



Experimental Evaluation of the Charging and Discharging Characteristics Of LiFePO_4 Batteries Under Different Charging Current Conditions with Constant Load Discharge

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ABSTRACT

This study experimentally evaluated the charging and subsequent constant-load discharge characteristics of a 12.8V, 30Ah, four-series-cell lithium iron phosphate (LiFePO_4) battery pack. The pack was protected by a 4S, 40A battery management system and supported by a 6A active balancer. Charging was performed with a constant-current/constant-voltage arrangement consisting of a 15V switch-mode power supply and an adjustable buck converter set to 14.4V. Three charging-current conditions were investigated: 5A, 10A and 15A, corresponding to approximately 0.17C, 0.33C and 0.50C. After each full charge and a one-hour balancing/rest period, the battery was discharged through an approximately 5A direct-current resistive load. Voltage, current, state of charge, time and discharge temperature were recorded. Trapezoidal integration was used to estimate charge input, delivered ampere-hour capacity and delivered watt-hour energy. Charging time decreased from 385 min at 5A to 205 min at 1A and 142 min at 15A, representing reductions of 46.8% and 63.1% relative to the 5A condition. However, the measured constant-load discharge duration decreased from 300 min after 5A charging to 250 min and 240 min after 10A and 15A charging. The corresponding delivered capacities were 25.03Ah, 20.85Ah and 20.03Ah, while delivered energies were 319.99Wh, 264.35Wh and 251.18Wh. The post-charge rested voltage also declined from 13.47V to 13.36V and 13.29V as charging current increased. Peak temperatures during the common 5A discharge remained close, ranging from 30.2°C to 30.6°C. The results demonstrate a clear time-performance trade-off in this particular battery pack and test sequence: higher charging current substantially shortened charging time but was followed by lower measured discharge duration, capacity and energy. Because each current condition was represented by a single recorded cycle, the findings establish descriptive pack-level behavior rather than statistically proven long-term degradation. Repeated randomized cycles, cell-level voltage logging, charge-temperature measurements and tighter cutoff sampling are recommended before generalizing the observed differences to LiFePO_4 batteries as a class.

1.0 INTRODUCTION

Electrochemical energy storage is central to renewable-energy systems, uninterruptible power supplies, electric mobility, telecommunications and stand-alone direct-current applications. In each of these systems, battery performance depends on more than the nameplate capacity. Charge acceptance, charge duration, terminal-voltage response, temperature, cell balance, depth of discharge and the control limits imposed by the battery management system jointly determine how much energy can be stored and later recovered. These interactions make experimentally measured charge-discharge behaviour essential for system design.

Lithium-ion batteries are available in several cathode chemistries. Lithium iron phosphate, commonly abbreviated *LFP* or LiFePO_4 , is distinguished by a robust olivine phosphate structure, a relatively flat operating-voltage plateau and strong thermal stability. The chemistry was established as a practical cathode system by Padhi, Nanjundaswamy and Goodenough (1997), and later work positioned LFP as an important option where cycle life, safety and power capability are valued. Modern battery systems still require strict control because overvoltage, under voltage, excessive current, cell imbalance and inappropriate temperature can reduce performance or create hazardous conditions (Habib et al., 2023; International Electro technical Commission [IEC], 2022).

A nominal 12.8V LiFePO_4 battery is normally formed by connecting four nominal 3.2V cells in series. Series connection increases voltage while the ampere-hour capacity remains that of one cell or one parallel group. Thus, a 4S, 30 Ah pack has a nominal stored energy of approximately 384Wh, calculated as 12.8V multiplied by 30Ah. The pack used in this study was charged to 14.4V, equivalent to 3.60V per cell, and was protected by a four-series-cell battery management system. An active balancer was also used to redistribute charge among series-connected cells near the upper state-of-charge region.

The conventional charging method for lithium-ion batteries is constant-current/constant-voltage charging. During the constant-current stage, the charger supplies a selected current and the battery voltage rises. When the terminal voltage reaches the specified upper limit, the charger holds the voltage approximately constant while the current tapers. This second stage allows cell polarization to relax and charge acceptance to decline as the battery approaches full state of charge. The relative duration of the two stages changes with charging current, internal resistance, temperature, state of health and charge cutoff criteria. Recent reviews continue to identify a trade-off between charging speed, heat generation and degradation risk (Ji et al., 2025; Leijon, 2025).

Charging current is often expressed as a C-rate. For a 30Ah battery, 5A corresponds to 0.167C, 10A to 0.333C and 15A to 0.500C. These rates are moderate compared with many fast-charge studies, but they are relevant to small stationary systems, solar-storage installations and laboratory chargers. Increasing the current should reduce the ideal constant-current charging time. In practice, the reduction is not exactly inversely proportional because the constant-voltage tail becomes important and because higher current produces greater ohmic and polarization voltage. As a result, a high-current charge may reach the voltage ceiling earlier even though electrochemical equilibration inside the cells is incomplete.

The discharge stage provides a practical test of the charge that can be recovered. A constant approximately 5A load was applied in the present study after each charging condition. Maintaining the same discharge current isolates the prior charging-current condition as the main deliberately varied factor. The discharge voltage of LFP remains comparatively flat through a broad middle state-of-charge region and then declines rapidly near the end of discharge. This plateau is useful for power delivery but complicates voltage-only state-of-charge estimation, because a small voltage error can correspond to a large SOC error in the flat region (Wang et al., 2023).

Temperature also affects internal resistance, capacity and reaction kinetics. Experimental studies show that battery capacity and voltage response vary with operating temperature, while high charging rates can amplify heat generation and aging stresses (Du et al., 2023; Lv et al., 2022). The present experiment recorded temperature during discharge, although it did not record cell or pack temperature throughout charging. The temperature data therefore support comparison of the common 5A discharge stage but cannot directly quantify charging heat.

This study addresses an applied engineering question: how does changing the CC setting from 5A to 10A and 15A affect the time required to charge a 30Ah, 12.8V *LiFePO₄* pack and the duration, capacity, energy and voltage behaviour observed during a subsequent constant-load discharge? The answer is relevant to charger selection and operating practice. A charger that reduces waiting time may not produce the same measured recoverable energy under the particular pack, balancing and cutoff conditions used.

2.0 LITERATURE REVIEW

The study of *LiFePO₄* battery charging and discharging characteristics is important for improving the performance, reliability, and safe operation of battery energy storage systems used in residential, industrial, renewable energy, and electric mobility applications. Several research efforts have been carried out to understand how different charging current conditions influence battery charging time, voltage response, temperature, energy storage, and subsequent discharge performance under a constant load. These investigations help provide useful information for selecting appropriate charging conditions and improving the overall utilization and service life of *LiFePO₄* batteries.

A number of researchers have conducted experimental studies to evaluate the performance of lithium iron phosphate batteries under different operating conditions. Some of these research studies include:

Wang et al. (2022) demonstrated rapid charging of energy-dense lithium-ion cells using asymmetric temperature modulation and a specialized electrolyte. The study confirms that fast charging can be engineered, but it also shows the importance of temperature and cell design that are absent from a basic buck-converter setup.

Lv et al. (2022) compared lithium-ion capacity at different temperatures and found that temperature materially changes discharge capacity and resistance. Their result supports controlling ambient temperature in future repeat tests.

Du et al. (2023) examined LFP cells under multiple thermoelectric aging paths and reported that charging rate and temperature jointly influence capacity deterioration. Their work involved repeated aging and diagnostic analysis, whereas the present study focuses on immediate pack-level recovery after one cycle per condition.

Tahir et al. (2023) compared multi-stage constant-current charging with CC-CV on a 2.6 Ah LFP cell. They reported reduced charging time with similar charged/discharged capacity and energy efficiency under an optimized staged protocol. The present study instead uses fixed CC settings and an assembled 30 Ah pack.

Wang et al. (2023) developed SOC-estimation methods for LFP under varying temperatures and emphasized the flat voltage plateau. This supports the decision to analyze integrated current and analyzer SOC rather than relying on terminal voltage alone.

Habib et al. (2023) reviewed BMS constraints, protection, estimation and balancing. Their review provides the system-level rationale for using both a 4S BMS and active balancing in the experiment.

Ashraf et al. (2024) reviewed cell-balancing circuits and explained how imbalance affects usable power and lifetime. The present work provides an applied context in which balancing quality may have influenced the high-SOC endpoint and later cutoff.

Leijon (2025) reviewed charging strategy and battery aging and concluded that faster charging and longer battery life often involve a trade-off. The current experiment observes a short-term charge-time versus measured-discharge trade-off but cannot establish aging.

Ji et al. (2025) reviewed conventional and intelligent fast-charging strategies, emphasizing transition criteria and battery models. Their work indicates that adaptive protocols are preferable to selecting current solely by time reduction.

3. DESIGN OF CHARGING CIRCUIT

Charging test circuit and measurement arrangement

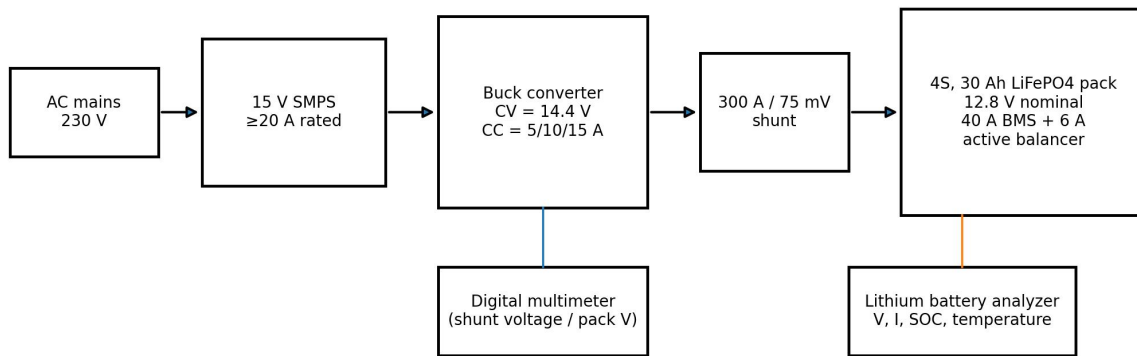


Figure 3.1: Charging test circuit and measurement arrangement.

3.1 BATTERY UNDER TEST

The battery under test was a nominal 12.8V, 30Ah LiFePO₄ pack configured as four 3.2V cell groups in series. Its nominal energy was 384Wh. The pack was connected to a 4S, 40A BMS and a 6A active balancer. The BMS provided overcharge, over discharge and overcurrent protection, while the balancer was intended to reduce cell-voltage differences after charging.

The experimental record states that the BMS disconnected the load at a nominal pack threshold of approximately 11.2V. The final logged points in the tables were between 10.55V and 10.62V. These lower values were treated as measured transient/end points rather than a revision of the stated BMS setting. Faster data logging around cutoff would be required to determine whether voltage sag, sampling delay or post-disconnection relaxation caused the difference.

3.2 MATERIALS AND EQUIPMENT

Table 3.1: Experimental materials and specifications.

Material	Specification	Function
LiFePO ₄ battery pack	30 Ah, 4S, 12.8 V nominal	Energy-storage device under test
Battery management system	4S, 40 A, for 3.2 V LFP cells	Cell monitoring and protective cutoff

Material	Specification	Function
Active balancer	6 A	Redistribution of charge among series cells
Buck converter	1500 W, 50 A, adjustable CV and CC	Set 14.4 V ceiling and 5/10/15 A current
Current shunt	300 A, 75 mV	Current determination from shunt voltage
Digital multimeter	Auto ranging	Pack voltage and shunt-voltage checks
DC resistive load	Nominal 5 A	Common constant-load discharge
SMPS charger	15 V, 20 A listed in materials	DC source for buck converter
Lithium battery analyzer	Voltage/current/SOC/temperature logging	Measurement and recording

Equipment-rating note: the procedure notes also refer to a 15 V, 30 A SMPS, while the materials list specifies 15 V, 20 A. Since the maximum regulated charge current was 15 A, either source rating provides nominal current headroom. This thesis records the materials-list value and flags the discrepancy for correction against the equipment nameplate before final institutional submission.

3.3 EXPERIMENTAL VARIABLES AND CONTROLS

Table 3.2: Experimental variables and control conditions.

Class	Variable	Level/condition
Independent variable	CC charging-current setting	5 A, 10 A, 15 A
Charge voltage control	CV set point	14.4 V
Discharge control	DC load current	Approximately 5 A
Battery control	Pack and BMS	Same 4S, 30 Ah pack and 4S 40 A BMS
Balancing/rest control	Post-charge period	Approximately 1 h
Measured charging variables	Time, pack voltage, cell average, current, SOC	Recorded at stated intervals
Measured discharge variables	Time, voltage, current, SOC, temperature	Recorded at stated intervals

CHARGING CIRCUIT

Charging test circuit and measurement arrangement

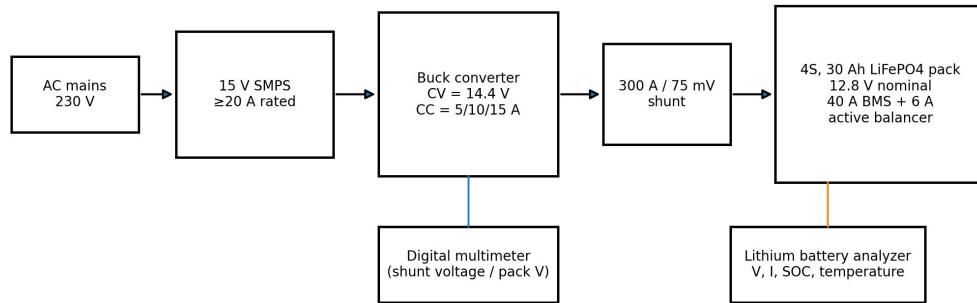


Figure 3.1: Charging test circuit and measurement arrangement.

The AC supply energized the 15V SMPS. The SMPS output supplied the buck converter, which reduced and regulated the output to the required battery charging voltage. The converter CV adjustment was set to 14.4V. The CC adjustment was set to 5A for the first test, 10A for the second and 15A for the third.

The shunt was placed in series with the battery current path. For a 300A/75mV shunt, the nominal sensitivity is 0.25mV/A. Current can therefore be calculated from the measured shunt voltage using

$$V = \frac{V_{Shunt}}{R_{Shunt}} \quad 3.1$$

$$\text{with } R_{Shunt} = \frac{75\text{mV}}{300\text{A}} = \frac{75 \times 10^{-3}\text{V}}{300\text{A}} = 0.00025\Omega$$

The battery analyzer provided the main logged variables, while the multi meter provided independent spot checks.

$$R_{Shunt} = \frac{0.07}{300} = 0.00025\Omega \quad 3.2$$

$$I = \frac{V_{Shunt}}{0.00025} \quad 3.3$$

3.5 CHARGING CIRCUIT

Constant-load discharge test circuit

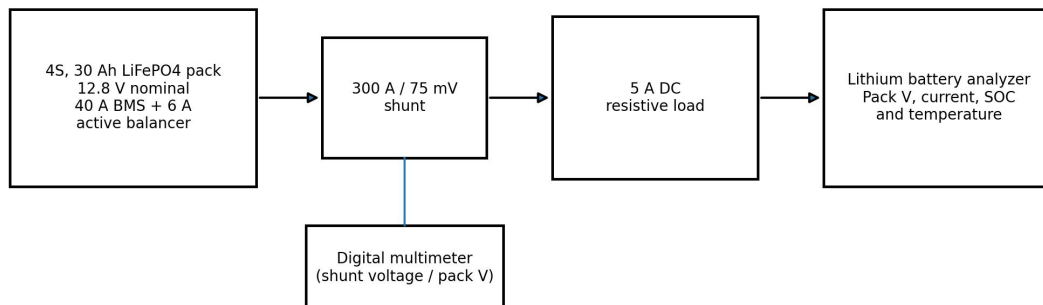


Figure 3.2: Constant-load discharge test circuit.

After the rest period, the charger was disconnected and the nominal 5A resistive load was connected to the BMS-protected output. The analyzer recorded discharge voltage, current, SOC and temperature. The discharge continued until BMS cutoff/end-of-test, after which the final measured point was recorded.

3.6 CHARGING CIRCUIT

- i. All series connections, terminal tightness, cable ratings, BMS sense leads and polarity were checked before energizing the system.
- ii. The 30Ah battery was connected to the 4S, 40A BMS and 6A active balancer.
- iii. The battery was discharged through the nominal 5A resistive load until BMS cutoff. The stated cutoff level was approximately 11.2V.
- iv. The SMPS was connected to the input of the adjustable buck converter. With the battery isolated, the converter output voltage was adjusted to 14.4V.
- v. For the first test, the converter CC limit was set to 5A. The battery was connected and time, pack voltage, average cell voltage, current and SOC were recorded at the intervals shown in Table 4.1.
- vi. Charging continued until the pack reached 14.4V, SOC was indicated as 100% and current had tapered to the final recorded value.
- vii. The charged battery was disconnected from the charger and allowed to rest for approximately one hour while the active balancer operated.
- viii. The nominal 5A DC load was connected. Discharge time, pack voltage, average cell voltage, current, SOC and temperature were recorded until cutoff.
- ix. The complete discharge-charge-rest-discharge sequence was repeated with CC limits of 10A and 15A.
- x. The resulting data were entered into separate charging and discharging tables and checked for unit consistency.

3.6 DATA REDUCTION AND CALCULATIONS

The charging currents corresponded to 0.167C, 0.333C and 0.500C. Charge and discharge ampere-hours were estimated by applying the trapezoidal rule to measured current and time. Watt-hours were estimated by integrating measured terminal power. This approach accounts for the current taper during CV charging and the small variation of the discharge current around 5A.

Nominal capacity recovery was calculated as delivered ampere-hours divided by 30Ah. Nominal energy recovery was calculated as delivered watt-hours divided by 384Wh. Apparent coulombic and energy ratios compared the subsequent discharge output with the battery-side input estimated from the charge measurements. They exclude upstream SMPS and buck-converter losses and should not be described as wall-plug efficiency.

Percentage change relative to the 5A charging condition was calculated for charge time, discharge capacity and discharge energy. The 5A condition was chosen as the reference because it was the lowest charging current and produced the longest discharge in the dataset.

$$Q \approx \sum \left[\frac{I_i + I_{i+1}}{2} \right] \Delta t \quad 3.4$$

$$E \approx \sum \left[\frac{V_i I_i + V_{i+1} I_{i+1}}{2} \right] \Delta t \quad .5$$

$$\text{Capacity Recovery (\%)} = \frac{Q_{\text{discharge}}}{30} \times 100 \quad 3.6$$

$$\text{Energy Recovery (\%)} = \frac{E_{\text{discharge}}}{384} \times 100 \quad 3.7$$

3.7 MEASUREMENT QUALITY, SAFETY AND ETHICAL CONSIDERATIONS

The study did not involve human participants, animals or personal data. Ethical considerations therefore centered on honest reporting, equipment safety and accurate representation of the evidence. No value was altered to force agreement with nominal battery specifications.

Electrical safety required correct polarity, insulated connections, appropriate cable current rating, secure terminals, ventilation and supervision. The BMS remained connected throughout the tests. The charging voltage was limited to 14.4V and the test did not intentionally overcharge, short-circuit, crush, puncture or thermally abuse the battery. These controls are consistent with the general protective intent of IEC 62619:2022.

Measurement uncertainty arose from multimeter accuracy, analyzer calibration, shunt tolerance, converter regulation and manual reading intervals. The 300A shunt is heavily oversized for 5–15A, so its output voltage was only about 1.25–3.75mV; this is measurable but makes resolution and contact-voltage errors important. A lower-current precision shunt would improve future measurements.

4.1 PRESENTATION OF RAW CHARGING DATA

Table 4.1: Measured LiFePO₄ charging profile under 5 A CC-CV regime.

Time (min)	Pack voltage (V)	Cell average (V)	Current (A)	SOC (%)
0	11.9	2.975	5.01	0
30	12.78	3.195	4.99	8
60	13.02	3.255	5	16
90	13.16	3.29	4.98	25
120	13.24	3.31	5.01	33
150	13.3	3.325	5	41
180	13.36	3.34	4.99	50
210	13.41	3.353	5	58
240	13.48	3.37	5.01	66
270	13.56	3.39	4.98	75
300	13.72	3.43	4.99	83
330	14.08	3.52	4.2	91
360	14.34	3.585	2.15	97
385	14.4	3.6	0.45	100

Table 4.2: Measured LiFePO₄ charging profile under 10 A CC-CV regime.

Time (min)	Pack voltage (V)	Cell average (V)	Current (A)	SOC (%)
0	11.9	2.975	10.02	0
30	12.92	3.23	9.98	16
60	13.18	3.295	10.01	32
90	13.28	3.32	9.99	48
120	13.38	3.345	10	65

Time (min)	Pack voltage (V)	Cell average (V)	Current (A)	SOC (%)
150	13.54	3.385	9.97	81
180	14.12	3.53	6.8	93
205	14.4	3.6	0.85	100

Table 4.3: Measured LiFePO₄ charging profile under 15 A CC-CV regime.

Time (min)	Pack voltage (V)	Cell average (V)	Current (A)	SOC (%)
0	11.9	2.975	15.05	0
30	13.06	3.265	14.96	24
60	13.26	3.315	15.02	49
90	13.46	3.365	14.98	73
120	14.22	3.555	9.4	91
142	14.4	3.6	1.1	100

Table 4.4: Five-ampere discharge profile after 5A charging.

Time (min)	Pack voltage (V)	Cell average (V)	Current (A)	SOC (%)	Temperature (°C)
0	13.47	3.368	5.04	100	26.8
30	13.14	3.286	4.98	91	27.4
60	13.03	3.258	5.02	82	28
120	12.9	3.225	5.01	64	28.8
180	12.75	3.188	4.97	46	29.5
240	12.59	3.148	5.05	27	29.9
270	12.46	3.115	5	14	30.1
285	12.18	3.045	4.96	7	30.2
295	11.78	2.945	5.03	2	30.1
300	10.62	2.655	4.99	0	29.9

Table 4.5: Five-ampere discharge profile after 10A charging.

Time (min)	Pack voltage (V)	Cell average (V)	Current (A)	SOC (%)	Temperature (°C)
0	13.36	3.34	5.02	100	27.2
30	13.07	3.268	4.99	89	27.9
60	12.93	3.233	5.04	78	28.6
120	12.74	3.185	4.97	59	29.3
180	12.53	3.133	5.01	39	29.9
210	12.39	3.098	5.03	26	30.1
230	12.18	3.045	4.96	15	30.3
240	11.9	2.975	5	8	30.2
248	11.46	2.865	5.05	2	30.1
250	10.58	2.645	4.98	0	30

Table 4.6: Five-ampere discharge profile after 15A charging.

Time (min)	Pack voltage (V)	Cell average (V)	Current (A)	SOC (%)	Temperature (°C)
0	13.29	3.323	5.03	100	27.5
30	13	3.25	4.97	87	28.3
60	12.82	3.205	5.01	74	29
120	12.57	3.143	5.04	53	29.8
180	12.32	3.08	4.98	31	30.3
210	12.15	3.038	5.02	18	30.5
225	11.88	2.97	4.96	10	30.6
235	11.52	2.88	5.01	4	30.5
238	11.18	2.795	5.04	1	30.4
240	10.55	2.638	4.99	0	30.3

4.3 DERIVED PERFORMANCE INDICATORS

Table 4.7: Derived charging and discharge performance indicators.

Charging current	C-rate	Charge time (min)	Charge input (Ah)	Charge input (Wh)	Rested discharge start (V)	Discharge time (min)	Delivered capacity (Ah)	Delivered energy (Wh)	Average discharge voltage (V)	Peak discharge temp (°C)
5 A	0.167	385	29.41	392.20	13.47	300	25.03	319.99	12.786	30.2
10 A	0.333	205	30.77	407.53	13.36	250	20.85	264.35	12.680	30.3
15 A	0.500	142	30.52	403.69	13.29	240	20.03	251.18	12.542	30.6

Table 4.8: Comparative changes relative to the 5 A charging condition.

Charging current	Charge time reduction vs 5 A (%)	Capacity change vs 5 A (%)	Energy change vs 5 A (%)	Capacity recovery (%)	Energy recovery (%)	Apparent coulombic ratio (%)	Apparent energy ratio (%)	Temperature rise (°C)
5 A	0.0	0.0	0.0	83.4	83.3	85.1	81.6	3.4
10 A	46.8	-16.7	-17.4	69.5	68.8	67.7	64.9	3.1
15 A	63.1	-20.0	-21.5	66.8	65.4	65.6	62.2	3.1

4.4 CHARGING VOLTAGE CHARACTERISTICS

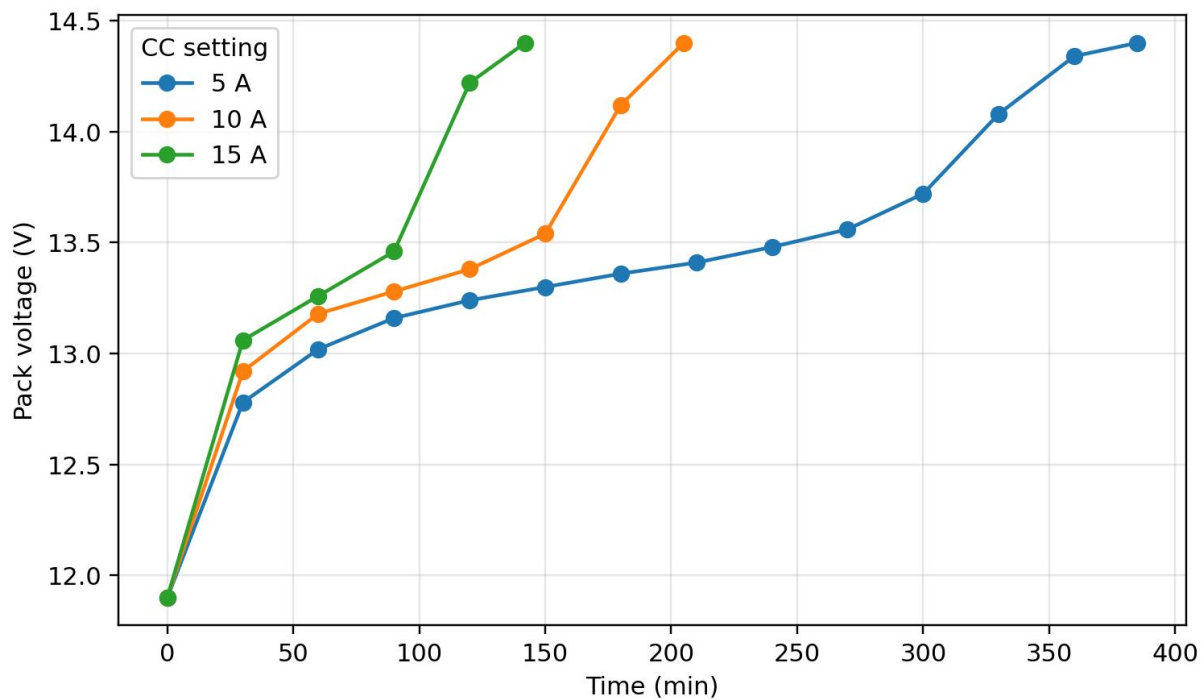


Figure 4.1: Pack voltage during charging at 5A, 10A and 15A.

The three voltage curves began at the same measured pack voltage of 11.9V. The 15A condition produced the most rapid initial rise: after 30min the pack was at 13.06V, compared with 12.92V at 10A and 12.78V at 5A. The current-dependent separation is consistent with a larger ohmic and polarization contribution at higher current.

The middle portions of all curves were comparatively flat, reflecting the LFP voltage plateau. At 90min, pack voltage was 13.16V at 5A, 13.28V at 10A and 13.46V at 15A. The higher-current curves approached the upper-voltage knee sooner. The 15A test reached 14.22V at 120min, while the 10A test reached 14.12V at 180min and the 5A test reached 14.08V at 330min.

All tests terminated at 14.4V. The voltage limit was therefore controlled consistently. However, equality of final terminal voltage does not prove equality of internal equilibrium SOC. Terminal voltage during current flow includes resistance and polarization. This is one reason a rest period was included and why rested starting voltage is examined later.

4.5 CHARGING CURRENT AND CC-CV TRANSITION

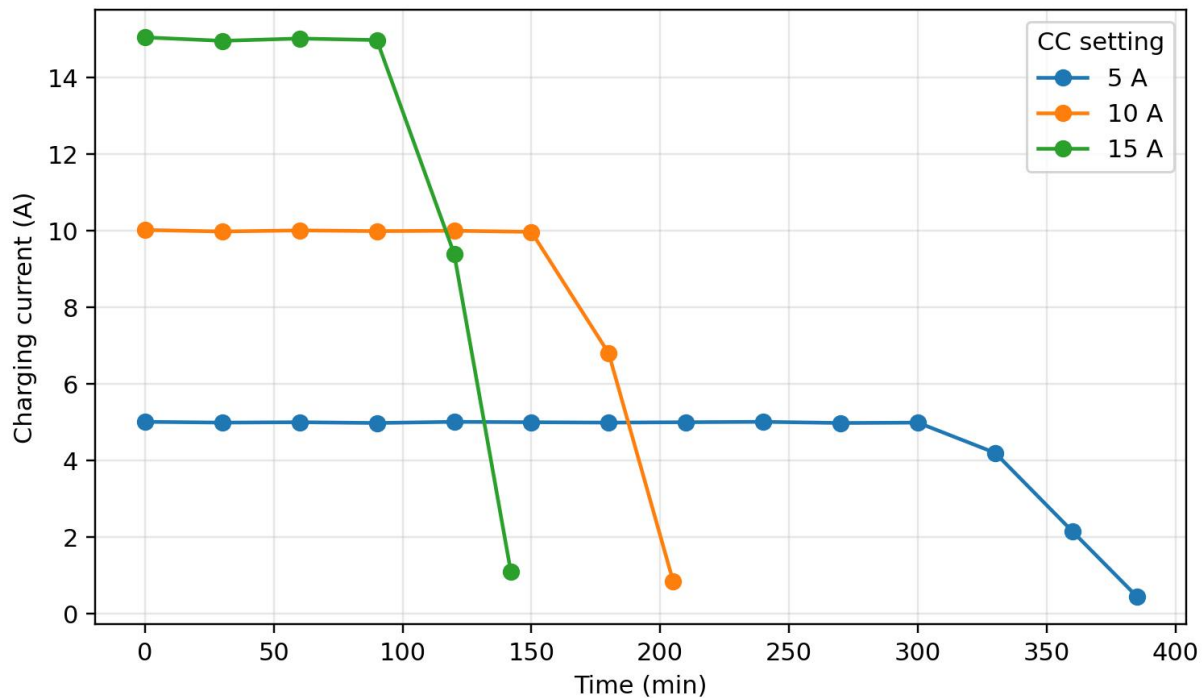


Figure 4.2: Measured current during the three CC-CV charging tests.

The measured current remained close to each converter setting during most of the charge. In the 5A test, values between 4.98A and 5.01A were recorded through 300min. Current then declined to 4.20A at 330min, 2.15A at 360min and 0.45A at 385min. The taper marks the CV stage.

In the 10A test, current remained approximately 10A through 150min, fell to 6.8A at 180min and reached 0.85A at 205min. In the 15A test, current remained approximately 15A through 90 min, fell to 9.4A at 120 min and reached 1.1A at 142min. The current taper began earlier in absolute time as the CC setting increased.

The final taper current was not identical among tests. It was 0.45A, 0.85A and 1.1A for the 5A, 10A and 15A conditions. If the full-charge decision was partly based on SOC indication rather than a common termination current, the high-current tests may have ended with a larger residual charge-acceptance current. A stronger protocol would use a fixed termination criterion, for example a defined fraction of capacity, and hold the CV stage until that threshold is met.

4.6 CHARGING TIME AND SOC PROGRESSION

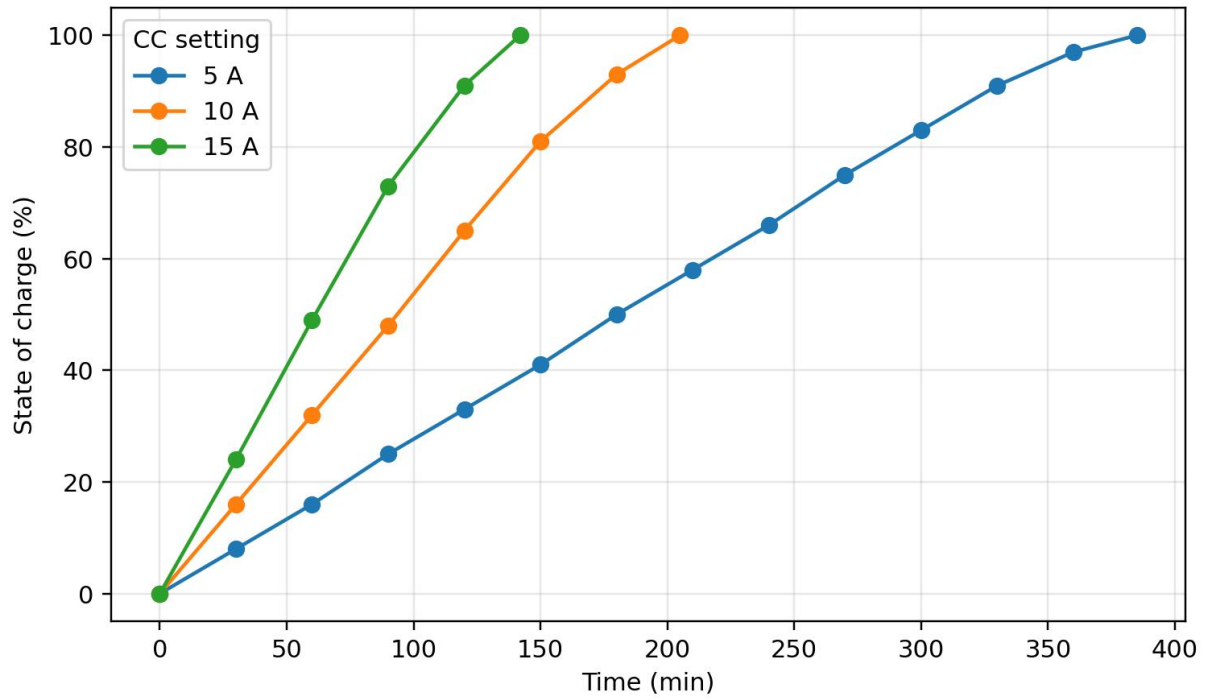


Figure 4.3: Recorded state of charge during charging.

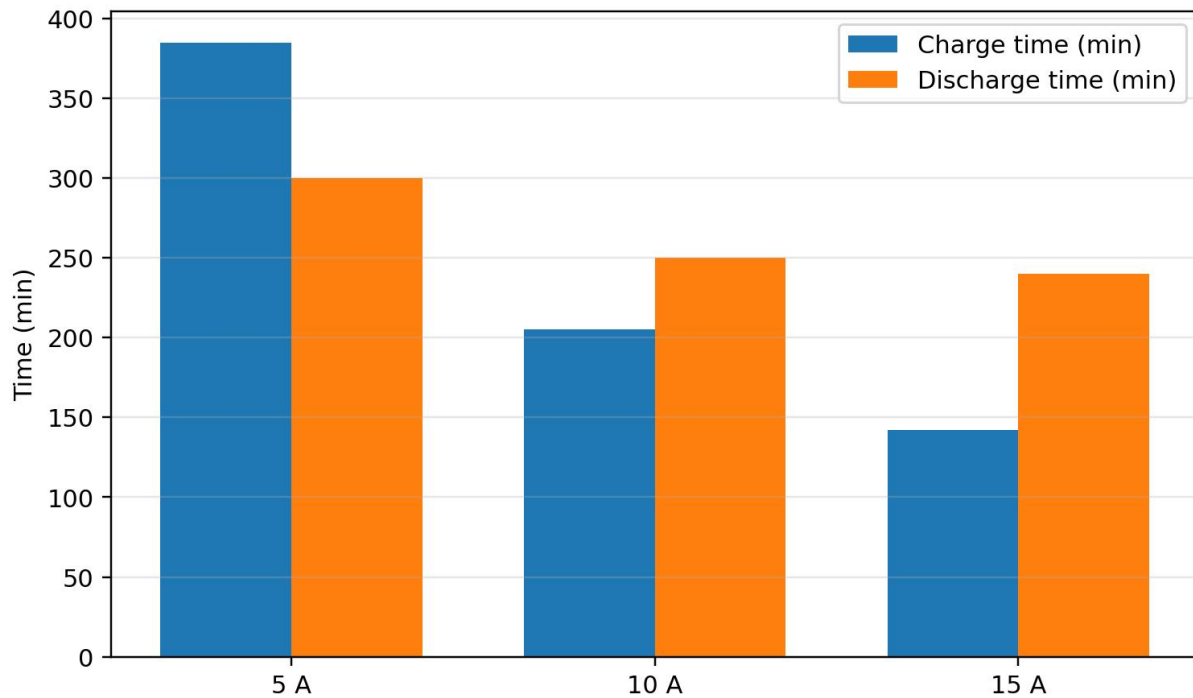


Figure 4.7: Comparison of charging time and subsequent 5A discharge time.

Total charging time was 385min at 5A, 205min at 10A and 142min at 15A. Doubling current from 5A to 10A reduced time by 180min, or 46.8%. Tripling current from 5A to 15A reduced time by 243min, or 63.1%. The ideal inverse-current times for transferring 30Ah would be 360min, 180min and 120min, before the CV tail and endpoint effects. The measured times exceeded those ideal values by 25min, 25min and 22min respectively.

The SOC trajectories were approximately linear through much of the CC stage. At 90min, SOC was 25% at 5A, 48% at 10A and 73% at 15A. This result confirms that charging-current control materially changed charge accumulation rate. The final SOC value of 100% was analyzer-derived and should be interpreted within the analyzer's calibration.

The estimated battery-side charge inputs were 29.41Ah, 30.77Ah and 30.52Ah. The values are close to the nominal 30Ah rating, which supports basic consistency of the charge measurements. The 5A integral was slightly below nominal, while the 10 A and 15A integrals were slightly above. Differences may arise from SOC endpoint definition, integration over coarse intervals, shunt uncertainty and analyzer calibration.

4.7 DISCHARGE VOLTAGE CHARACTERISTICS

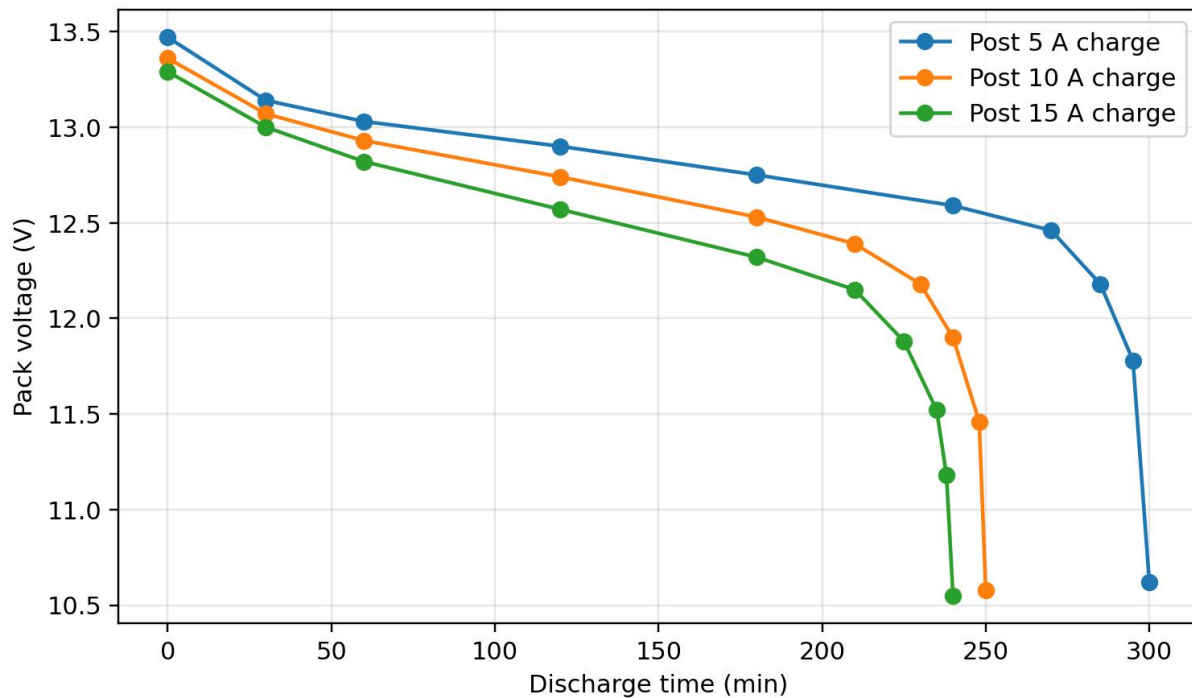


Figure 4.4: Pack voltage under the common approximately 5 A discharge.

The post-rest starting voltages were 13.47V after 5A charging, 13.36V after 10A charging and 13.29V after 15A charging. Because all batteries were nominally reported at 100% SOC before rest, the descending rest voltage is an important observation. It suggests that the high-current conditions may have produced a lower equilibrium charge state, greater residual imbalance, different relaxation behavior or a measurement offset.

After the initial voltage decline, all tests showed an LFP plateau. At 60min, voltage was 13.03V, 12.93V and 12.82V following 5A, 10A and 15A charging respectively. At 180min, the corresponding voltages were 12.75V, 12.53V and 12.32V. The voltage separation therefore persisted through the plateau and was not limited to an initial surface-charge effect.

Near the end of discharge, each curve fell rapidly. The final readings were 10.62V, 10.58V and 10.55V. These points are below the stated 11.2V BMS threshold. The most plausible methodological explanations are transient voltage sag under load, a reading taken immediately before/after electronic cutoff, analyzer timing delay or an inaccurate nominal cutoff statement. Individual-cell logging at one-second intervals would resolve this uncertainty.

The average discharge voltages calculated from delivered Wh/Ah were 12.786V, 12.680V and 12.542V. The lower average voltage after higher-current charging amplified the energy difference beyond the capacity difference.

4.8 DISCHARGE DURATION AND DELIVERED CAPACITY

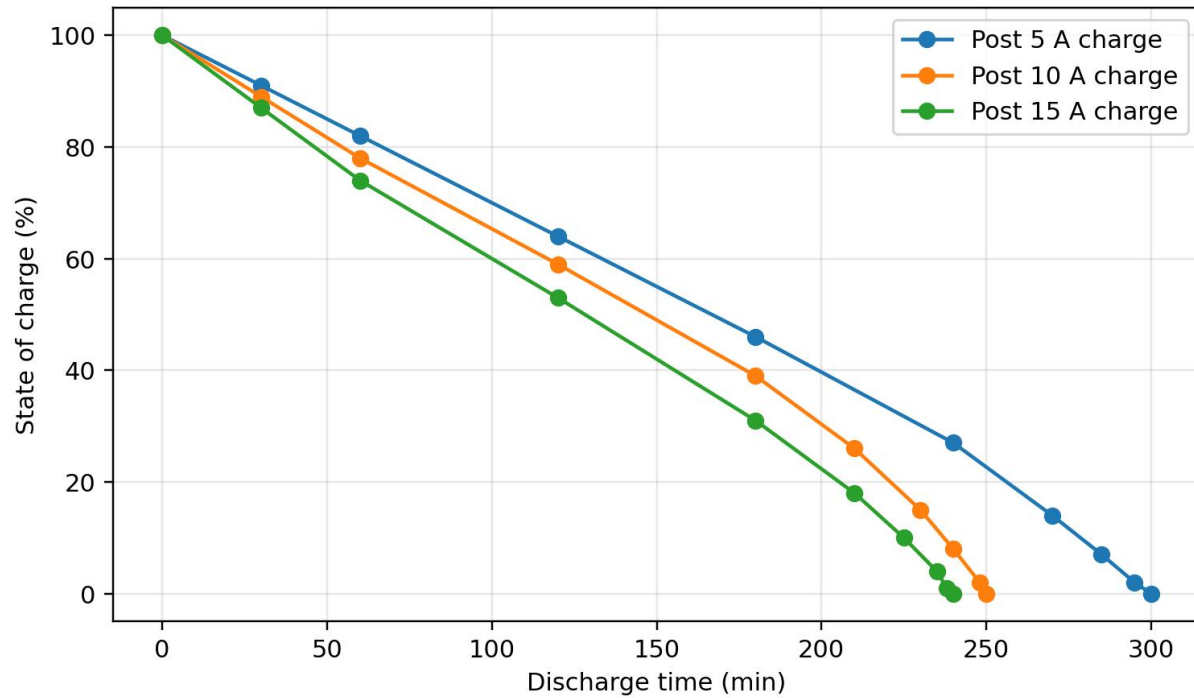


Figure 4.5: State-of-charge progression during the common 5 A discharge.

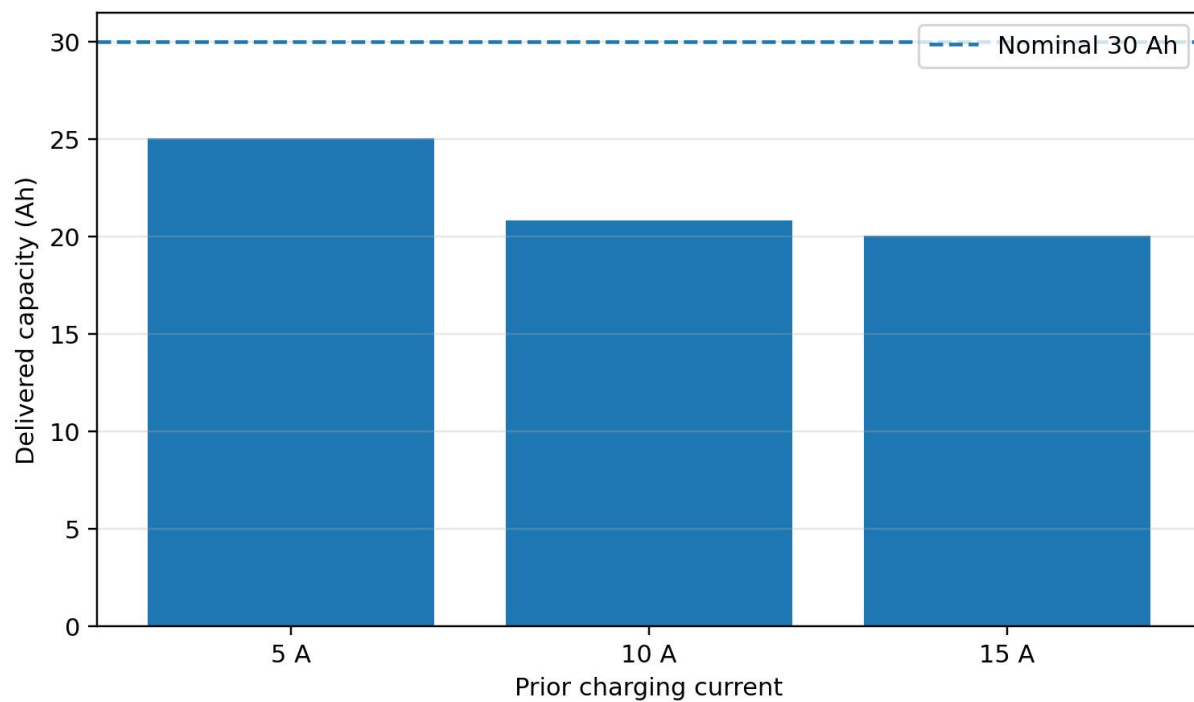


Figure 4.8: Delivered ampere-hour capacity after each charging-current condition.

The discharge duration was 300min after 5A charging, 250min after 10A charging and 240min after 15A charging. At an approximately 5A load, these durations correspond closely to the integrated capacities of 25.03Ah, 20.85Ah and 20.03Ah. Relative to the 5A condition, the 10A condition delivered 16.7% less capacity and the 15A condition delivered 20.0% less.

When compared with the 30Ah nameplate rating, the measured capacity recoveries were 83.4%, 69.5% and 66.8%. These figures should not be interpreted as permanent state-of-health values. Nameplate capacity depends on manufacturer test conditions, cutoff voltage, temperature, rest period and initial conditioning. The study instead shows that the same pack delivered substantially different capacity in the three recorded cycles.

The difference between 10A and 15A was smaller than the difference between 5A and 10A. Capacity declined by approximately 0.82Ah when charging current increased from 10A to 15A, compared with a 4.18Ah decline from 5A to 10A. This may indicate a nonlinear response, but with one cycle per condition it may also reflect cycle variability or sequence effects.

The analyzer SOC curves broadly followed discharge time, but SOC reached zero at the final logged point in each test. Since LFP voltage is flat, the SOC display likely depended heavily on current integration. Any failure to reset the analyzer to the true capacity or any shunt bias would affect the SOC percentage. The independently calculated ampere-hours provide a transparent comparison.

4.9 DELIVERED ENERGY AND APPARENT CHARGE-TO-DISCHARGE RATIOS

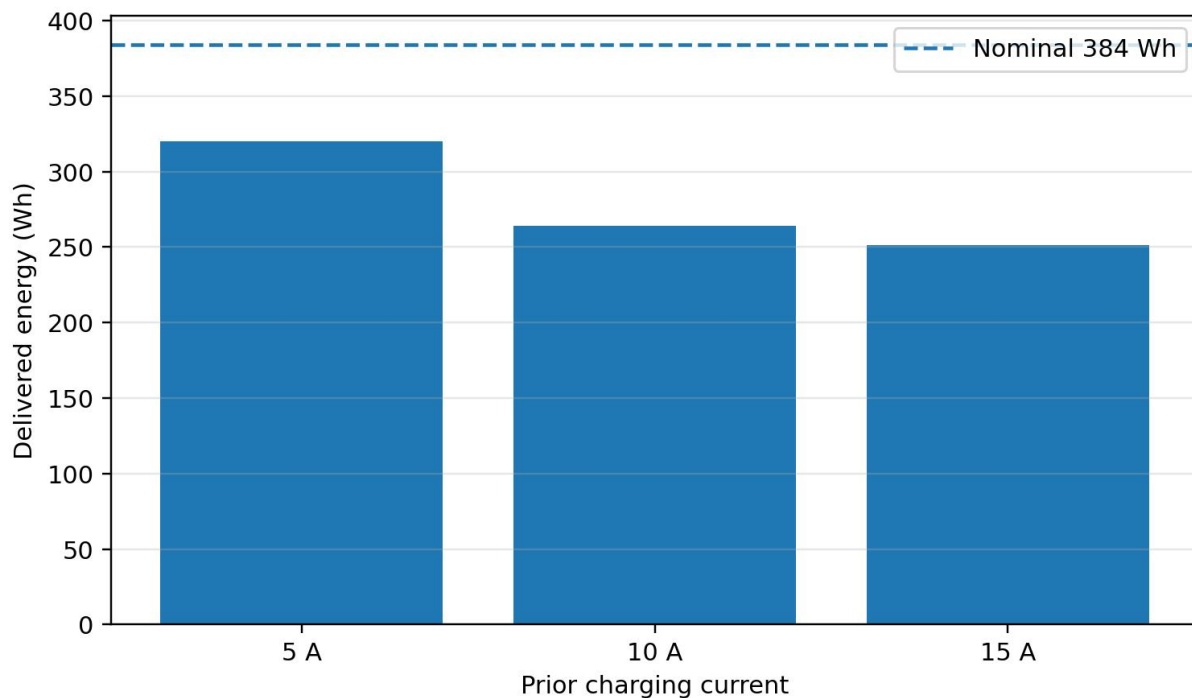


Figure 4.9: Delivered watt-hour energy after each charging-current condition.

Delivered energy was 319.99Wh after 5A charging, 264.35Wh after 10A charging and 251.18Wh after 15A charging. Relative to the 5A condition, energy declined by 17.4% and 21.5% for 10A and 15A charging. The reductions exceeded the average-voltage differences alone and mainly reflect the shorter discharge duration.

The nominal energy of the pack is 384Wh. Measured energy recoveries were therefore 83.3%, 68.8% and 65.4%. Again, these are recovery values under the experimental cutoff and load, not certified energy efficiencies or SOH measurements.

Estimated battery-side charging energies were 392.20Wh, 407.53Wh and 403.69Wh. Dividing delivered discharge energy by these inputs gives apparent energy ratios of 81.6%, 64.9% and 62.2%. Typical healthy lithium-ion cells can show high coulombic efficiency under controlled cycling, so the low high-current ratios in this dataset should trigger methodological investigation. Possible contributors include incomplete effective charge at the common 14.4V endpoint, unequal termination current, cell imbalance, analyzer calibration, coarse integration and cycle-order effects. It would be scientifically inappropriate to assign the entire difference to irreversible chemical loss after a single charge.

4.10 TEMPERATURE RESPONSE DURING DISCHARGE

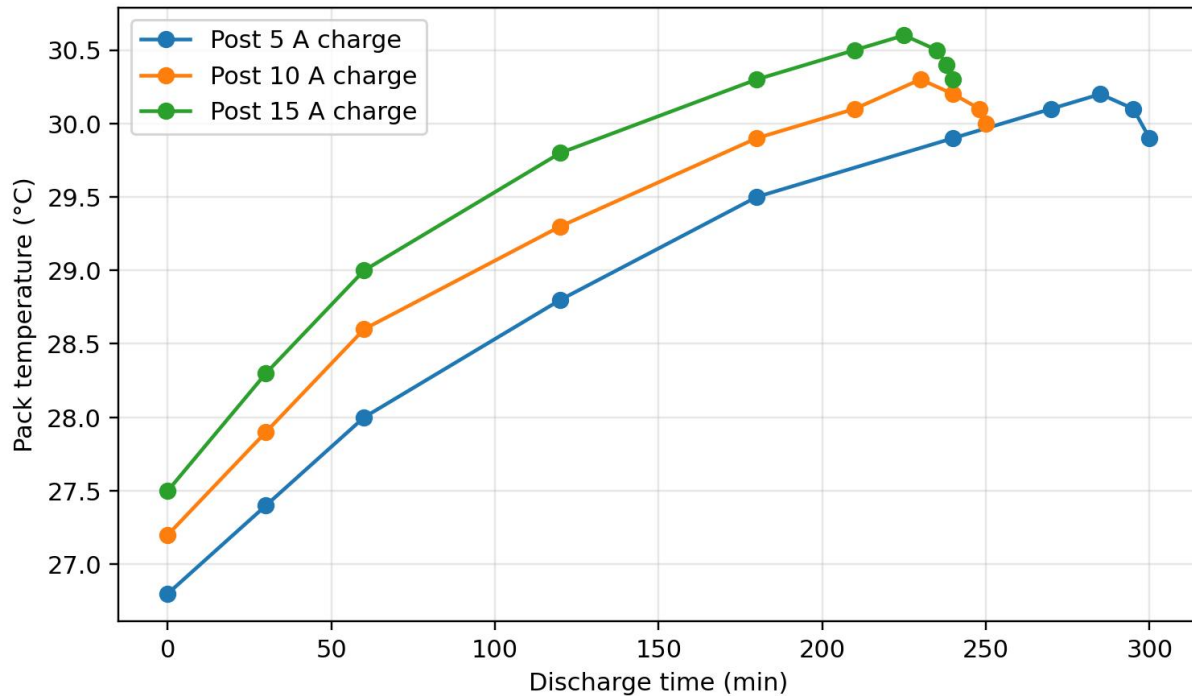


Figure 4.6: Pack temperature during the common approximately 5 A discharge.

The initial discharge temperatures were 26.8 °C, 27.2 °C and 27.5 °C. Peak temperatures were 30.2 °C, 30.3 °C and 30.6 °C, corresponding to rises of 3.4 °C, 3.1 °C and 3.1 °C. The similar increases are expected because discharge current was approximately the same in all tests.

The highest absolute temperature occurred after 15A charging, but that test also began at the highest temperature. The data do not establish that the 15A charge caused more discharge heating. Furthermore, the one-hour rest allowed much of any charging heat to dissipate. Continuous charge-temperature logging is required to assess the thermal effect of charging current, as emphasized by rate-temperature studies such as Du et al. (2023).

All measured discharge temperatures remained moderate. Nevertheless, the temperature sensor location was not specified. A single surface sensor may not capture internal hotspots, cell-to-cell gradients or heat at BMS MOSFETs and terminals.

4.11 INTEGRATED COMPARISON OF THE THREE CHARGING CONDITIONS

The 5A condition provided the slowest charge but the highest rested voltage, longest discharge time, highest delivered capacity, highest delivered energy and highest apparent energy ratio. In the recorded experiment, it therefore provided the strongest measured energy-recovery performance.

The 10A condition nearly halved charging time, reducing it from 6.42h to 3.42h. The cost was a 50min reduction in discharge duration and a 4.18Ah reduction in delivered capacity relative to 5A. This condition may be attractive where turnaround time is important and the reduced measured runtime is acceptable, but the observed capacity difference should first be verified through repeated tests.

The 15A condition produced the fastest charge at 2.37h, but the subsequent discharge lasted 4.00h and delivered 20.03Ah. Compared with 10A, charging time improved by 63min while discharge duration decreased by only 10 min. On the supplied data alone, 15A appears to offer a better time trade-off than 10A, but both yielded substantially less measured energy than 5A.

A practical interpretation is therefore conditional. If the priority is maximum measured runtime and energy recovery, 5A is preferred. If fast turnaround dominates, 15A is preferred among the tested settings. If battery longevity is the priority, the experiment is insufficient because it did not measure repeated aging. Contemporary literature warns that high rate, high SOC and temperature can accelerate degradation, but the tested rates are moderate and long-term evidence must come from controlled cycling (Du et al., 2023; Leijon, 2025).

4.12 COMPARISON WITH PUBLISHED STUDIES

The observed reduction in charging time with increasing current agrees with CC-CV theory and with published charging-strategy research. Tahir et al. (2023) showed that charging time can be reduced using a carefully staged current profile. The present fixed-current system also reduced time, but its subsequent discharge recovery varied strongly, underscoring the difference between current increase and protocol optimization.

The persistent lower voltage after higher-current charging is consistent with the role of polarization in terminal voltage. Ji et al. (2025) reviewed fast-charge transition criteria and battery models, noting the need to account for internal state rather than terminal voltage alone. In the present experiment, the same 14.4V endpoint may have been reached at different internal conditions.

The potential role of cell imbalance agrees with BMS and balancing literature. Ashraf et al. (2024) explained that unequal cells constrain pack capacity, while Habib et al. (2023) identified cell equalization and protection as core BMS functions. Because only average cell voltage was recorded, the study could not determine whether one cell reached the upper or lower threshold earlier in the high-current tests.

The temperature data do not conflict with literature showing higher heat at higher charging rate because charging temperature was not measured. Similar discharge temperature rises reflect the common load. The literature comparison therefore supports the need for simultaneous cell voltage and temperature logging during the charge stage.

4.13 VALIDITY OF THE MAIN FINDING

The main descriptive finding is valid for the supplied measurements: higher charging current shortened charging time and was followed by lower measured constant-load discharge output. This statement is directly supported by the recorded time, voltage and current data and by numerical integration.

A stronger causal statement, such as “higher charging current permanently reduces $LiFePO_4$ capacity,” is not supported. Permanent degradation requires repeated capacity tests, baseline checks, controlled temperature and statistical replication. The current results may represent incomplete effective charge, balance limitations, cycle order or measurement bias in addition to any electrochemical rate effect.

This distinction is important for engineering decisions. The data justify retesting the pack and reviewing the high-current termination criterion. They do not justify rejecting 10A or 15A charging for every 30Ah LFP battery.

5. Summary of the Study and Conclusion

5.1 SUMMARY OF THE STUDY

The study evaluated a 12.8V, 30Ah, 4S $LiFePO_4$ battery using three CC-CV charging-current settings and a common constant-load discharge. The test system consisted of a 15V SMPS, a 1500W adjustable buck converter, a 300A/75mV shunt, a digital multi meter, a lithium battery analyzer, a 4S 40A BMS, a 6A active balancer and a nominal 5A DC resistive load.

The battery was first discharged to BMS cutoff, then charged at 5A, 10A or 15A with a 14.4V CV ceiling. After reaching the stated full-charge condition, it rested and balanced for approximately one hour before discharge. Raw voltage, current, SOC, time and temperature data were converted into charge and energy indicators by trapezoidal integration.

Charging time decreased from 385min at 5A to 205min at 10A and 142min at 15A. Subsequent discharge time decreased from 300min to 250min and 240min. Delivered capacity was 25.03Ah, 20.85Ah and 20.03Ah. Delivered energy was 319.99Wh, 264.35Wh and 251.18Wh. The rested starting voltage and average discharge voltage also decreased as prior charging current increased. Discharge temperature rises were similar because the same load was used.

The analysis identified important limitations: lack of replication, fixed test order, absence of individual-cell traces, no charge-temperature data, uncertain cutoff sampling, oversized shunt and inconsistent SMPS current rating in the notes. These limitations restrict the conclusion to observed short-term pack behavior.

5.2 CONCLUSION

The experiment demonstrated that increasing charging current from 5A to 10A and 15A substantially reduced CC-CV charging time for the tested 30Ah $LiFePO_4$ pack. The reduction was practically significant: 10A saved 180min and 15A saved 243min relative to 5A.

The faster charging conditions were followed by lower measured performance during the common approximately 5A discharge. The 5A charge produced the longest runtime and greatest delivered capacity and energy. The 10A and 15A charges produced 16.7% and 20.0% less delivered capacity and 17.4% and 21.5% less delivered energy than the 5A condition.

For this specific test sequence, 5A provided the best measured energy recovery, while 15A provided the shortest charge time. The choice therefore depends on whether runtime or turnaround time is prioritized. The 10A condition lay between the two but did not provide a clearly superior combined outcome in the single-cycle dataset.

The study cannot confirm that charging at 10A or 15A caused permanent battery degradation. The differences may involve unequal CV termination current, incomplete balancing, cycle order, analyzer calibration, cutoff transients or actual rate-dependent charge acceptance. Replicated testing is required before a causal or lifetime conclusion can be made.

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