicz, Senior Principal Electrical Engineer

May 3, 2017

Agenda

- Company Overview
- Project Overview
- V2G Laboratory Testing
- Conclusions

Company Overview



Independent, nonprofit, applied scientific research and development professional services organization.

Leverage research, development, test and evaluation work to provide transformative, full lifecycle solutions.

Offer the complete ability to fully design, develop, test, prototype, and build.

Support our clients' core mission objectives with customized solutions and strive to exceed expectations.

30
YEARS OF
INNOVATION

550
EMPLOYEES

20
LOCATIONS

Affiliates

Enterprise Ventures Corporation (EVC) is CTC's technology commercialization arm and is organized as a wholly owned for-profit affiliate of CTC. EVC transfers advanced technologies designed and created by CTC and others to the industrial base. Together, CTC and EVC provide full lifecycle support services to clients, from innovative concepts through production and deployment.

CTC Foundation is a conduit for giving. Donations go to educational institutions, the arts, and charitable and community-service groups throughout the United States.

Leading Innovation



Staff Disciplines	
Electrical/Mechanical/Metallurgical & Materials Engineering	16%
Computer Science & Mathematics	18%
Communications Technology	17%
Environmental & Chemical Engineering	17%
Engineering & Science	13%
Business & Other	19%

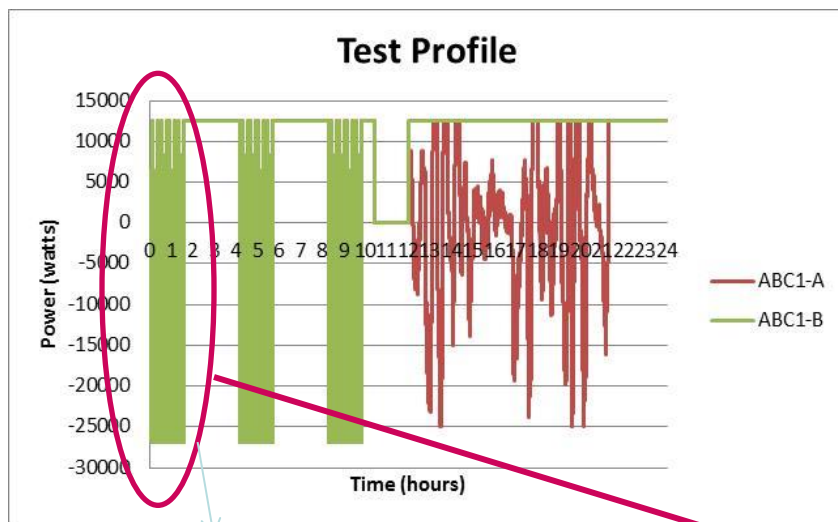
Our reach is broad; our areas of expertise, diverse. Clients can take advantage of a wide breadth and depth of core services available through CTC's science, engineering, and technology professionals.

Project Overview

- Objective
 - Conduct independent laboratory testing of PEV battery systems
 - Evaluate the effects of V2G operations
 - Complement the PEV-V2G Program at LAAFB.
- Tasks
 - Obtain PEV V2G Test Articles
 - Perform Laboratory Testing & Modeling
 - Develop Second Life Battery Application Design & Battery Determine of Condition
 - Benefits Analysis
- Client – California Energy Commission
- Period of Performance - 06/30/2013 - 09/29/2017

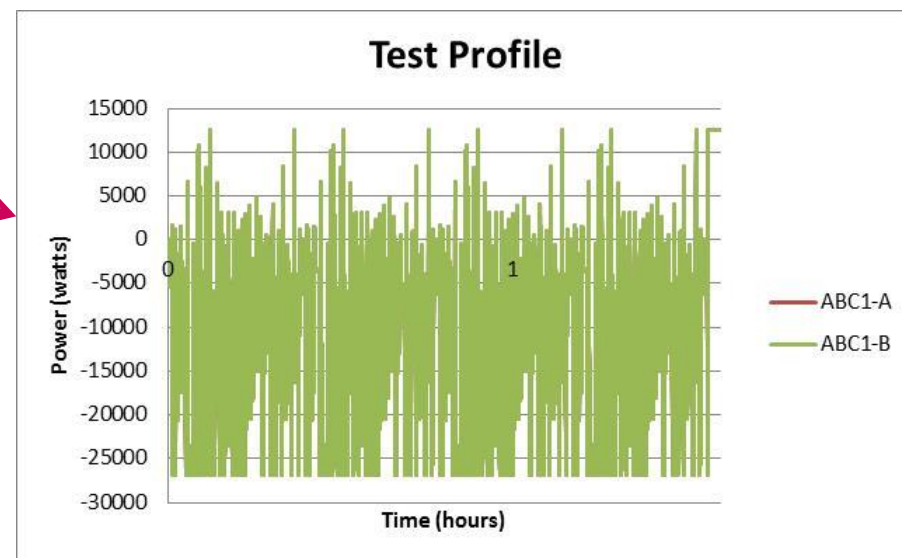
Testing Approach

- A 24-hour test cycle that subjects both battery packs to simulated driving missions in the first 12 hours and subjects the V2G Pack (Driving + V2G) to simulated V2G operations in the next 12 hours while the Control Pack (Driving) remains idle



Energy	
Driving	V2G
56.34 kWh	36.3 kWh discharge
0.65 kWh Regen	29 kWh charge

Aggressive test profile was developed while adhering to the battery specifications (Peak limits & maximum continuous peak discharge for 30 seconds).



Test Approach - Daily Standard Test Cycle

- Details

Driving Scenario

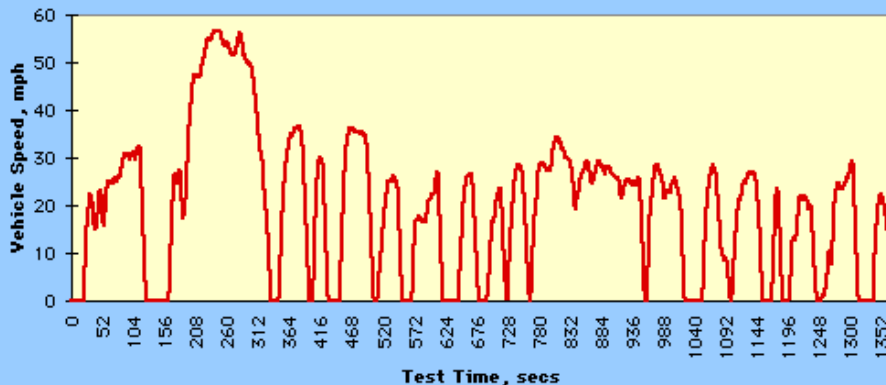
- Executes the Urban Dynamometer Driving Schedule (UDDS), modified to comply with test bed constraints
- Simulates an urban route of 7.5 mi (12.07 km) with frequent stops
- Maximum speed is 56.7 mph (91.25 kph)
- Average speed is 19.6 mph (31.5 kph)

V2G Scenario

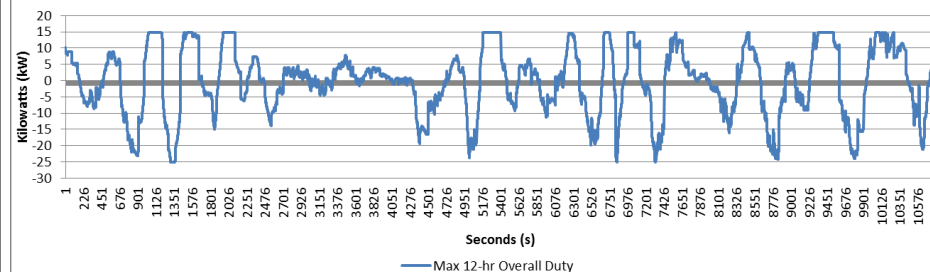
- Based on the Regulation Energy Management (REM) Duty Cycle established by CSE and KnGrid, which is based on a 7-day CAISO Automated Generation Control (AGC) signal from July 1-7, 2010
- Identified the most aggressive 12-hour period using maximum signal frequency, energy transfer and overall duty

EPA Urban Dynamometer Driving Schedule

Length 1369 seconds - Distance = 7.45 miles - Average Speed = 19.59 mph



Rows 107555-118354
07/05/2010 23:29:52 - 07/06/2010 11:29:44

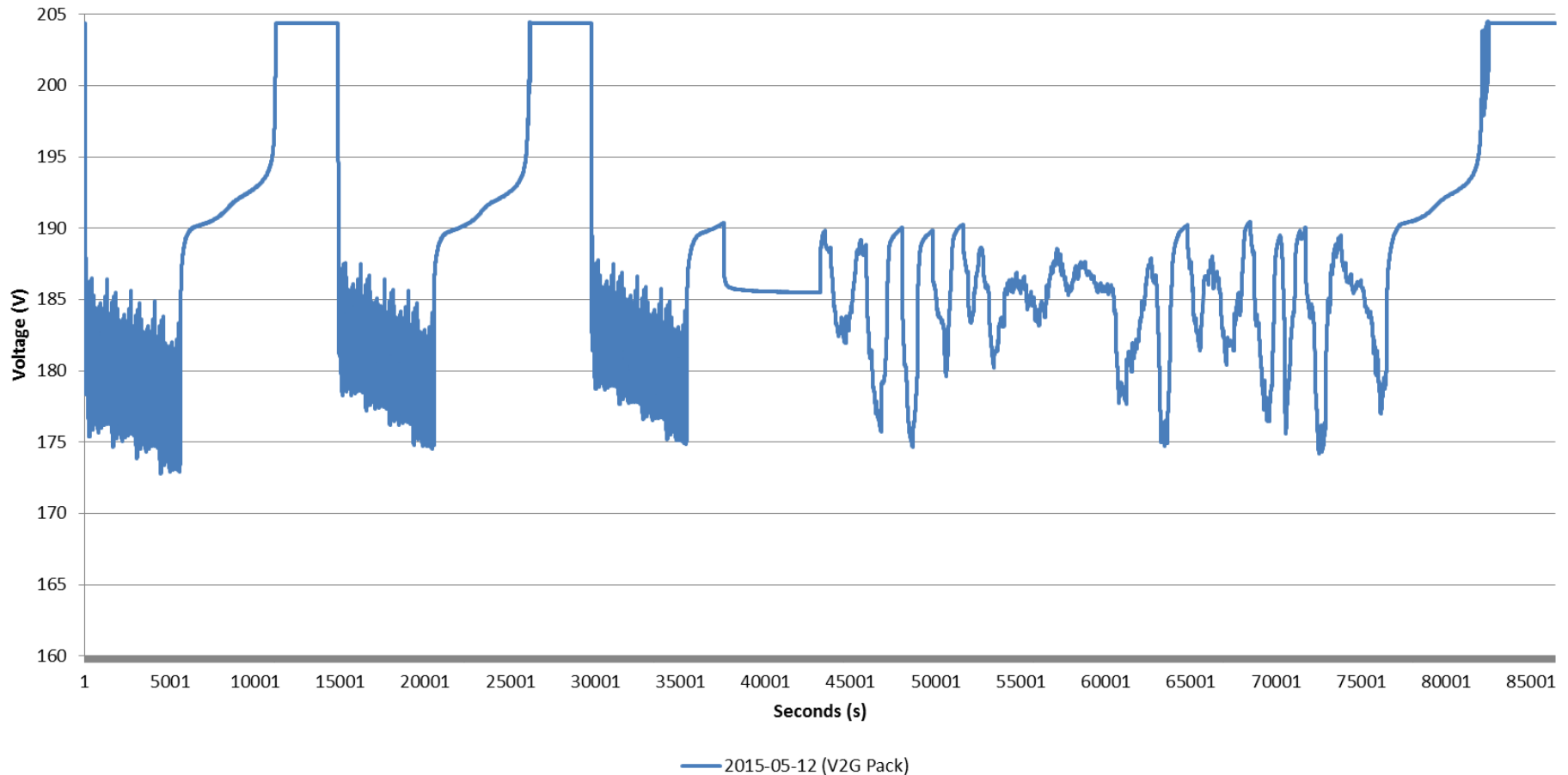


Laboratory Research and Testing - Battery Tests

- Monthly State-of-Health (SOH) Test Cycle
 - Test cycle providing a means of comparing battery capacity over time
 - Based on the Recurrent Power Battery Capacity Testing Procedure developed by Massachusetts Institute of Technology Lincoln Laboratory (MIT LL)
 - Discharges each pack at 1/4C rate to a minimum voltage and charges to the maximum voltage, energy removed from each battery is the metric being compared over time
- Nameplate Capacity Comparison (NCC) Test Cycle
 - Test cycle measurement of pack energy capacity that is directly comparable to the manufacturer nameplate
 - After the battery packs are fully charged and rested, packs are discharged at a 1/5 C rate (per specification). The energy discharged is the metric of interest. The packs are then recharged.

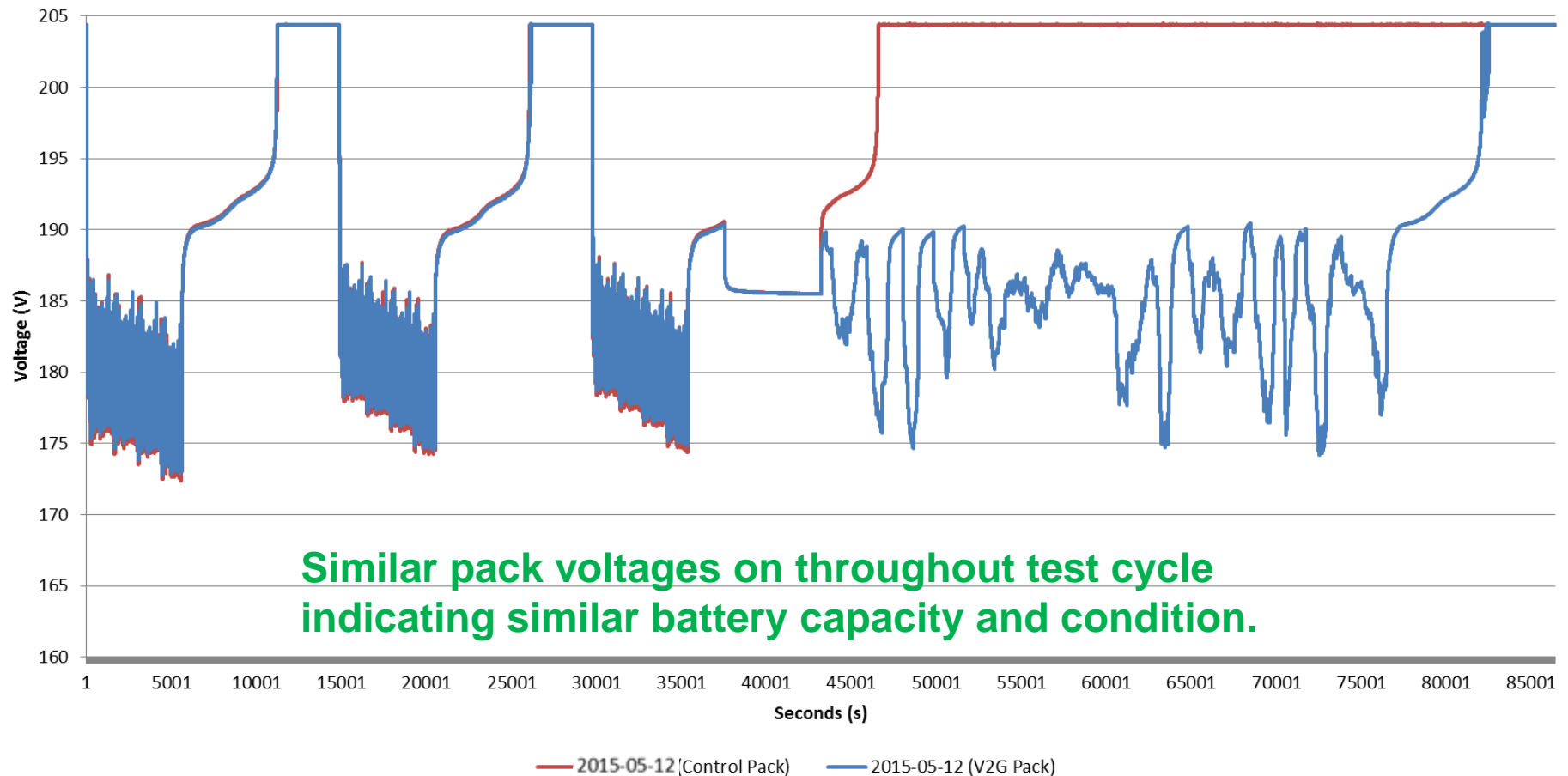
Laboratory Research and Testing - Daily Standard Test Cycle Pack Voltage Comparison – Both Packs

Daily Standard Test Cycle - V2G Pack and Control Pack (Voltage Comparison)



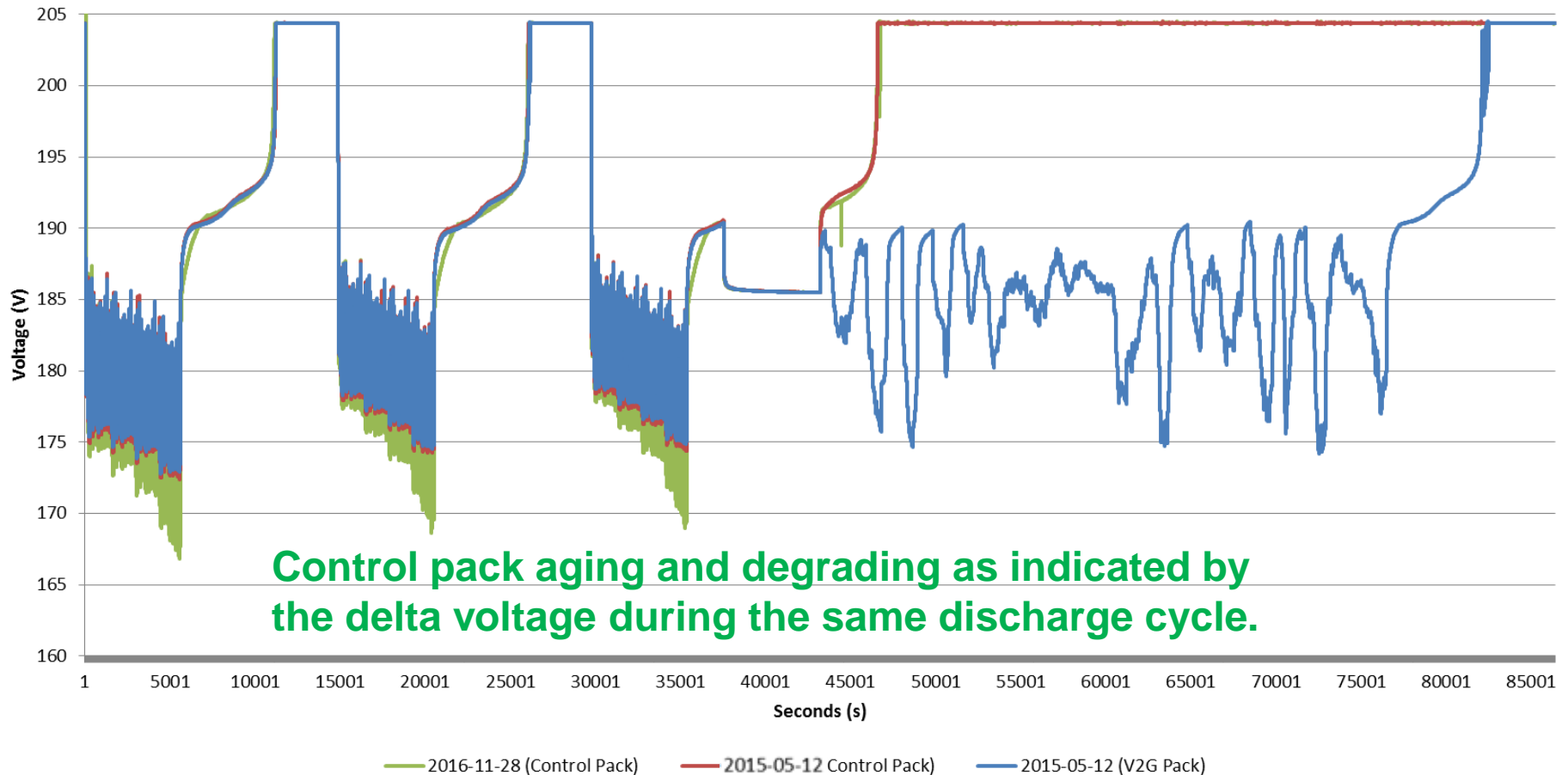
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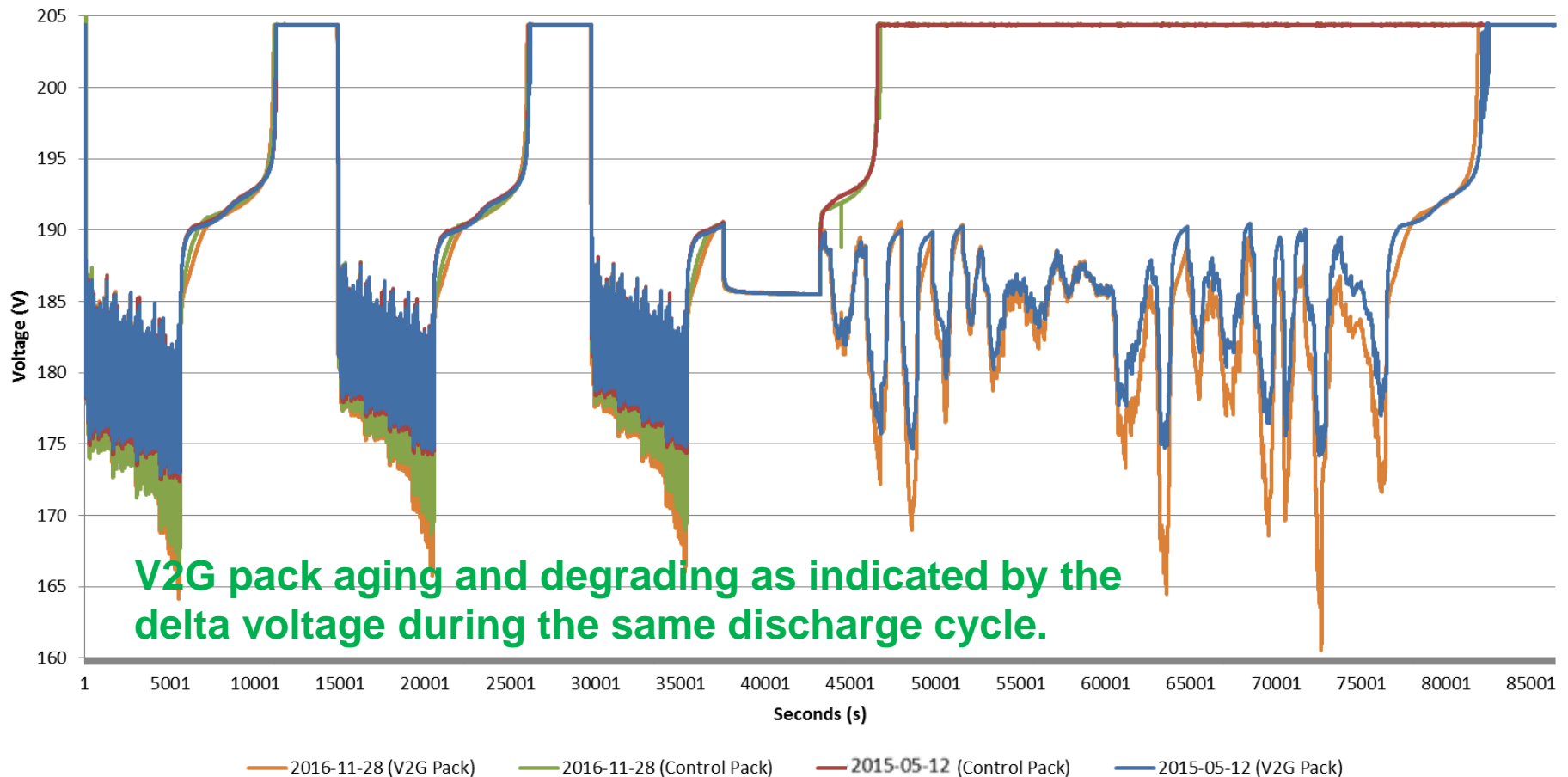
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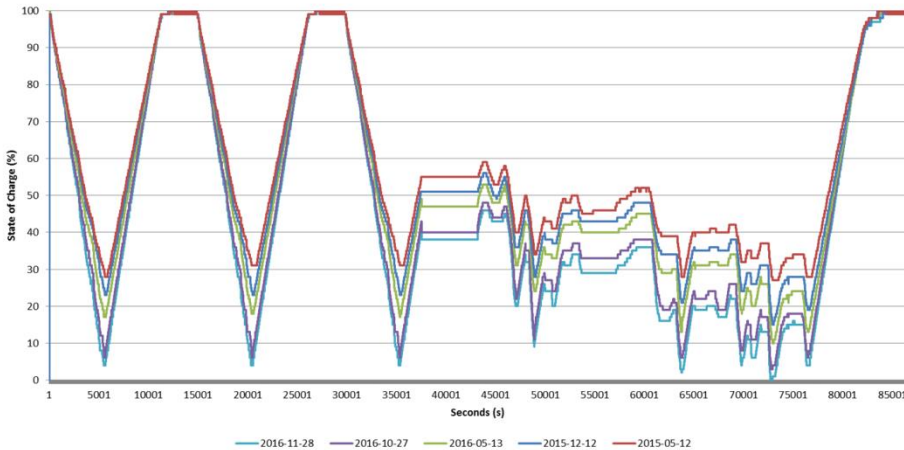
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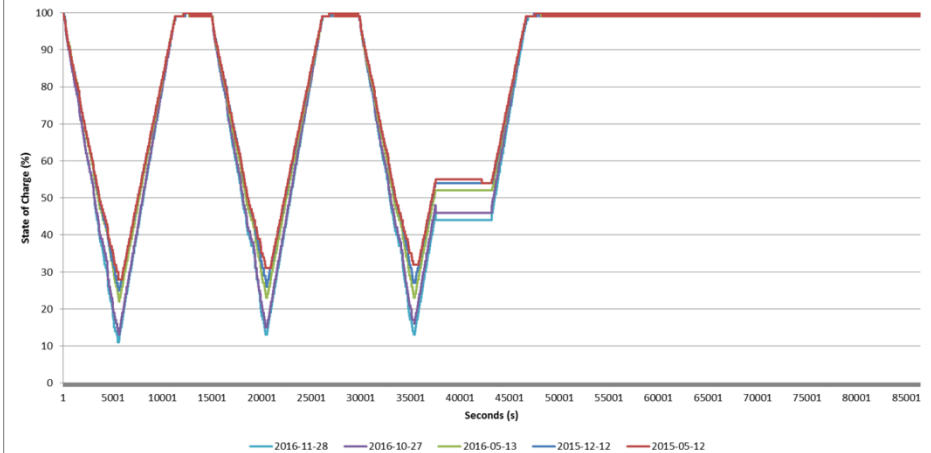


Laboratory Research and Testing - Daily Standard Test Cycle Battery Pack Comparison

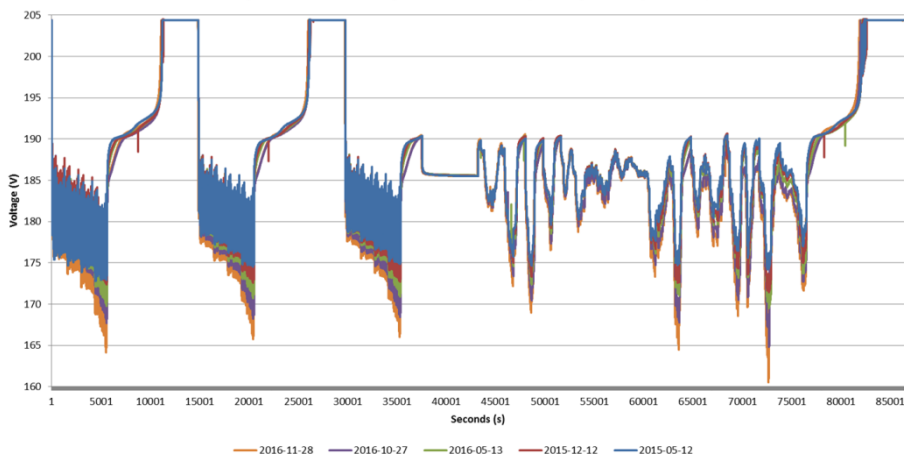
Daily Standard Test Cycle - V2G Pack (SOC Comparison)



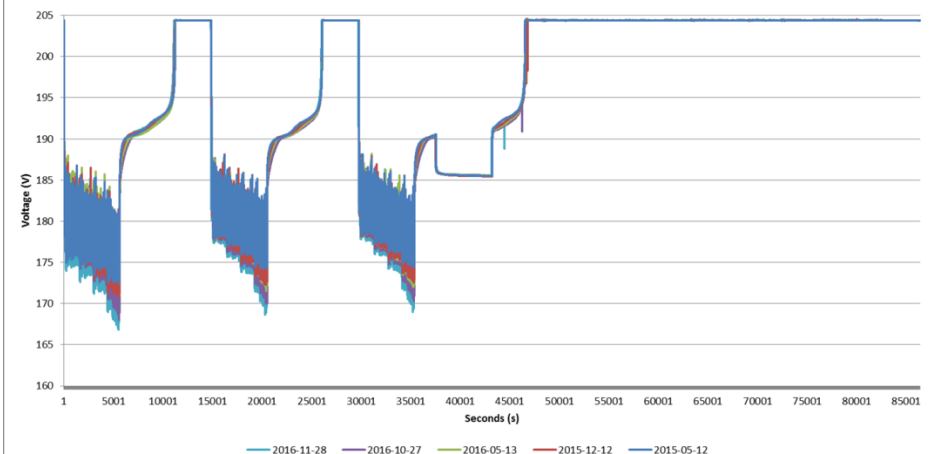
Daily Standard Test Cycle - Control Pack (SOC Comparison)



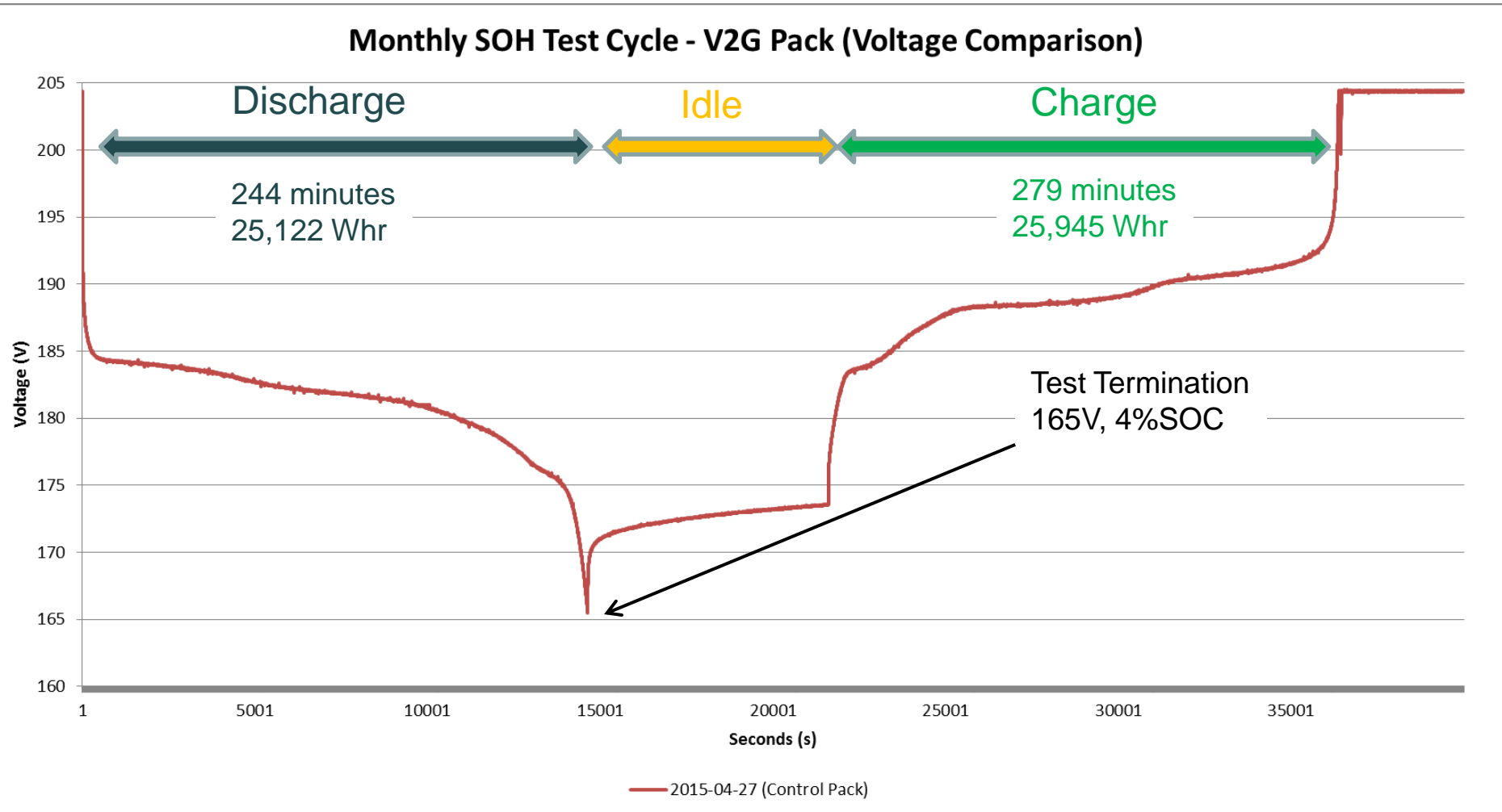
Daily Standard Test Cycle - V2G Pack (Voltage Comparison)



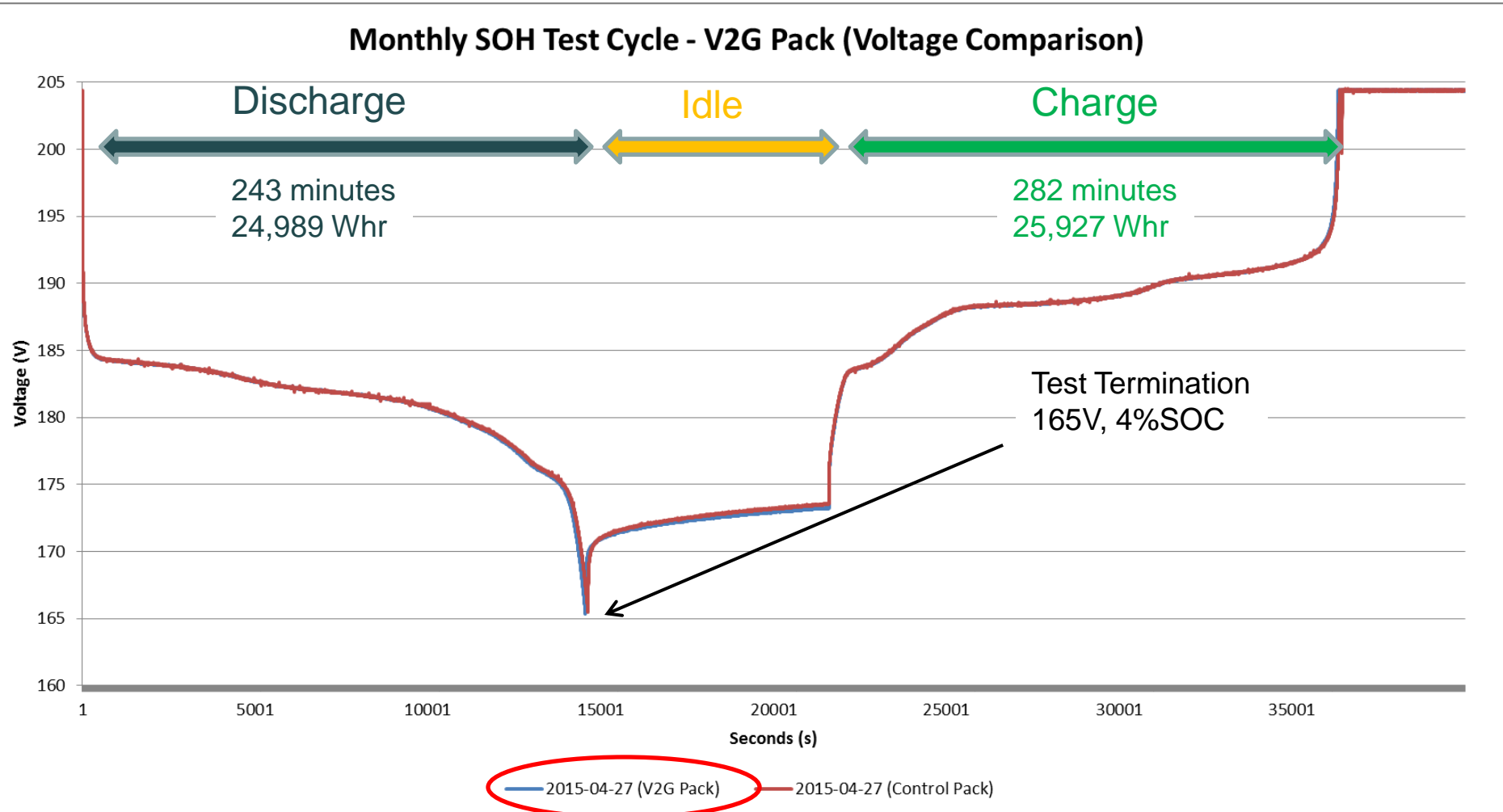
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Laboratory Research and Testing - Monthly SOH Test Cycle Pack Voltage Comparison – Both Packs

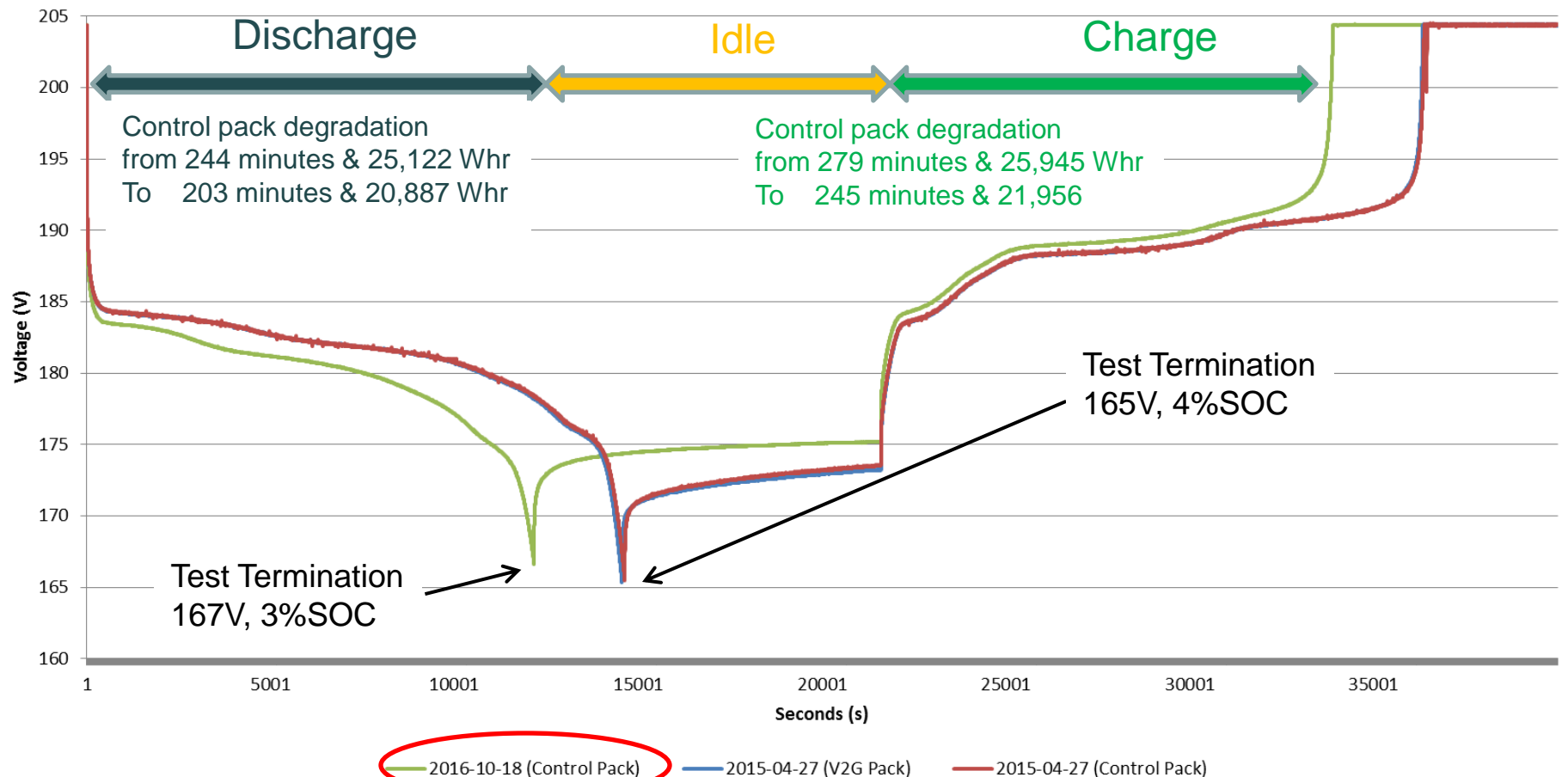


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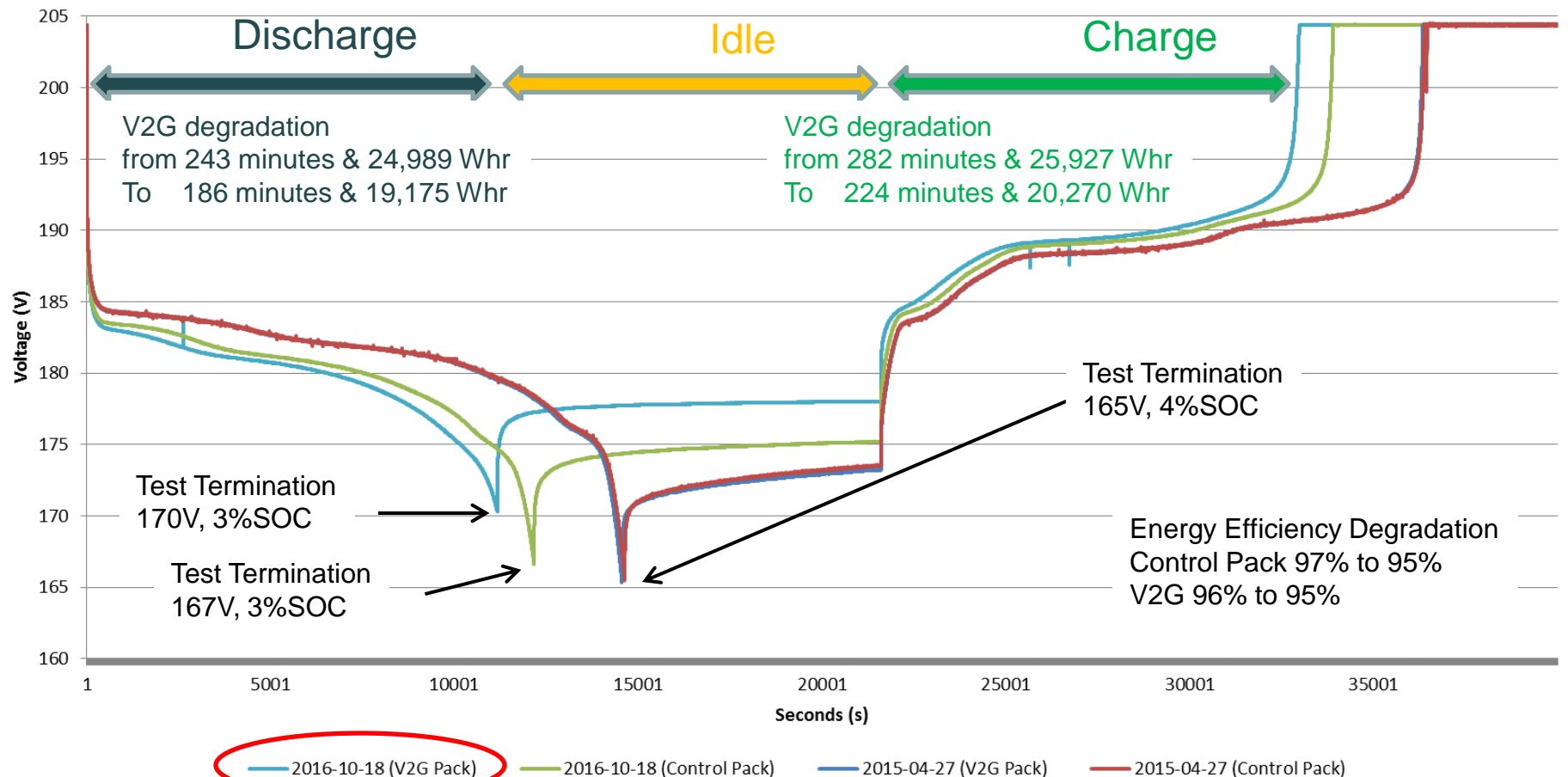
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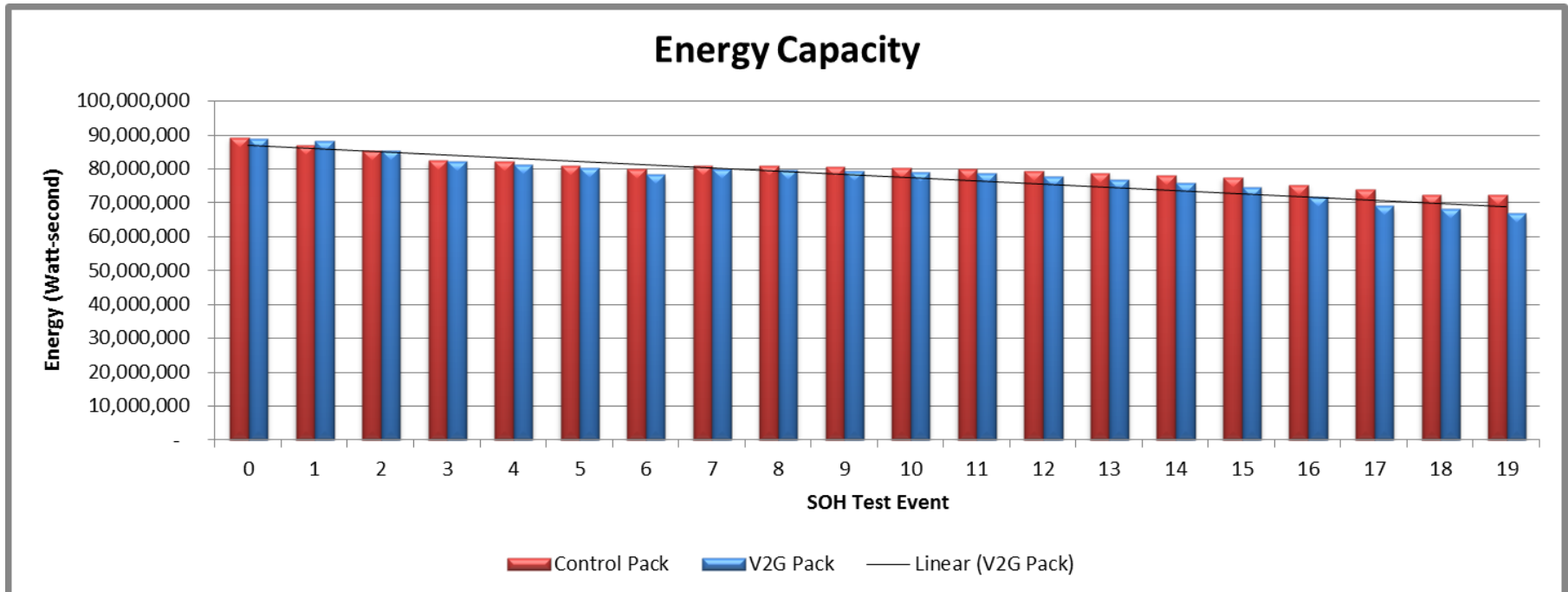
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Monthly SOH Test Cycle - V2G Pack (Voltage Comparison)



Laboratory Research and Testing – Preliminary Results

Metric	Control Pack (Driving)	V2G Pack (Driving + V2G)
SOH Temporal Degradation <i>as of 6/13/2016</i>	13%	15%
V2G Degradation <i>as of 6/13/2016</i>	-	2%
SOH Temporal Degradation <i>as of 11/30/2016</i>	19%	25%
V2G Degradation <i>as of 11/30/2016</i>	-	6%
NCC Remaining Capacity (Amp-Hours)	118.0 Ah (86%)	107.3 Ah (78%)
NCC Remaining Capacity (Watt-Hours)	21,271 Wh (86%)	19,358 Wh (78%)



Conclusions

Pack Energy (kWh)			
V2G Pack		Control Pack	
49761	-45959	31565	-28838

Test Date	V2G (kWh)	% of Rated Capacity	Control (kWh)	% of Rated Capacity
20161114	-19.43	78.6%	-21.30	86.1%
20170101	-18.42	74.5%	-20.69	83.7%
20170102	-18.45	74.6%	-20.73	83.8%

- V2G pack saw 1.6 times the kWh than the control pack.
- V2G pack had 9.2% less of rated capacity than the control pack.
- Continue quantifying cycles, DOD, temperature, etc.
- V2G doesn't significantly degrade battery capacity based on this testing.

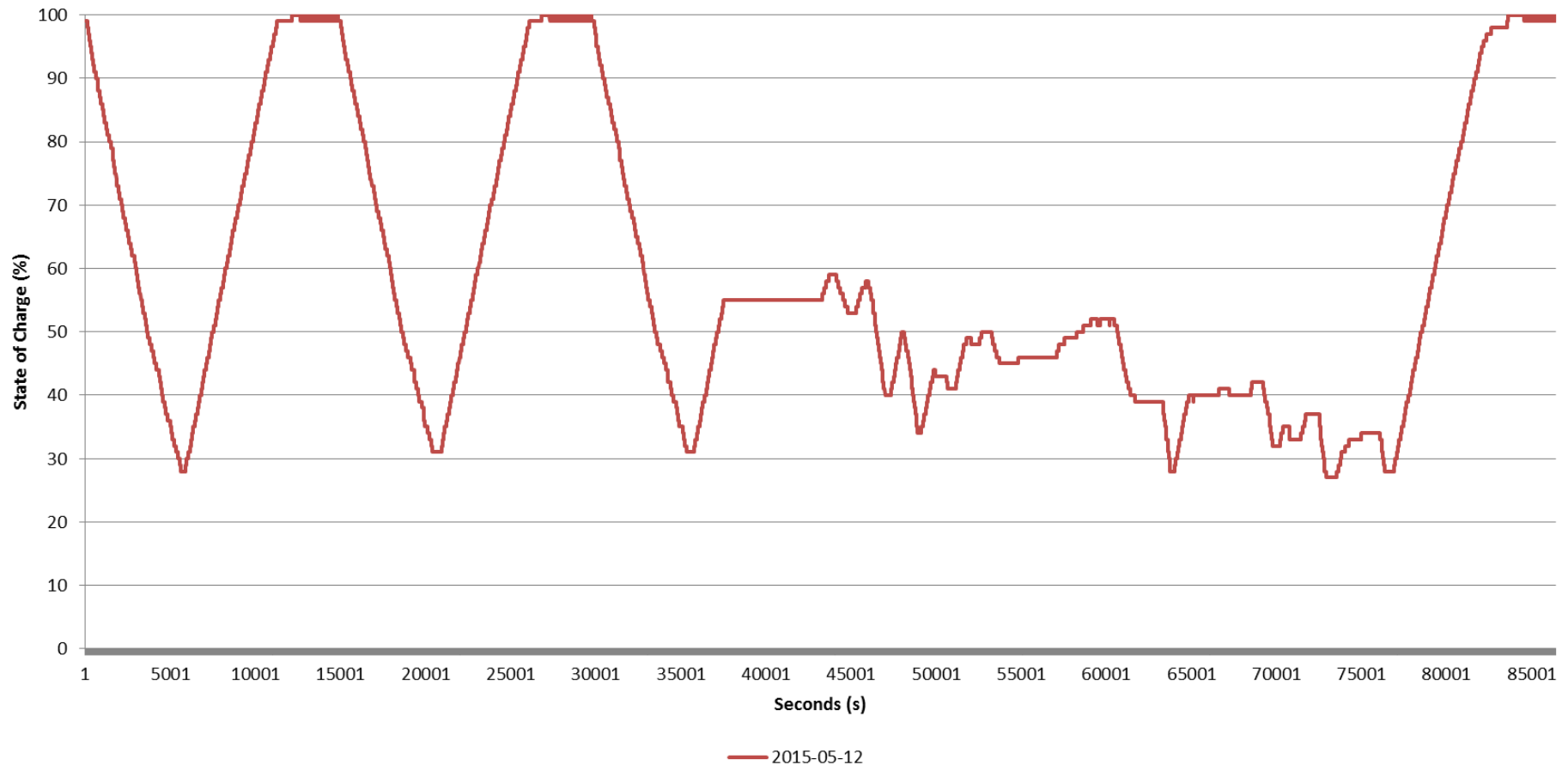
Backup Slides

Task 5: Perform Laboratory Research and Testing

- Selected Timed Sequence Daily Standard Test Cycle
SOC Comparison – V2G Pack

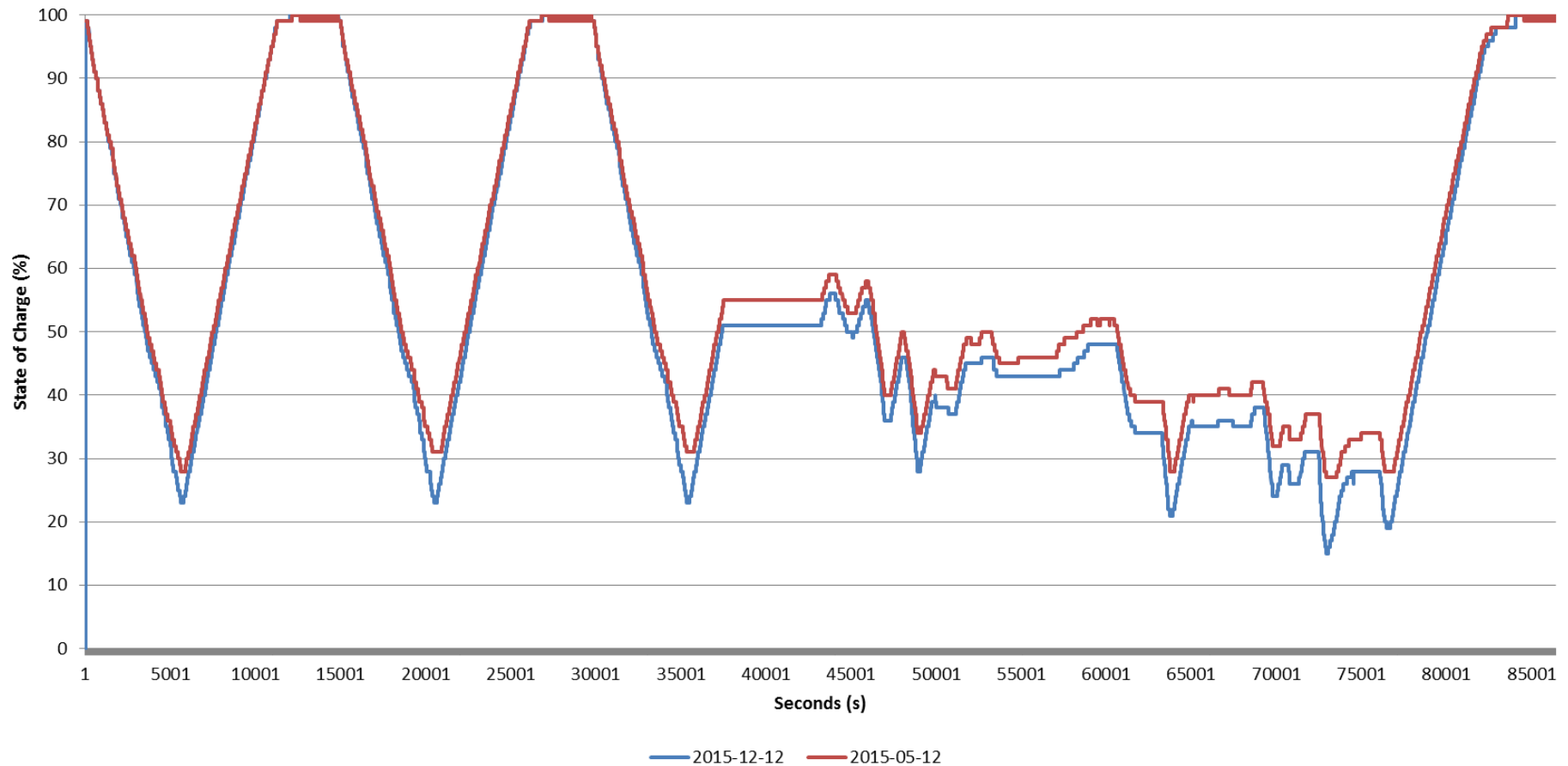
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Daily Standard Test Cycle - V2G Pack (SOC Comparison)



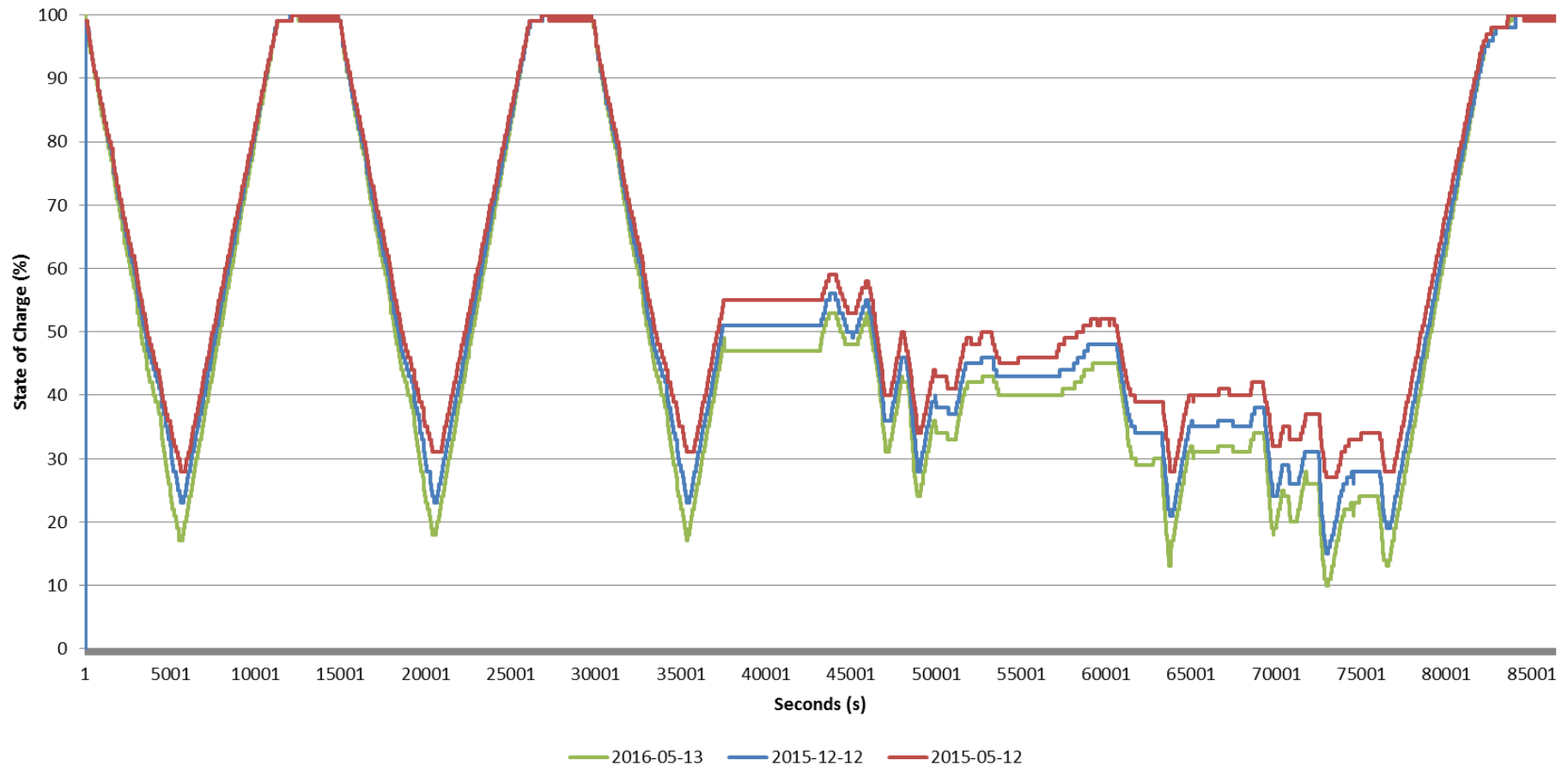
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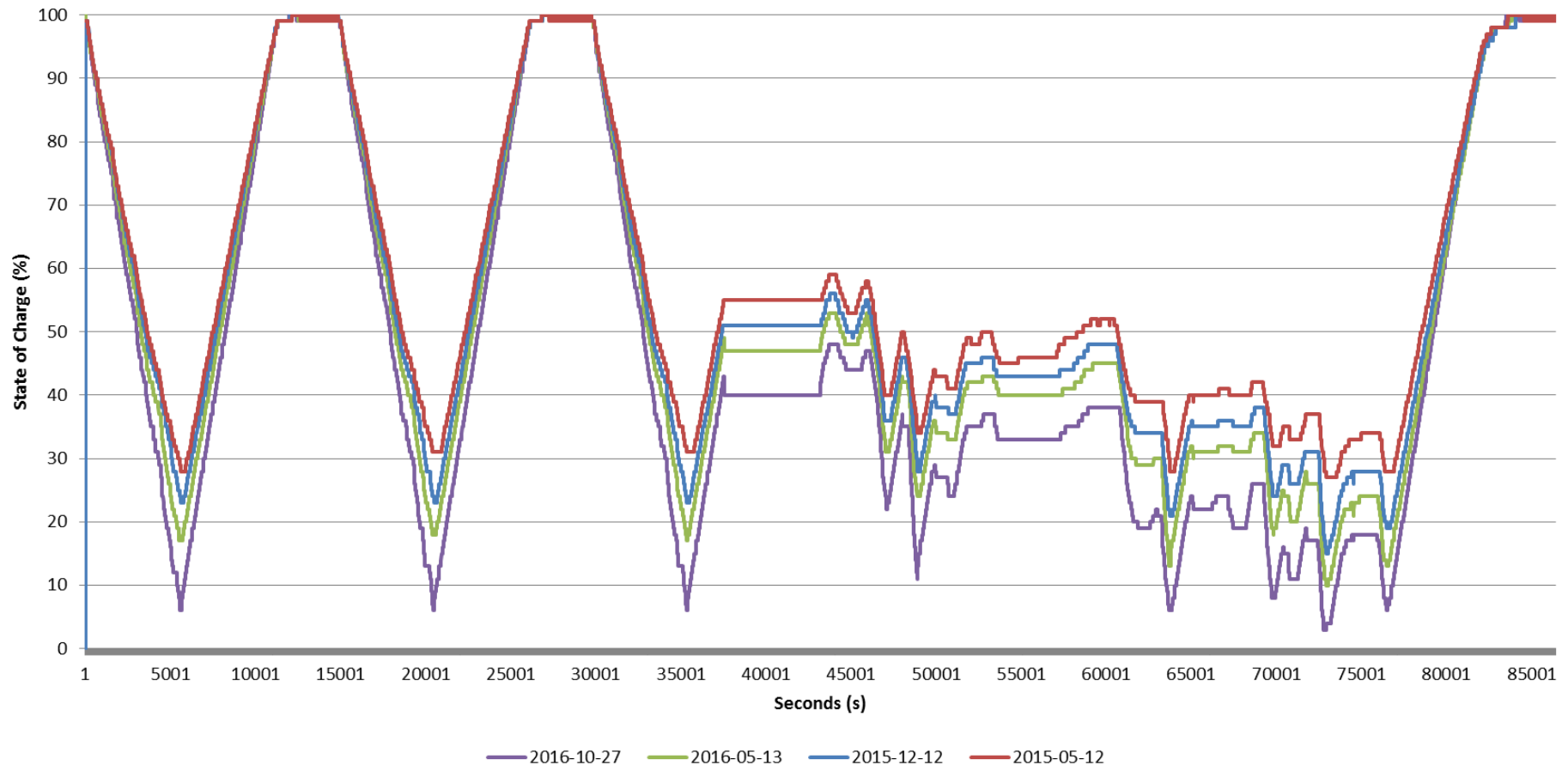
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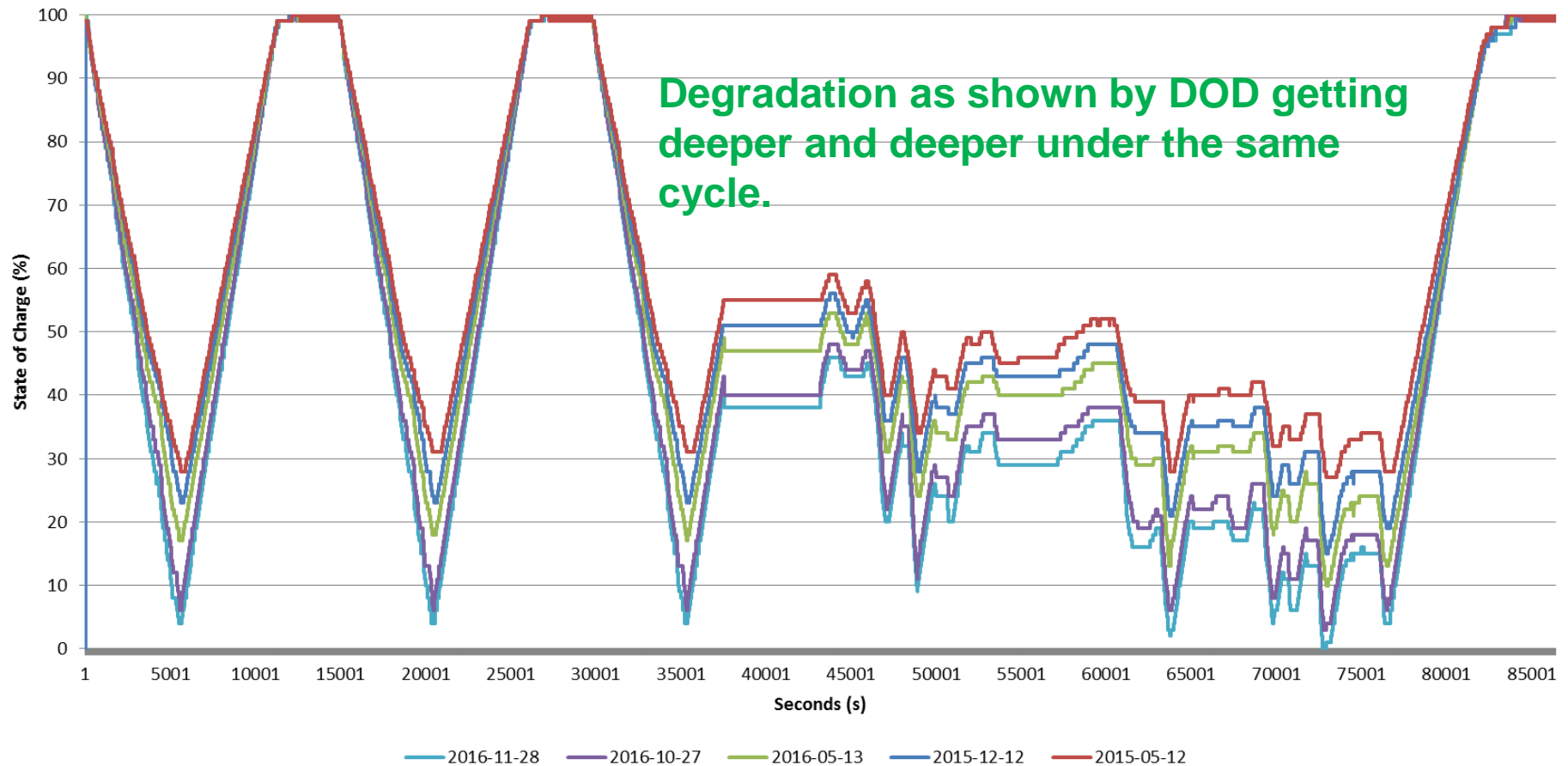
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Daily Standard Test Cycle - V2G Pack (SOC Comparison)



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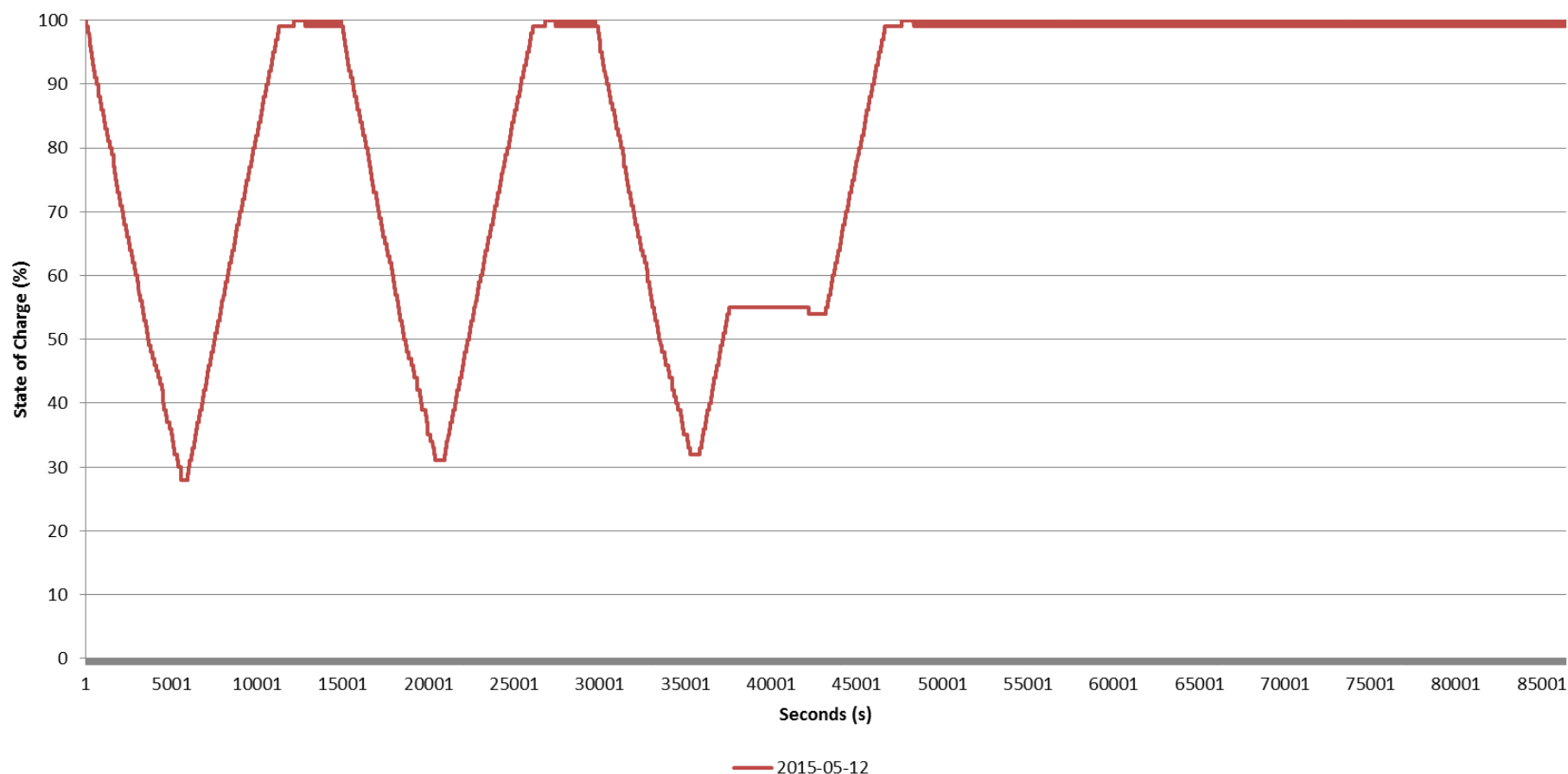


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SOC Comparison – Control Pack

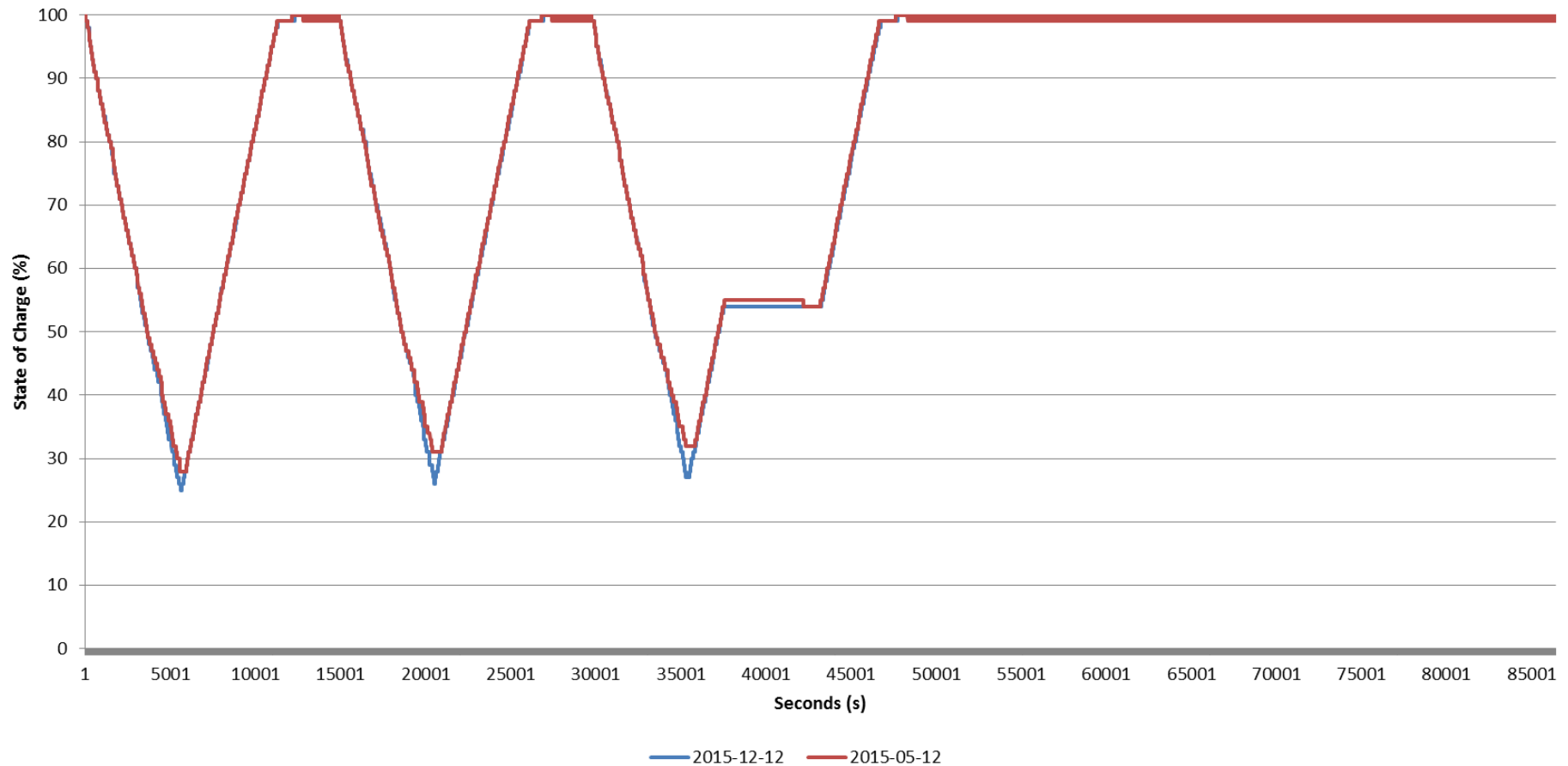
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Daily Standard Test Cycle - Control Pack (SOC Comparison)



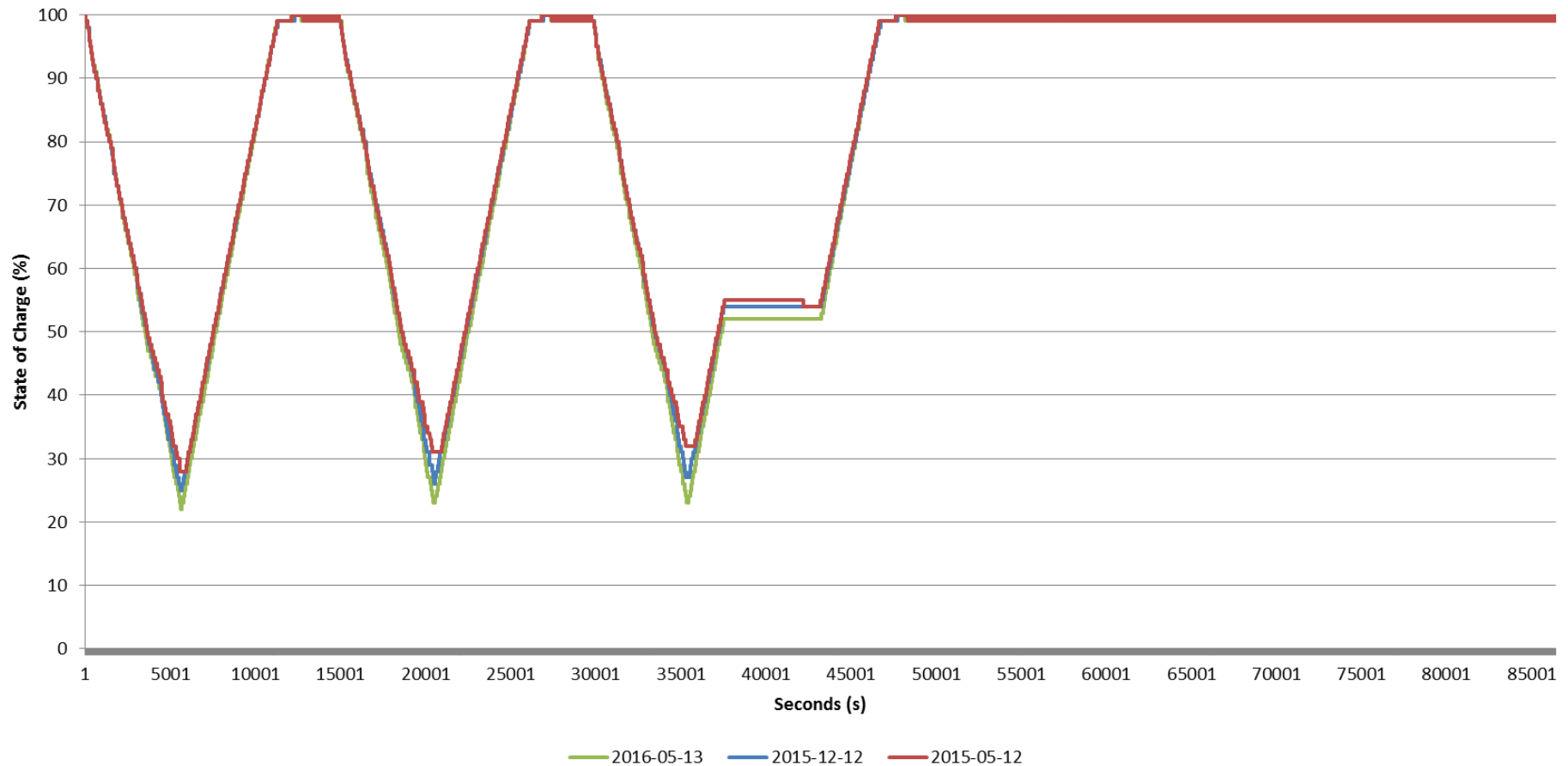
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Daily Standard Test Cycle - Control Pack (SOC Comparison)



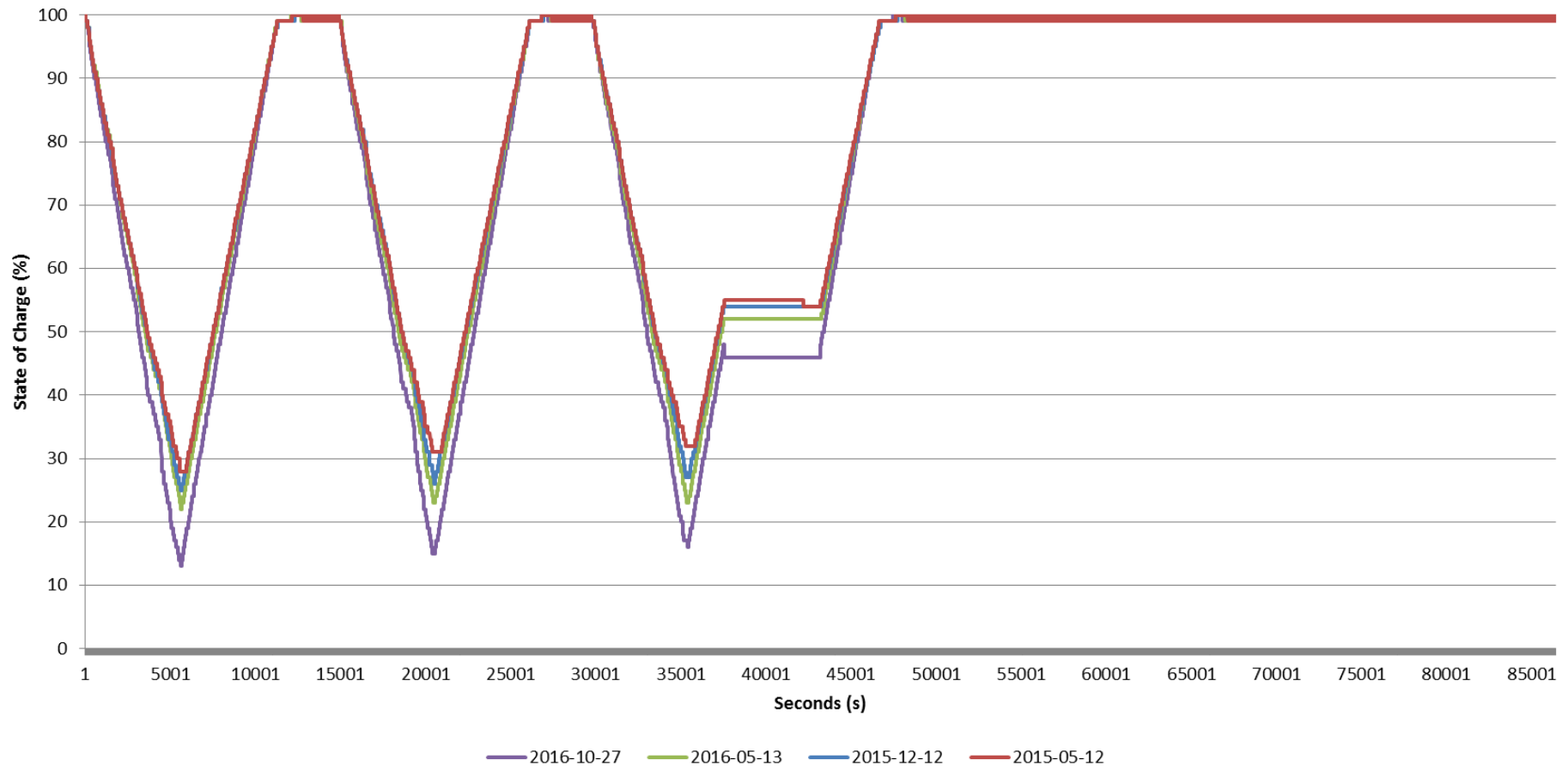
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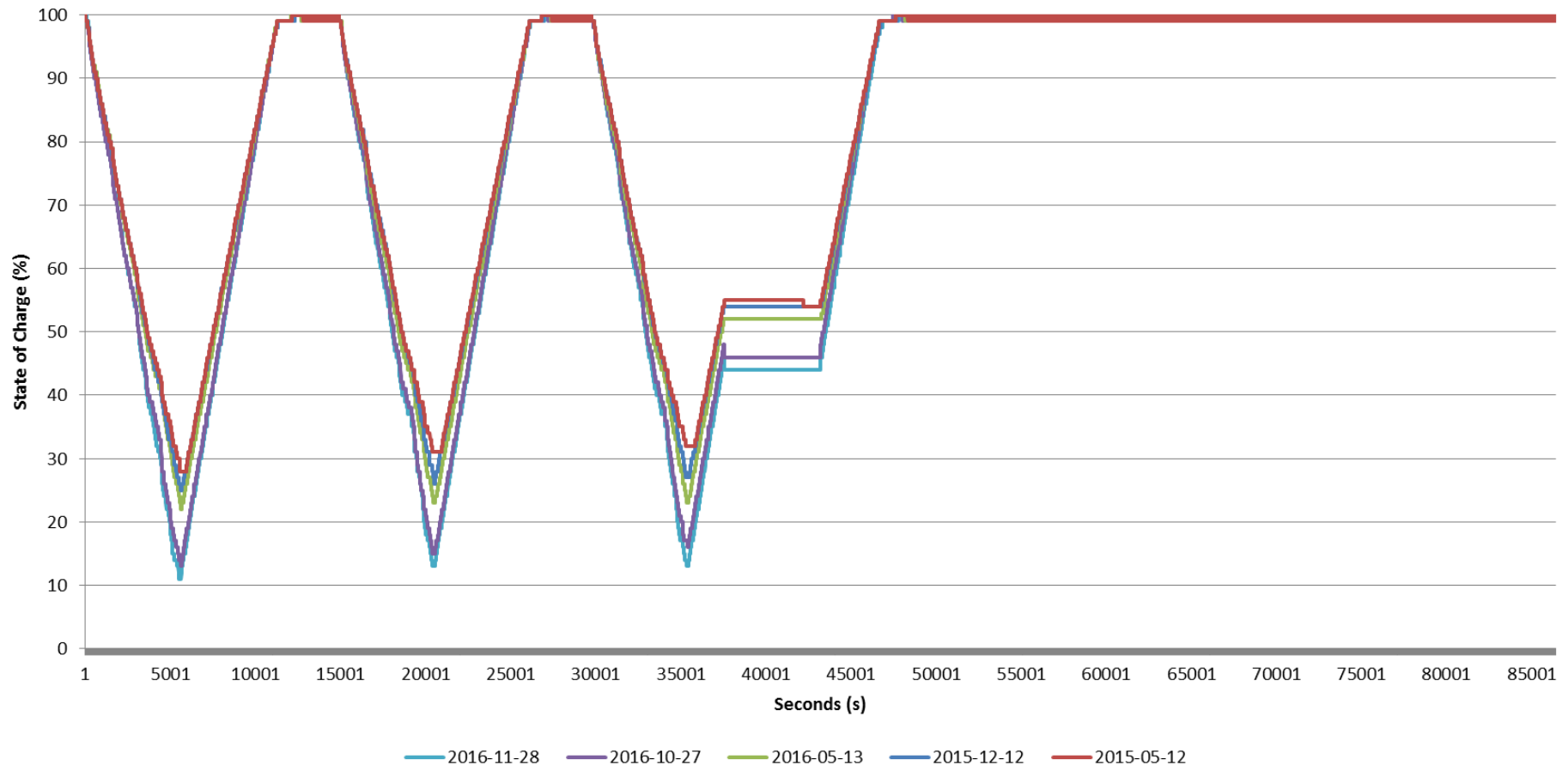
Daily Standard Test Cycle - Control Pack (SOC Comparison)



Task 5: Perform Laboratory Research and Testing - Daily Standard Test Cycle

SOC Comparison – Control Pack

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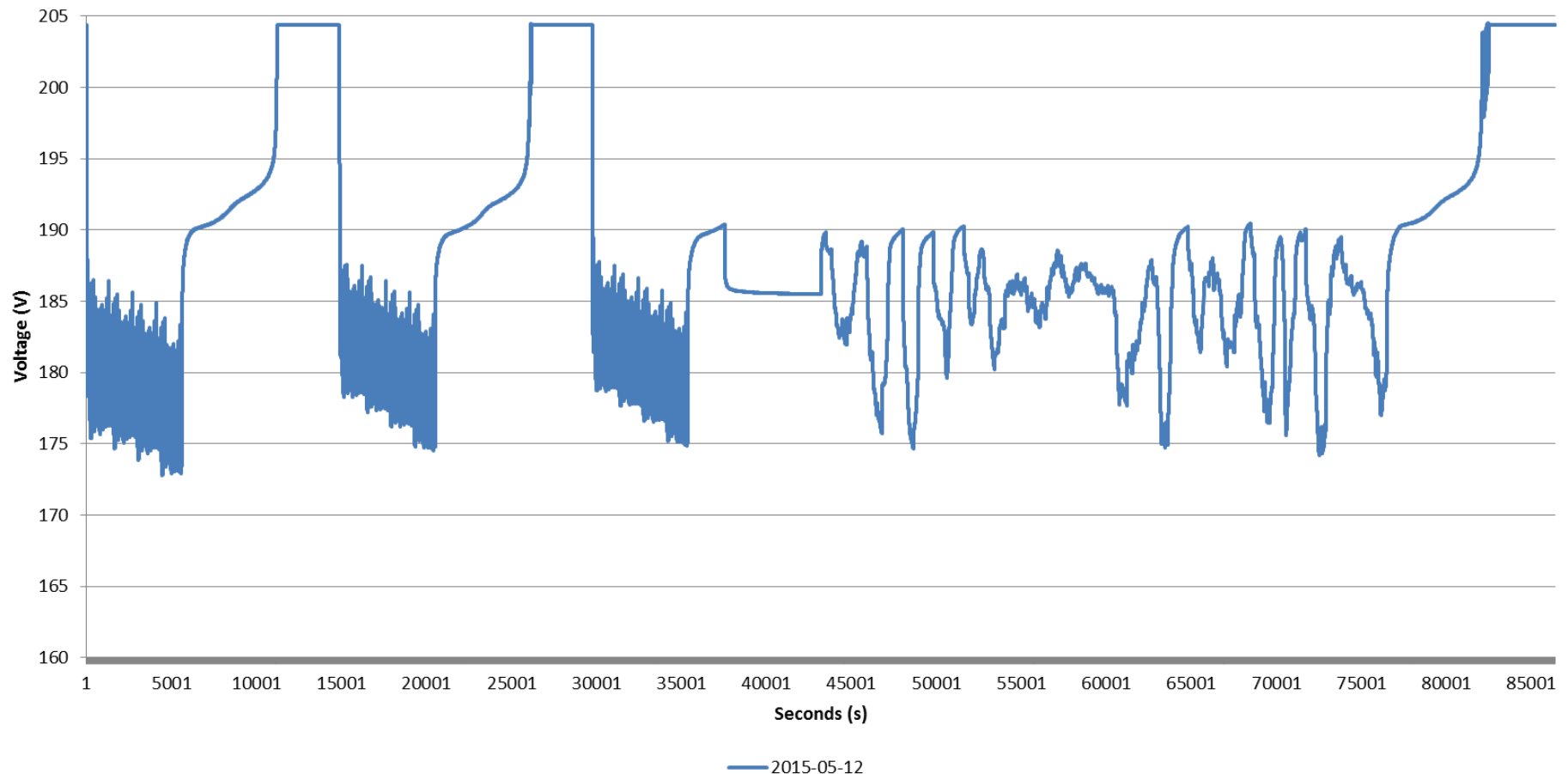


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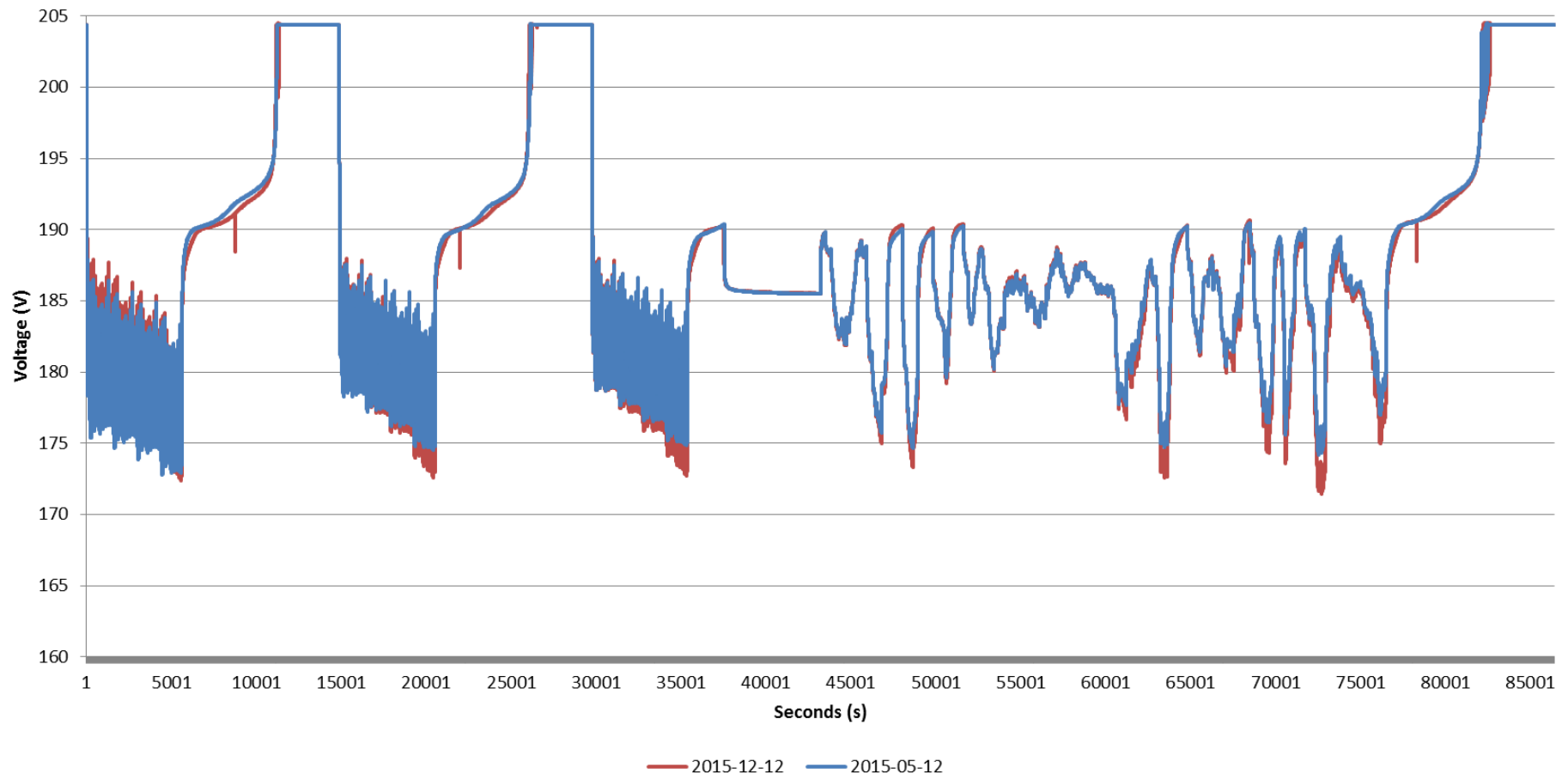
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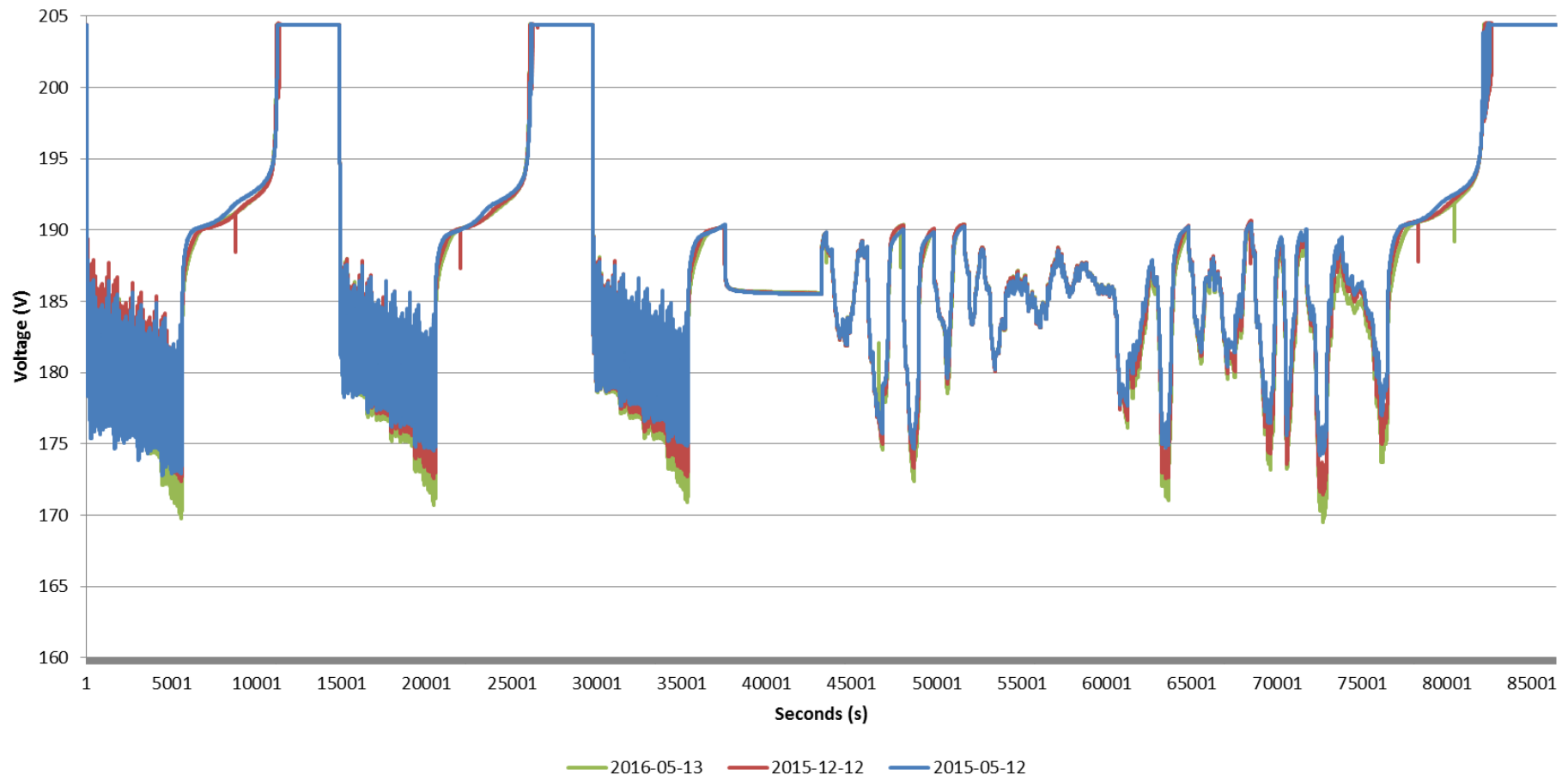
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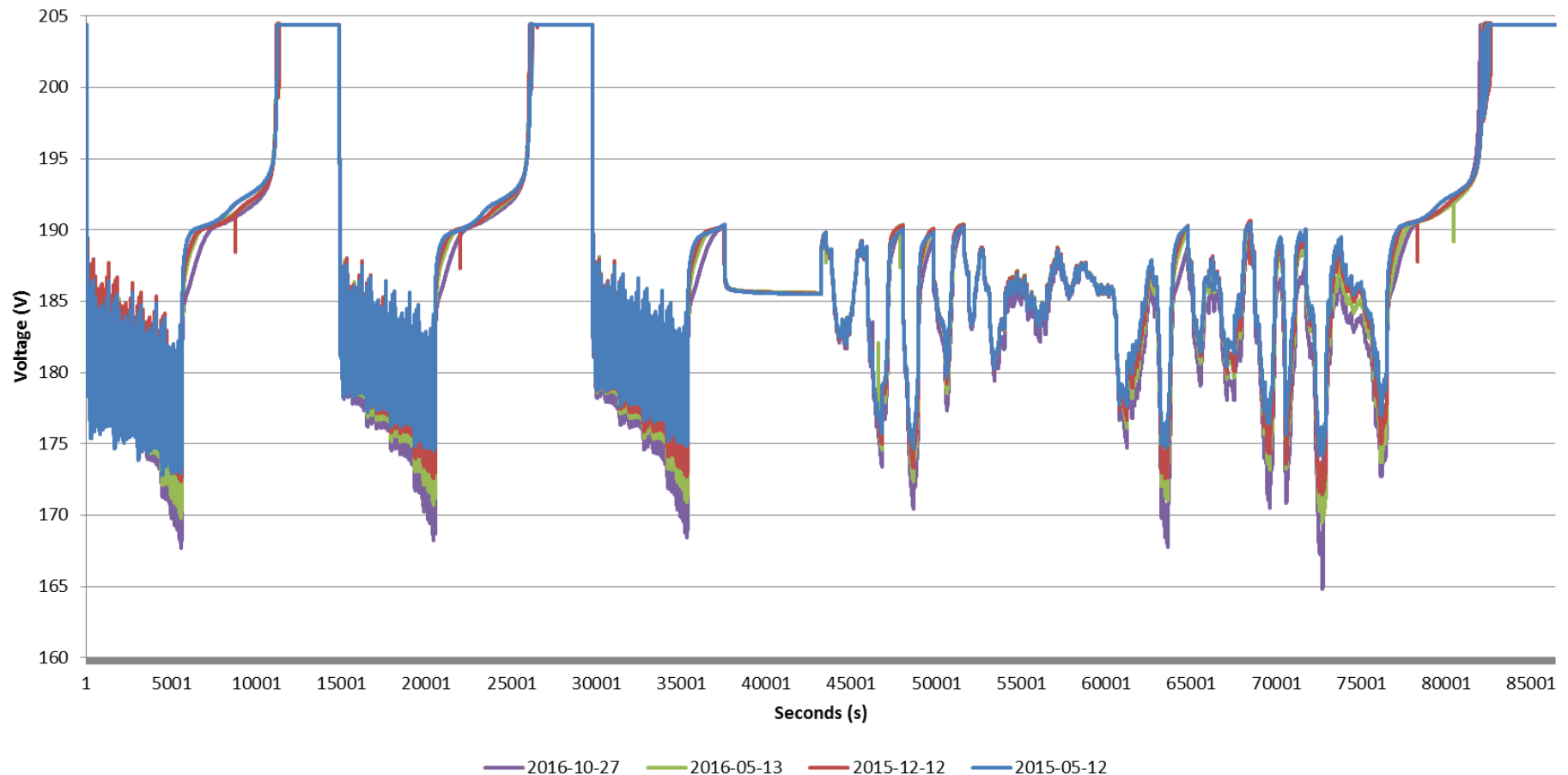
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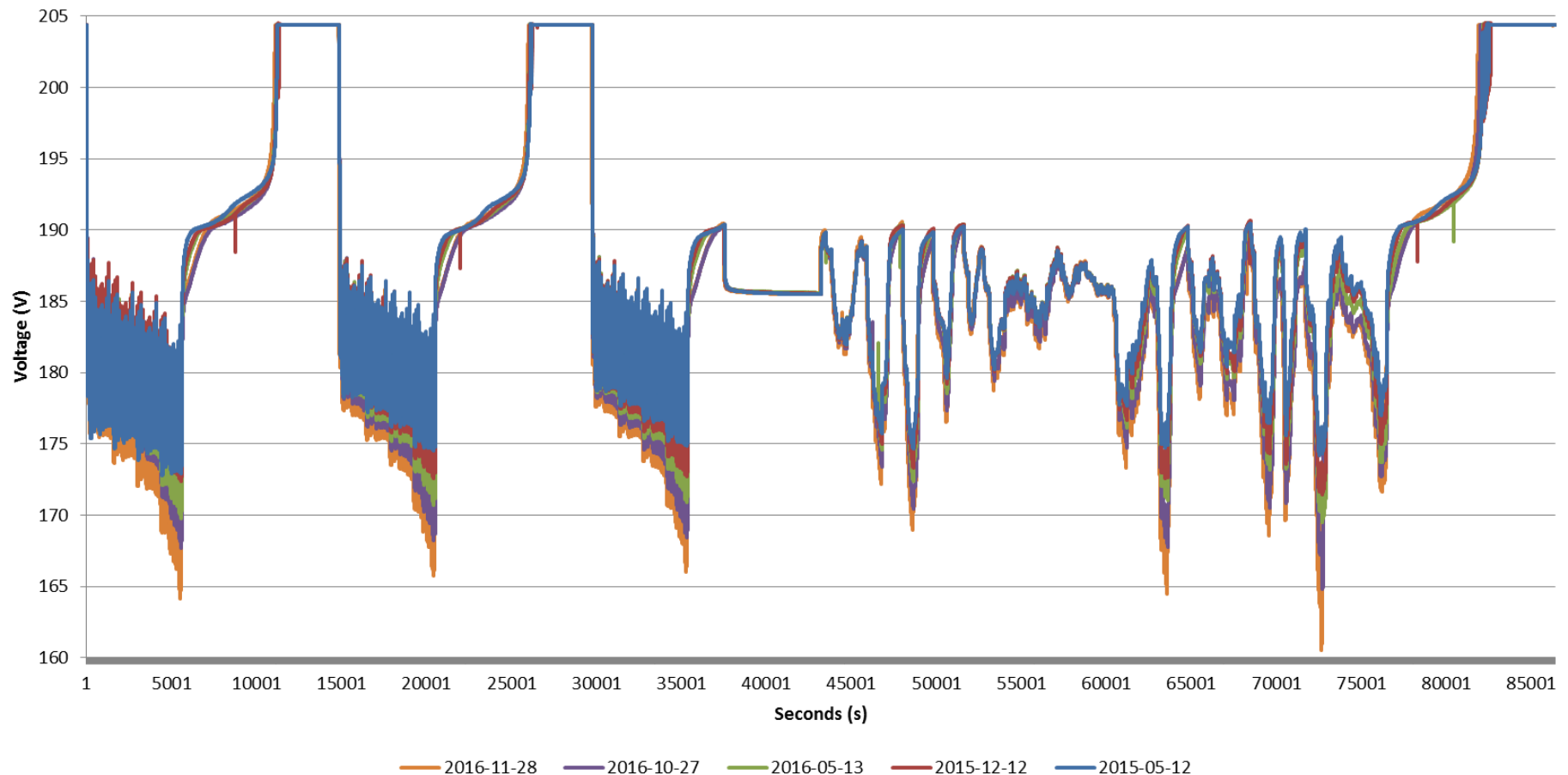
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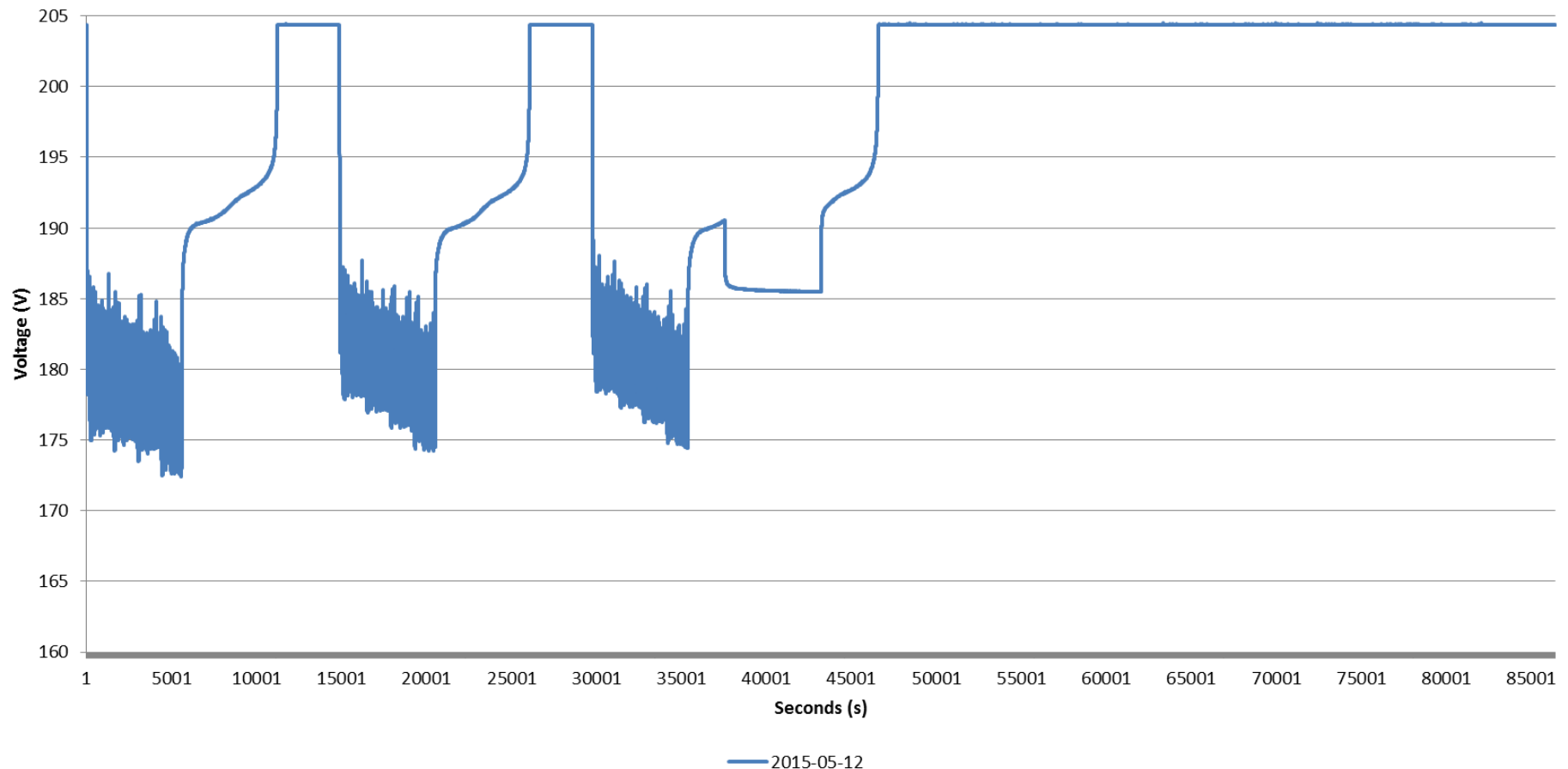


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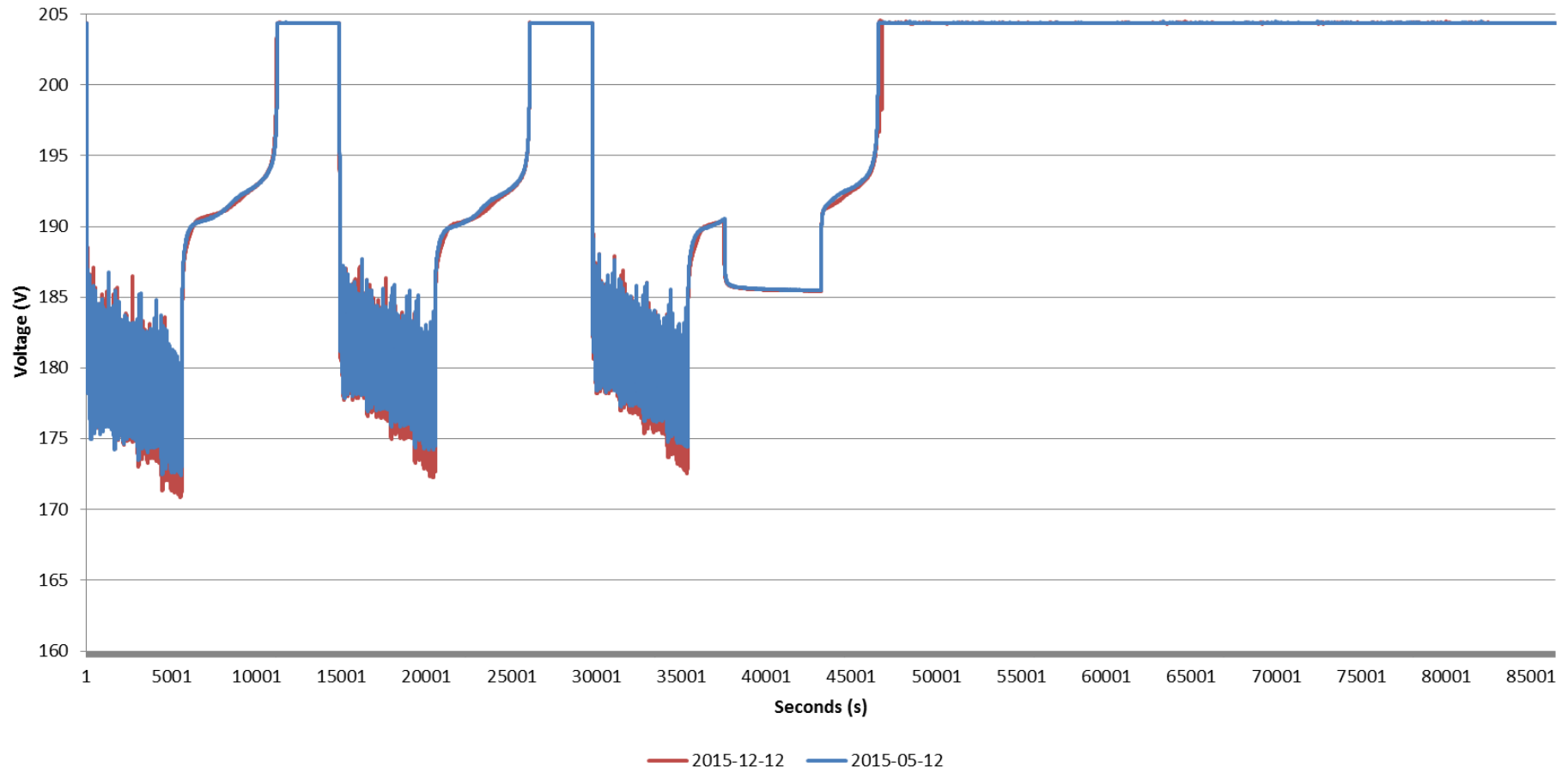
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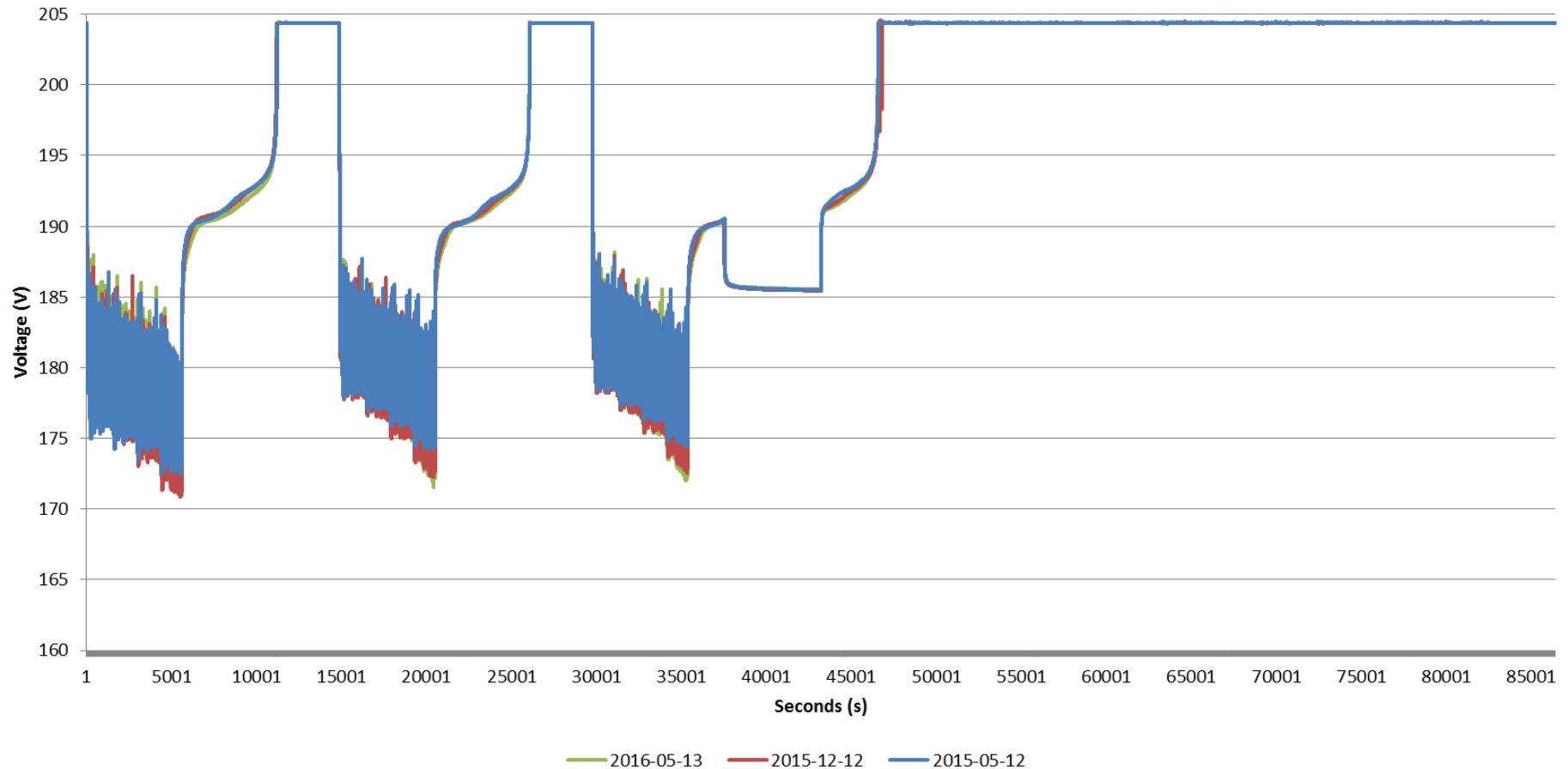
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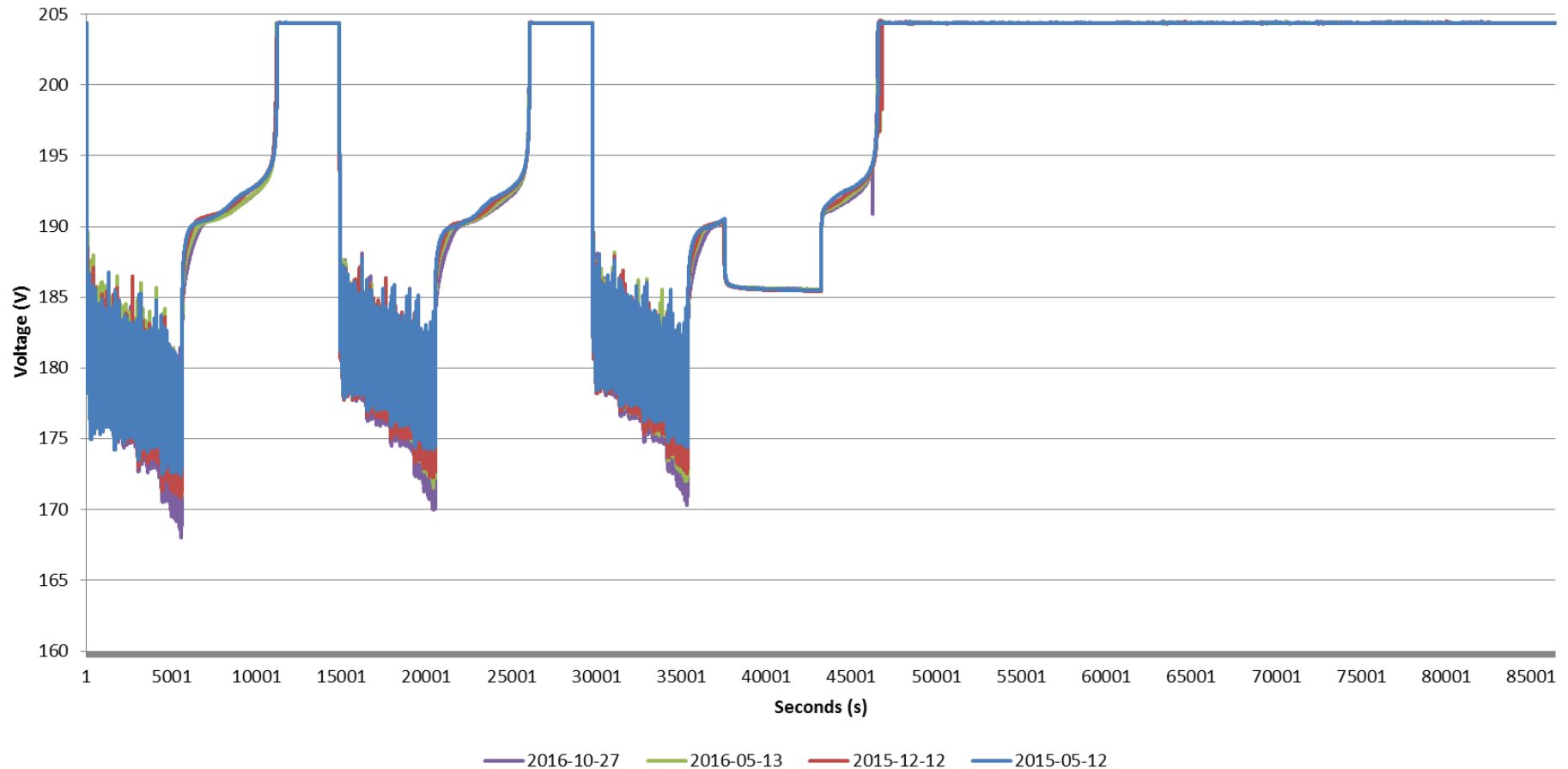
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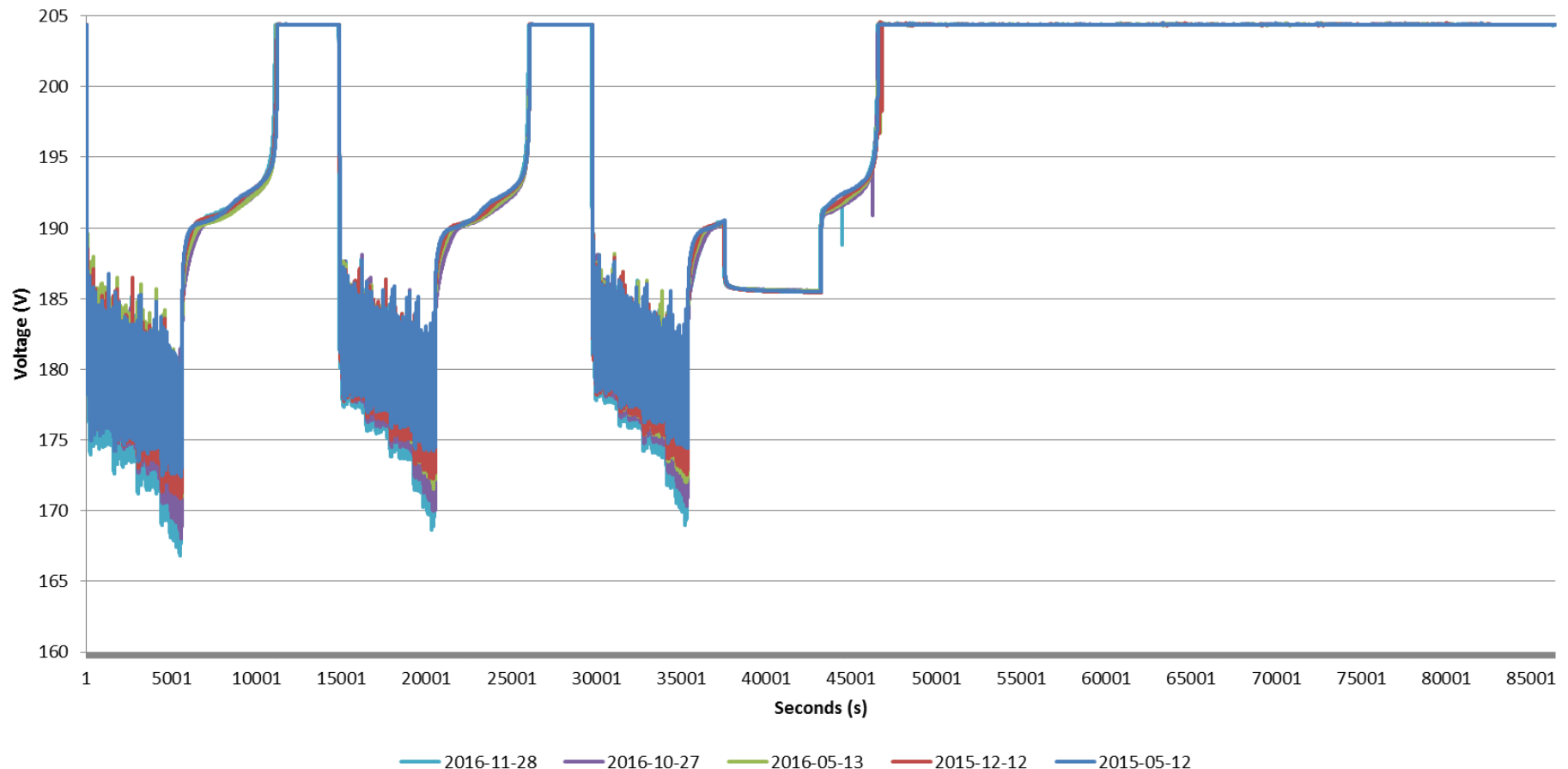
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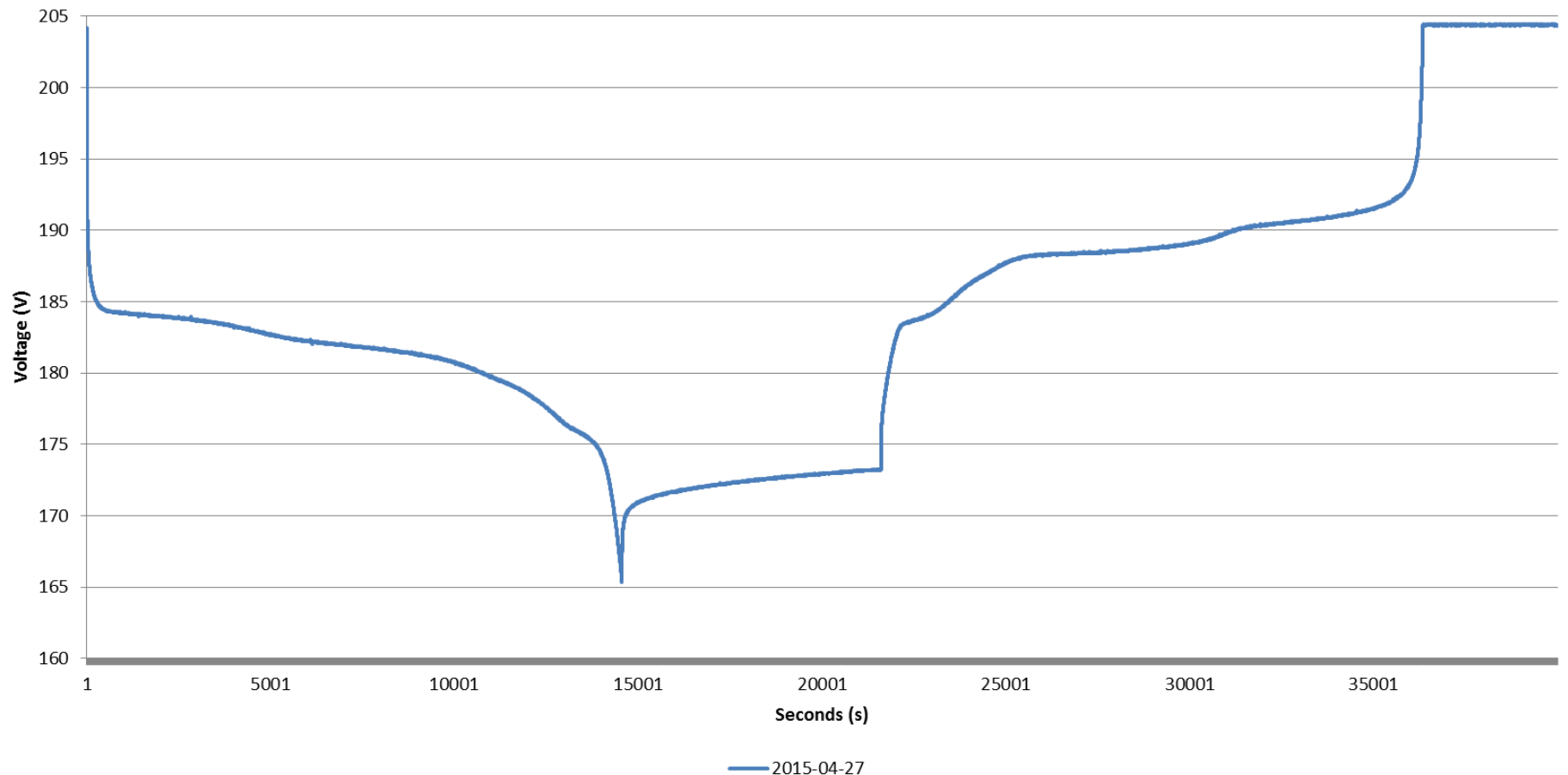
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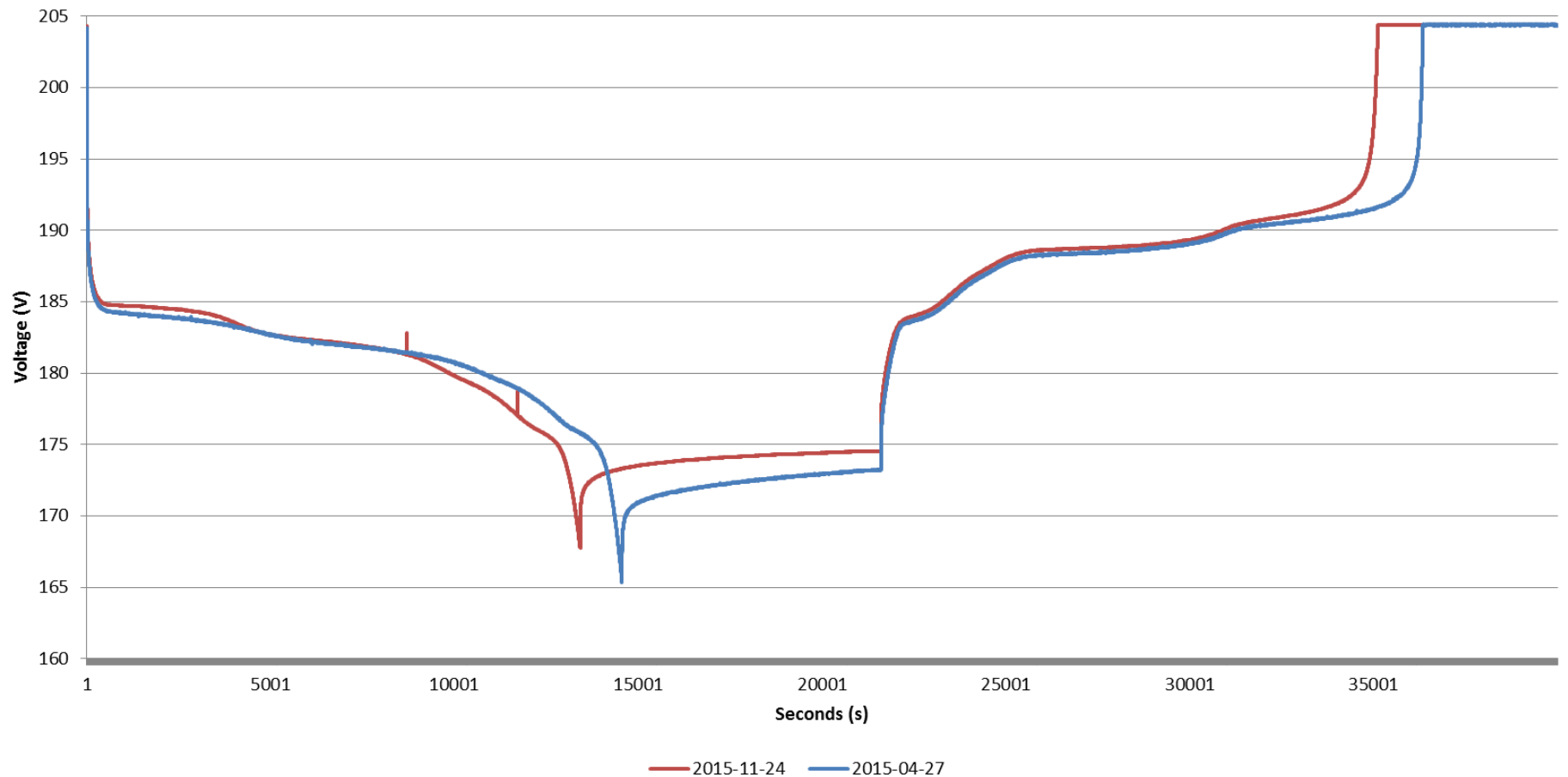
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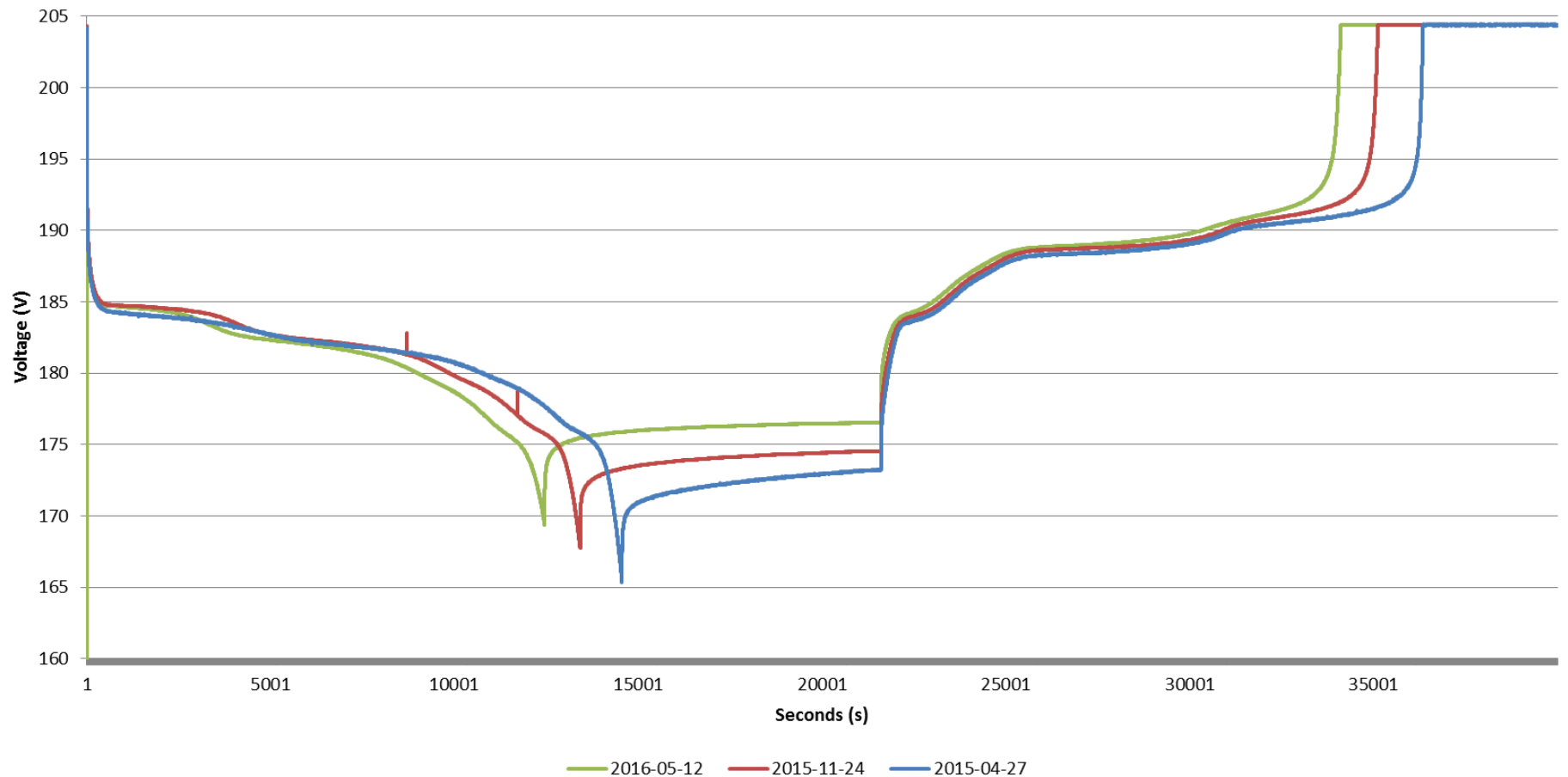
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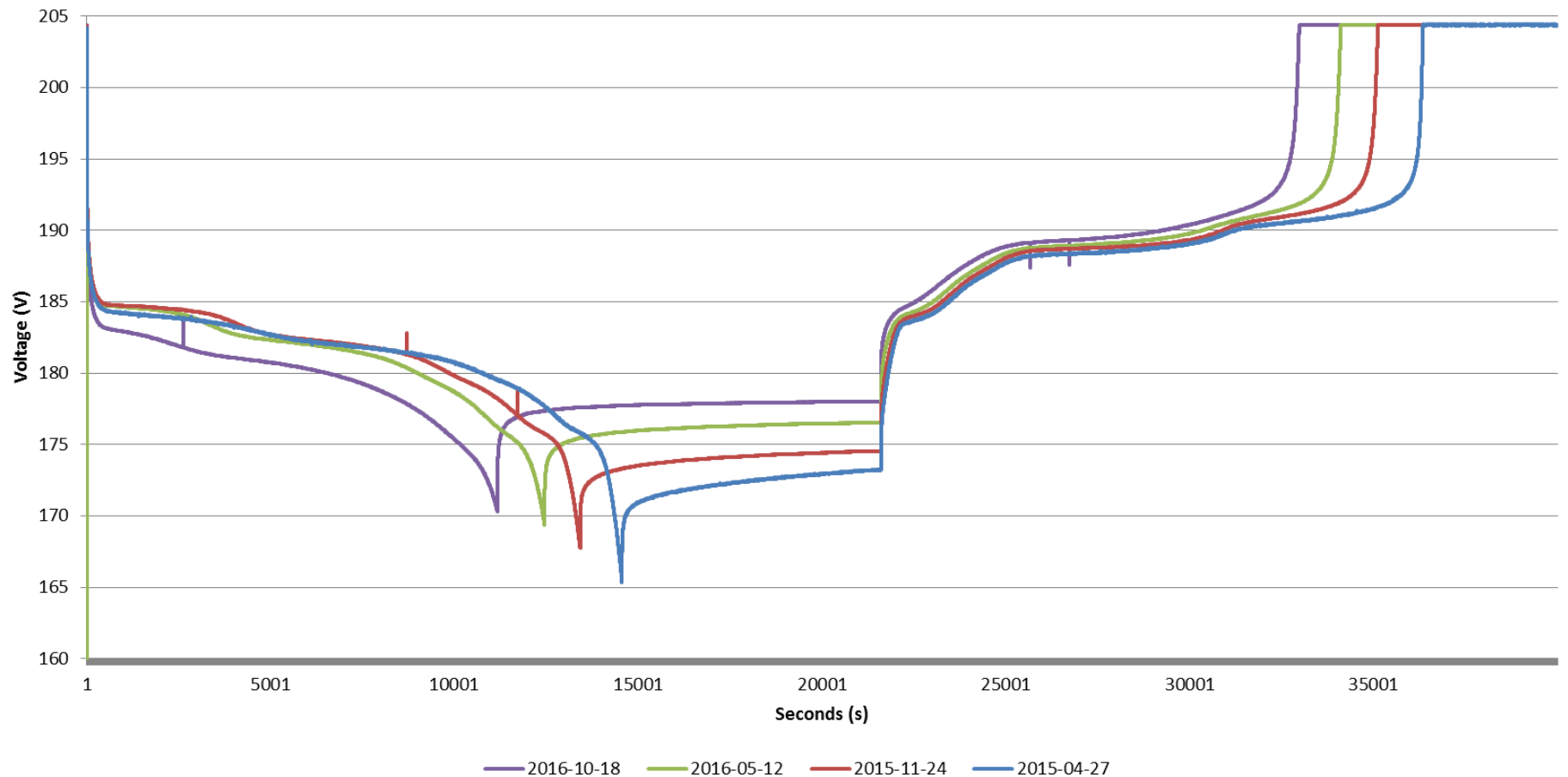
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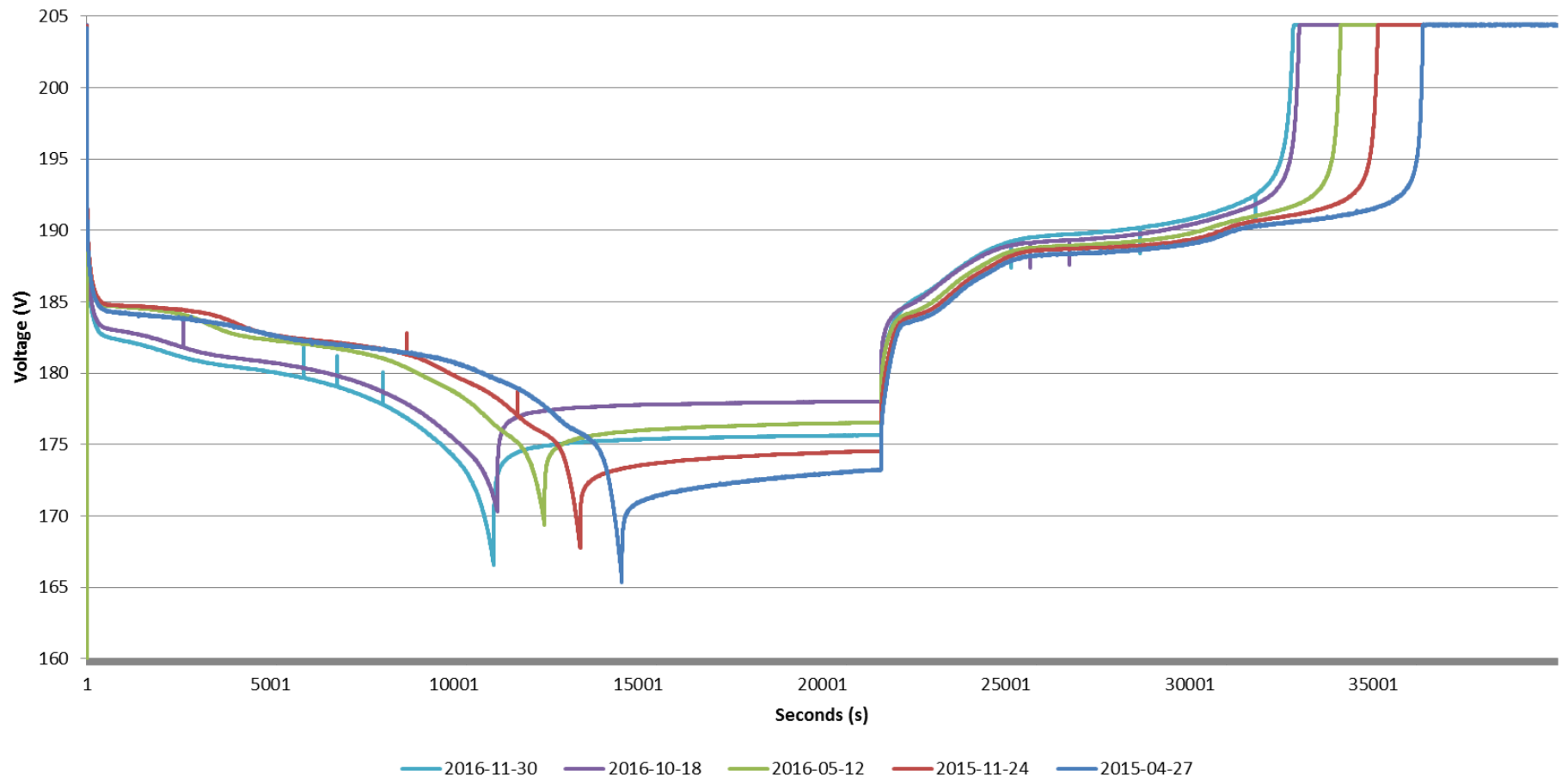
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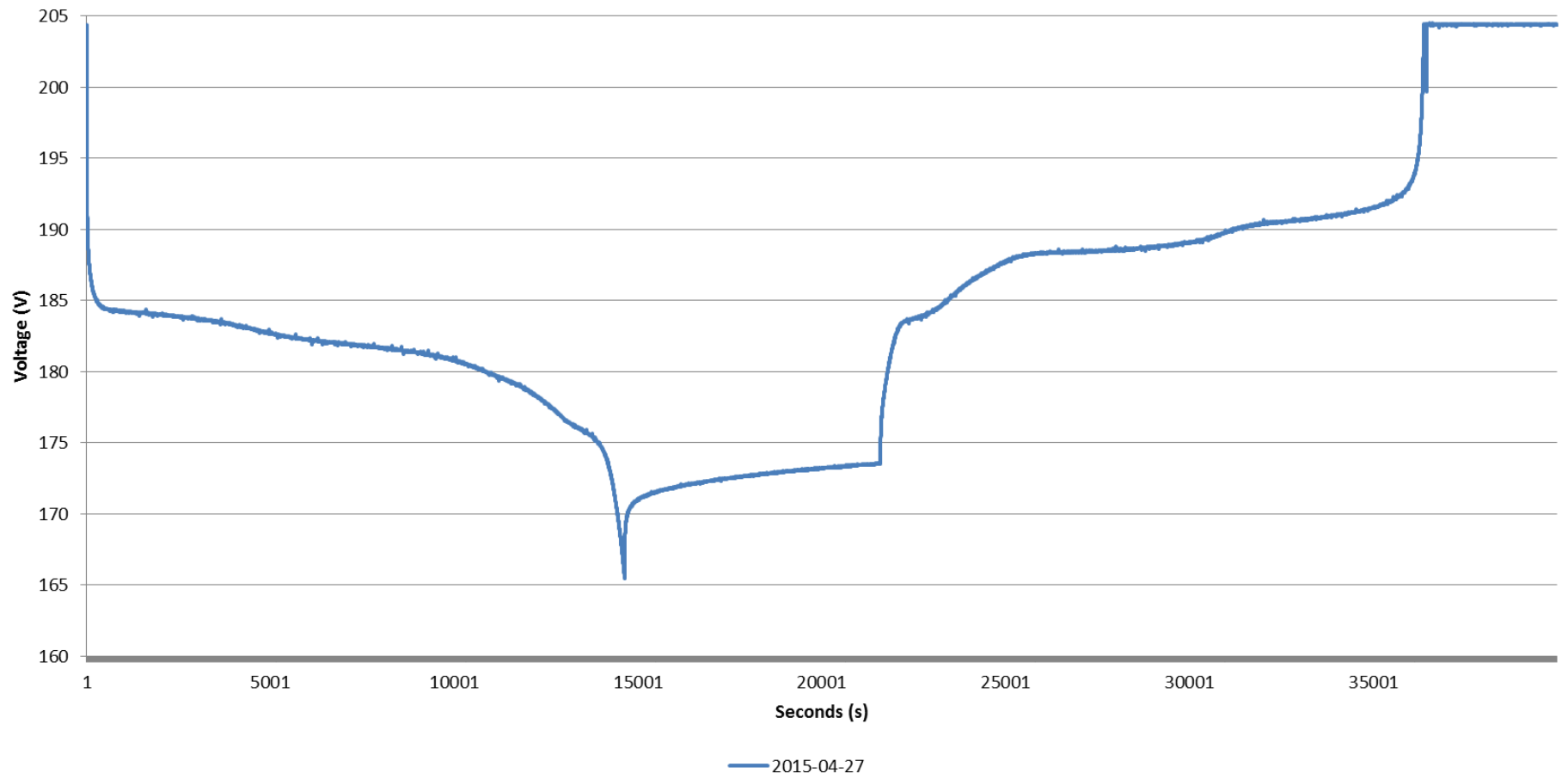
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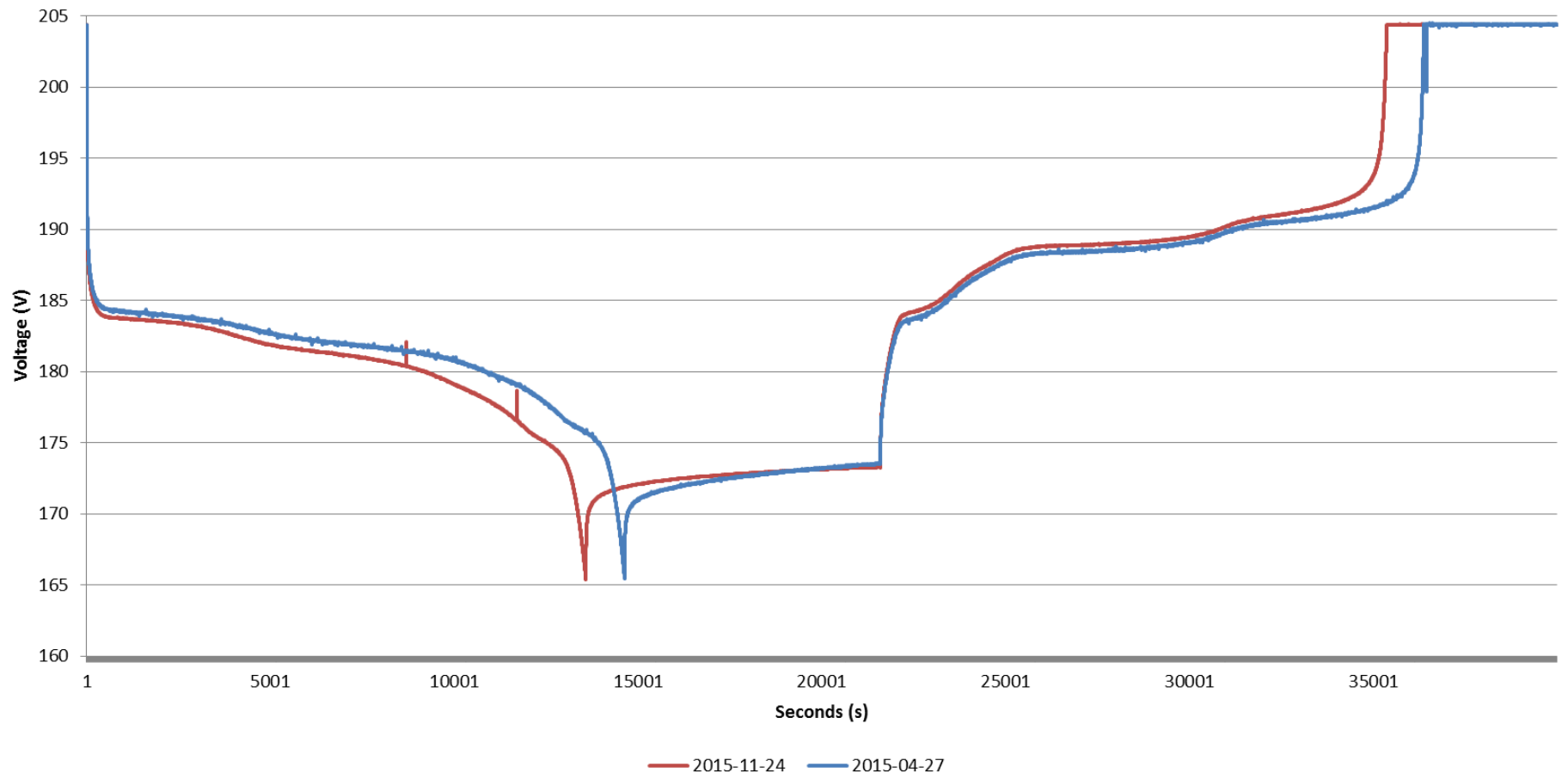
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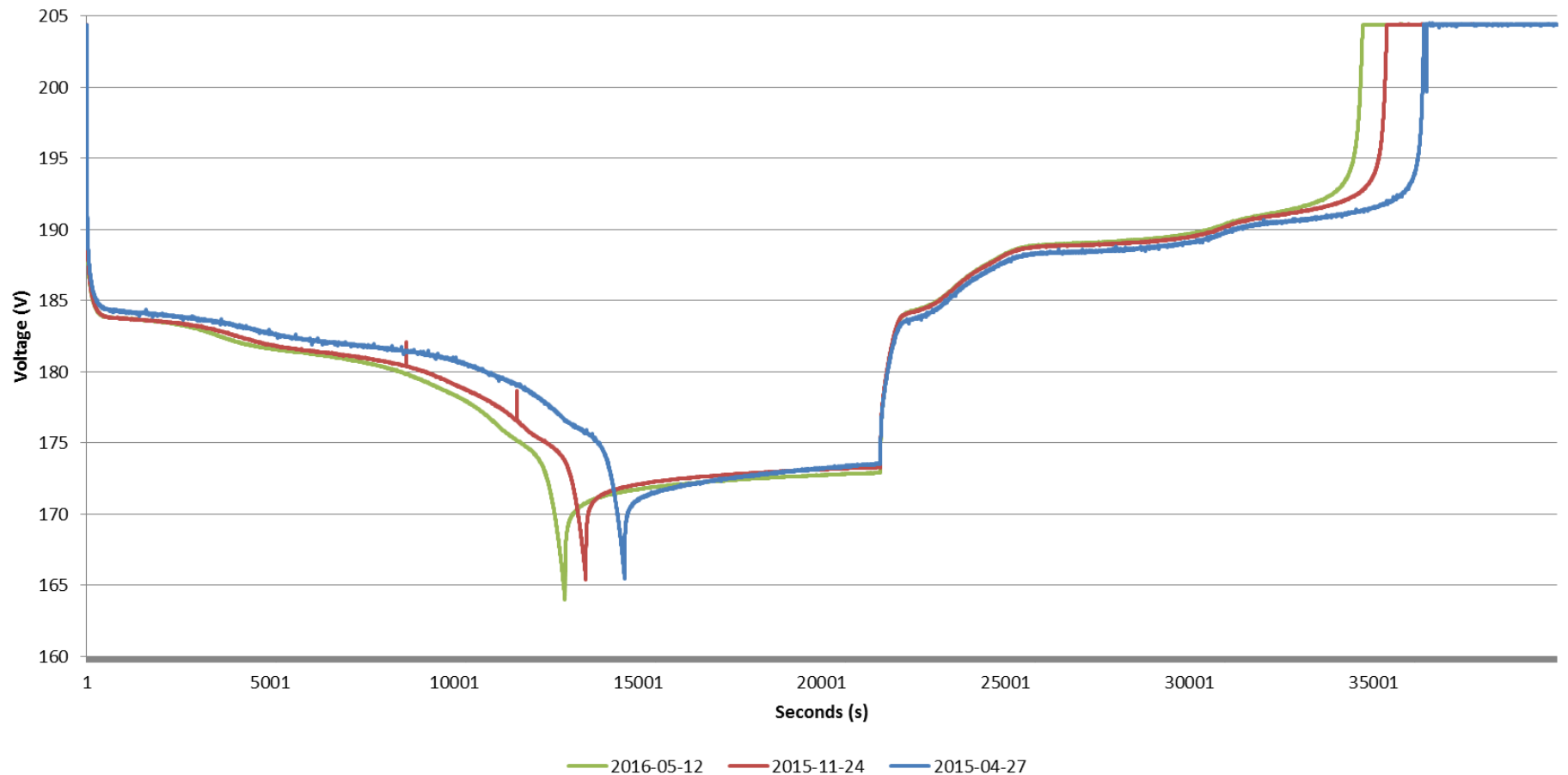
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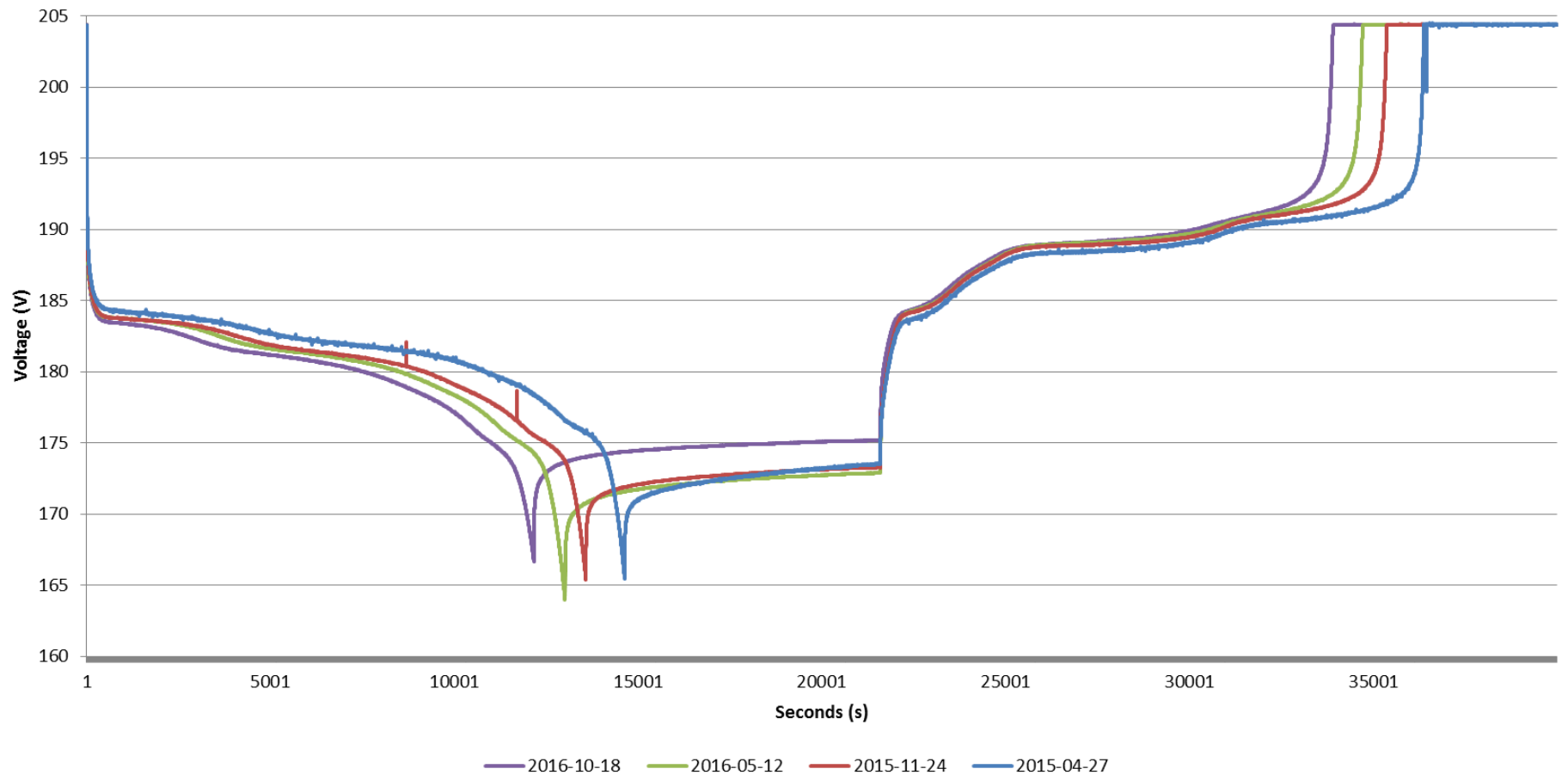
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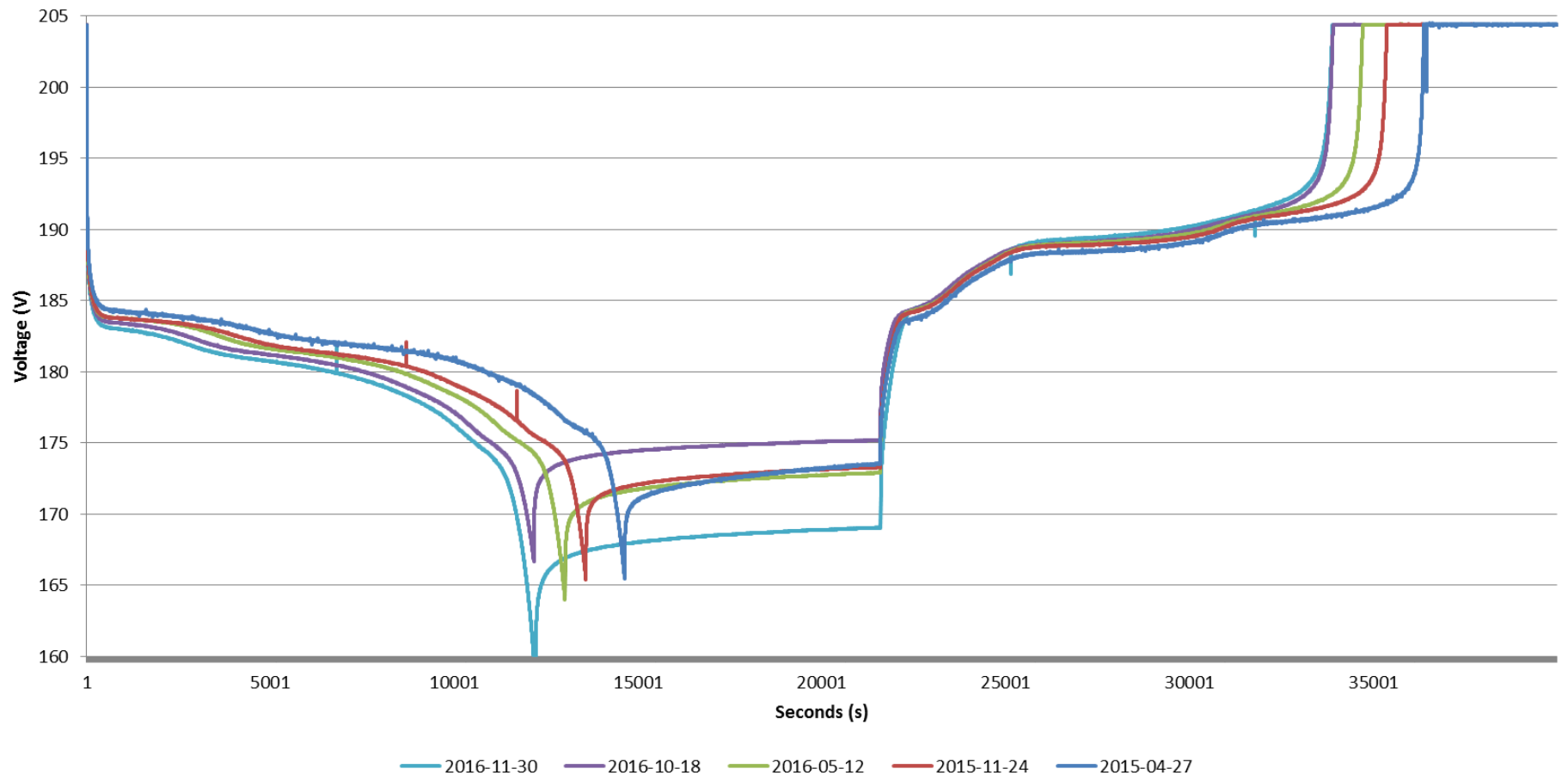
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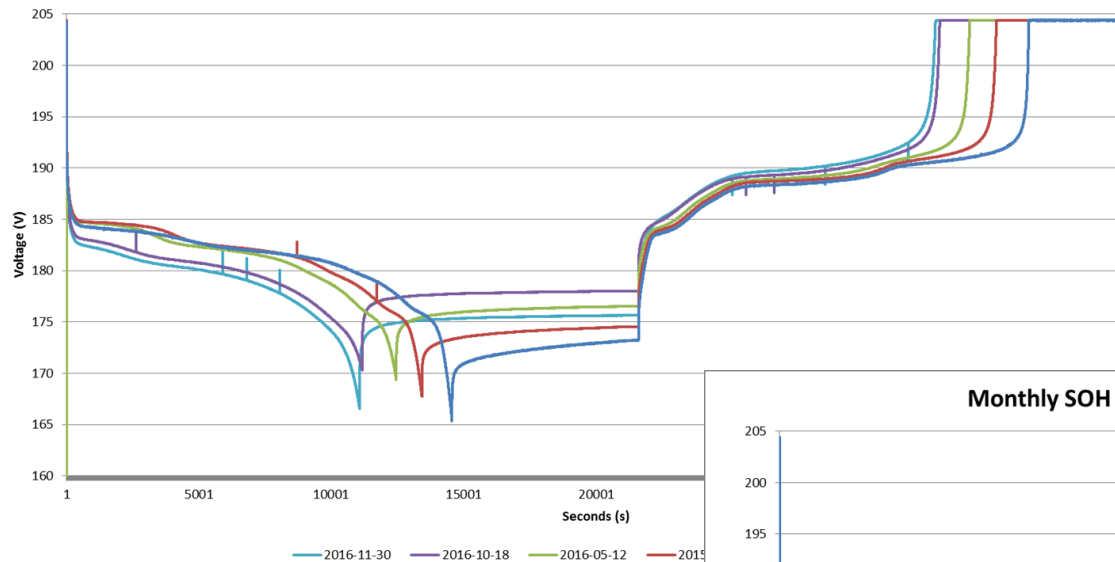
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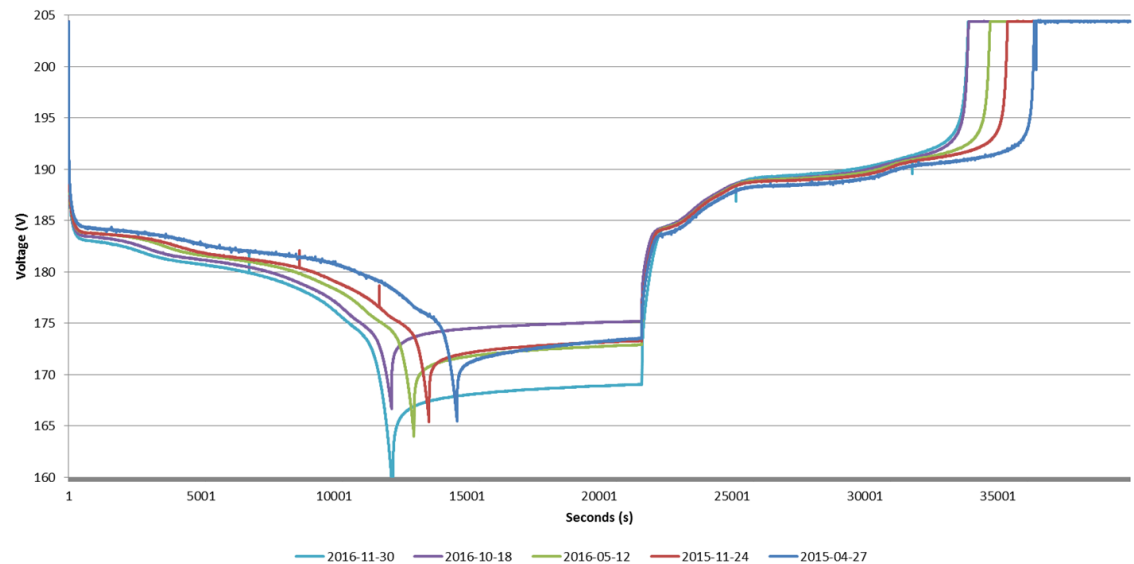


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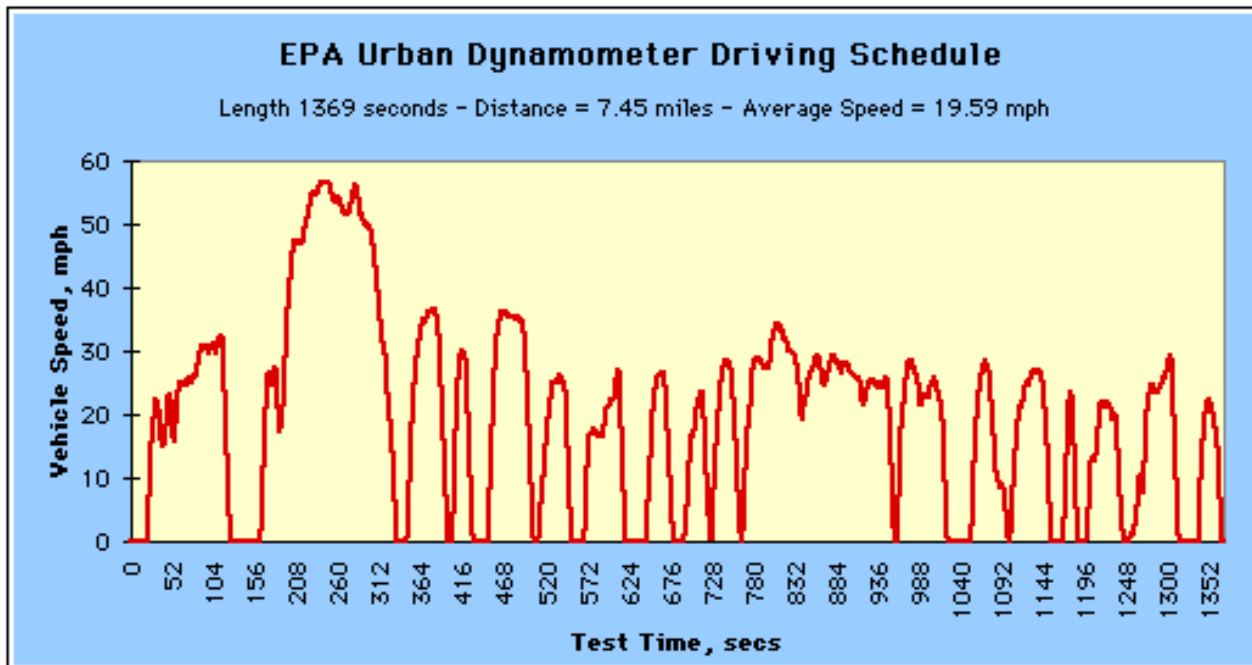


Monthly SOH Test Cycle - Control Pack (Voltage Comparison)



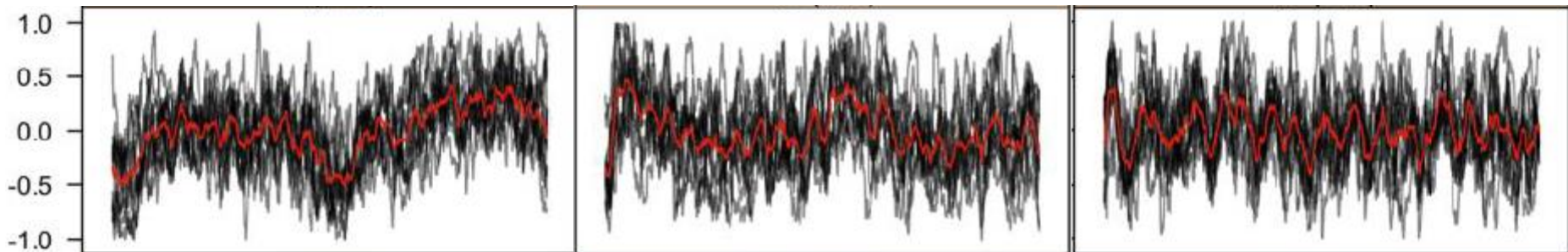
Urban Dynamometer Driving Schedule

- Simulates an urban route of 7.5 mi (12.07 km) with frequent stops. The maximum speed is 56.7 mph (91.25 kph) and the average speed is 19.6 mph (31.5 kph).



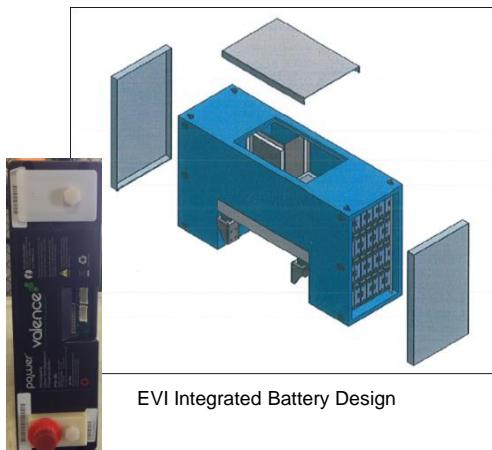
Frequency Regulation Ancillary Service

- Batteries used to correct short-term changes in the 60-hertz electric grid alternating current (AC) frequency
- Cluster 1: Curves with directionality and sign of the signal changing from positive to negative or vice versa.
- Cluster 10: A low frequency signal.
- Cluster 17: High frequency signals oscillating symmetrically around zero. This case is quite straightforward and is ideal for batteries.

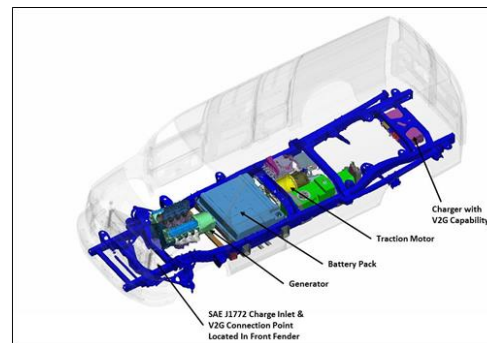


Procured Systems

Vendor/ Manufacturer	Number of systems procured	Kilowatt- hour (kWh) capacity per battery	Battery Chemistry	Vehicle Type	Operational Mode (miles/mo)
EVI - Range Extended Electric Vehicle (REEV)	4	53.8	LiFeMgPO4	Hybrid	Stake/Box (300)
VIA - VTRUX vans	7	21.1	LiFePO4	Hybrid	Cargo/Passenger (300-350)
EVAOS – F-150, F-250 Kits	5	26.9	LiFePO4	Hybrid	Light Duty (100-500)



EVI Integrated Battery Design



VIA Integrated Battery Design



EVAOS Energy Storage Module (F250)

Battery Specifications

Battery Type	Lithium iron magnesium phosphate (LiFeMgPO ₄) battery modules (14/pack)
Form Factor / Cell	Battery Council International (BCI) Form Factor 27
Battery Chemistry	LiFeMgPO ₄
Battery Capacity (kWh)	24.7
Nominal Voltage (VDC)	12.6 (module) 179 (pack)
Module Energy (kWh)	24.7 (pack)
Capacity (Ah)	138
Specific Energy (Wh/kg)	91 (per module)
Energy Density (kWh/M ³)	138 Wh/L (per module)
Module Size - Length (cm)	30.6
Module Size - Width (cm)	17.3
Module Size - Height (cm)	22.5
Volume (cm ³)	11,911