

Constant-Current Charging of Capacitor Banks

Practical Design Guide for ATI CC/CV High-Voltage Supplies

Claim boundary: Published ATI family context is separated from release-critical ordered-model ratings, thresholds, timing, and measured behavior.

ANHVPS-9 · Rev. B · Application Note

Purpose. This improved application note explains why a discharged capacitor bank should be treated primarily as a current-control problem, how a constant-current/constant-voltage high-voltage power supply charges the bank predictably, and how the stored energy must be discharged, measured, grounded, and controlled before human access. It is written for electronic engineers, technicians, test engineers, and safety reviewers who integrate ATI high-voltage supplies into capacitor-bank systems.

Document type:

Application Note.

Audience:

Design engineers, test engineers, technicians, and system safety authorities.

Scope:

Capacitor-bank charging with CC/CV high-voltage supplies, including sizing equations, transition behavior, bleeder discharge, layout, and verification.

Claim boundary:

No model-specific rating, accuracy, certification, or test result is asserted unless verified from a controlled product source. Uncertain items are marked **To Be Verified**.

CLAIM BOUNDARY — GUIDANCE, NOT A SUBSTITUTE FOR CONTROLLED PRODUCT DATA

This Application Note supplies first-order design equations, educational examples, and integration guidance. It is not a product datasheet and does not assert model-specific voltage, current, power, accuracy, protection threshold, safe-access threshold, certification, or measured waveform performance unless backed by a controlled ATI datasheet, released product specification, qualification record, or approved safety procedure. Items that require such evidence are marked **To Be Verified**.

SAFETY WARNING — STORED ENERGY REMAINS AFTER SHUTDOWN

A capacitor bank can remain hazardous after the supply is disabled, after input power is removed, and after the visible system is quiet. Do not touch terminals, bus bars, interconnects, cables, or loads until the applicable discharge procedure has been completed, residual voltage has been measured with a rated instrument, and the bank has been grounded under the approved safe-access procedure. The safe-access threshold, wait time, grounding method, and lockout/tagout steps must be approved by the responsible safety authority for the actual system.

Revision note. This Rev. B application-note draft was rewritten and expanded from the ANHVPS-9 source material, source-summary review, issue report, external references, and later Grok/Claude recommendations. It preserves the supported technical thesis while improving structure, conservative claim control, visual hierarchy, practical verification guidance, terminology consistency, and intuitive explanation.

Evidence Classification Used in This Application Note

To prevent educational examples from being mistaken for product guarantees, this document separates physics, examples, product-family context, and model-specific claims. That discipline is especially important in high-voltage capacitor-bank systems, where a casual phrase can become a dangerous assumption.

Evidence class	How it is used here	Release requirement
Universal physics and equations	Relations such as $i = C \cdot dV/dt$, $t = C \cdot V / I$, $E = 1/2 \cdot C \cdot V^2$, and RC discharge are used as first-order design tools.	Confirm assumptions and units for the actual circuit.
Educational examples and cartoons	Example numbers and analogies teach behavior; they are not ratings, guarantees, or approved safety limits.	Replace all example values with actual system parameters.
ATI product-family context	Family-level statements explain where CC/CV high-voltage supplies fit in capacitor-bank charging systems.	Verify against current ATI product pages and controlled product literature.
Model-specific ratings and measured behavior	Voltage, current, power, ripple, protection behavior, overshoot, safe-access threshold, wait time, and compliance claims are not asserted generically.	Keep marked To Be Verified until confirmed by controlled datasheets, qualification records, or approved procedures.

Contents at a Glance

Section	Design question answered
1. Executive design rule	What is the simplest correct way to think about a capacitor-bank charger?
2. The water-tank analogy	How can a technician intuitively understand current, voltage, energy, and safe access?
3. Why capacitor charging is a current-control problem	Why is a plain constant-voltage source a poor tool for an empty capacitor bank?
4. Core sizing equations	How do capacitance, voltage, current, time, energy, and power relate?
5. ATI product-family context and claim boundaries	What can be said about ATI capacitor-charging supplies without inventing model data?
6. CC to CV transition	What should be verified at the knee of the charge curve?
7. Repetition rate and duty cycle	How should shot rate, recharge time, average power, and peak power be separated?
8. Bleeder discharge and safe access	How is residual voltage reduced, measured, and controlled after shutdown?
9. Layout, interconnect, and component selection	What hidden elements dominate discharge performance and reliability?
10. Verification plan and release checklist	What measurements should be captured before the design is treated as controlled?

1. Executive Design Rule

A capacitor bank does not draw the convenient current that the designer wishes it would draw. At the instant it is discharged, it behaves like a very low-impedance load and asks the source for whatever current the source and interconnect can deliver. A constant-current charger solves that problem by choosing the current first, letting the capacitor voltage rise at the resulting rate, and then handing control to a voltage clamp when the programmed voltage is reached.

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Capacitor current law:      i(t) = C · dV/dt
Constant-current ramp:     dV/dt = I_charge / C
Charge time to setpoint:   t_charge = C · V_set / I_charge
Stored energy at setpoint: E = 1/2 · C · V_set2
    
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The most important safety consequence is that charge current controls how fast the bank gets dangerous, not how dangerous it is when charged. The final stored energy is set by capacitance and voltage, so a slow gentle charge and a fast aggressive charge can leave exactly the same stored-energy hazard.

2. Intuitive Analogy: Filling a Pressure Tank with a Metered Pump

The most useful analogy is a water tank being filled by a pump. **Capacitance** is the tank size, **voltage** is pressure, **current** is flow rate, and **stored energy** is the dangerous compressed volume in the tank. A constant-voltage-only source is like opening a fire hose to an empty tank: the initial surge is limited mainly by plumbing resistance. A constant-current charger is like a metered pump: the flow is held to a controlled value while the pressure rises predictably.

Cartoon 1 · Metered pump versus uncontrolled fill

Controlled Charging

CV-only: surge

CITY WATER MAIN
Unlimited flow (constant pressure)

PRESSURE (VOLTAGE) SURGE!

CAPACITOR BANK (High-Voltage)

DANGER
Uncontrolled dV/dt
High stress on capacitor

$$\frac{dV}{dt} = \frac{I}{C}$$

CC/CV: smooth ramp

CC/CV HVPS
CC MODE → CV MODE

REGULATED PUMP
Controlled flow

FLOW (CURRENT)
L/min

PRESSURE (VOLTAGE) SMOOTH RAMP

VOLTAGE (PRESSURE)
Graph showing CC (Constant Current) and CV (Constant Voltage) modes.

CAPACITOR BANK (High-Voltage)

SAFETY LINE

- Controlled $dV/dt = I/C$
- Lower stress on capacitor
- Improved lifetime and reliability

Use this analogy only as a teaching aid. The engineering equations and model-specific ratings still govern the actual design.

The analogy also explains why a charged bank remains dangerous after shutdown. Turning off the pump does not empty the pressure tank. The stored energy remains until a controlled drain removes it and the pressure is verified. In the electrical system, the controlled drain is the bleeder network and the verification is an absence-of-voltage measurement using rated equipment.

Cartoon 2 · Energy grows with voltage squared

WATER VOLUME = STORED ENERGY
More water means more stored energy

PRESSURE GAUGE = VOLTAGE STRESS
Higher pressure means higher voltage stress on the capacitor

Small voltage changes at high V can mean a lot of stored energy.

THE ANALOGY
This tank doesn't hold fuel. It holds "pressure" that stores energy in the field.

KEY IDEA
Stored energy grows with the square of voltage: $E = \frac{1}{2} CV^2$
Small ΔV at high V → large ΔE

REMEMBER
 ✓ Water volume → stored energy
 ✓ Pressure → voltage stress
 ✓ Tank rating → voltage rating

A capacitor is not a battery bottle; it is a pressure tank for electric field energy.

Educational illustration only. Stored energy follows $E = 1/2 C V^2$, so doubling voltage quadruples stored energy for the same capacitance; replace all example values with actual system parameters.

Cartoon 3 · The bleeder is a controlled drain

INITIAL VOLTAGE
 V_0

VOLTAGE DECAY (RC DISCHARGE)
 $V(t) = V_0 e^{-\frac{t}{RC}}$

BLEEDER RESISTOR
CONTROLLED DRAIN (SET THE TIME CONSTANT RC)

SLOW, SAFE DISCHARGE

HARD SHORT: TOO VIOLENT (marked with a red X)

Control the current, then verify the voltage.

A bleeder is a controlled drain, not a magic erase button.

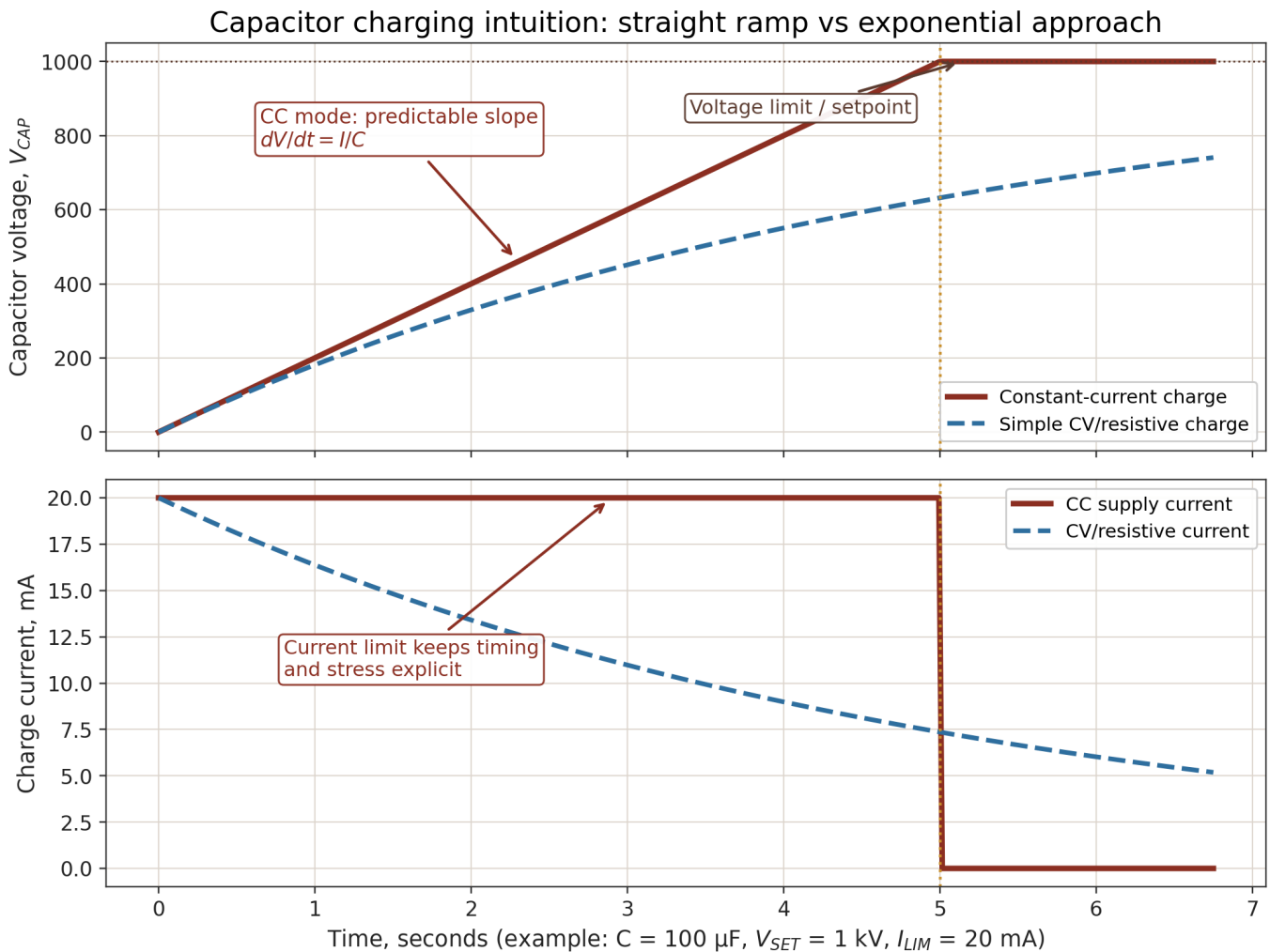
Educational illustration only. A bleeder reduces voltage over time, but the technician must still measure and ground under the approved site procedure before access.

3. Why Capacitor Charging Is a Current-Control Problem

A resistor has an immediate voltage-current relation. A capacitor has a derivative relation: current determines the rate of voltage change. This is the reason a discharged capacitor bank is difficult for an ordinary voltage source. At zero initial voltage, a large capacitor looks like a short circuit until charge accumulates. External capacitor-charger guidance similarly describes an uncharged capacitor as a short-circuit-like load at the beginning of the charge and an open-circuit-like load once it is charged.[1] [2]

Resistor-limited charging can tame the surge, but the voltage follows an exponential response and the resistor dissipates energy as heat. Constant-current charging instead produces a controlled linear voltage ramp. TDK-Lambda's published explanation gives the same practical contrast: resistor-limited charging follows an exponential relation, while a constant-current charger raises capacitor voltage at a predictable linear rate and gives the design relation $t = C \cdot V / I$.[1]

Figure 1 · Constant-current charging produces a linear ramp



Conceptual figure. All numerical values are illustrative; replace them with confirmed capacitance, set voltage, rated or measured model current, and actual system parameters before using the calculation in a design file.

DESIGN RULE

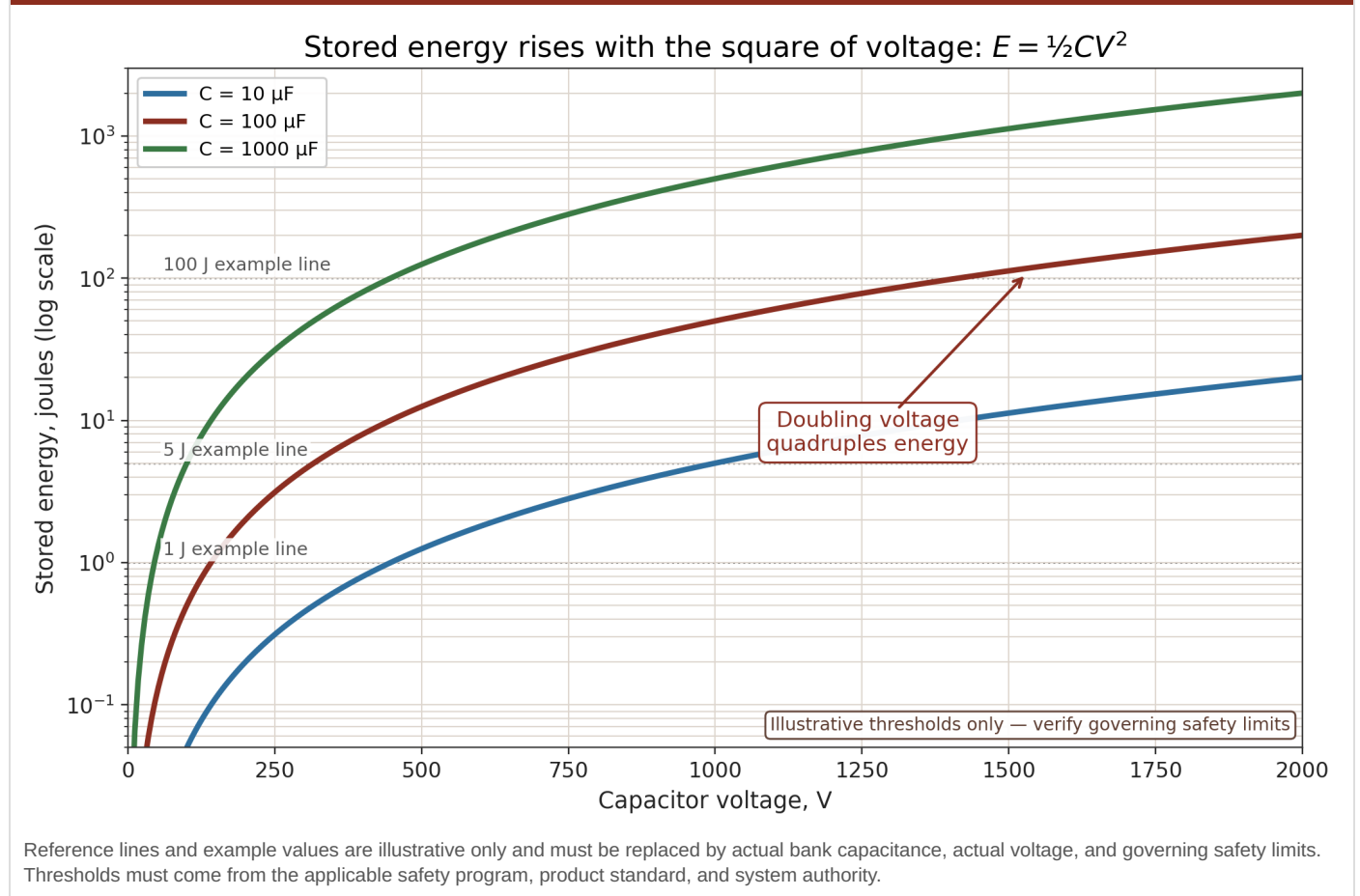
Use current to set the ramp and voltage to stop the ramp. The CC phase controls dV/dt and charge time. The CV phase clamps the final bank voltage and supplies leakage or bleeder current after the bank reaches setpoint.

4. Core Sizing Equations

Four quantities size most capacitor-bank charging applications. The table deliberately separates quantities that affect supply stress from quantities that affect human and equipment hazard. Charge current changes time and peak charger power; it does not change the energy stored at the target voltage.

Quantity	Relation	Design meaning	Release status
Charge time	$t = C \cdot V_{\text{set}} / I_{\text{charge}}$	Time required for an ideal CC ramp from 0 V to V_{set} .	Use confirmed C, V_{set} , and rated or measured current.
Ramp rate	$dV/dt = I_{\text{charge}} / C$	Voltage slope during the true CC portion of the charge.	Verify on the assembled bank.
Stored energy	$E = 1/2 \cdot C \cdot V_{\text{set}}^2$	End-state energy and primary safety hazard.	Calculate from actual total capacitance and actual voltage.
Peak instantaneous output power	$P_{\text{inst,max}} = I_{\text{charge}} \cdot V_{\text{set}}$	Instantaneous output power near the top of the ideal ramp.	Confirm output-power rating, input-power requirement, losses, and thermal limits.
Average ramp output power	$P_{\text{avg,ramp}} = E / t = 1/2 \cdot I_{\text{charge}} \cdot V_{\text{set}}$	Ideal output-energy average over a full 0-to- V_{set} CC ramp.	Use with duty-cycle analysis; not a substitute for datasheet or thermal ratings.

Figure 2 · Stored energy rises as the square of voltage



Worked example: 10 µF charged to 2 kV

The example below is retained because it makes the relations tangible. It is not a specification for any ATI model or customer system.

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Given: C = 10 μF, V_set = 2 kV, I_charge = 5 mA
Charge time:      t = (10e-6 F · 2000 V) / 0.005 A = 4.0 s
Ramp rate:       dV/dt = 0.005 A / 10e-6 F = 500 V/s
Stored energy:   E = 0.5 · 10e-6 F · (2000 V)2 = 20 J
Peak instantaneous output power: P_inst,max = 0.005 A · 2000 V = 10 W

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If the target charge time is reduced to 1 s while capacitance and voltage remain the same, the required charge current becomes 20 mA and the peak instantaneous output power becomes 40 W. The final stored energy remains 20 J. This is the essential distinction: current buys speed, while voltage and capacitance define the end-state stored-energy hazard.

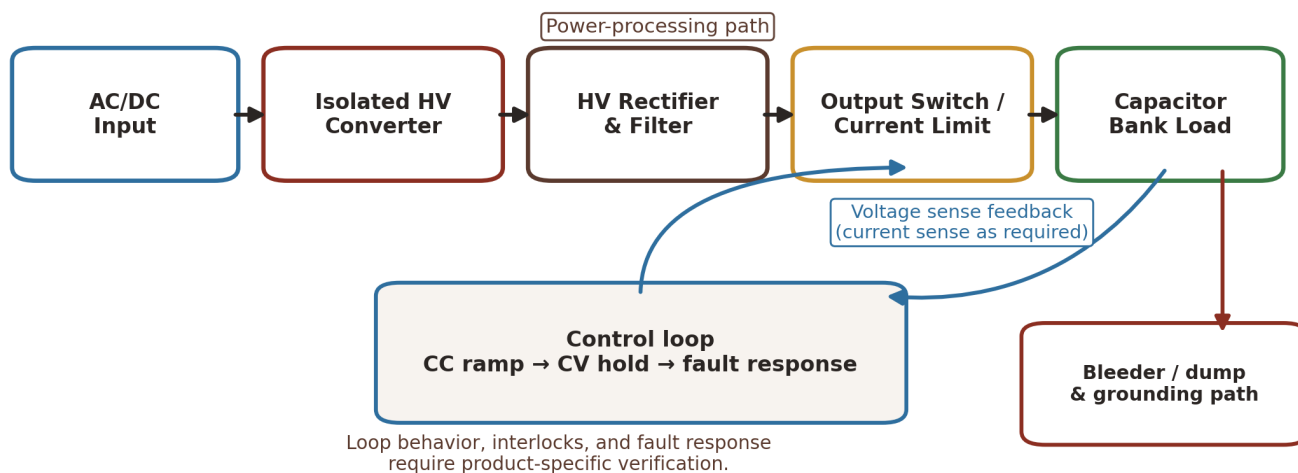
5. ATI Product-Family Context and Claim Boundaries

ATI’s public high-voltage product pages are useful as **published family context**, not as controlled evidence for an ordered SKU. They identify a broad high-voltage power-supply portfolio and classify capacitor-charging high-voltage supplies as a specific family. The public ATI category text describes Constant Current/Constant Voltage products for capacitor charging with “constant current for charging capacitors with clamped voltage,” and it supports family-level context such as 12 V/24 V input families, a 100 V to 50 kV output range, a 100 W to 5 kW power range, listed overvoltage, overcurrent, and short-circuit protection categories, and published family-level context for ripple and efficiency.[5] The newer ATI catalog site also presents high-voltage power-supply categories that include capacitor-charging supplies, AC-DC supplies, DC-DC supplies, I/O proportional supplies, and X-ray supplies.[6]

Those public pages may be cited for the application-note topic, the published family envelope, and the family-level concept of CC/CV capacitor charging. Some individual public product pages also provide model-level context for selected configurations, including example pages in ATI’s public catalog and shop site.[7] [8] A public page still is not the same thing as a controlled release record for a particular ordered configuration. The selected model’s voltage, current, power, ripple limit, efficiency, clamp accuracy, control-loop behavior, transition overshoot, ringing, settling time, protection thresholds, fault-recovery timing, certifications, and safe-access performance must be confirmed from the current controlled datasheet, product-control record, approved safety procedure, or measured qualification result.

Statement type	Acceptable wording in this application note	What must be verified before product release
Family positioning	ATI publishes capacitor-charging CC/CV supplies as part of its high-voltage supply portfolio; the family envelope, protection categories, ripple context, and efficiency context may be cited as public family context with URL and access date.	Confirm the current ATI source and do not convert family-envelope language into an ordered-model guarantee.
Specific model voltage/ current/power/ripple/efficiency	Public model pages may be cited only as published model context. Release wording remains To Be Verified until matched to the ordered SKU and controlled record.	Released datasheet title, revision, SKU, ordered options, test conditions, and qualification data.
Protection behavior	Published protection categories may be mentioned as family context; thresholds, timing, arc handling, recovery mode, and fault behavior remain To Be Verified .	Protection thresholds, response time, allowable arc/short duty, and fault recovery.
CC to CV transition	State CC-to-CV operation as a family-level operating mode and require waveform verification for the actual bank.	Measured overshoot, ringing, settling time, and repeatability on the assembled bank.
Safety threshold and wait time	Use example calculations only; mark governing threshold as To Be Verified .	Approved safety procedure, energy assessment, lockout/tagout method, and measurement tool.

Functional architecture of a capacitor-charging high-voltage supply



Conceptual only: actual pin names, ratings, interlocks, compensation, and monitor outputs are product-specific and must be verified.

Conceptual architecture only. It illustrates the CC/CV control concept and safe-access functions, but it does not imply unverified pin names, ratings, compensation values, protection thresholds, interlock circuits, or regulatory compliance.

6. The CC to CV Transition: The Knee of the Curve

The linear CC ramp is only the first half of the engineering problem. The more sensitive region is the knee where the supply stops forcing charge current and begins clamping voltage. A transition that overshoots can stress the bank dielectric, the load, and insulation margins. A transition that rings can create repetitive voltage peaks. A transition that settles slowly can make charge-time repeatability worse than the simple $t = C \cdot V / I$ equation suggests.

The improved design practice is to specify not only the charge current and voltage setpoint, but also the verification waveform. The test should capture the last portion of the ramp, the overshoot above V_{set} , any ringing frequency and decay envelope, and the steady CV hold behavior while the bleeder remains connected.

TO BE VERIFIED ON ASSEMBLED HARDWARE

Actual CC current, V_{set} accuracy, overshoot, ringing, settling time, hold stability, and response after a partial discharge must be measured on the intended bank, cable, enclosure, and load configuration. Do not infer those values only from an ideal equation.

7. Repetition Rate, Peak Power, and Average Power

In a repetitive pulsed system, the capacitor bank is charged, discharged into the load, and recharged. The back-to-back ideal repetition ceiling is the reciprocal of the single-shot charge time: if a full recharge takes t_{charge} , the ideal ceiling is $f_{max} = 1/t_{charge} = I_{charge}/(C \cdot V_{set})$. That ceiling is only a mathematical starting point; the sustainable repetition rate is governed by average output power, input power, losses, thermal recovery, protection behavior, and system duty cycle. External capacitor-charger guidance distinguishes occasional charging from high-repetition applications and warns that repetitive discharge or arcing can overheat limiting components if the supply is not designed for the duty.[3]

Back-to-back ideal recharge ceiling: $f_{\max} = I_{\text{charge}} / (C \cdot V_{\text{set}})$
 Instantaneous ramp output power: $P_{\text{inst}}(t) = I_{\text{charge}} \cdot V(t)$
 Ideal 0-to- V_{set} ramp average power: $P_{\text{avg,ramp}} = 1/2 \cdot I_{\text{charge}} \cdot V_{\text{set}}$
 Energy delivered after partial discharge: $E_{\text{shot}} = 1/2 \cdot C \cdot (V_{\text{set}}^2 - V_{\text{residual}}^2)$
 Minimum repetitive average output power: $P_{\text{avg}} \geq E_{\text{shot}} \cdot f_{\text{repetition}}$

Example current into 10 μF at 2 kV	Ideal charge time	Ideal full-ramp ceiling	Peak instantaneous output power	Stored energy
5 mA	4.0 s	0.25 Hz	10 W	20 J
20 mA	1.0 s	1.0 Hz	40 W	20 J
100 mA	0.2 s	5.0 Hz	200 W	20 J

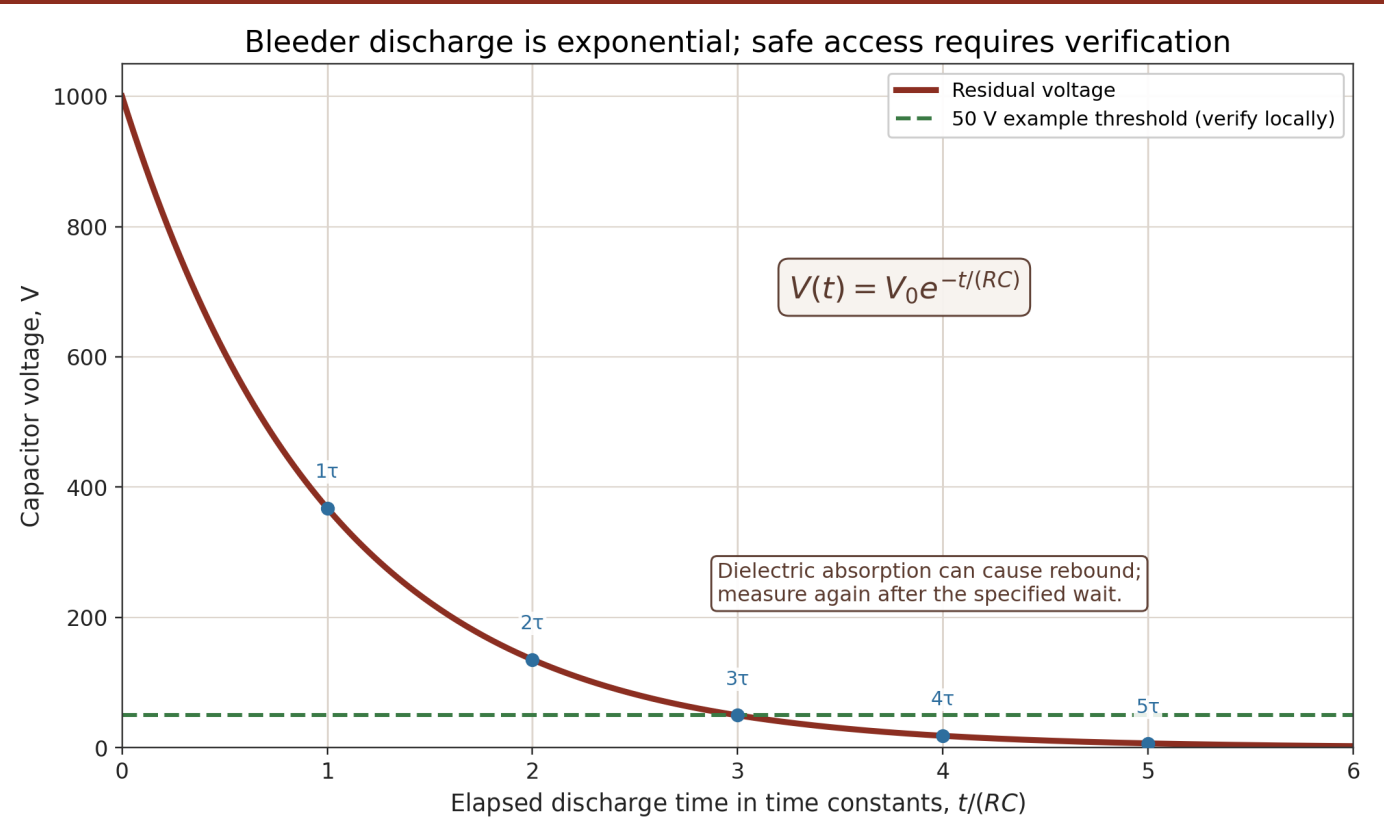
These example rows are useful for intuition, but they are not product claims. The f_{\max} relation is an ideal full 0-to- V_{set} recharge ceiling; it excludes CV settling, controller dead time, thermal recovery, protection recovery, load timing, and system-level duty-cycle limits. If the bank does not fully discharge between shots, use the partial-discharge energy relation instead of the full $1/2 C V^2$ value. For example, returning a 10 μF bank from 1.2 kV residual voltage to a 2.0 kV setpoint requires $E_{\text{shot}} = 1/2 \cdot 10 \mu\text{F} \cdot (2.0^2 - 1.2^2) \text{ kV}^2 = 12.8 \text{ J}$, not the full 20 J. A selected supply must still be checked for continuous output power, peak instantaneous output power, thermal environment, allowable repetition rate, short-circuit behavior, and recovery from faults.

8. Bleeder Discharge and Safe Access

Discharge design must be treated as part of the product design, not as a service afterthought. A bleeder resistor drains voltage exponentially after charging stops. The designer chooses the resistance by balancing wait time, standing loss, voltage rating, power rating, failure mode, and the current that the supply must provide while holding CV.

Residual voltage: $V(t) = V_0 \cdot \exp[-t / (R_{\text{bleeder}} \cdot C_{\text{total}})]$
 Time to threshold: $t_{\text{safe}} = R_{\text{bleeder}} \cdot C_{\text{total}} \cdot \ln(V_0 / V_{\text{safe}})$
 Standing bleeder loss: $P_{\text{bleeder}} = V_{\text{set}}^2 / R_{\text{bleeder}}$

Figure 4 · Bleeder discharge is exponential, not instantaneous



The 50 V line and time-constant markers are illustrative calculation aids only, not universal permission-to-touch values. Replace example values with actual capacitance, bleeder resistance, cable capacitance, safety threshold, and governing wait-time procedure.

Bleeder for 10 μF @ 2 kV	$\tau = RC$	Time to 50 V	Loss @ 2 kV	Engineering interpretation
100 kΩ	1.0 s	3.7 s	40 W	Fast discharge but large continuous waste and resistor heating.
1 MΩ	10 s	37 s	4 W	Balanced starting point for the example bank, subject to voltage and power ratings.
10 MΩ	100 s	6.1 min	0.4 W	Lower loss but longer service wait and higher reliance on procedure discipline.

Virginia Tech's capacitor-safety guidance states that capacitors may retain hazardous energy after de-energization and recommends permanently connected bleeder resistors where practical, suitable discharge devices, visible grounding methods, and discharge to a selected threshold before access.[9] Jefferson Lab's public Electrical Safety page frames electrical safety around safe work practices, hazardous-energy control, lockout/tagout, trained personnel, and capacitor-discharge training availability; it is cited here as a public safety-program example rather than as an ATI procedure.[10] EFCOG BP261 provides ground-stick best-practice guidance for achieving an electrically safe work condition through energy removal, verification, maintaining the safe condition, and risk assessment.[11] These references support conservative safe-access practice; they do not replace the customer's applicable safety authority, product standard, or site-approved procedure.

A TIMER ALONE NEVER PROVES SAFETY

A failed-open bleeder, disconnected bank section, high-voltage cable capacitance, or dielectric absorption can leave residual voltage after the expected wait. Measure at the accessible terminal with a properly rated instrument, discharge and ground with approved hardware, and re-measure after a wait interval if dielectric absorption is relevant. Keep the grounding device installed while work is performed when the approved procedure requires it.

Safe-access sequence for high-voltage capacitor systems



Safe access begins only after energy is removed, voltage is verified, and grounding is applied. If the voltage reappears, stop and investigate before touching the circuit.

Sequence is conceptual and must be converted into the site-approved lockout/tagout and high-voltage access procedure.

9. Layout, Interconnect, and Component Selection

The charging current may be modest, but the discharge current can be violent. A bank that looks gentle during a multi-second charge can deliver a microsecond-scale pulse with high current, high dI/dt , and severe mechanical and thermal stress. Therefore, layout should be qualified for the discharge event, not only for the charge current.

Design element	Why it matters	Recommended engineering action	Status

Bank capacitor	Must tolerate DC voltage, pulse current, ESR heating, ESL effects, voltage reversal, and dielectric absorption.	Select pulse-rated dielectric and margins appropriate to the discharge waveform.	To Be Verified per application.
Bleeder resistor string	Sets discharge time and standing loss; failure can leave the bank charged.	Use HV-rated resistor technology, voltage/power derating, and consider redundancy or monitorability.	To Be Verified.
Series balancing network	Unequal section voltage can overstress one capacitor in a stack.	Use balancing resistors or an approved balancing method across series sections.	Required when dictated by stack design.
Bus and joints	Inductance causes ringing; resistance causes heating and drift.	Use short, wide, low-inductance conductors; verify joint resistance and temperature rise.	To Be Verified.
High-voltage cable	Cable capacitance stores energy and affects discharge timing.	Include cable capacitance in C_total for energy and bleeder calculations.	Required for accurate safety timing.
Creepage and clearance	Contamination and geometry determine insulation margin.	Design to the applicable voltage, environment, pollution degree, and standard.	To Be Verified.

Component selection should be documented as an engineering record. The application note may recommend the method, but the final system record must state the actual capacitor type, voltage margin, ripple-current rating, ESR/ESL limits, bleeder string, resistor derating, creepage/clearance basis, interlock logic, and measurement procedure.

10. Verification Plan and Release Checklist

A CC/CV supply and a calculated bleeder do not by themselves make the design safe, repeatable, or ready for release. The assembled bank must be measured. The following matrix is intentionally written in the language of a design-review record so the integrator can convert it into a test plan.

Verification item	Measure or inspect	Confirms	Owner role	Acceptance basis
Charge ramp	V(t), slope, current limit, and repeatability during CC.	$dV/dt \approx I/C$ and charge time matches prediction.	Test engineer	Project specification; measured data.
CC to CV transition	Overshoot, ringing, settle time, and clamp stability.	No overstress at setpoint and stable hold.	Design + test	Bank rating and model-specific limits.
CV hold	Voltage versus time with bleeder connected.	Supply can hold setpoint without hunting or overheating.	Test engineer	Datasheet and thermal limits.
Bleeder decay	Terminal voltage after shutdown versus time.	Discharge reaches selected threshold within approved wait time.	Safety + test	Approved safe-access procedure.
Residual voltage rebound	Voltage after discharge and after wait interval.	Dielectric absorption is controlled.	Safety engineer	Procedure-specific threshold.
Discharge waveform	Peak current, dI/dt , ringing, and load energy.	Bank, bus, joints, load, and enclosure are qualified for pulse duty.	Test engineer	System discharge specification.
Interlock and grounding	Door switch, E-stop, drive removal, discharge path, and grounding strap.	Human access controls operate as designed.	Safety engineer	Site safety authority and product standard.

Release checklist

No.	Question	Required answer before release
1	What sets the charge current?	Required charge time and selected model current rating; both recorded.
2	What ends the charge?	CV clamp at V_{set} ; measured transition confirms no unacceptable overshoot.
3	What is the stored energy?	$E = 1/2 C_{total} V_{set}^2$, including bank and cable capacitance.
4	How is residual energy removed?	Bleeder network, approved wait time, measurement, manual discharge/grounding, and lockout/tagout.
5	What carries discharge current?	Low-inductance bus, joints, capacitor ESR/ESL, and load path qualified by waveform testing.
6	Which items remain uncertain?	All unverified model ratings, thresholds, tolerances, and certifications are marked To Be Verified .

11. Conclusion

Charging a capacitor bank is best understood as controlled energy transfer into storage. A CC/CV high-voltage supply makes the initial condition manageable by choosing the charge current and producing a predictable voltage ramp. The voltage clamp ends the charge, but the handoff must be measured because overshoot and ringing can stress the bank. The final energy is then fixed by capacitance and voltage and remains hazardous until discharged, verified, and grounded.

The improved engineering message is therefore simple: **control the current, verify the clamp, calculate the energy, design the bleeder, and never replace measurement with assumption**. When sizing the system, keep peak instantaneous output power, ideal ramp-average output power, input-power demand, and thermal duty cycle separate; the word “power” is too expensive to leave ambiguous in a capacitor charger. A polished application note should teach this clearly while keeping every model-specific rating, safety threshold, and release-controlled claim inside its proper evidence boundary.

References

Reference-numbering note: References are numbered independently in each deliverable in this review package.

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- [9] Virginia Tech Environmental Health & Safety, "Capacitors." <https://ehs.vt.edu/programs/occupational-safety/electrical-safety-in-research-operations/capacitors.html> (accessed June 3, 2026).
- [10] Jefferson Lab, "Electrical Safety." <https://www.jlab.org/esh/electricalsafety> (accessed June 3, 2026).
- [11] EFCOG Electrical Safety Task Group, "Using Ground Sticks to Discharge Capacitance," BP261, July 12, 2023. <https://efcog.org/wp-content/uploads/Wgs/Safety%20Working%20Group/Best%20Practices/Worker%20Safety%20-%20Health/Electrical%20Safety/BP261%20Using%20Ground%20Sticks%20%28Hooks%29%20to%20Discharge%20Capacitance.pdf> (accessed June 3, 2026).

Document Control

Revision	Date	Status	Summary of change
Rev. B	June 2, 2026	Draft for review	Rewritten as a more complete application note with conservative claim control, ATI-styled header/footer, sampled maroon table and subtitle color, official logo, corrected figures, analogy cartoons, verification matrix, and visible references.

Controlled-source note. Model-specific values must be replaced by controlled ATI datasheet entries and measured qualification results before release. The example $10 \mu\text{F} / 2 \text{ kV}$ calculations are educational aids only.