

Analyzing Accuracy of a Battery Fuel Gauge System

BMS – Applications

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Outline

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 2. Gauging Accuracy
2. Common Terminology
3. How to Compute Accuracy
4. Test Cases
 1. Common Loads
 2. Variable Loads
 3. Low Temperature
5. Questions

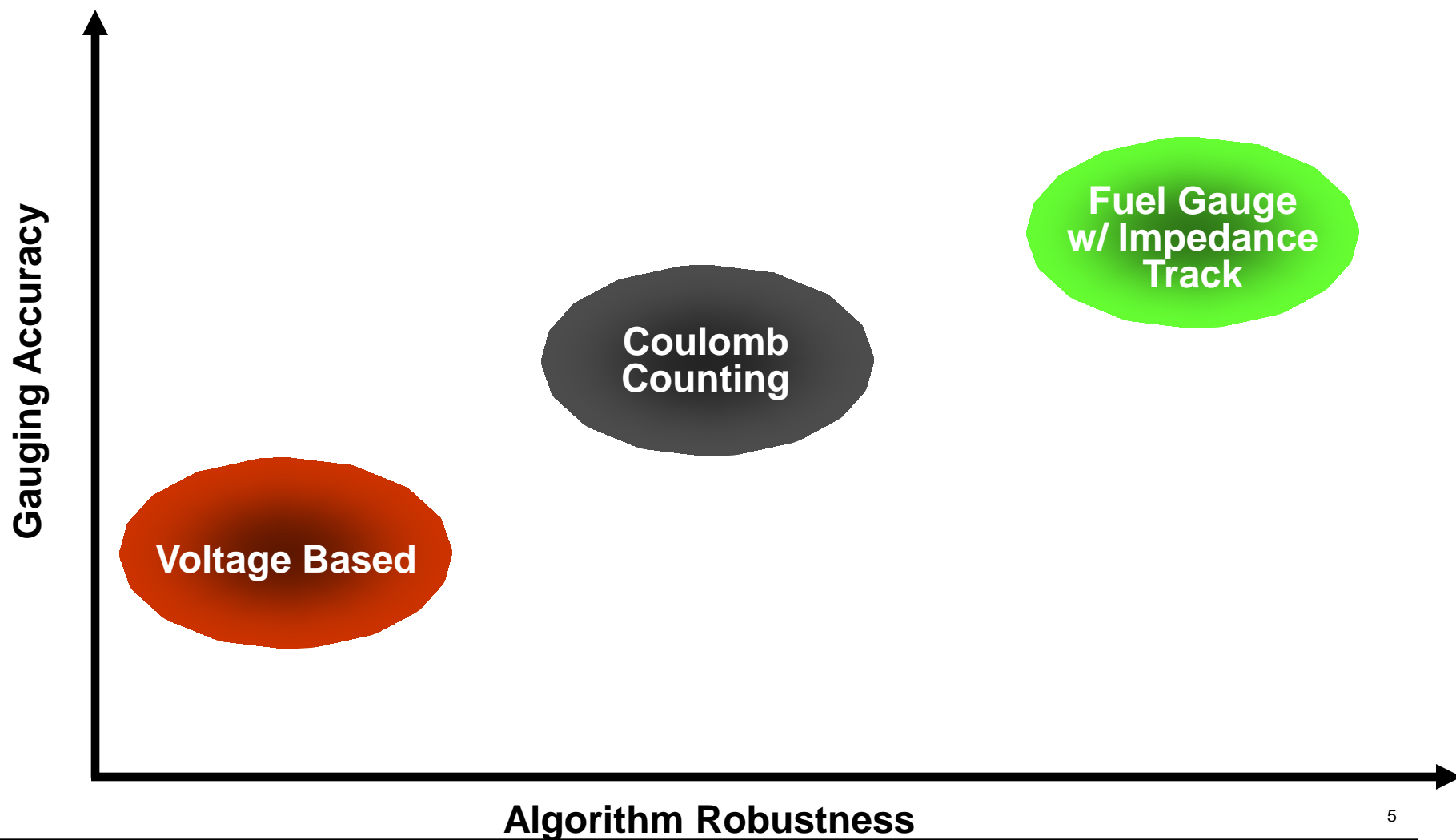
Defining Accuracy

Measurement Accuracy v. Gauging Accuracy

Defining Accuracy

- A fuel gauge algorithm needs to have data from the battery. A gauge gathers data from the battery through various measurements. Gauge measurements include
 - Battery voltage
 - Current flowing into and out of the battery
 - Battery temperature
- Measurement accuracy is dependent upon the gauge's hardware and is independent of gauging accuracy
- Gauging accuracy is dependent upon the robustness of the gauging algorithm and the gauge's measurement accuracy.
 - Poor measurement accuracy can lead to poor gauging accuracy

Gauging Accuracy



Gauging Accuracy

Cell Voltage Measurement

- Measures cell voltage
- Advantage: Simple
- Not accurate over load conditions

Coulomb Counting

- Measures and integrates current over time
- Affected by cell impedance
- Affected by cell self discharge
- Standby current
- Cell Aging
- Must have full to empty learning cycles
- Must develop cell models that will vary with cell maker
- Can count the charge leaving the battery, but won't know remaining charge without complex models
- Models will become less accurate with age

Impedance Track™

- Directly measures effect of discharge rate, temp, age and other factors by learning cell impedance
- No host algorithms or calculations

Measurement Accuracy

- Voltage
 - Accurate voltage measurements are critical for
 - Initialization of relaxed cell
 - Updates during self-discharge of cell
 - Correction for coulomb counting error
 - TI fuel gauges use a 15 bit ADC to provide accurate voltage measurements
- Current
 - Accurate coulomb counting is critical to
 - Capture low sleep currents
 - Capture short load spikes
 - Capture proper passed charge
 - TI fuel gauges have a dedicated 15 bit integrating ADC (i.e. coulomb counting hardware)
- Temperature
 - Accurate temperature measurements are critical for
 - Proper compensation of resistance
 - Proper compensation of predicted runtime
 - TI fuel gauges provide flexible temperature measurement options
 - External measurements with cell's thermistor or board hotspot
 - Host can write the temperature to the fuel gauge
 - Internal IC temperature measurements

Common Terminology

Common Terminology

- Chemical Capacity (Qmax)
 - Total chemical capacity of the battery, mAh
- Remaining Capacity (RM)
 - Useable capacity of the battery from current state to empty state, mAh
- Full Charge Capacity (FCC)
 - Amount of charge passed from a fully charged state until termination voltage, mAh
- Relative State of Charge (RSOC) : 0% -100%
 - $RSOC = RM / FCC$
- Depth of Discharge (DOD): 0% - 100%
 - 0% is charged to the brim, 100% is completely empty of energy
 - Does not depend on load or temperature or system characteristics
- Passed Charge (dQ or passedQ)
 - Integration of current with respect to time.

Common Terminology-Cont'd

- Coulomb
 - A unit of electric charge. It is the charge carried by a one ampere current in one second
- Terminate Voltage (EDV)
 - Voltage at which the system can no longer operate; target for 0% SOC
- Reserve Capacity
 - Capacity that is left after reaching 0% SOC

How to Compute Accuracy

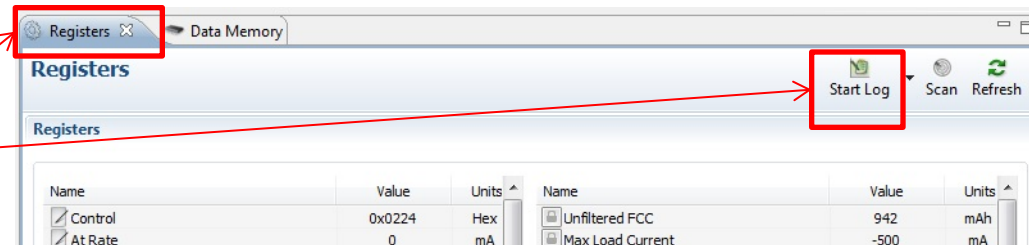
Conduct a Test

- Start with a properly configured gauge
 - Ensure gauge has been calibrated
 - For IT gauge, this means a properly created golden image

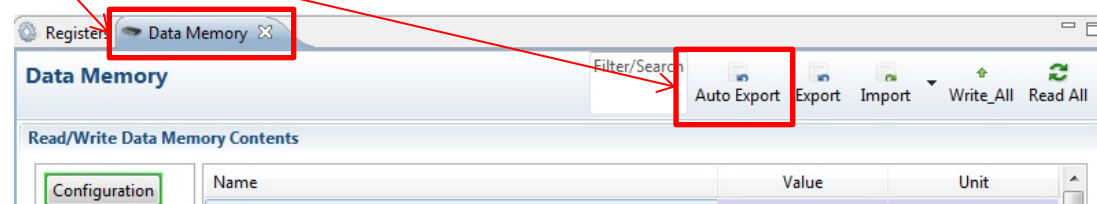
- Start logging:
 - Log DataRAM registers
 - Open Registers plug-in
 - Click “Start Log”
 - Log interval: 1 to 10 seconds
 - Export Data Memory (optional)
 - Open Data Memory plug-in
 - Click “Auto Export”

- Fully charge at room temp.

- Discharge to terminate voltage using desired load.

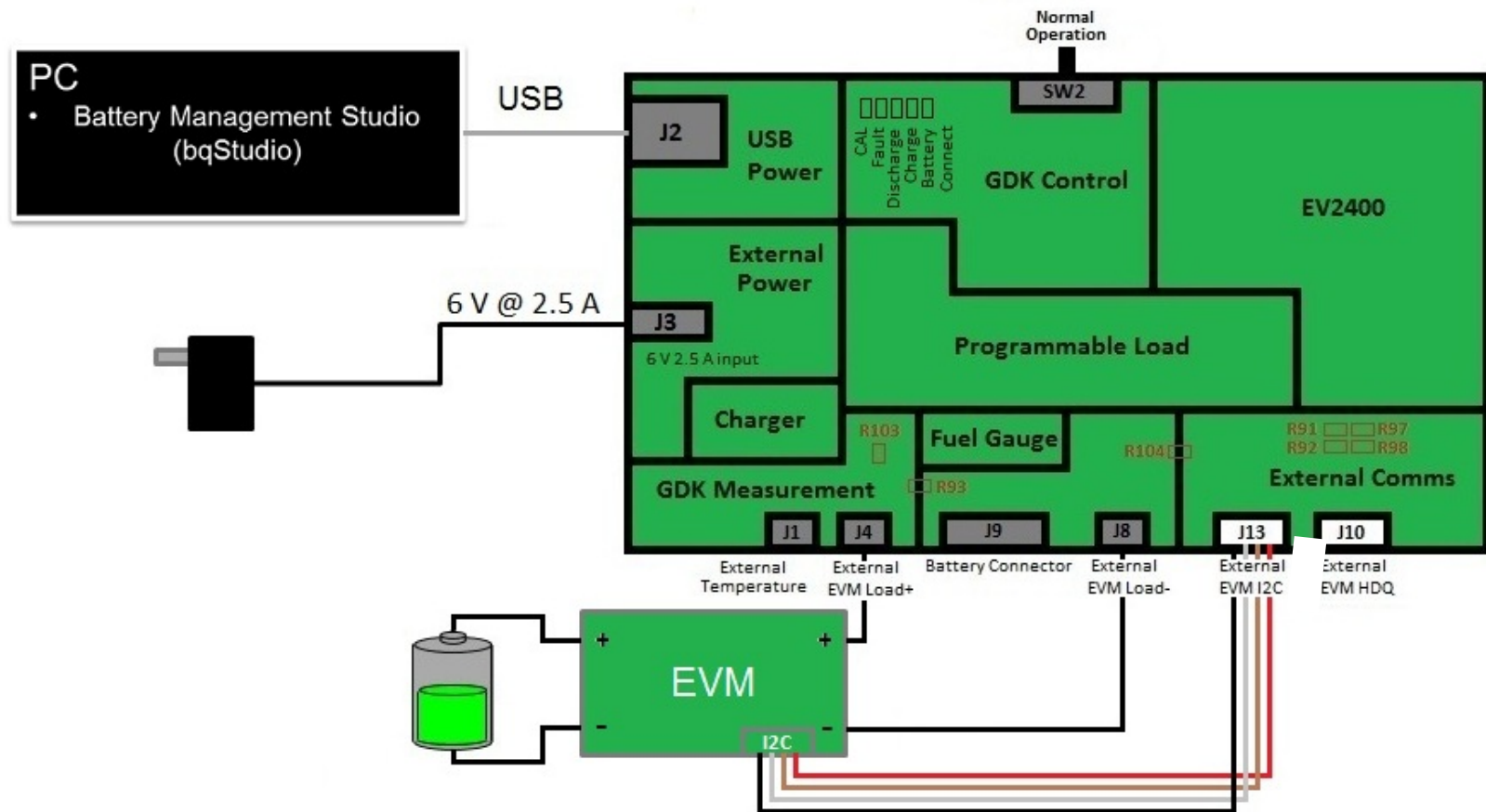


**Logging interval set in Window -> Preferences -> Registers



**Export interval set in Window -> Preferences -> Data Memory

Testing Made Easy with the Gauge Development Kit



Simple inspection

- Log gauge data every 1-10 seconds
- Import to spreadsheet and plot voltage, SOC, current, etc.
- Inspect
 - Does it report 0% at or near your true terminate voltage?
 - If not, by how much capacity and/or run-time was it off?
 - Does it look smooth or have large jumps?
- Very subjective and difficult to gauge relative error magnitude

Steps for Computing Accuracy

1. Start with gauge log
2. Calculate a new column: Calculated dQ = rolling sum of current_reading*time_since_last_log_point
 - Start from full condition and go to empty condition (EDV)
3. Calculate FCC_true = Integrated capacity from fully charged state down to termination voltage
 - Simple integration: capacity = constant current * total discharge time from full to terminate voltage
 - More accurate integration: calculate each log point Current*Tdelta and keep a rolling sum.
4. Calculate a new column: Calculated_RM = FCC_true – calculated_dQ
 - True remaining capacity at any point (mAh)
5. Calculate a new column: Calculated_SOC = Calculated_RM / FCC_true * 100
 - True relative state of charge (%)
6. Calculate a new column: SOC_error = (Calculated_SOC – SOC_gauge)
 - SOC_gauge is “State of Charge” in IT gauge log files
7. Plot voltage, RSOC_true, RSOC_gauge, RSOC_error
8. Summarize in table showing
 1. % error at the point when termination voltage is reached
 2. Max % error

Steps for Computing Accuracy

- Start with Gauge log
- Create new column for calculated passed charge (dQ)
 - Calculated_dQ = rolling sum of current_reading * time_since_last_log_point
 - Start from full and calculate until empty (or discharge stops)
 - Excel formula: $(\text{ElapsedTime}_{N+1} - \text{ElapsedTime}_N) * |\text{AvgCurrent}_N| / 3600 + \text{Calculated_dQ}_{N-1}$

deepsavedata2014_bq27142014_v105_learningcycle_2100mAh_4350mV_20141007_accuracyWaik1nrough.xlsx - Microsoft Excel

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Clipboard Font Paragraph Styles Cells

Calibri 11

General

Conditional Formatting Styles

Insert Delete Format

Autofill Clear

fx

=(A3566-A3565)*ABS(F3565)/3600+H3564

	A	B	C	D	E	F	G	H	I	J	K	L	M
	ElapsedTime	Temperature	Voltage	RemCap	FullChgCap	AvgCurrent	StateofCharge	Passed Charge	Calculated dQ	Calculated RM	Calculated SOC	RM Error	SOC Error
3565	20516.906	26	4244	1514	1514	-301	100	0	0.468305833				
3566	20522.507	26	4237	1514	1514	-300	100	0	0.8739725				
3567	20527.375	26	4235	1514	1514	-300	100	1	1.340639167				
3568	20532.975	26	4232	1514	1514	-301	100	1	1.808861389				
3569	20538.575	26	4230	1514	1514	-301	100	2	2.215963889				
3570	20543.444	25.9	4228	1514	1514	-300	100	2	2.682547222				
3571	20549.043	25.9	4227	1514	1514	-301	100	3	3.204280556				
3572	20555.283	25.9	4225	1514	1514	-300	100	3	3.727030556				
3573	20561.556	25.9	4224	1514	1514	-301	100	4	4.250018056				
3574	20567.811	25.9	4222	1514	1514	-301	100	4	4.773172778				
3575	20574.068	25.9	4221	1514	1514	-300	100	5	5.231922778				
3576	20579.573	25.9	4220	1514	1514	-300	100	5	5.700006111				
3577	20585.19	25.9	4219	1514	1514	-301	100	6	6.223160833				
3578	20591.447	25.9	4218	1514	1514	-301	100	6	6.746148333				
3579	20597.702	25.9	4217	1514	1514	-301	100	7	7.269219444				
3580	20603.958	25.9	4217	1513	1514	-300	100	7	7.790469444				
3581	20610.213	25.8	4216	1513	1514	-300	100	8	8.350719444				

Steps for Computing Accuracy

- Calculate FCC_true = Integrated capacity from fully charged state down to termination voltage

Microsoft Excel screenshot showing a data table for battery capacity calculation. The formula bar displays:
$$I6611 = (A6612 - A6611) * ABS(F6611) / 3600 + I6610$$

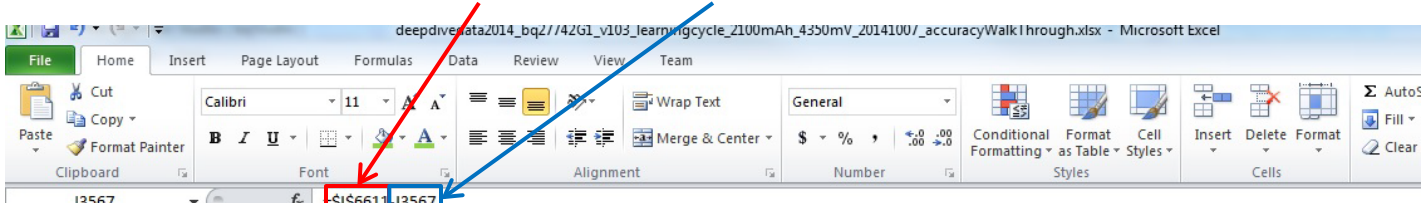
	A	B	C	D	E	F	G	H	I	J	K	L	M
	ElapsedTime	Temperature	Voltage	RemCap	FullChgCap	AvgCurrent	StateofCharge	Passed Charge	Calculated dQ	Calculated RM	Calculated SOC	RM Error	SOC Error
6591	38156.382	26	3141	1	1469	-301	1	1475	1473.509059				
6592	38161.25	26	3136	1	1469	-301	1	1475	1473.977282				
6593	38166.85	26	3130	1	1469	-301	1	1476	1474.498931				
6594	38173.089	26	3123	1	1469	-301	1	1476	1475.023424				
6595	38179.362	26	3117	1	1471	-301	1	1477	1475.546495				
6596	38185.618	26	3110	1	1471	-301	1	1477	1476.069483				
6597	38191.873	26	3103	1	1471	-301	1	1478	1476.530013				
6598	38197.381	26	3098	1	1471	-300	1	1478	1476.997929				
6599	38202.996	26	3090	1	1473	-300	1	1479	1477.519346				
6600	38209.253	26	3083	1	1473	-301	1	1479	1478.042417				
6601	38215.509	26	3075	1	1473	-301	1	1480	1478.449352				
6602	38220.376	26	3070	1	1473	-300	1	1480	1478.916186				
6603	38225.978	26	3062	1	1473	-300	1	1481	1479.437352				
6604	38232.232	26	3054	1	1473	-301	1	1481	1479.844371				
6605	38237.1	26	3047	1	1476	-301	1	1482	1480.312677				
6606	38242.701	26	3039	1	1476	-301	1	1482	1480.780899				
6607	38248.301	26	3032	1	1476	-301	1	1483	1481.187834				
6608	38253.168	26	3025	1	1476	-301	1	1483	1481.656224				
6609	38258.77	26	3016	1	1476	-300	1	1483	1482.122891				
6610	38264.37	26	3006	1	1476	-301	1	1483	1482.591916				
6611	38269.262	26.4	3000	0	1476	-163	0	1483	1482.781804				

Calculated FCC_true

Terminate Voltage

Steps for Computing Accuracy

- Calculate a new column: $\text{Calculated_RM} = \text{FCC_true} - \text{Calculated_dQ}$
 - True remaining capacity at any point (mAh)
 - Excel formula: $\text{\$FCC_true} - \text{Calculated_dQ}_N$

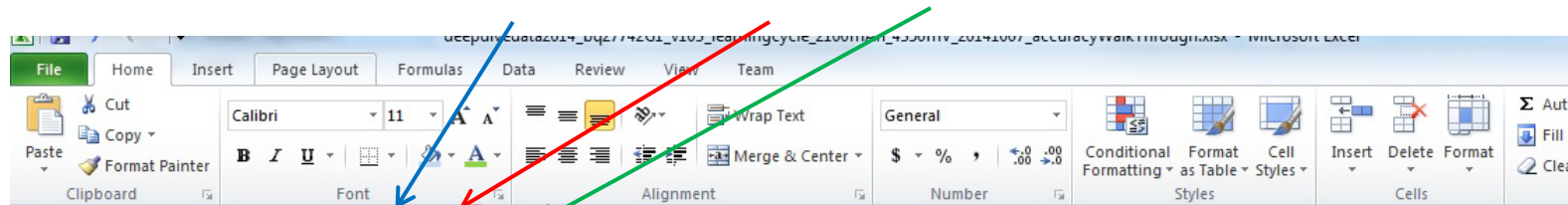


The screenshot shows an Excel spreadsheet with the following columns: A (ElapsedTime), B (Temperature), C (Voltage), D (RemCap), E (FullChgCap), F (AvgCurrent), G (StateofCharge), H (Passed Charge), I (Calculated dQ), J (Calculated RM), K (Calculated SOC), L (RM Error), and M (SOC Error). The formula bar shows the formula $=\$F\$6611-I3567$ for cell J3567. Red and blue arrows point to the formula bar and the 'Calculated RM' column header respectively.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	ElapsedTime	Temperature	Voltage	RemCap	FullChgCap	AvgCurrent	StateofCharge	Passed Charge	Calculated dQ	Calculated RM	Calculated SOC	RM Error	SOC Error
3567	20527.375	26	4235	1514	1514	-300	100	1	1.340639167	1481.441165			
3568	20532.975	26	4232	1514	1514	-301	100	1	1.808861389	1480.972943			
3569	20538.575	26	4230	1514	1514	-301	100	2	2.215963889	1480.56584			
3570	20543.444	25.9	4228	1514	1514	-300	100	2	2.682547222	1480.099257			
3571	20549.043	25.9	4227	1514	1514	-301	100	3	3.204280556	1479.577524			
3572	20555.283	25.9	4225	1514	1514	-300	100	3	3.727030556	1479.054774			
3573	20561.556	25.9	4224	1514	1514	-301	100	4	4.250018056	1478.531786			
3574	20567.811	25.9	4222	1514	1514	-301	100	4	4.773172778	1478.008631			
3575	20574.068	25.9	4221	1514	1514	-300	100	5	5.231922778	1477.549881			
3576	20579.573	25.9	4220	1514	1514	-300	100	5	5.700006111	1477.081798			
3577	20585.19	25.9	4219	1514	1514	-301	100	6	6.223160833	1476.558643			
3578	20591.447	25.9	4218	1514	1514	-301	100	6	6.746148333	1476.035656			
3579	20597.702	25.9	4217	1514	1514	-301	100	7	7.269219444	1475.512585			
3580	20603.958	25.9	4217	1513	1514	-300	100	7	7.790469444	1474.991335			
3581	20610.213	25.9	4216	1513	1514	-300	100	8	8.250719444	1474.531085			
3582	20615.736	25.9	4215	1512	1514	-301	100	8	8.719108889	1474.062695			
3583	20621.338	25.9	4214	1512	1514	-300	100	9	9.240358889	1473.541445			
3584	20627.593	26	4214	1511	1514	-300	100	9	9.761692222	1473.020112			
3585	20633.849	25.9	4213	1511	1514	-300	100	10	10.16735889	1472.614445			
3586	20638.717	25.9	4212	1510	1514	-301	100	10	10.63558111	1472.146223			
3587	20644.317	26	4212	1510	1514	-300	100	11	11.15683111	1471.624973			
3588	20650.572	26	4211	1509	1514	-301	100	11	11.56393361	1471.217871			

Steps for Computing Accuracy

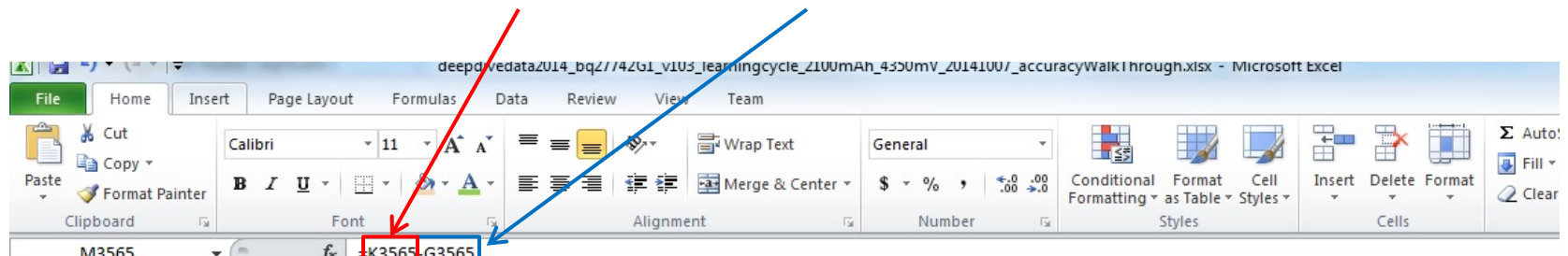
- Calculate a new column: $\text{Calculated_SOC} = \text{Calculated_RM} / \text{FCC_true} * 100$
 - True state of charge at any point (%)
 - Excel formula: $\text{Calculated_RM} / \$\text{FCC_true} * 100$



	A	B	C	D	E	F	G	H	I	J	K	L	M
	ElapsedTime	Temperature	Voltage	RemCap	FullChgCap	AvgCurrent	StateofCharge	Passed Charge	Calculated dQ	Calculated RM	Calculated SOC	RM Error	SOC Error
3566	20522.507	26	4237	1514	1514	-300	100	0	0.8739725	1481.907832	99.94105859		
3567	20527.375	26	4235	1514	1514	-300	100	1	1.340639167	1481.441165	99.90958621		
3568	20532.975	26	4232	1514	1514	-301	100	1	1.808861389	1480.972943	99.87800893		
3569	20538.575	26	4230	1514	1514	-301	100	2	2.215963889	1480.56584	99.85055361		
3570	20543.444	25.9	4228	1514	1514	-300	100	2	2.682547222	1480.099257	99.81908685		
3571	20549.043	25.9	4227	1514	1514	-301	100	3	3.204280556	1479.577524	99.78390074		
3572	20555.283	25.9	4225	1514	1514	-300	100	3	3.727030556	1479.054774	99.74864606		
3573	20561.556	25.9	4224	1514	1514	-301	100	4	4.250018056	1478.531786	99.71337536		
3574	20567.811	25.9	4222	1514	1514	-301	100	4	4.773172778	1478.008631	99.67809338		
3575	20574.068	25.9	4221	1514	1514	-300	100	5	5.231922778	1477.549881	99.64715491		
3576	20579.573	25.9	4220	1514	1514	-300	100	5	5.700006111	1477.081798	99.61558699		
3577	20585.19	25.9	4219	1514	1514	-301	100	6	6.223160833	1476.558643	99.58030502		
3578	20591.447	25.9	4218	1514	1514	-301	100	6	6.746148333	1476.035656	99.54503432		
3579	20597.702	25.9	4217	1514	1514	-301	100	7	7.269219444	1475.512585	99.50975798		
3580	20603.958	25.9	4217	1513	1514	-300	100	7	7.790469444	1474.991335	99.47460446		
3581	20610.213	25.9	4216	1513	1514	-300	100	8	8.250719444	1474.531085	99.44356483		
3582	20615.736	25.9	4215	1512	1514	-301	100	8	8.719108889	1474.062695	99.41197627		
3583	20621.338	25.9	4214	1512	1514	-300	100	9	9.240358889	1473.541445	99.37682275		
3584	20627.593	26	4214	1511	1514	-300	100	9	9.761692222	1473.020112	99.34166361		
3585	20633.849	25.9	4213	1511	1514	-300	100	10	10.16735889	1472.614445	99.31430512		
3586	20638.717	25.9	4212	1510	1514	-301	100	10	10.63558111	1472.146223	99.28272784		

Steps for Computing Accuracy

- Calculate a new column: $SOC_error = SOC_true - SOC_gauge$
 - Excel formula: $Calculated_SOC_N - SOC_gauge_N$



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Clipboard Font Alignment Number Styles Cells

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Wrap Text

General

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Conditional Formatting as Table Styles

Insert Delete Format

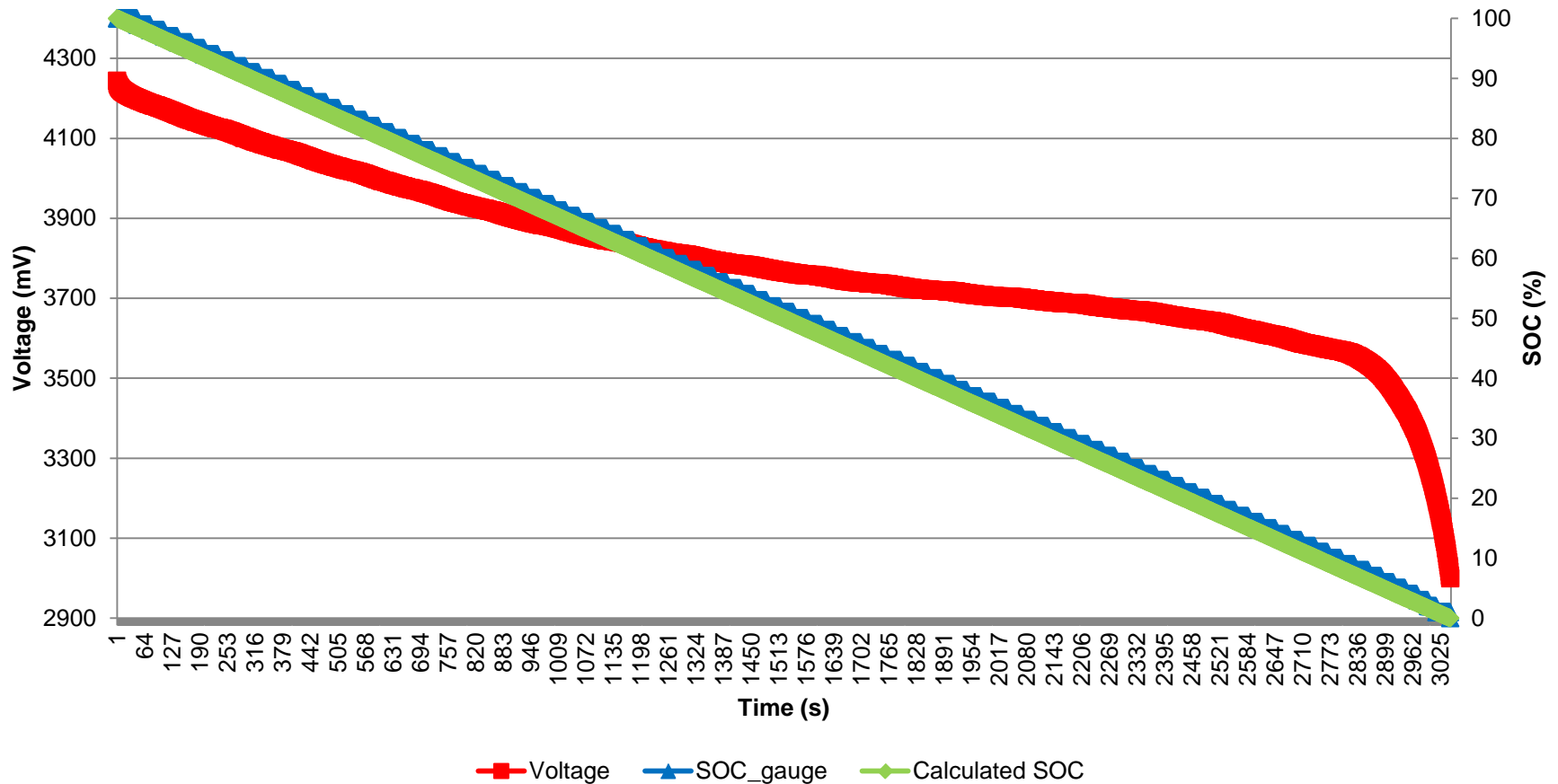
Auto: Fill Clear

M3565 fx =K3565-G3565

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	ElapsedTime	Temperature	Voltage	RemCap	FullChgCap	AvgCurrent	StateofCharge	Passed Charge	Calculated dQ	Calculated RM	Calculated SOC	RM Error	SOC Error
3565	20516.906	26	4244	1514	1514	-301	100	0	0.468305833	1482.313498	99.96841708	-2.136963212	-0.03158
3566	20522.507	26	4237	1514	1514	-300	100	0	0.8739725	1481.907832	99.94105859	-2.164321699	-0.05894
3567	20527.375	26	4235	1514	1514	-300	100	1	1.340639167	1481.441165	99.90958621	-2.195794075	-0.09041
3568	20532.975	26	4232	1514	1514	-301	100	1	1.808861389	1480.972943	99.87800893	-2.227371359	-0.12199
3569	20538.575	26	4230	1514	1514	-301	100	2	2.215963889	1480.56584	99.85055361	-2.25482668	-0.14945
3570	20543.444	25.9	4228	1514	1514	-300	100	2	2.682547222	1480.099257	99.81908685	-2.286293436	-0.18091
3571	20549.043	25.9	4227	1514	1514	-301	100	3	3.204280556	1479.577524	99.78390074	-2.321479552	-0.2161
3572	20555.283	25.9	4225	1514	1514	-300	100	3	3.727030556	1479.054774	99.74864606	-2.356734234	-0.25135
3573	20561.556	25.9	4224	1514	1514	-301	100	4	4.250018056	1478.531786	99.71337536	-2.392004932	-0.28662
3574	20567.811	25.9	4222	1514	1514	-301	100	4	4.773172778	1478.008631	99.67809338	-2.427286908	-0.32191
3575	20574.068	25.9	4221	1514	1514	-300	100	5	5.231922778	1477.549881	99.64715491	-2.458225378	-0.35285
3576	20579.573	25.9	4220	1514	1514	-300	100	5	5.700006111	1477.081798	99.61558699	-2.489793295	-0.38441
3577	20585.19	25.9	4219	1514	1514	-301	100	6	6.223160833	1476.558643	99.58030502	-2.525075271	-0.41969
3578	20591.447	25.9	4218	1514	1514	-301	100	6	6.746148333	1476.035656	99.54503432	-2.56034597	-0.45497
3579	20597.702	25.9	4217	1514	1514	-301	100	7	7.269219444	1475.512585	99.50975798	-2.595622307	-0.49024
3580	20603.958	25.9	4217	1513	1514	-300	100	7	7.790469444	1474.991335	99.47460446	-2.563335021	-0.5254
3581	20610.213	25.9	4216	1513	1514	-300	100	8	8.250719444	1474.531085	99.44356483	-2.594374652	-0.55644

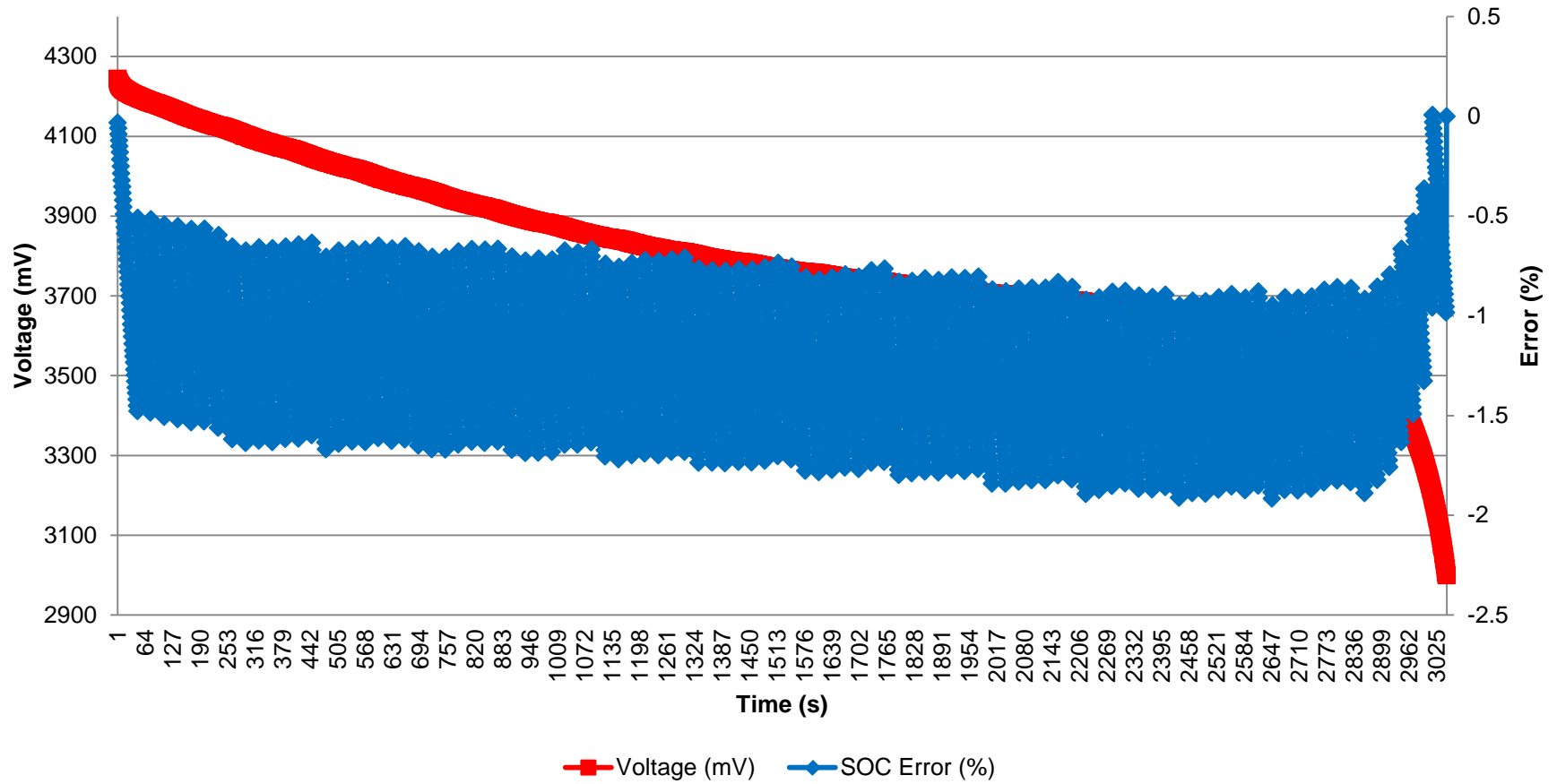
Steps for Computing Accuracy

SOC, Calculated SOC v. Time



Steps for Computing Accuracy

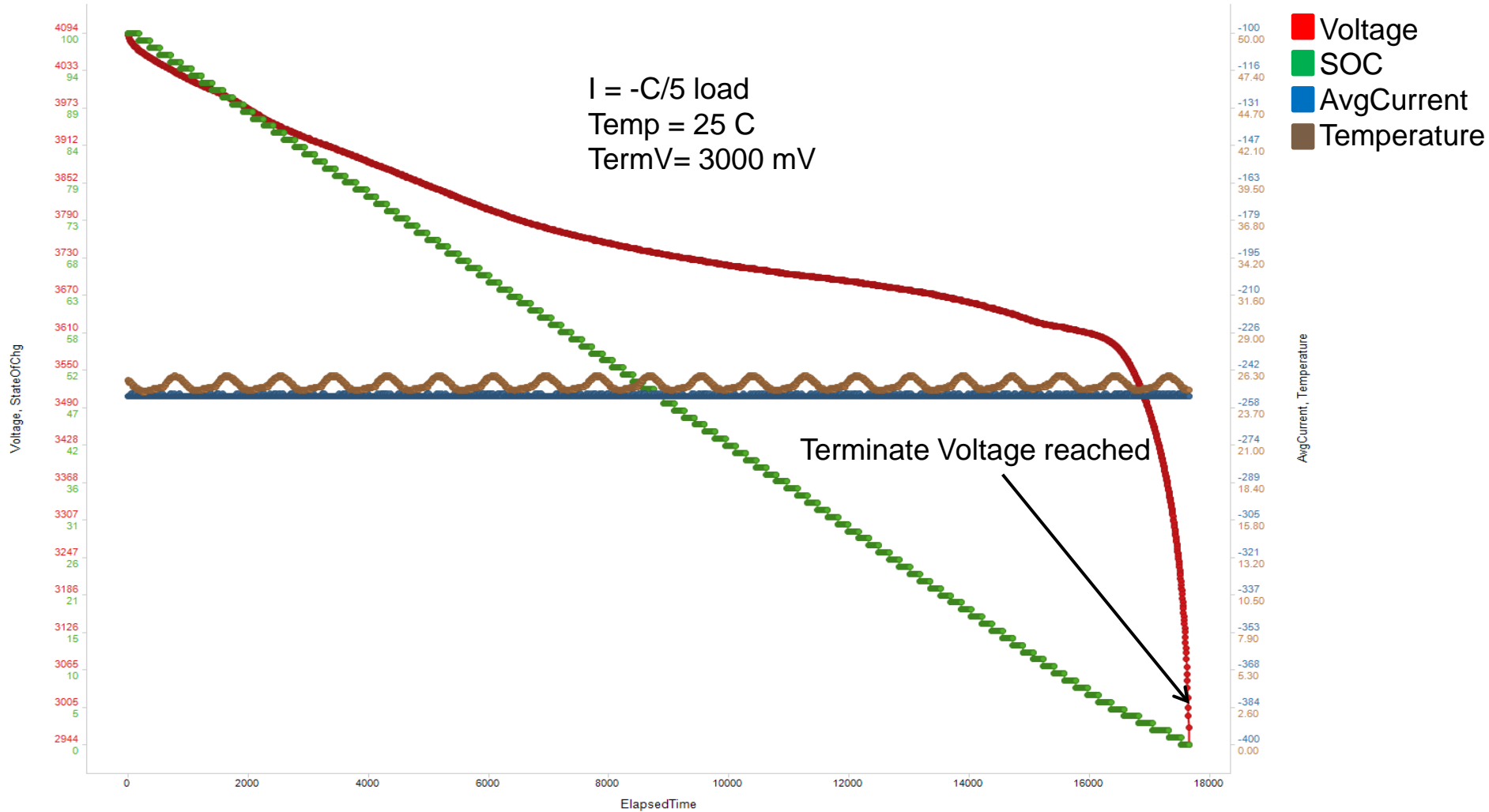
SOC Accuracy



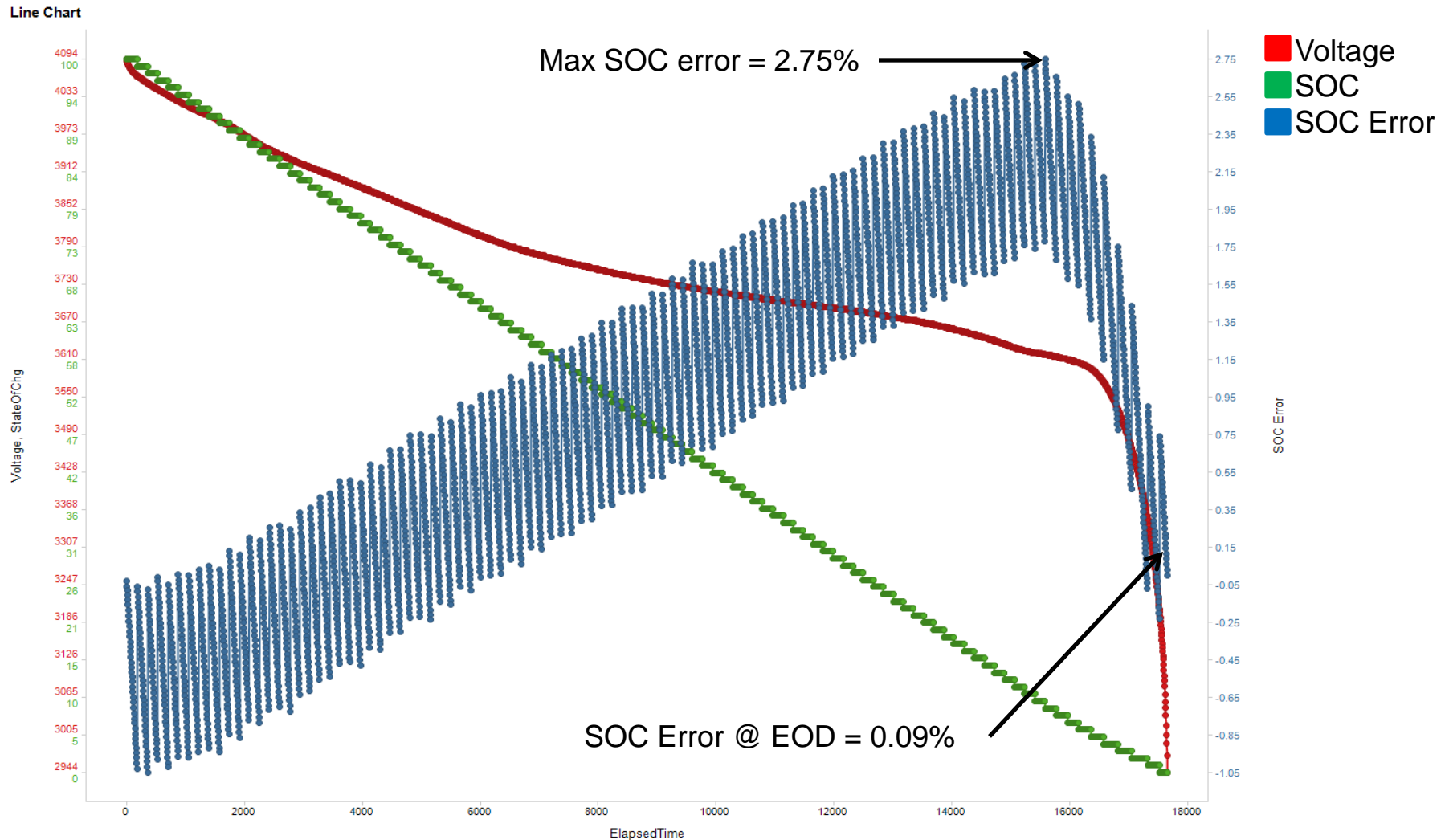
Test Cases

bq27421 – Standard C/5 Discharge

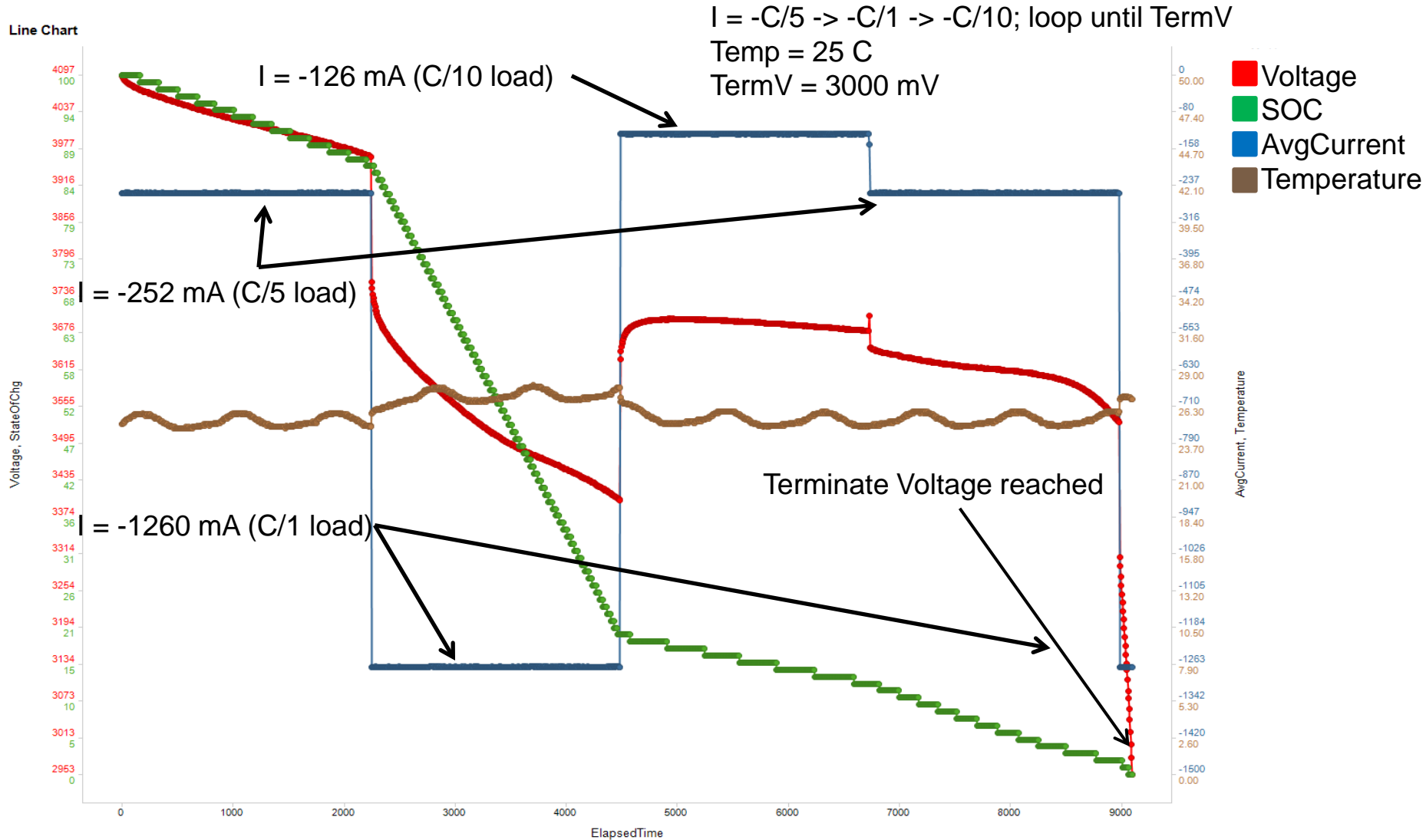
Line Chart



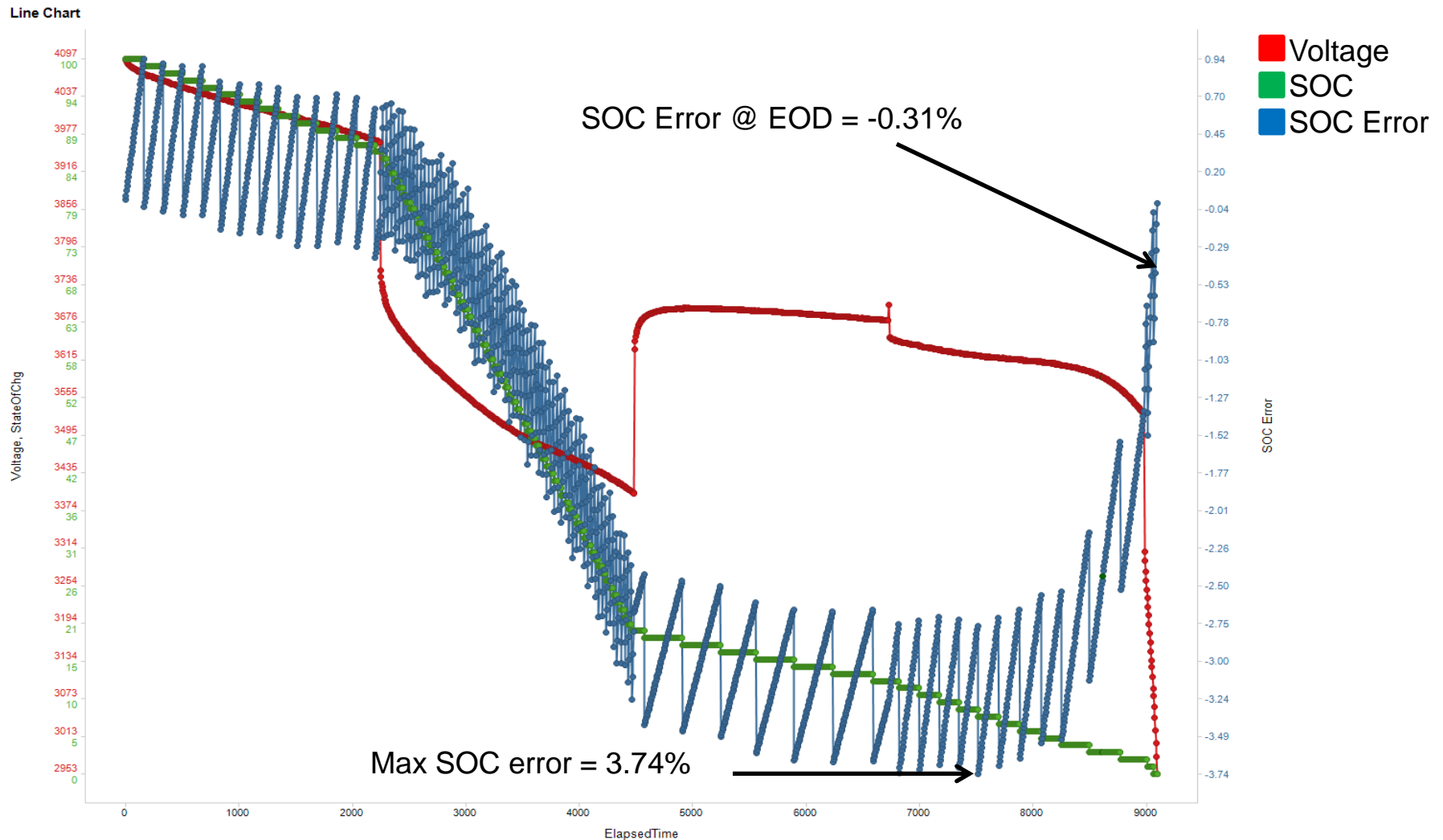
bq27421 – Standard C/5 Discharge



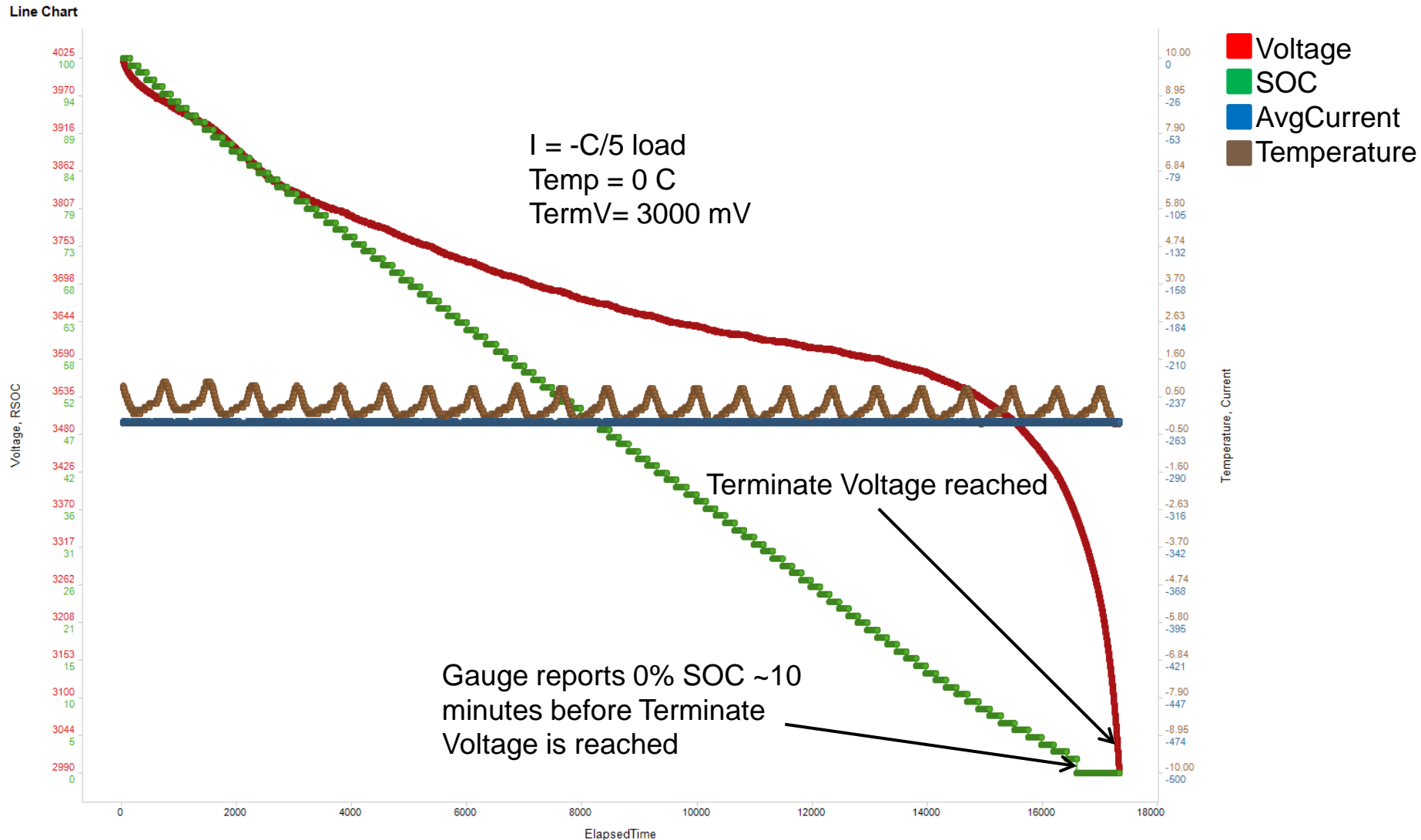
bq27421 – Variable Load



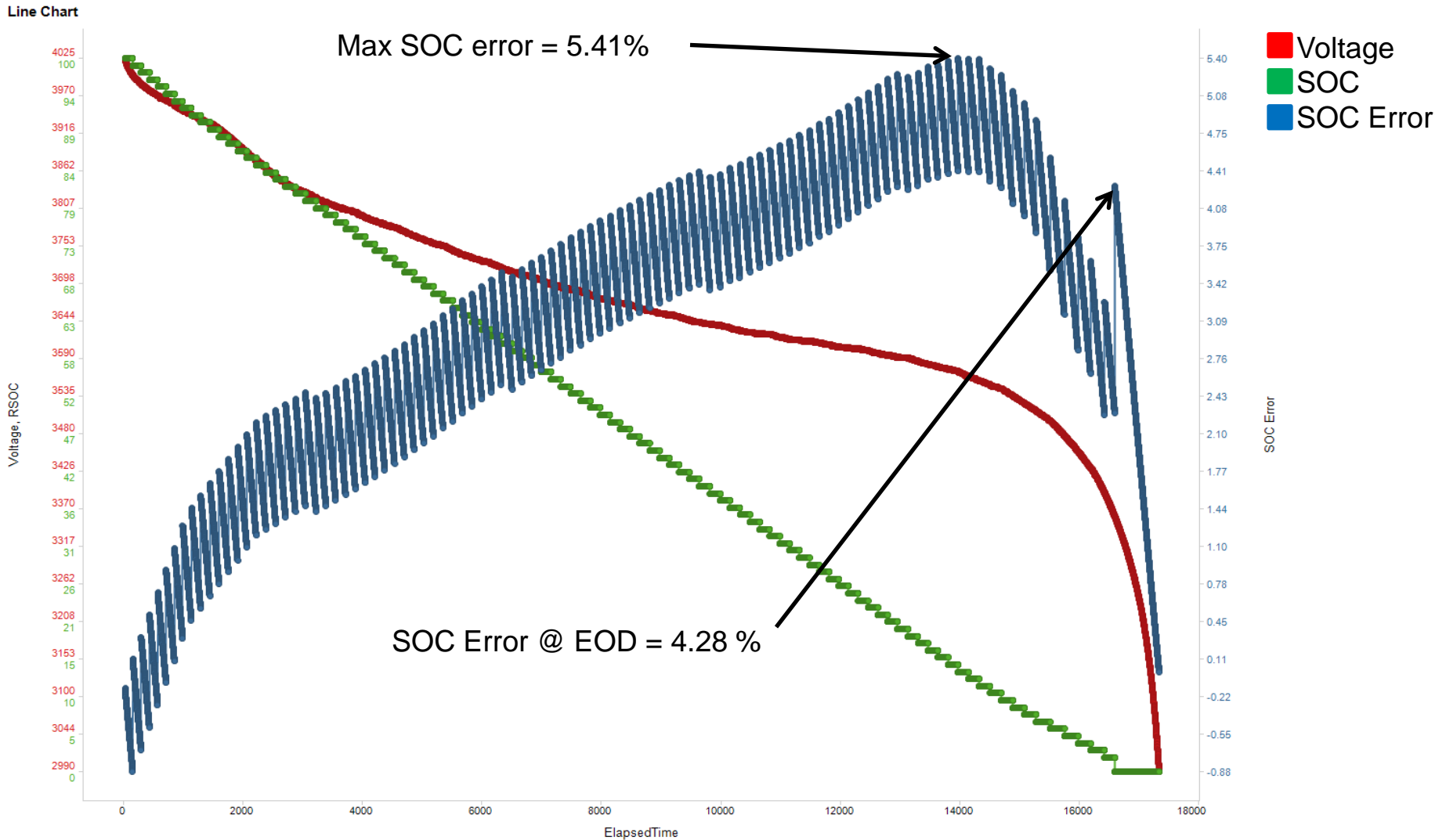
bq27421 – Variable Load



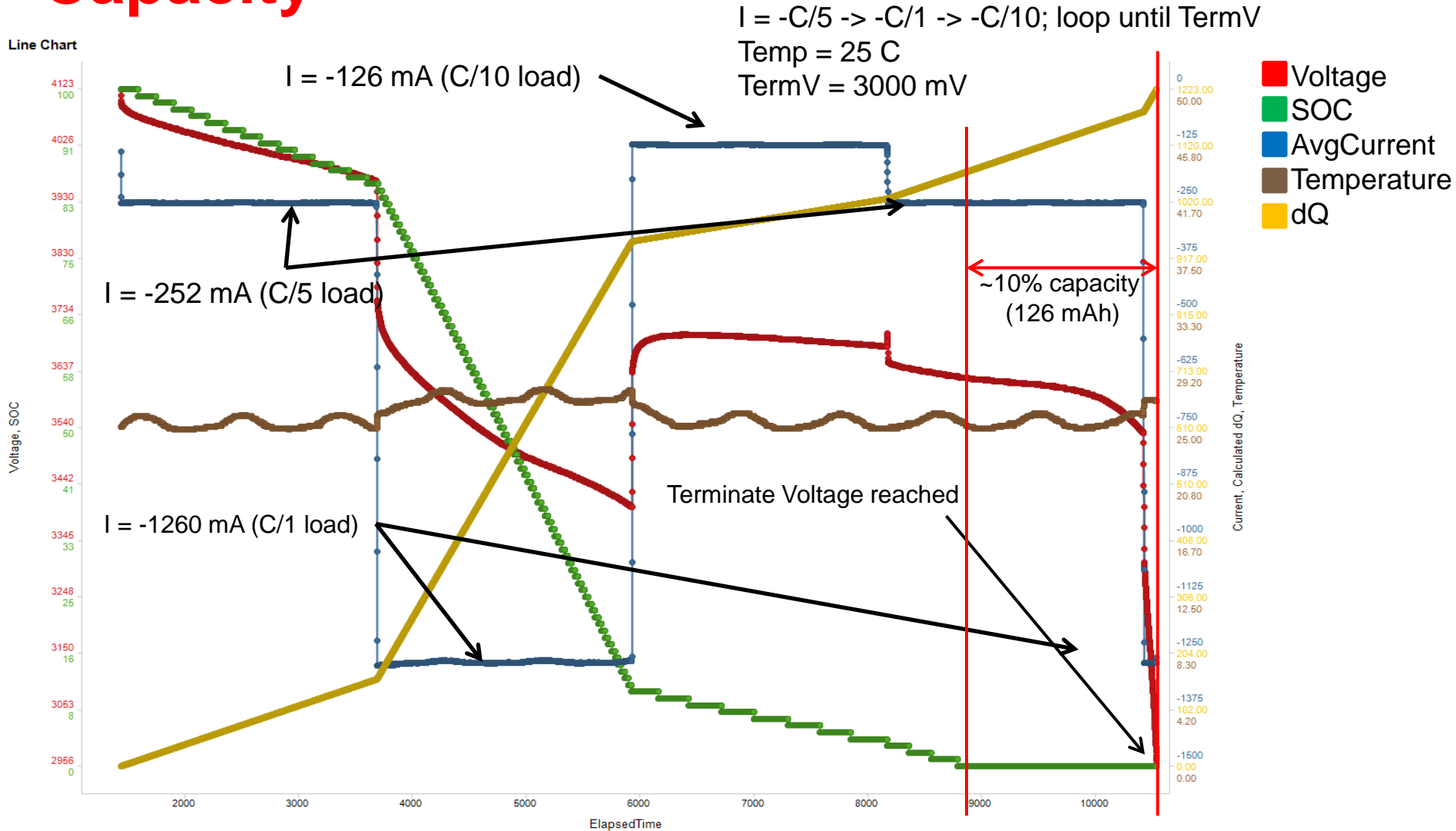
bq27421 – C/5 Discharge, Cold Temp



bq27421 – C/5 Discharge, Cold Temp

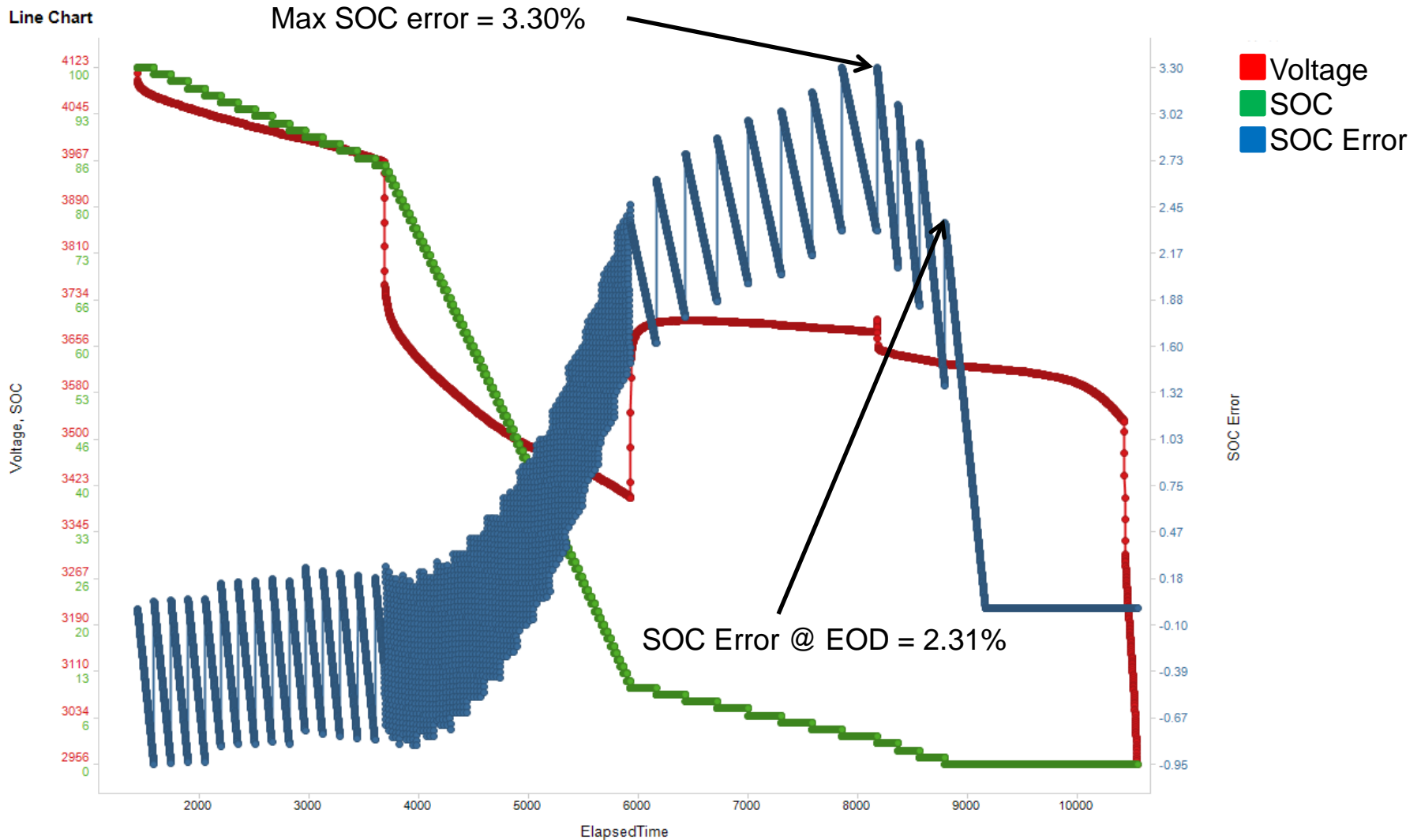


bq27421 – Variable Load with Reserve Capacity

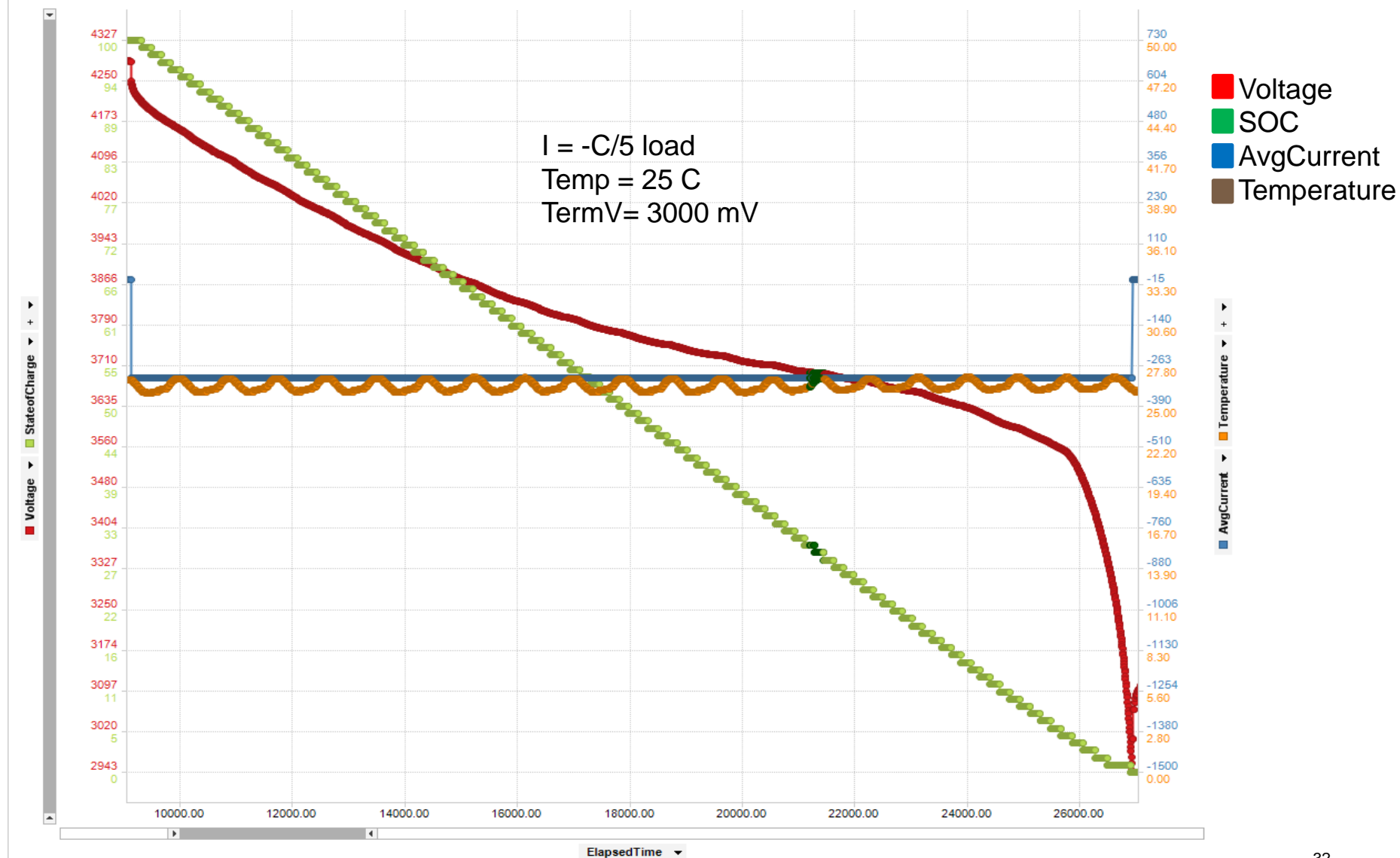


bq27421 – Variable Load with Reserve Capacity

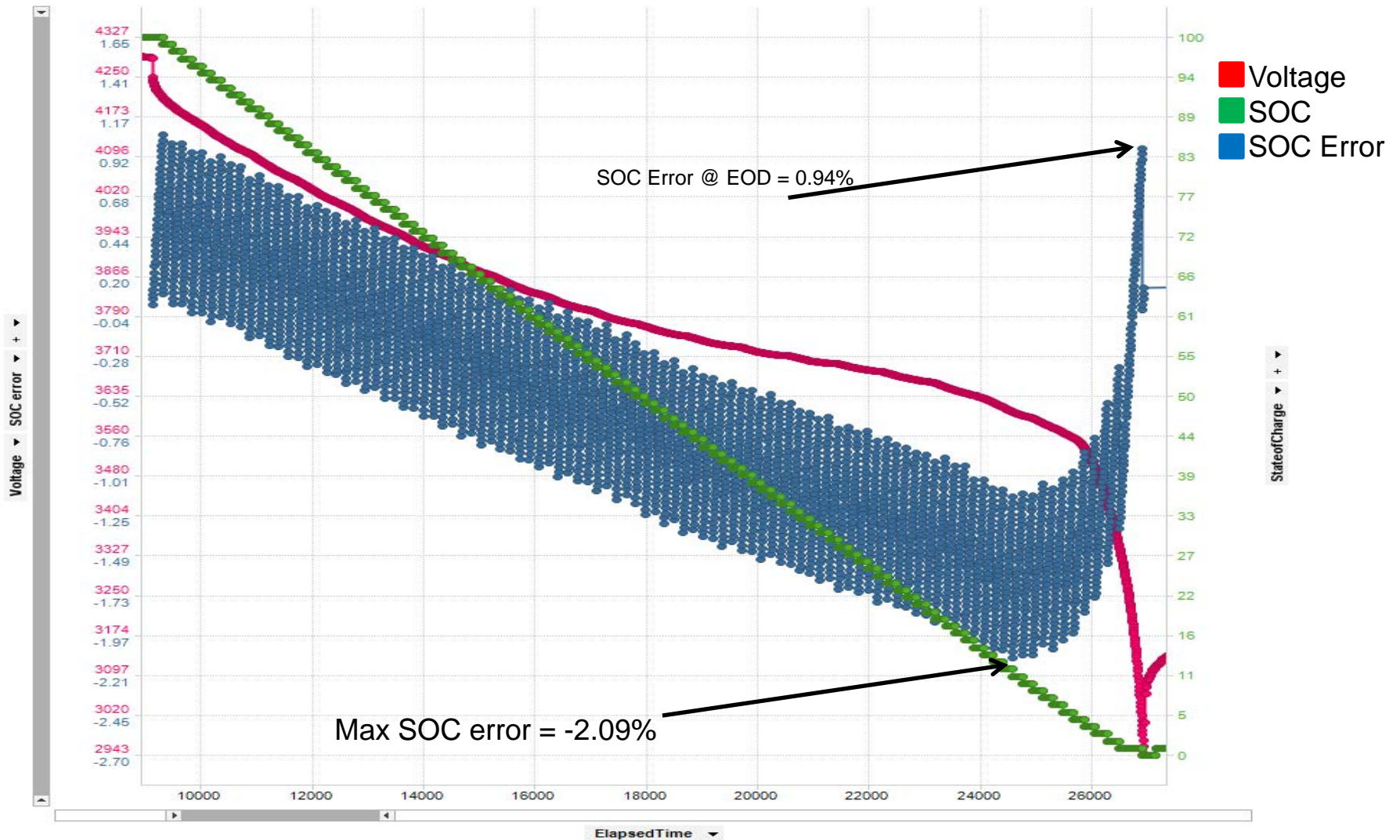
Line Chart



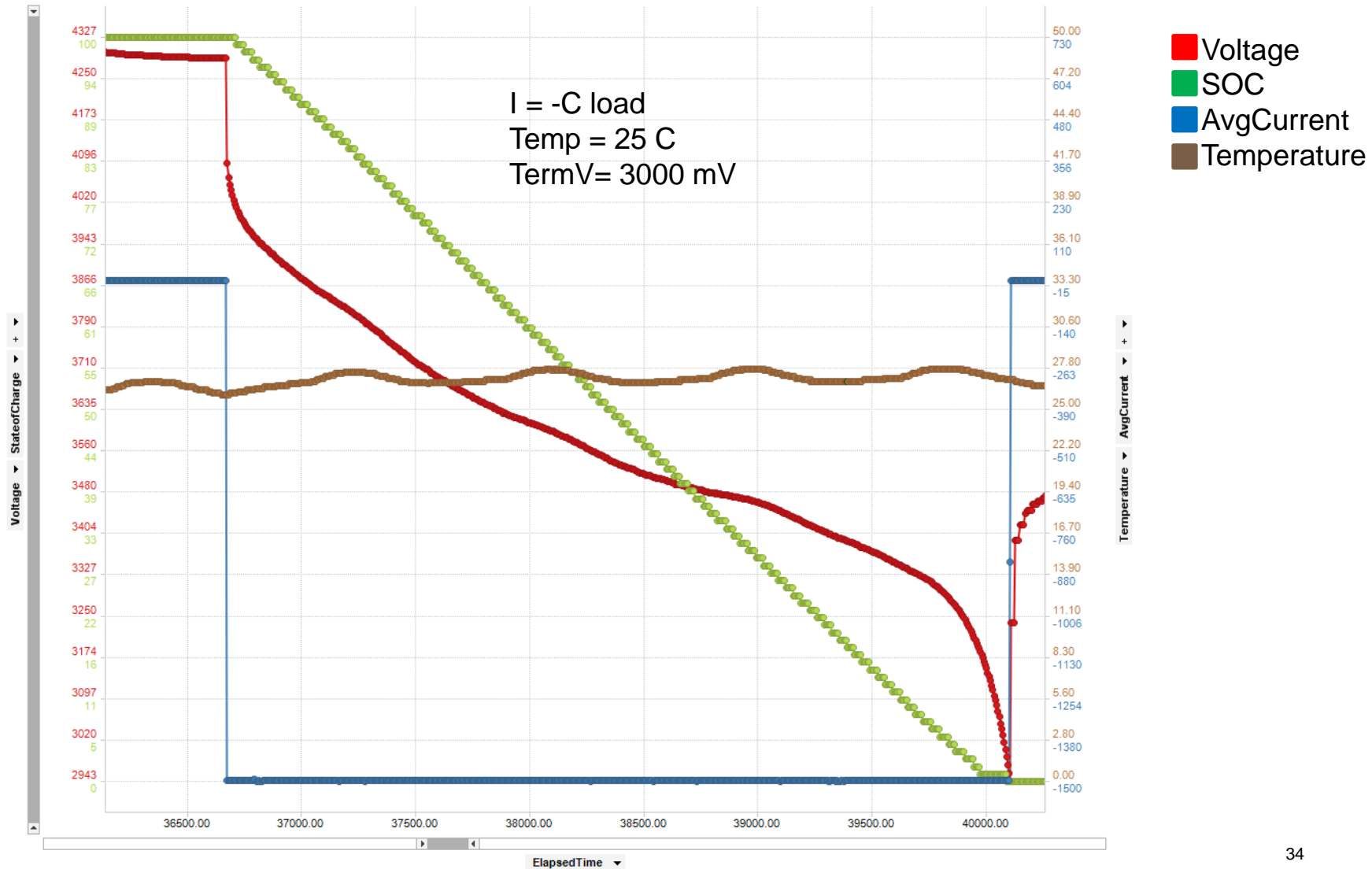
bq27742 – Standard C/5 Discharge



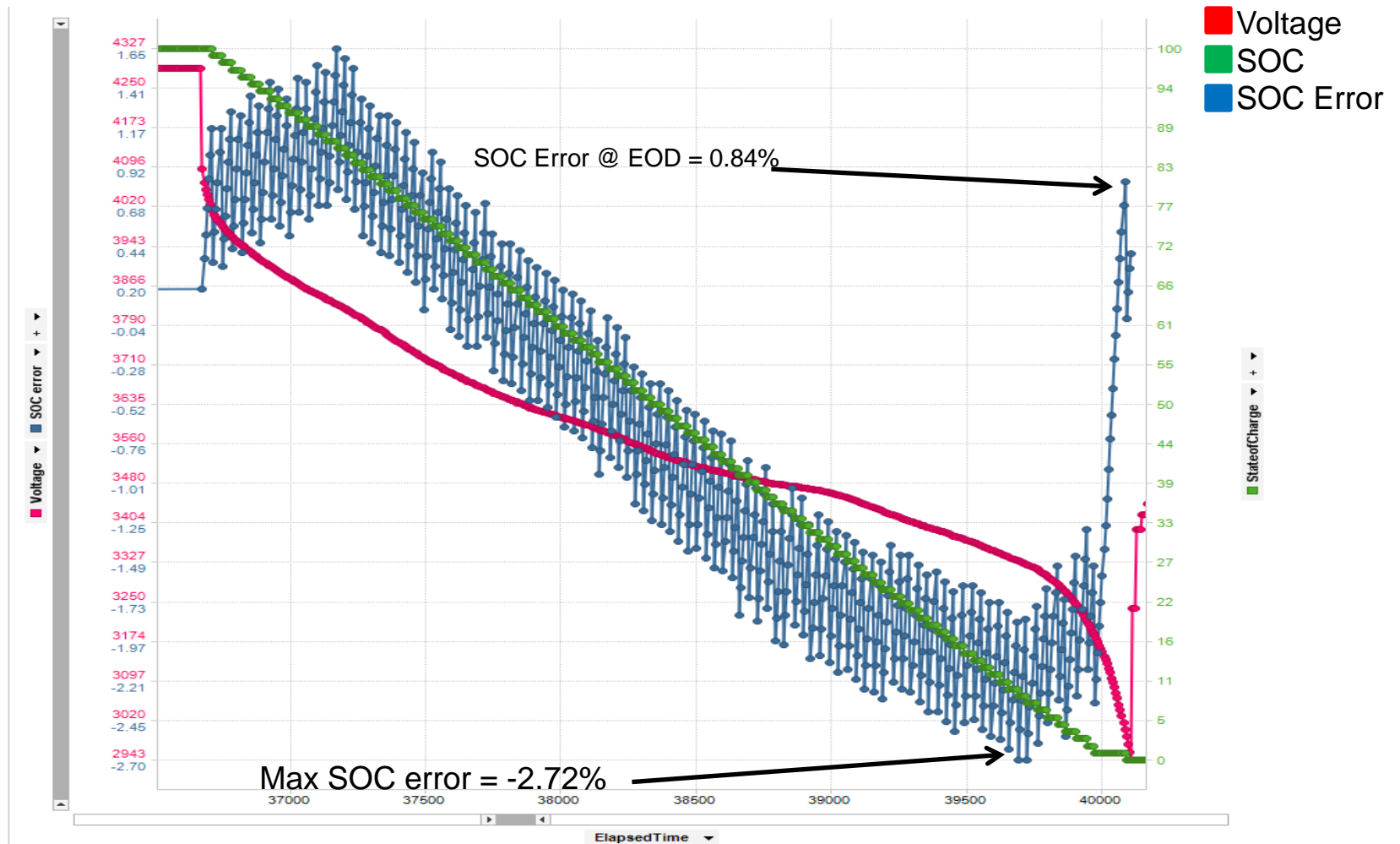
bq27742 – Standard C/5 Discharge



bq27742 -C Discharge

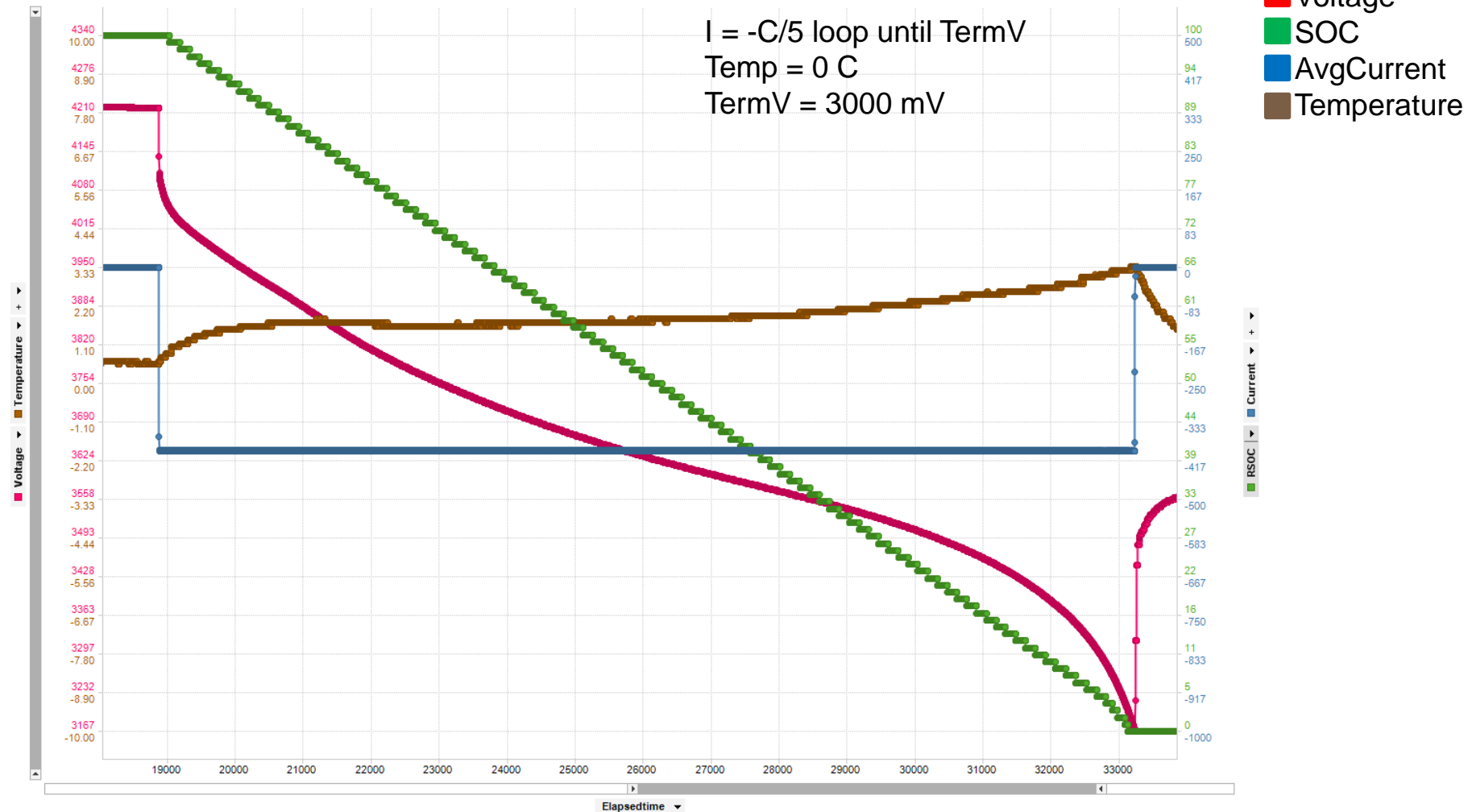


bq27742 -C Discharge

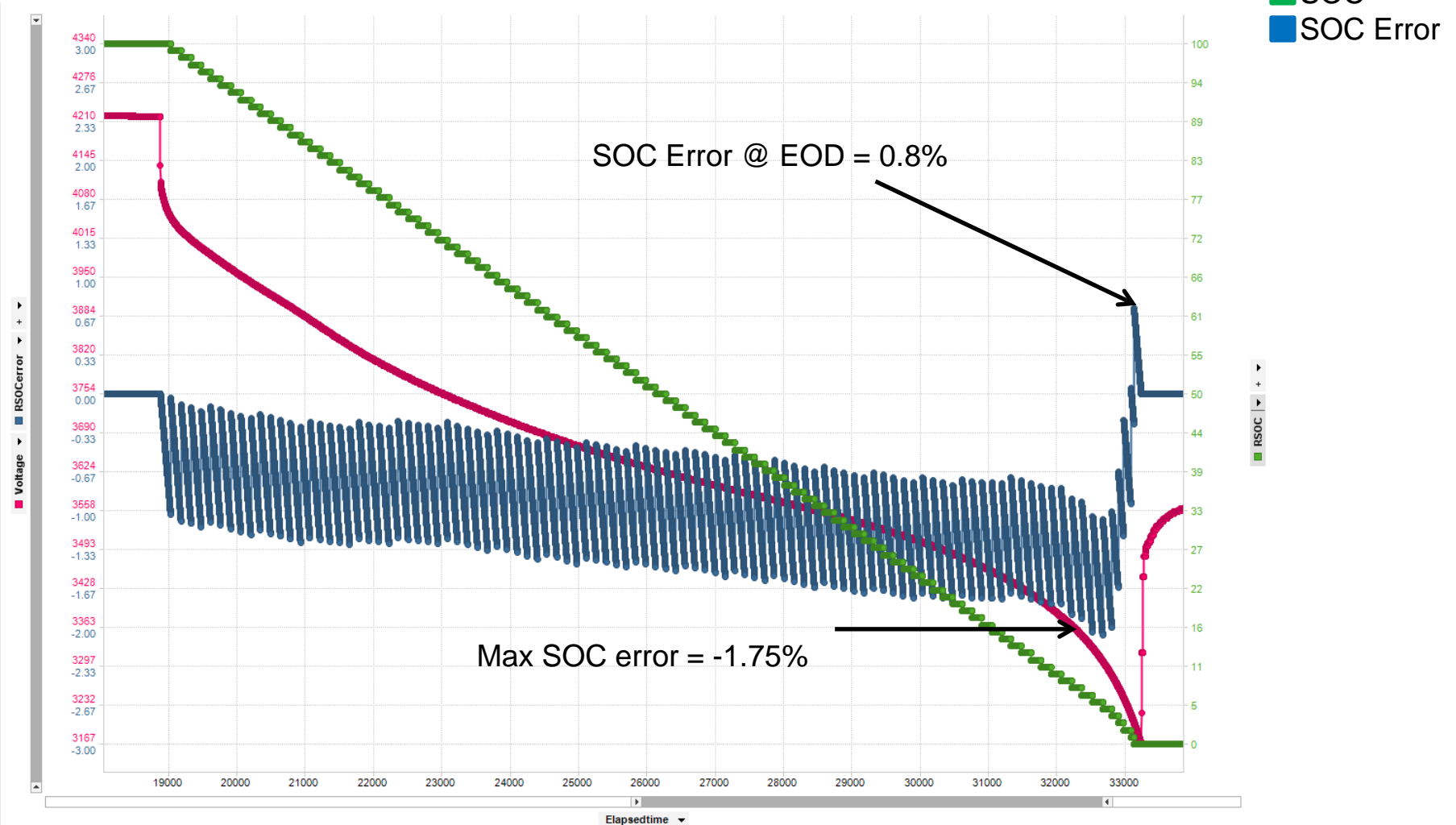


bq275xx – Cold temp, C/5 Load

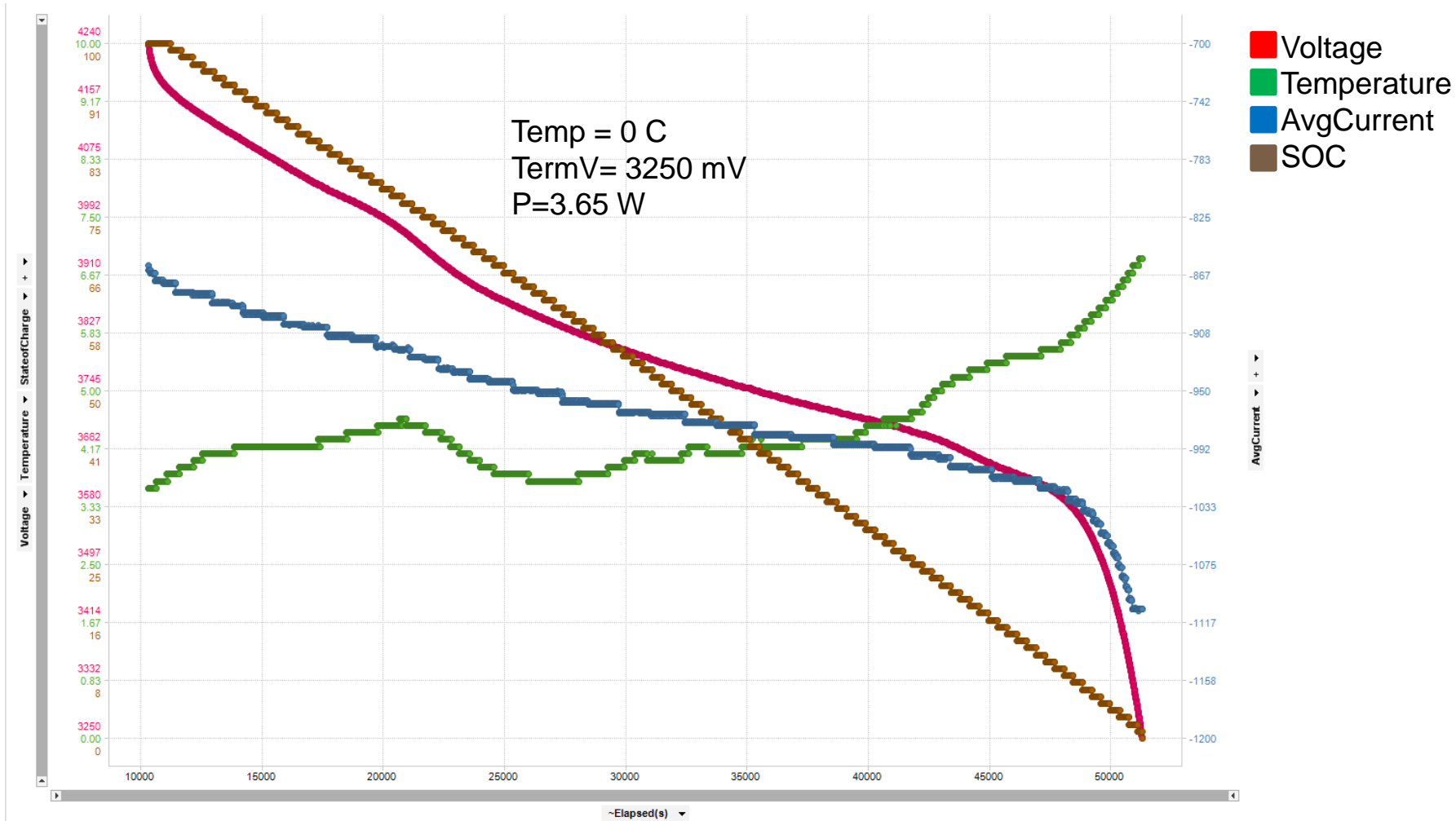
Line Chart



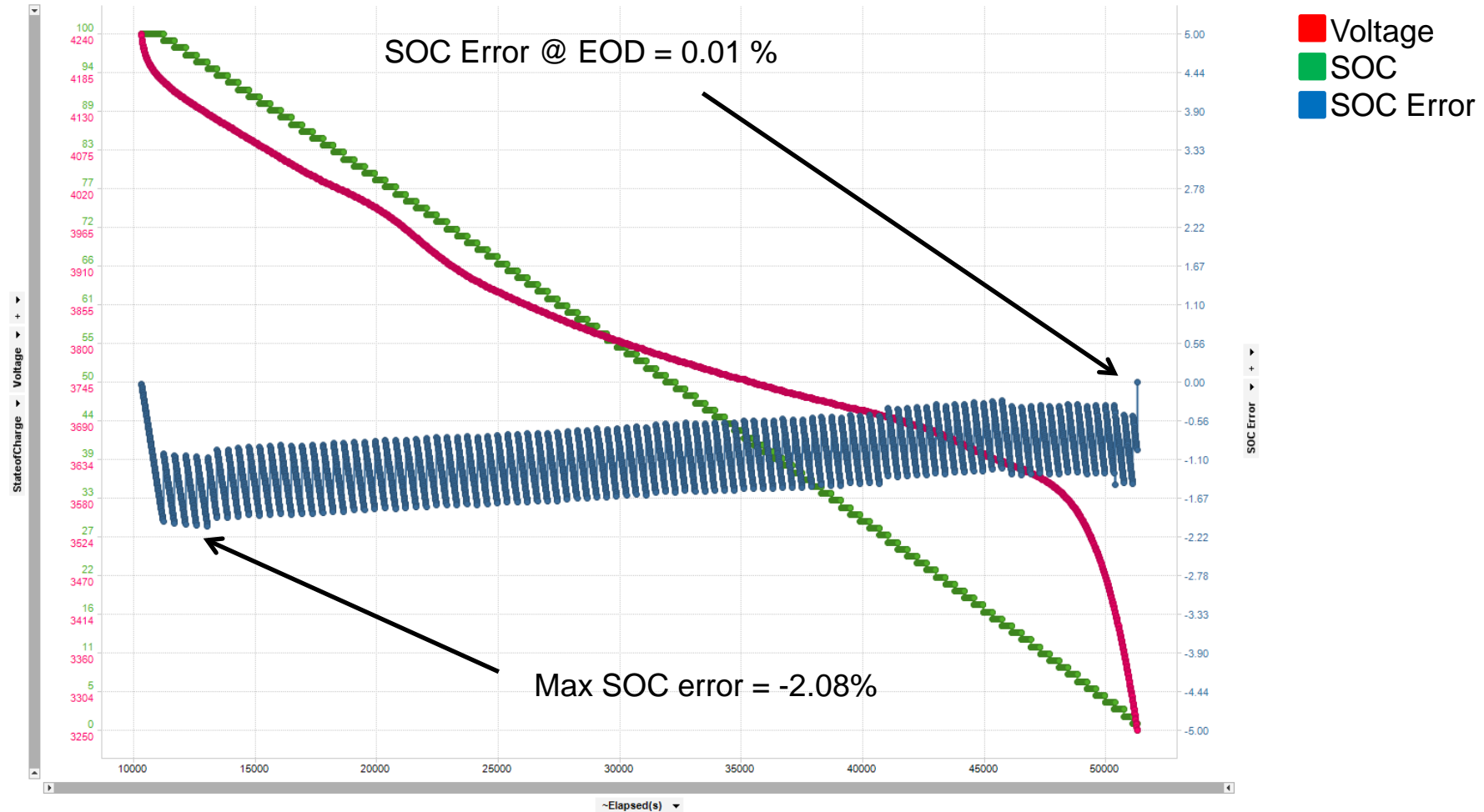
bq275xx – Cold temp, C/5 Load



bq275xx – Constant Power, Cold Temperature



bq275xx – Constant Power, Cold Temperature



Conclusions

Conclusion

- Gauging accuracy is dependent on the hardware measurement accuracy
- A more robust algorithm provides better accuracy. Impedance Tracking is the industry's most robust algorithm.
- To compute true accuracy, you need to know the actual capacity extracted from the battery for that particular test scenario.
- To compute true accuracy:
 - Integrate current in order to compute actual capacity extracted from the battery (FCC true)
 - Compute true remaining capacity (RM) by subtracting the integrated current from FCC true
 - Compute true SOC by dividing RM by FCC True.
 - Subtract gauge reported SOC from true SOC
- Use Impedance track for best gauging accuracy.

Questions??