# Unexpected Currents at Connection

Inrush, Discharge, Arcing, and Hidden Transient Effects

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Have you ever heard—or even said—something like:

> **When the battery is connected,**
>
> “Our new power stage (or cycler) is causing unexpectedly high currents from the battery.”
>
> “We’re seeing currents we’ve never seen before.”
>
> “Two identical test systems behave differently during pack connection.”

These issues are often treated as separate problems. In reality, they are frequently different expressions of the same underlying effect: how the test system interacts with the battery at the moment of connection.

**In Many Cases, It’s Not Just the Battery—It’s the Test System.**

This can be difficult to reconcile—particularly when two “identical” test systems produce different results.

### Seen During Cycler Development

In prior work at NH Research (NHR), an early platform—the 9200-4912, a 120V/200A battery cycler released in 2011—did not expose the issue. However, during development of the 9200-4960, a 600V/40A cycler based on the same design philosophy, the behavior became clear.

When the main contactor closed while connected to a live electric vehicle (EV) battery, a current transient **exceeding 800 A** was observed during validation.

### Real-World Customer Case

Similar behavior has been observed in the field with systems based on DC regenerative loads.

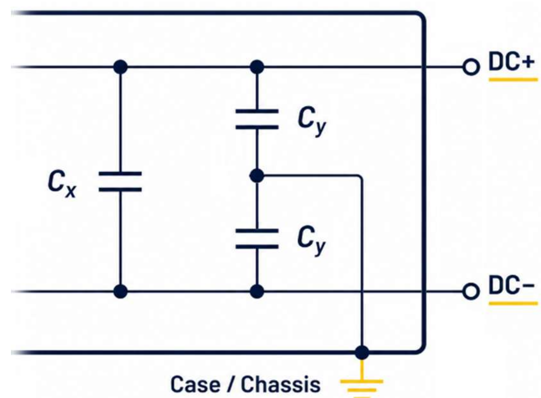
In one case, a customer using two “identical” test systems experienced different outcomes during battery connection—one system consistently tripped an over-current condition, while the other did not.

**Despite appearing unrelated, the root cause in both cases was the same.**

## What Happens at Connection

When a battery is connected to a test system, the first interaction is not controlled by the software command. It is controlled by physics.




Most power conversion devices include output capacitance, particularly switching-based systems. In battery test applications, that capacitance can become an energy storage element connected directly to the battery terminals.

This capacitance may come from bulk output capacitors, output filtering, EMI suppression networks, cable capacitance, or parasitic elements. Regardless of the source, the effect is similar: stored energy exists at the test system terminals before or during connection.

> **The basic relationship is:** $I_{transient} \approx C \cdot \frac{\Delta V_C}{\Delta t}$
>
> Current is driven not only by the capacitance value, but also by how quickly the terminal voltage changes.

In this relationship, **Δt is not the contactor's published closing time**.
It is the effective time over which the capacitance voltage changes once an electrical path is established. A mechanical contactor may have a relatively slow closing specification, yet still produce a fast, high-current transient at the instant of electrical contact.

This relationship also explains why increased voltage and a faster effective connection were identified as key contributors to the observed >800 A transient during NHR 9200-4960 validation—exceeding 20× the product's rated current specification.

> **Practical Takeaway**
>
> A modest voltage mismatch can still produce a large current when connection is fast and available impedance is low.

### Why “Identical” Systems Behave Differently

Even when two test systems use the same hardware and appear identical, connection current is shaped by the complete battery-to-test-system interaction—not by a single device specification.

Small differences can change the transient:

| Difference | Why it matters |
|---|---|
| Paralleled cyclers | Increase capacitance and reduce path impedance |
| Cable length / placement | Changes resistance, inductance, and loop area |
| Contact resistance / bounce | Alters peak current and energy dissipation |
| Precharge state | Sets the initial voltage mismatch |
| Battery type / condition | Affects voltage stiffness,<br>impedance, SOC, SOH, temperature, and recent use |
| Control-loop state | Changes how the converter responds at closure |

**Transient severity depends on:**

voltage mismatch · stored energy · impedance · timing · battery dynamics · control state

Because these dependencies include the battery itself, the inrush transient cannot be fully characterized by the test-system specification alone.

> **The transient is not a property of the cycler alone.**
> **It is a property of the complete connected system.**

### How Similar Systems Manage Connection Transients

EV battery systems, EV chargers, and battery cyclers all manage the same basic problem: stored energy may exist at a voltage different from the battery. The goal is to reduce that voltage difference before a low-impedance connection is made.

The common solution is not simply to close the contactor. It is to align voltage first, then close the main current path.

| System Type | Common Strategy | Purpose |
|---|---|---|
| EV battery pack | Precharge DC link before main closure | Limits DC-link inrush |
| EV charger | Match voltage before connection | Avoids uncontrolled current |
| Battery cycler | Precharge / pre-discharge / matching | Aligns output with battery |
| Supply / load | Varies; not always battery-oriented | Verify before use |

### Practical Considerations — Connection Current Is a System Behavior

Do not let the contactor become the component that equalizes voltage. Use a controlled method to reduce voltage across the contactor first, then close the main current path. General power supplies and regenerative loads may complicate this process because some designs intentionally discharge output capacitance when disabled or disconnected, recreating the voltage mismatch that precharge is intended to prevent.

Unexpected connection current is created by the interaction of stored energy, voltage mismatch, impedance, timing, contactors, control state, and battery dynamics.

Dr. Volt helps engineering teams identify these interactions before they become nuisance trips, contactor wear, measurement artifacts, or unsafe connection events.
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