AI OPEN
DATA CENTER:
Power Distribution

# 2-Wire vs. 3-Wire at 800VDC: Grounding, Fault Behavior, and Protection for AI Data Centers

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OCP PLATINUM Member

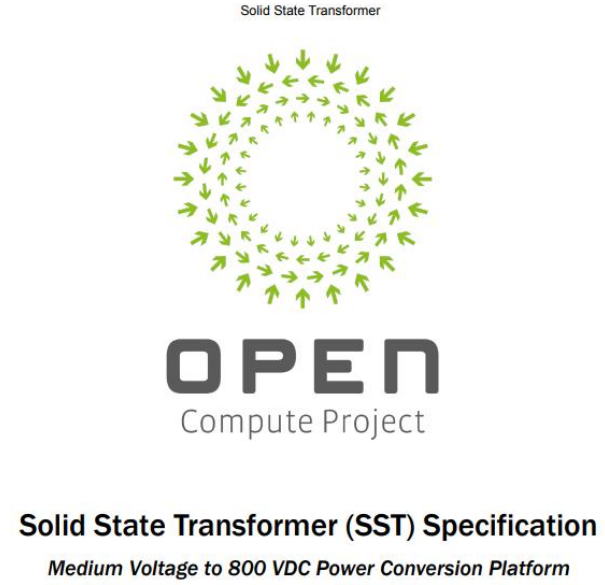
**Acknowledgement:** We would like to thank our former Siemens colleague Gopal Mondal for his contributions to this study.

# 800 VDC in Data Centers Presents New Challenges

## AI demand is rewriting power economics, and OCP is active in development




[OCP Diablo 400 refers to ±400VDC]




[OCP SST Specs refer to 800VDC]

- **Both architectures can maintain safe and resilient operations—at what cost?**
- **Which practices are critical in both architectures?**

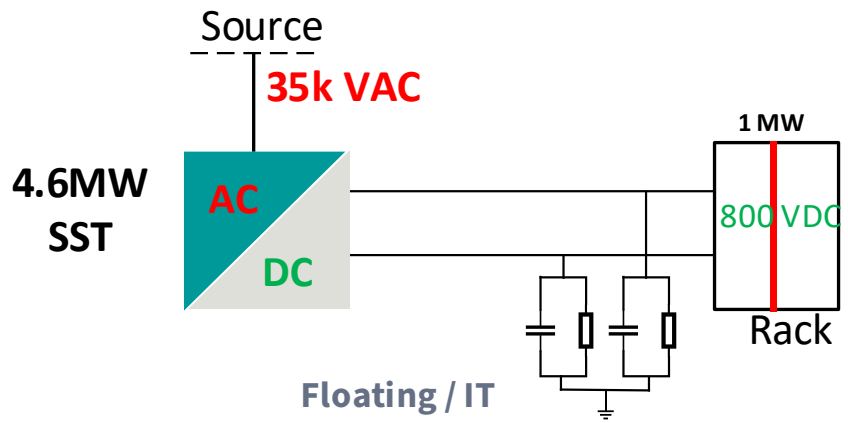
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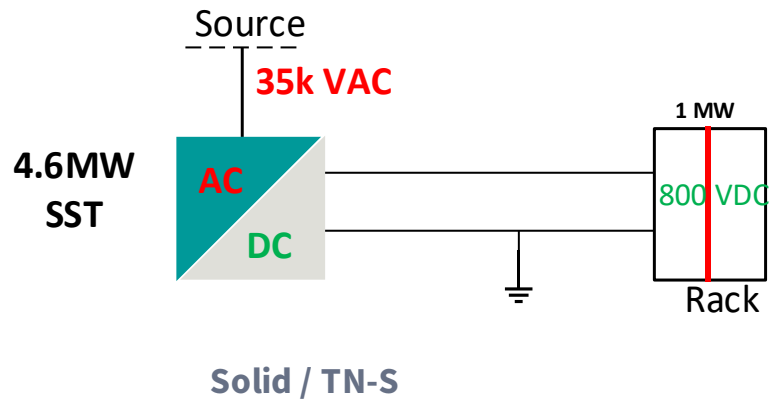
**Where 2-wire and 3-wire differ:**

- **Build cost and hardware count**
- **Power density and usable capacity**
- **Protection cost and downtime exposure**
- **…**

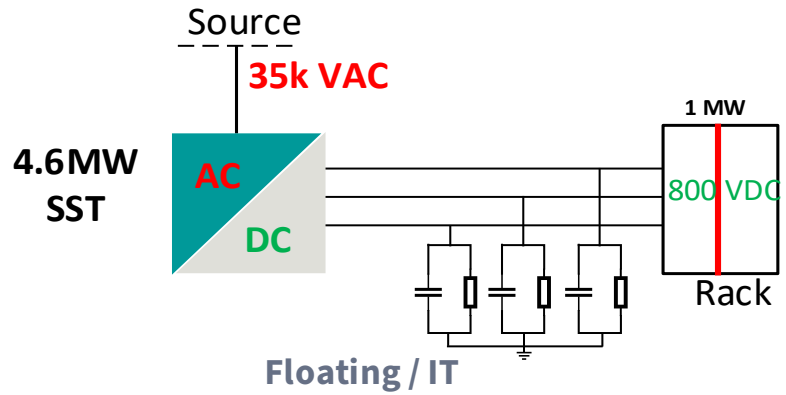
# Two DC Architectures, Two Grounding Options

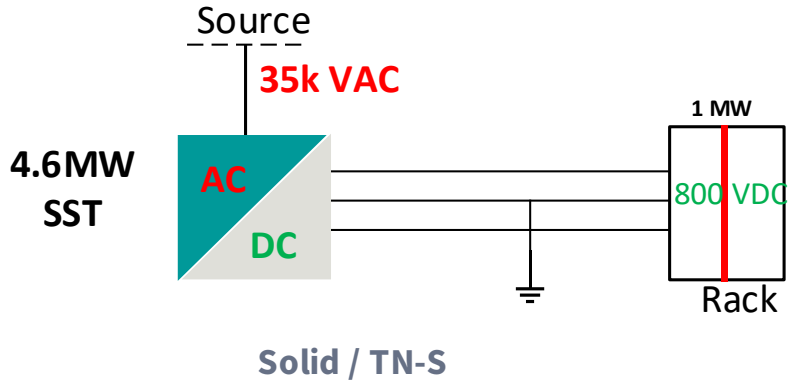
## 2-wire: 800 V across P–N



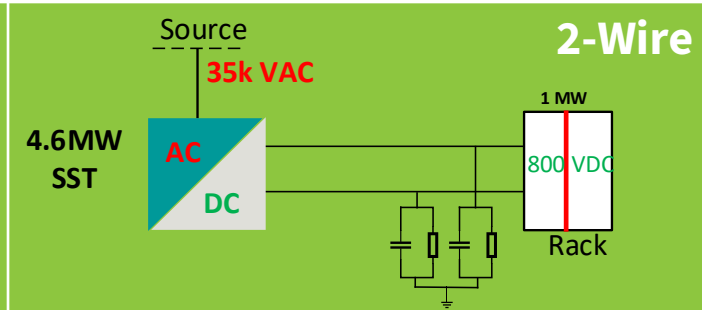
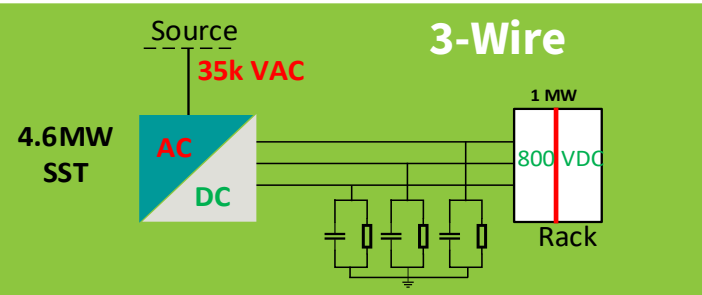

## 3-wire: 400 V across P–M and M–N



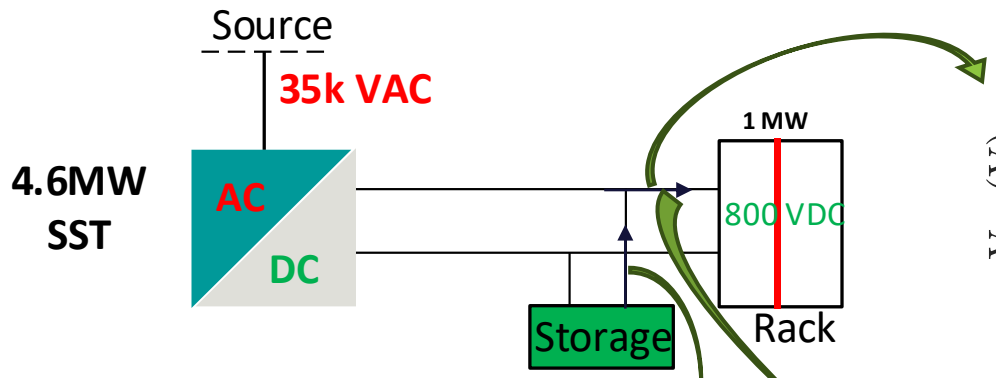




**Both architectures evaluated with floating and solid grounding!**

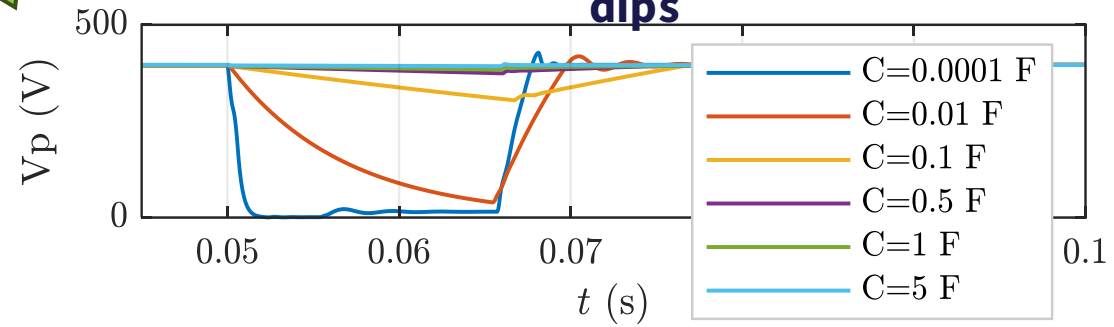
# Trade-offs in One View

| | |  |  |
|---|---|---|---|
| **System implementation** | **System complexity** | **Low** | **High** |
| | **Load Voltage** | **800 VDC** | **±400 VDC** |
| | **Balancing components** | **No** | **Yes** |
| **Power delivery** | **Power density w/ same conductor size** | **High** | **Low** |
| | **Load flexibility** | **Low** | **High** |
| **Protection implications** | **Fault energy** | **High** | **Low** |

# Local Storage: Power Quality v.s. Fault current

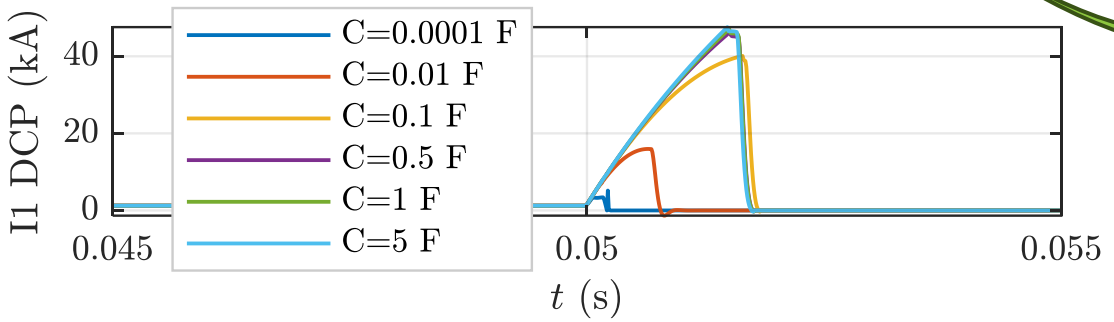



**Local storage sizing for ride-through during voltage dips**



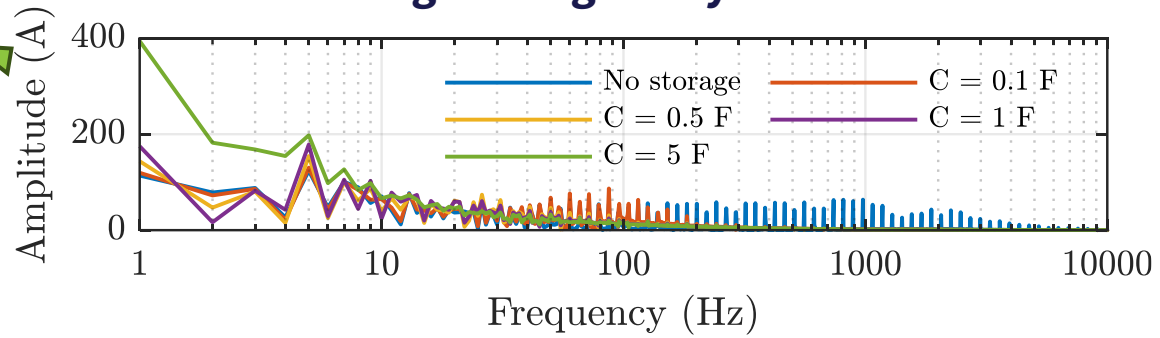

Increasing storage extends ride-through

**Local storage discharge current**




Increasing storage can contribute to large fault current

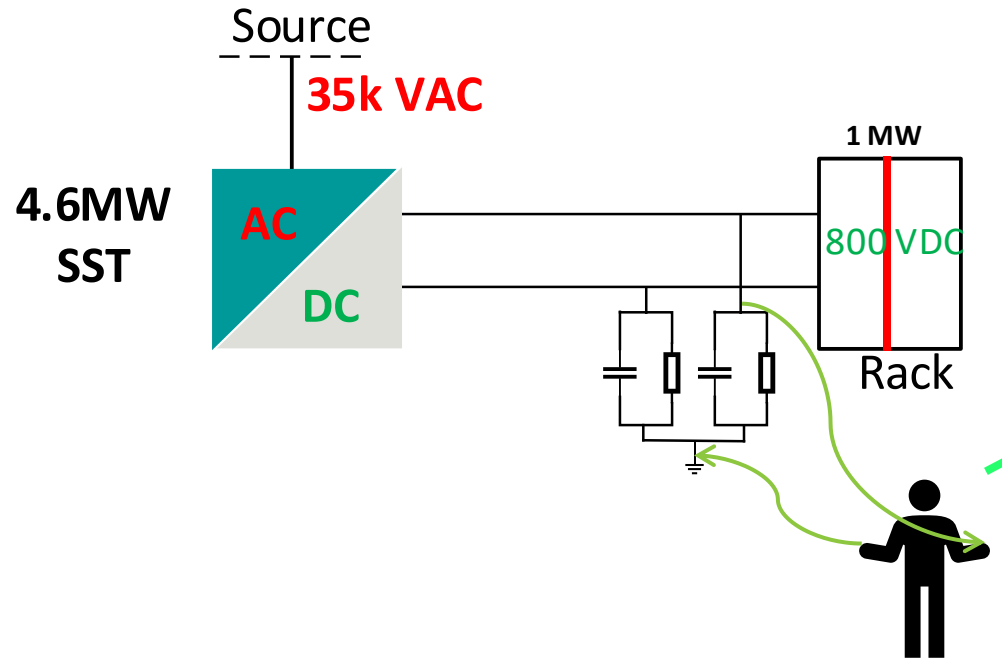
**Local storage sizing for dynamic loads**




Increasing storage effectively remove high frequency components

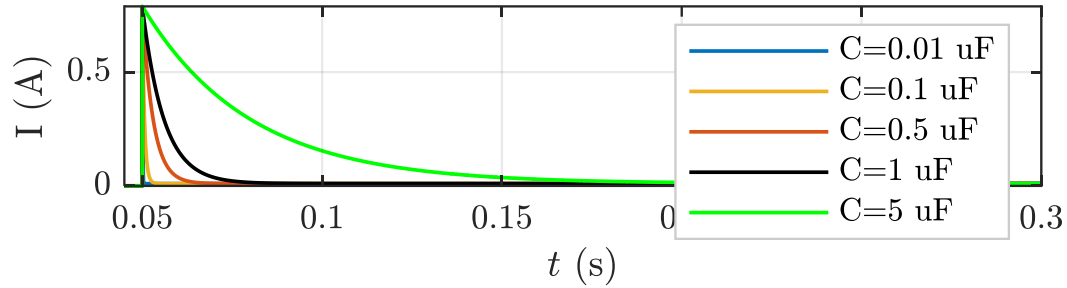
**Storage has value—but oversized storage without fast protection becomes a fault liability.**

# Parasitic Capacitance Needs to Be Considered for Safety




**Parasitic capacitance discharge through human body in ungrounded system**

**Higher capacitance → longer exposure**



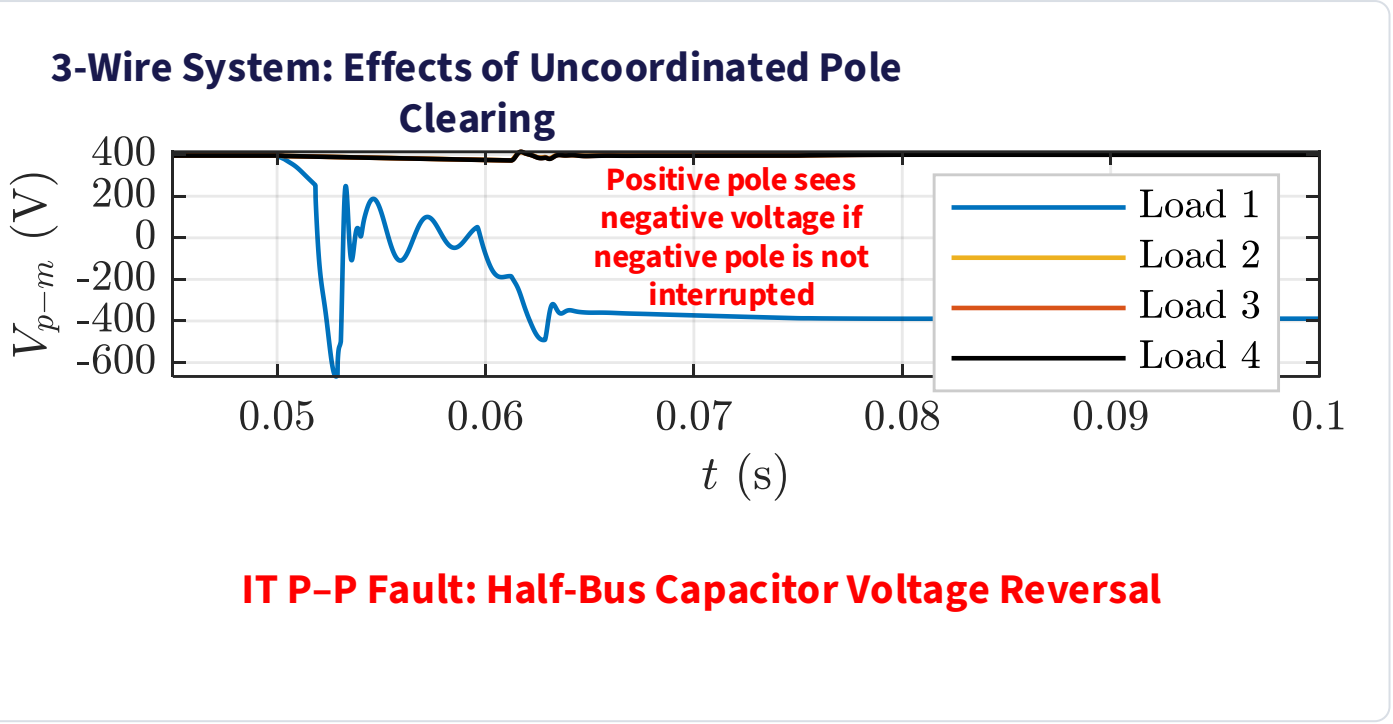

**Human Body Current vs. Parasitic Capacitance**

| Parasitic Capacitance (µF) | IEC 60479-2 effect zone | UL 1400-1 Current-Duration Assessment |
|---|---|---|
| <0.5 | No fibrillation risk | Compliant |
| 1 | No fibrillation risk | Exceeds threshold |
| 5 | Low to average risk of fibrillation | Exceeds threshold |

- **At the first ground fault, parasitic capacitance discharges through the body.**
- **Higher capacitance prolongs exposure:** 0.3 ms at 0.01 µF vs. 151 ms at 5 µF.
- **Both architectures behave similarly; limiting parasitic capacitance improves personnel safety.**

# Half-Isolation Is Not Isolation

**Opening a single pole is not enough to take a rack safely offline.**




**IT P–P Fault: Half-Bus Capacitor Voltage Reversal**

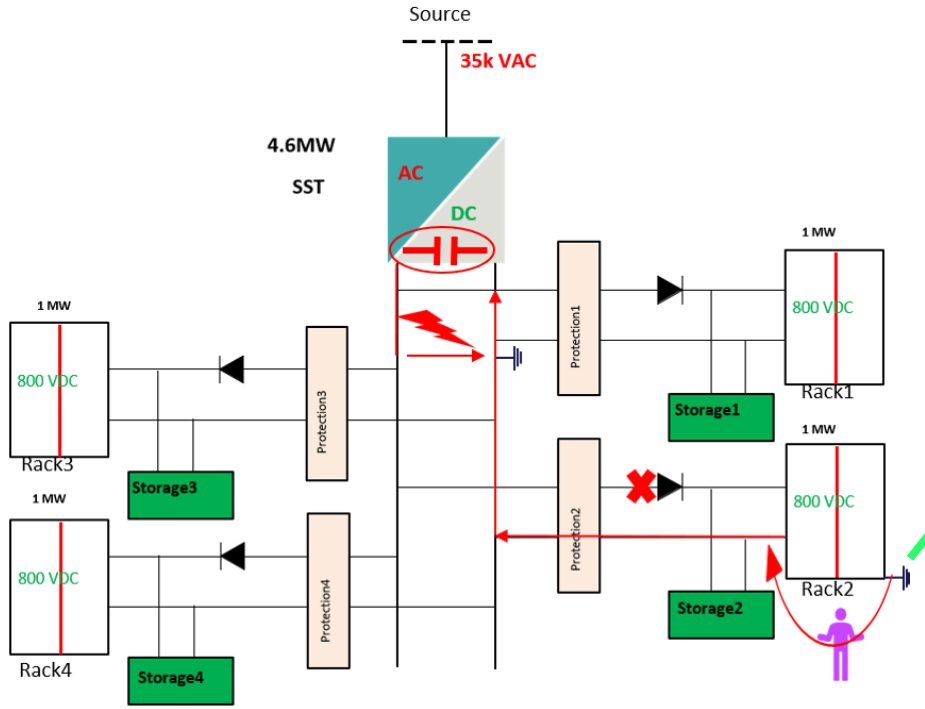
- **3-wire**
  - **IT P–P Fault:** partial clearing can reverse the voltage on half the bus.
  - **TN-S P–G Fault:** current still flows after one pole opens through the other pole—the rack is not isolated.
- **2-wire**
  - **IT Double ground fault:** capacitors in faulty racks continue to be charged by DC bus and stay at full voltage ！

**Opening one pole can reroute current and redistribute voltage—it does not guarantee that the rack is de-energized.**

# Half-Isolation Is Not Isolation – Not Safe for Maintenance

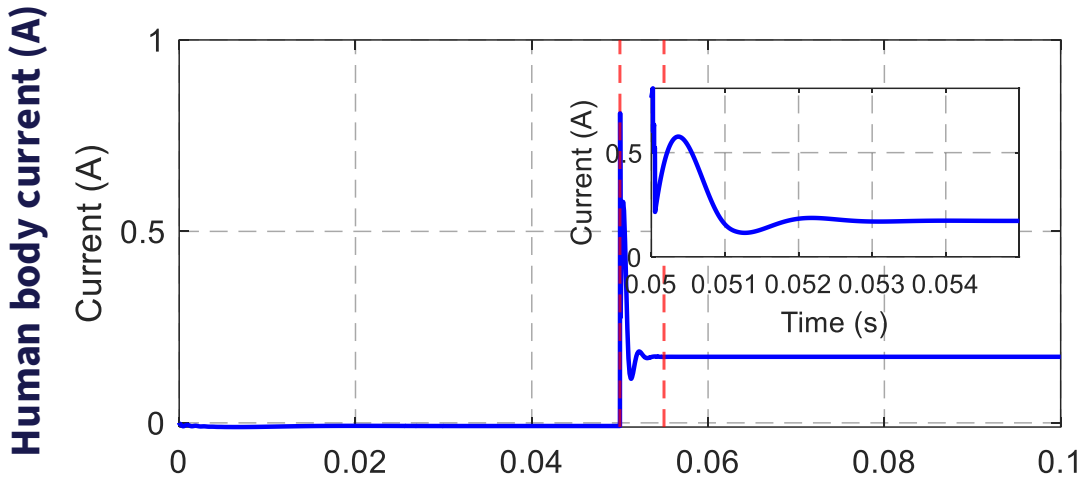
**Opening a single pole is not enough to take a rack safely offline.**

**2-Wire grounded System**




**Possible personnel-current path**

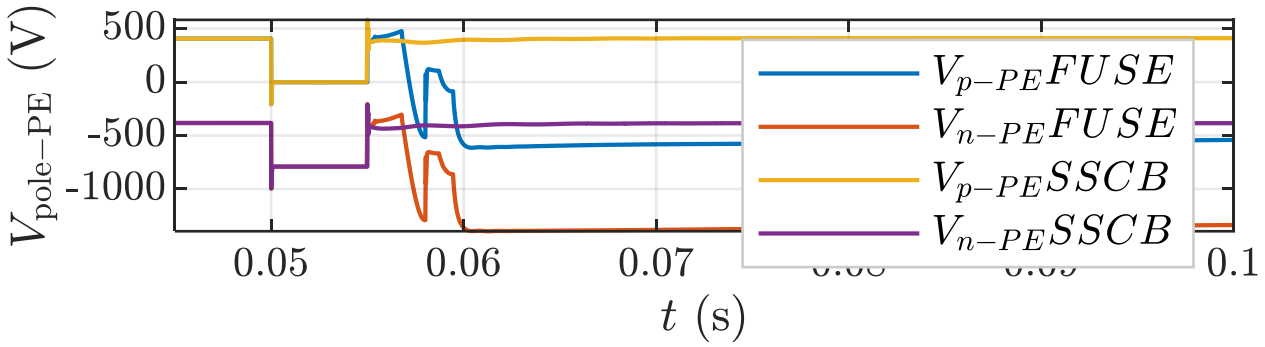
**DC unique fault scenario as large DC link capacitor keeps the voltage up during discharge**




- **Current NEC does not require grounded pole to open**
- **Potentially hazardous conditions during maintenance if a ground fault happens elsewhere**

# Protection device: Faster Protection Reduces Total Cost of Ownership (TCO)

## Example: DC bus voltage during double ground fault in floating (IT) systems



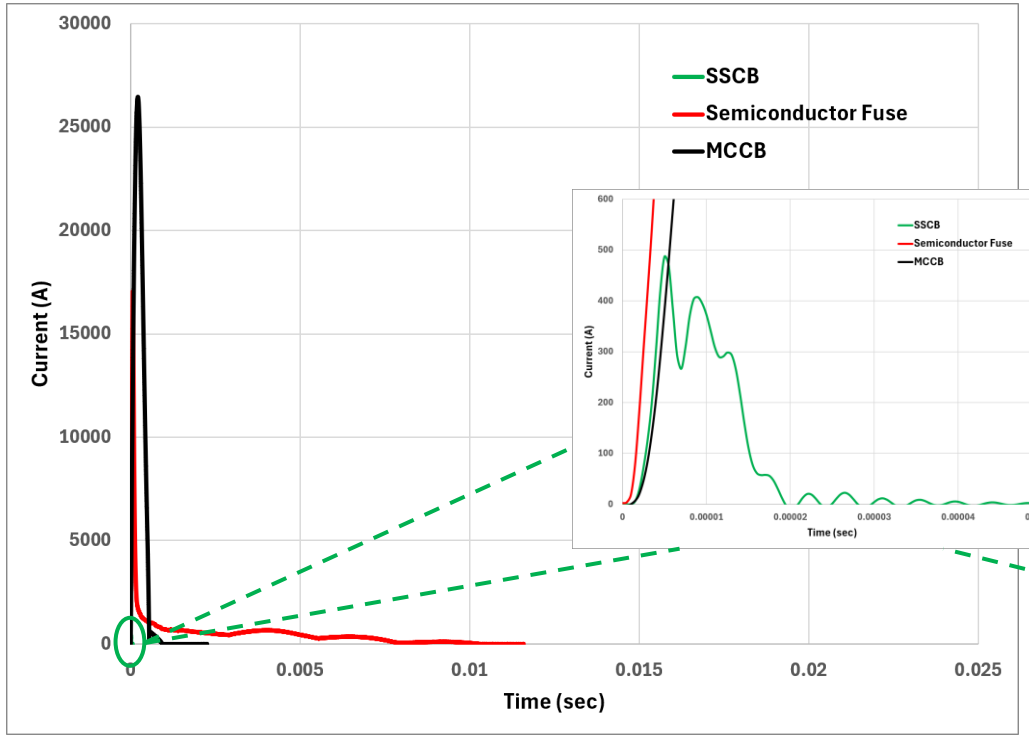

**DC Bus Pole-to-Ground Voltages in a 2-Wire System with IT Grounding**

- **Faster interruption significantly improves power quality during interruption**
  - **Partial-isolation risk: Uncoordinated pole opening shifts the DC bus relative to earth.**
- **Faster interruption significantly reduces local storage needed for power quality**
  - **Fuse: 300mF for 373V**
  - **SSCB: 10mF for ~400V**

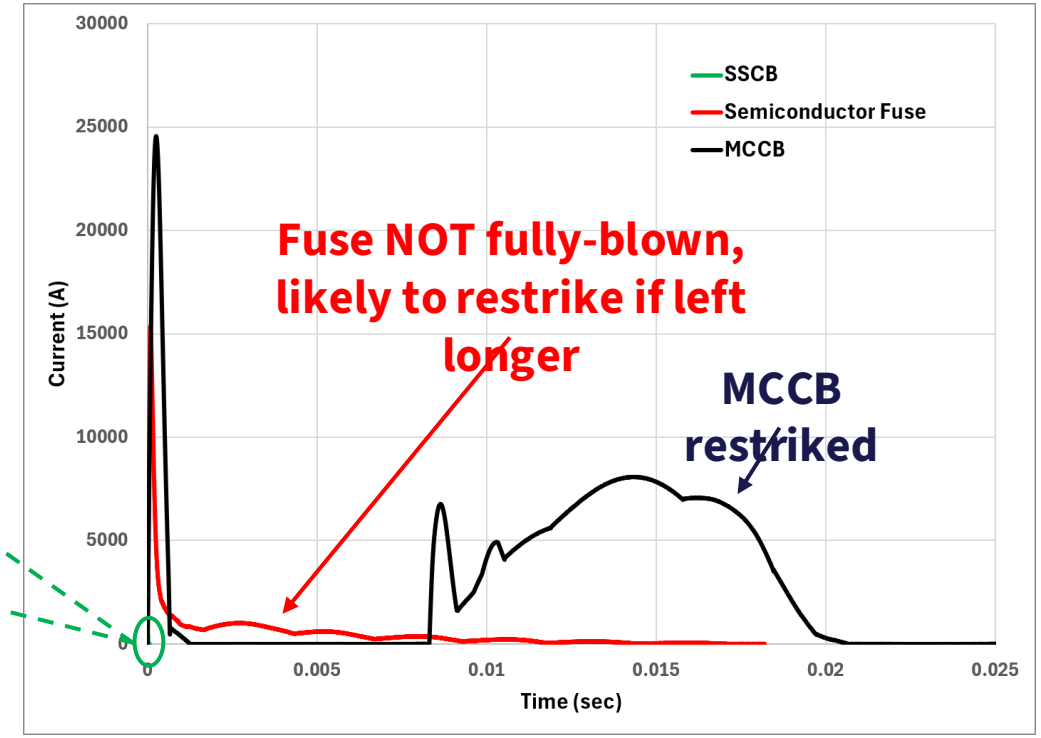
| | Interruption performance | Efforts to achieve selectivity | Protection against capacitor discharge | Realistic fault protection | Disconnect switch needed? | Storage needed for operation stabilities | Redundancy design flexibility | Heat dissipation | Component cost |
|---|---|---|---|---|---|---|---|---|---|
| Fuse | Ok | High | Inconsistent | Inconsistent | Yes | Large | Low | Med | Low |
| SSCB | Excellent | Low | Excellent | Excellent | No | Small | High | Med | High |

# Protection Against Capacitor Discharge

**800VDC 20mF discharge over 6-ft of cable**



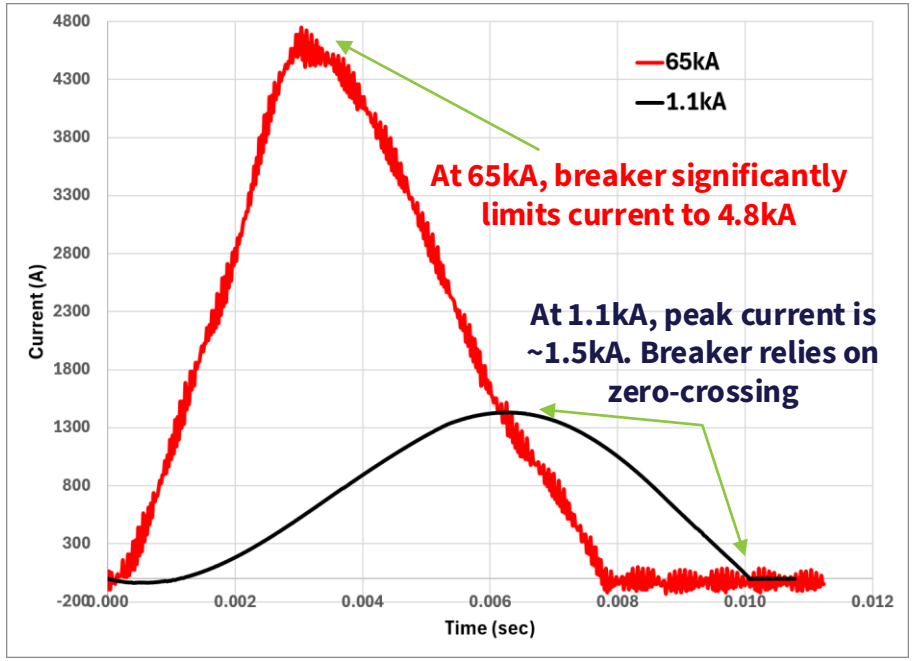

**800VDC 20mF discharge over 10-ft of cable**




- **Performance of both MCCBs and fuses are sensitive to circuit conditions, e.g. cable length. Restrikes possible, which increases interruption time**
- **SSCBs are not affected by cable length**

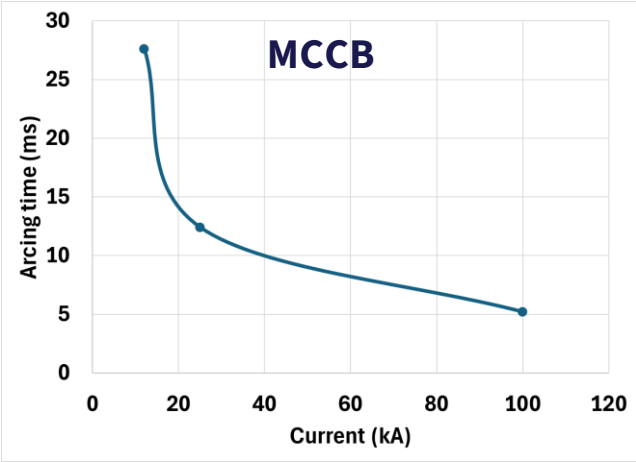
# Consider Realistic Faults

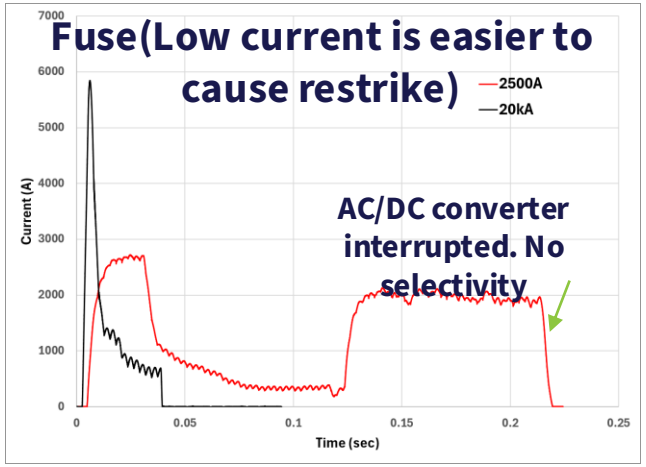
## AC fault interruption with a circuit breaker




- **In AC, bolted-short circuit faults are worst-case scenarios**
- **Zero-crossings improves interruption performances at lower fault current levels**

## DC fault interruption




- **In DC, bolted-short circuit faults are NOT worst-case scenarios**
- **Need to consider realistic faults:**
  - Failed capacitors
  - Failed insulations
  - Magnetizing current that drives high primary side current
  - Clamping components failures
  - Power electronics failures
  - …
- **SSCBs are not affected by fault current levels**

# What to Do Next

## Actions for your DC distribution decision

1. **Choose architecture, grounding, redundancy and protection together for safe, stable and serviceable operations**

2. **Recognize the unique aspects of DC distribution and the unique aspect of data center applications**

3. **Plan for all fault scenarios**
   **Assess realistic fault scenarios**—capacitor discharges, realistic fault currents, full range coordination and so on

4. **Workforce training to raise awareness, proper operating procedures and PPE**

Comparison of 2-Wire and 3-Wire DC Power Architectures for Hyperscale Data Centers Based on SST-Interfaced Distribution Systems

Protections for Data Centers Powered by Direct Current

# Thank You!

