AI OPEN
DATA CENTER:
Power Distribution



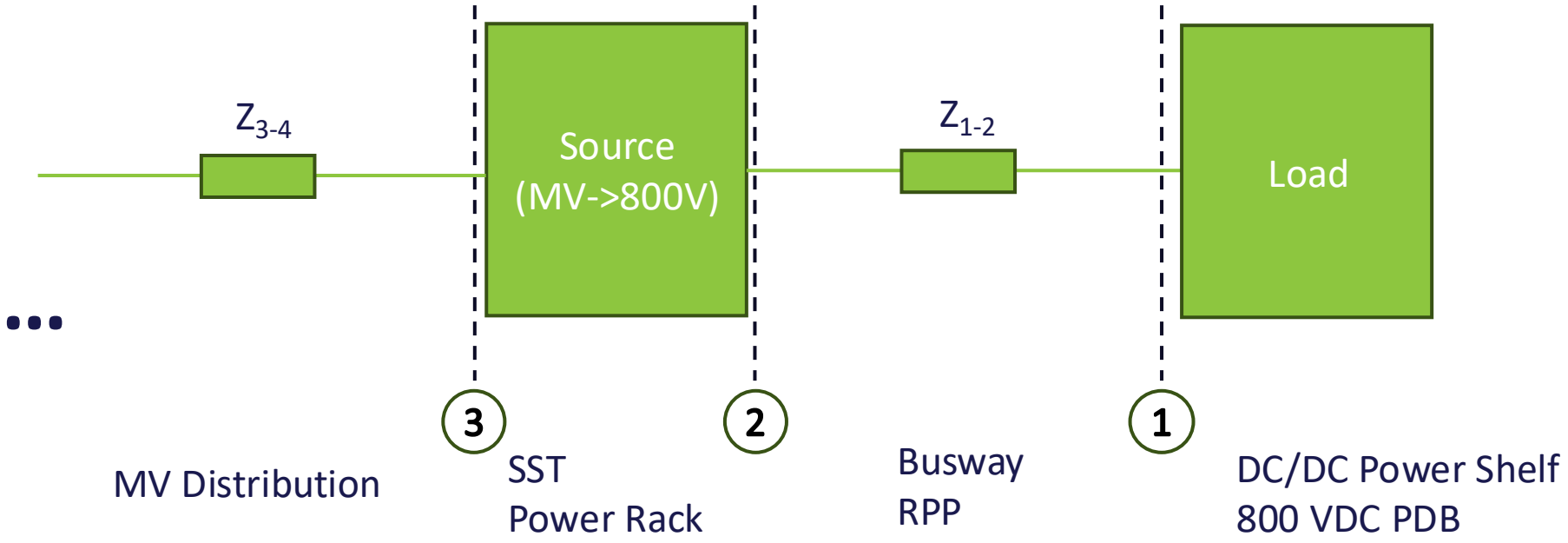
# Defining End-to-End 800 VDC System Performance Requirements

Jared Huntington *Power Architect, Nvidia*

Mike Tu *Principal Electrical Engineer, Nvidia*

# Simplifying the problem

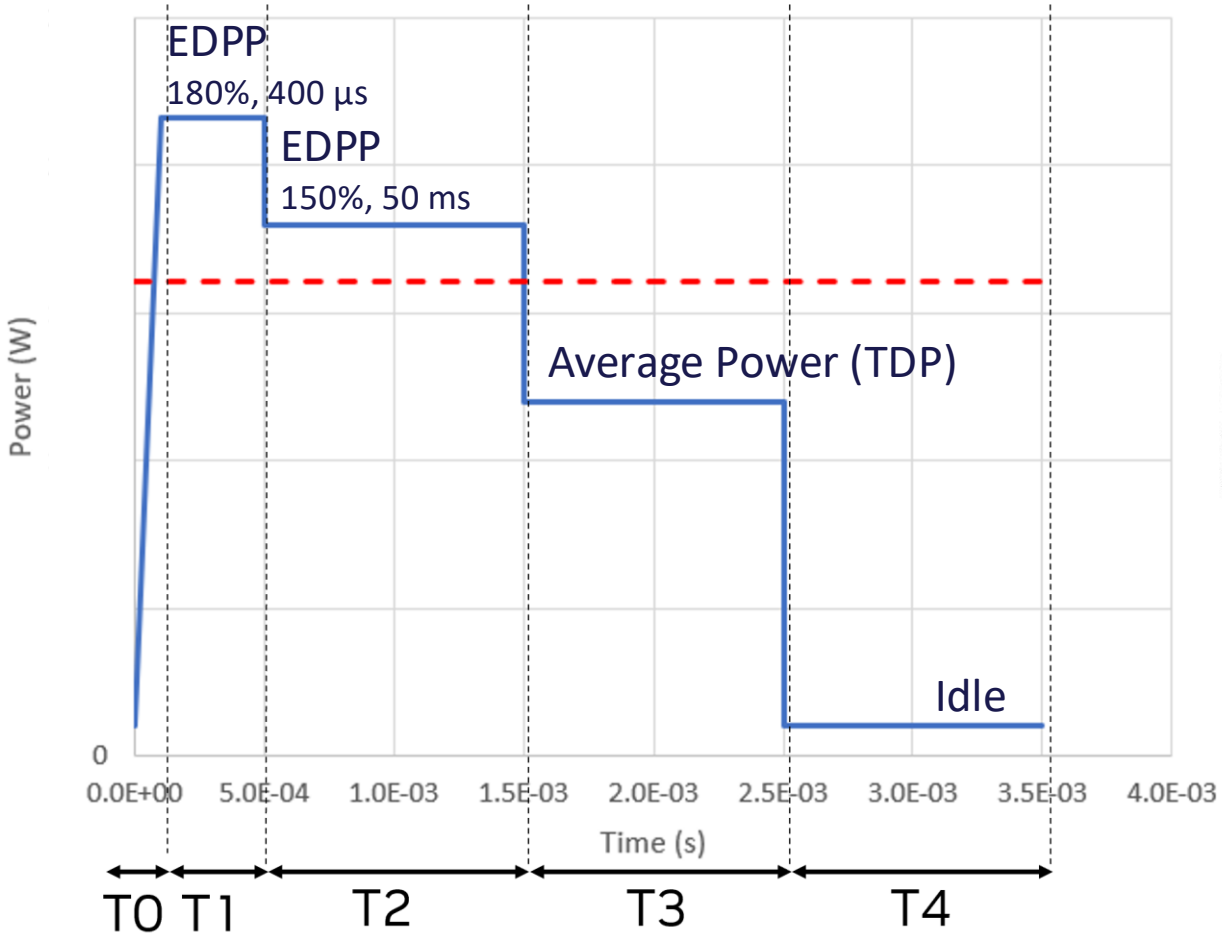
- Interoperability is a requirement for industry to deploy quickly
- Stable and defined 800 VDC bus behavior
- Scalable power for different generations and use cases

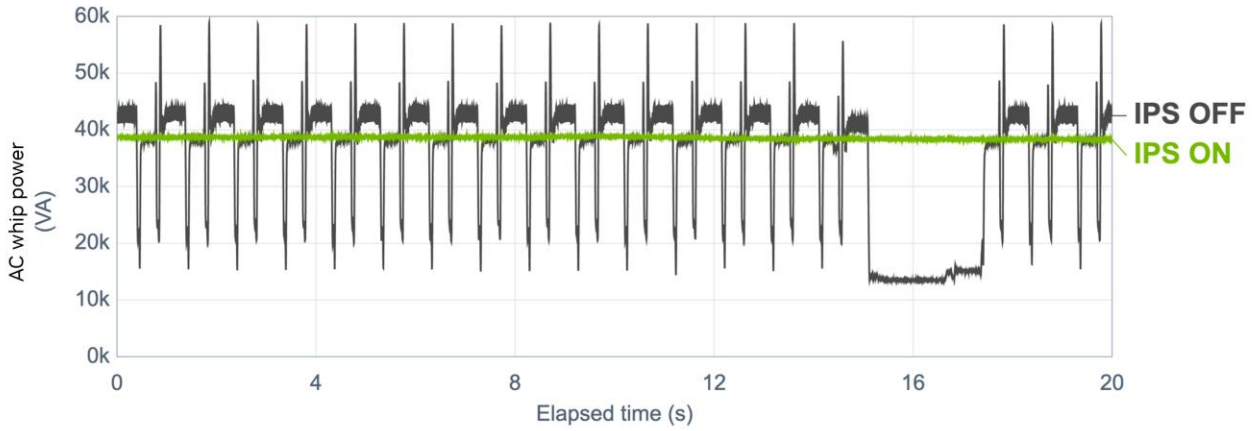


# What do we need to lock down?

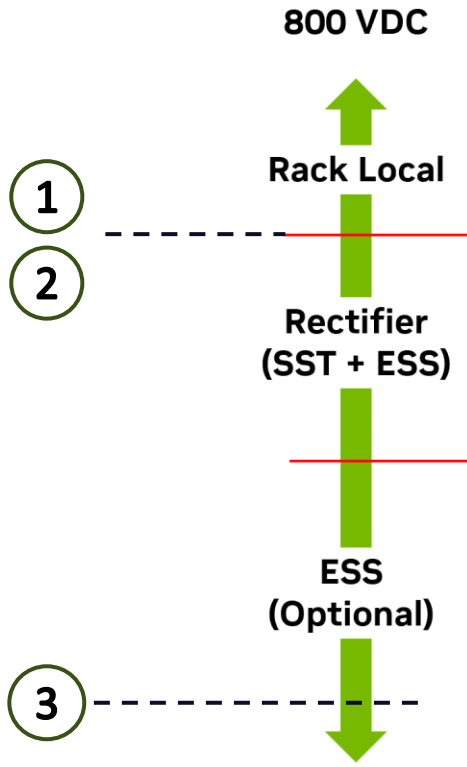
- Where do we put energy storage and what are requirements?
- Rack input electrical interface
- What distribution impedance can be supported?
- Rack startup negotiation
- Grounding
- Protection

# GPU Dynamic Load

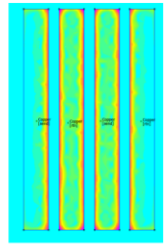


# Energy Storage Location

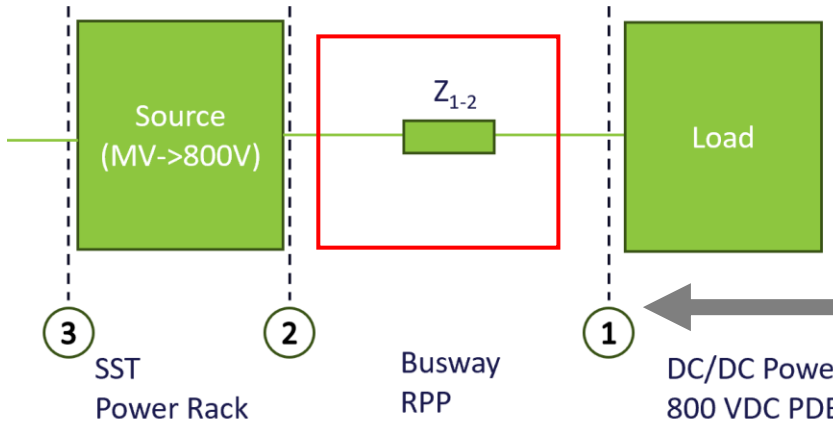


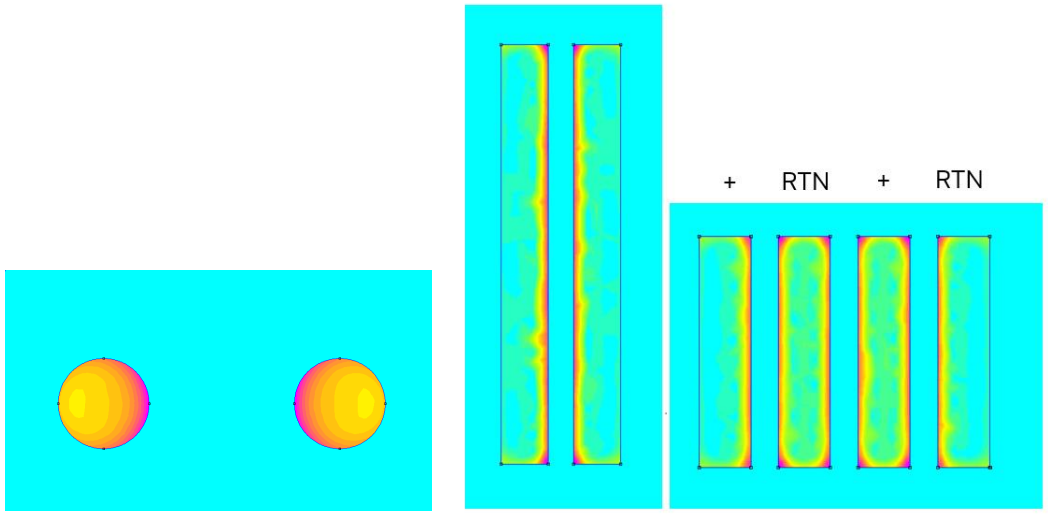

| Reason | | J/kWGPU | kW/kWGPU | Repitition Rate |
|---|---|---|---|---|
| Datacenter Distribution | Busway AC Losses (500 Hz Corner Freq.) | | 1 | 10 Hz |
| Datacenter (SSCB) | 1 ms holdup (SSCB) | 1 | 1.5 | 1 per week |
| Datacenter (MCCB) | 20 ms holdup (MCCB) | 20 | 1.5 | 1 per week |
| GPU Perf | EDPP GPU | 37.5 | 0.5 | 10 Hz |
| GPU Perf | EDPP Rack | 19.5 | 0.3 | 10 Hz |
| GPU Perf | EDPP + Idle GPU | 75 | +0.5,-1 | 10 Hz |
| GPU Perf | EDPP + Idle Rack | 39 | +0.5,-1 | 10 Hz |
| Grid | Low Voltage Ridethrough | 250 | 1.5 | 2 per year |
| GPU Perf | Idle 1 second | 1000 | 0.8 | 0.1 Hz |
| Datacenter (Opt. Backup Gen.) | 60s holdup - gen backup | 60000 | 1.5 | 2 per year |
| Datacenter (Opt. Backup Gen.) | 90s holdup - gen backup | 90000 | 1.5 | 2 per year |
| Grid | Large Load Ramp Rate | | | 1 per week |
| Grid | Intra-minute volatility | | | Continuous |
| Grid | Oscillations | | | Continuous |
| Grid | Harmonics | | | Continuous |
| Grid | Grid outage – 2 hours | 7.2 MJ | 1.5 | 2 per year |



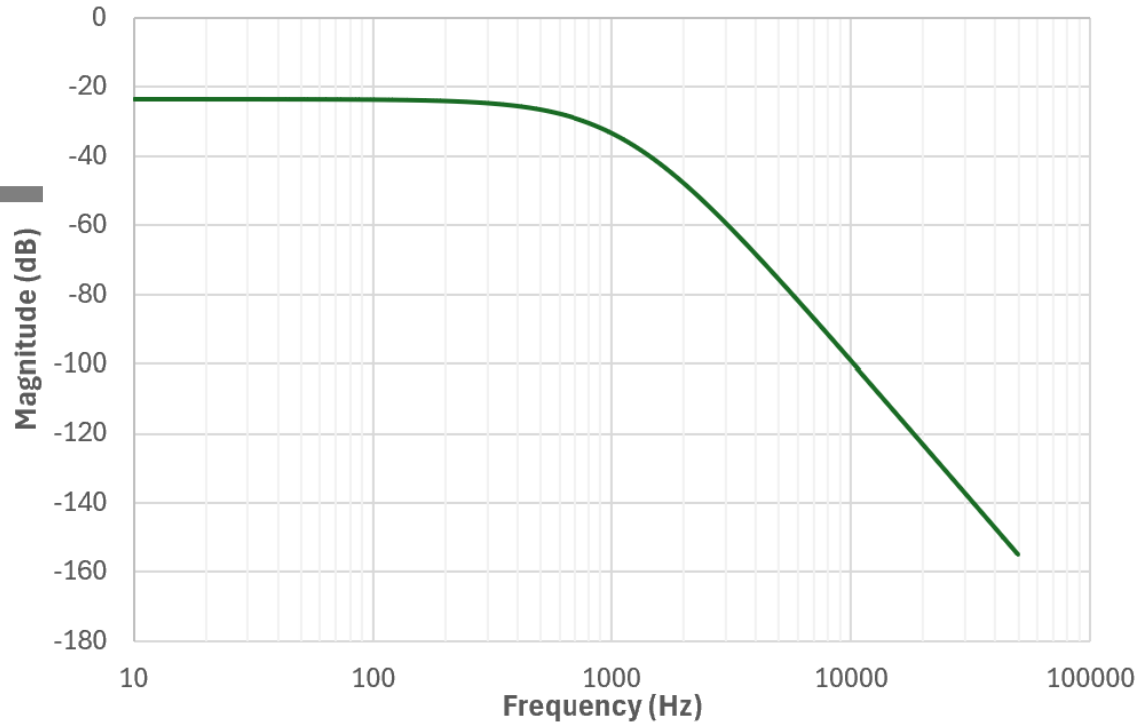
Increase busway and breaker current requirements by 11%

# Skin Effect



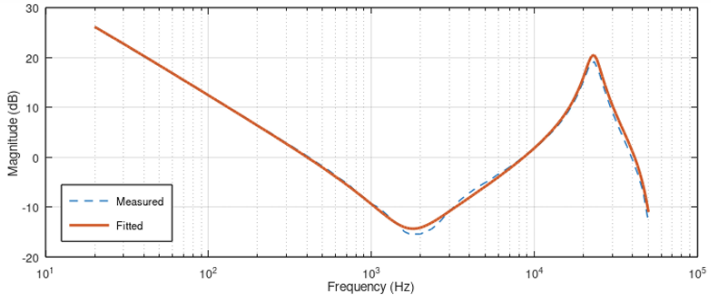

Reduce by ~44% @1kHz



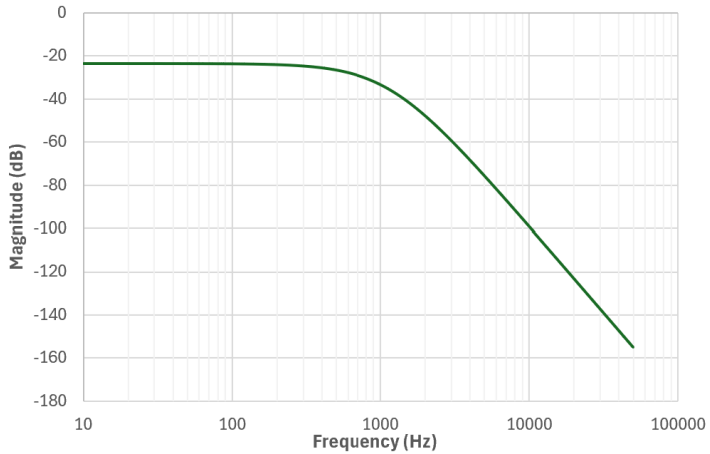
# Rack Behavior – DCDC Power Shelf

| Parameter | Unit | Value |
|---|---|---|
| Power consumption peak (4M3) | kW | 92.6 |
| Power consumption steady state (4M3) | kW | 71.3 |
| Power consumption idle (4M3) | kW | 20.0 |
| Power consumption peak (4M3 non-redundant) | kW | 123.5 |
| Power consumption steady state (4M3 non-redundant) | kW | 95.0 |
| Power consumption idle (4M3 non-redundant) | kW | 26.6 |
| Converter Rating | kW | 95 |
| Input slew rate per whip | A/µs | 0.6 |
| Input Capacitance | µF/kW | 26 |

**Input Impedance**

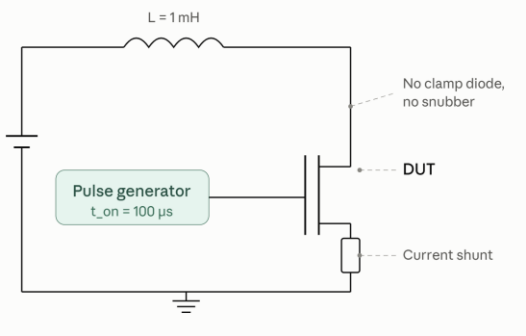



**Output to Input Transfer Function**



# DC Voltage Requirements

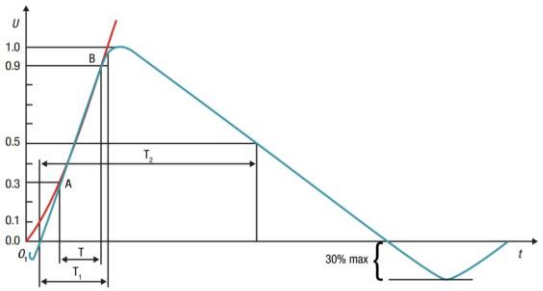
## Unclamped Inductive Load



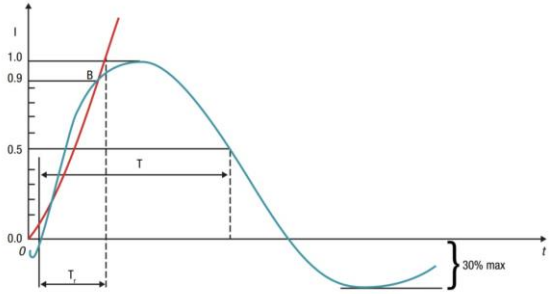




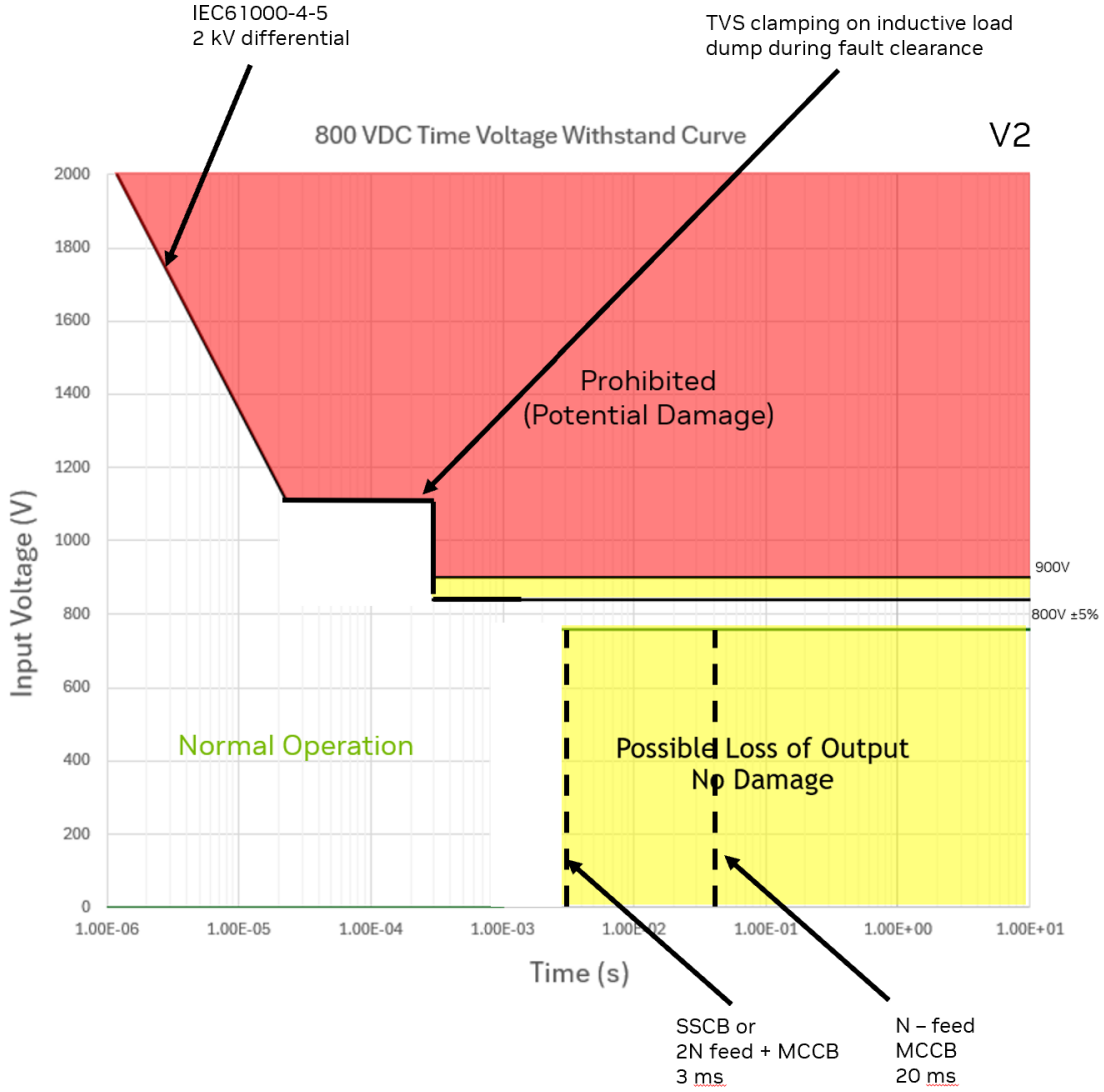
## IEC61000-4-5 – Surge Requirements



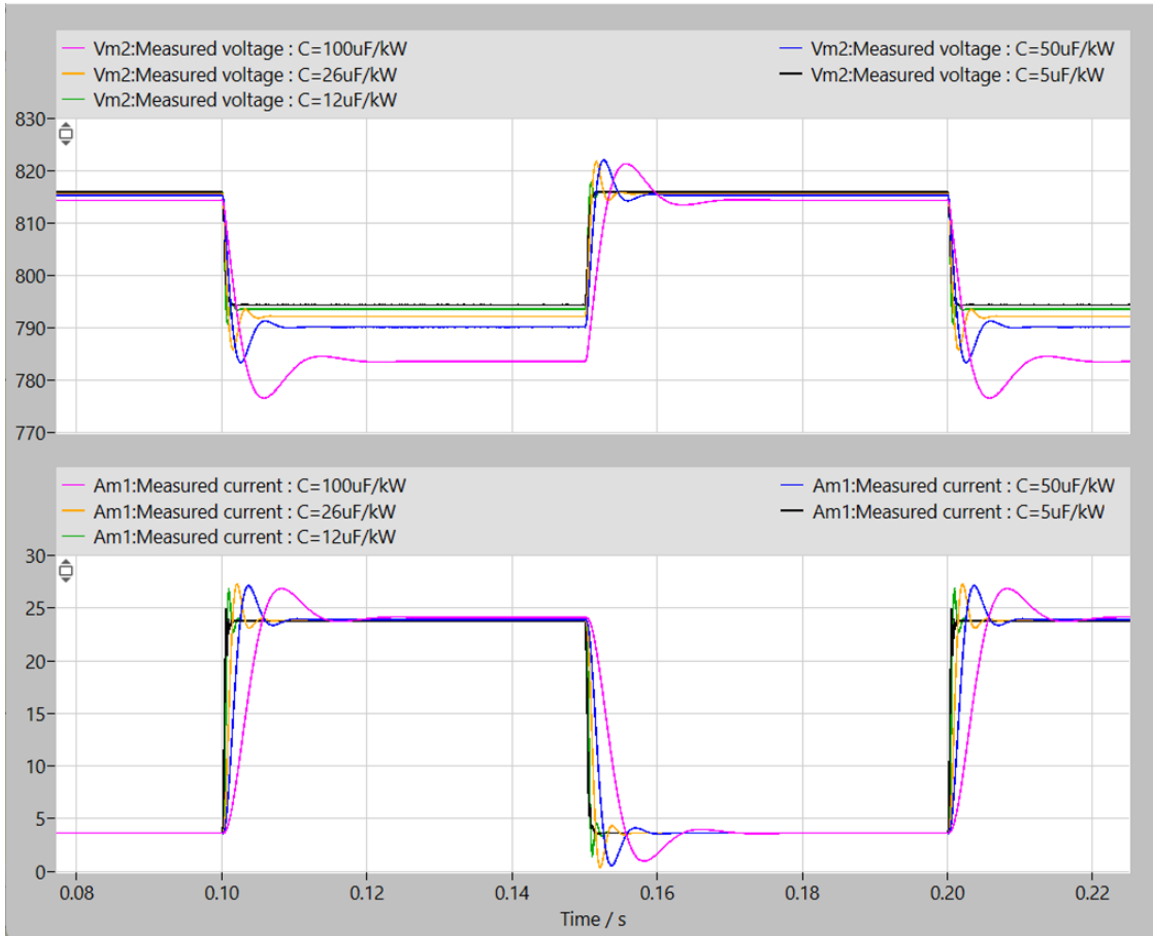

Front time: $T_1 = 1.67 \times T = 1.2\mu s \pm 30\%$
Time to half-value: $T_2 = 50\mu s \pm 20\%$

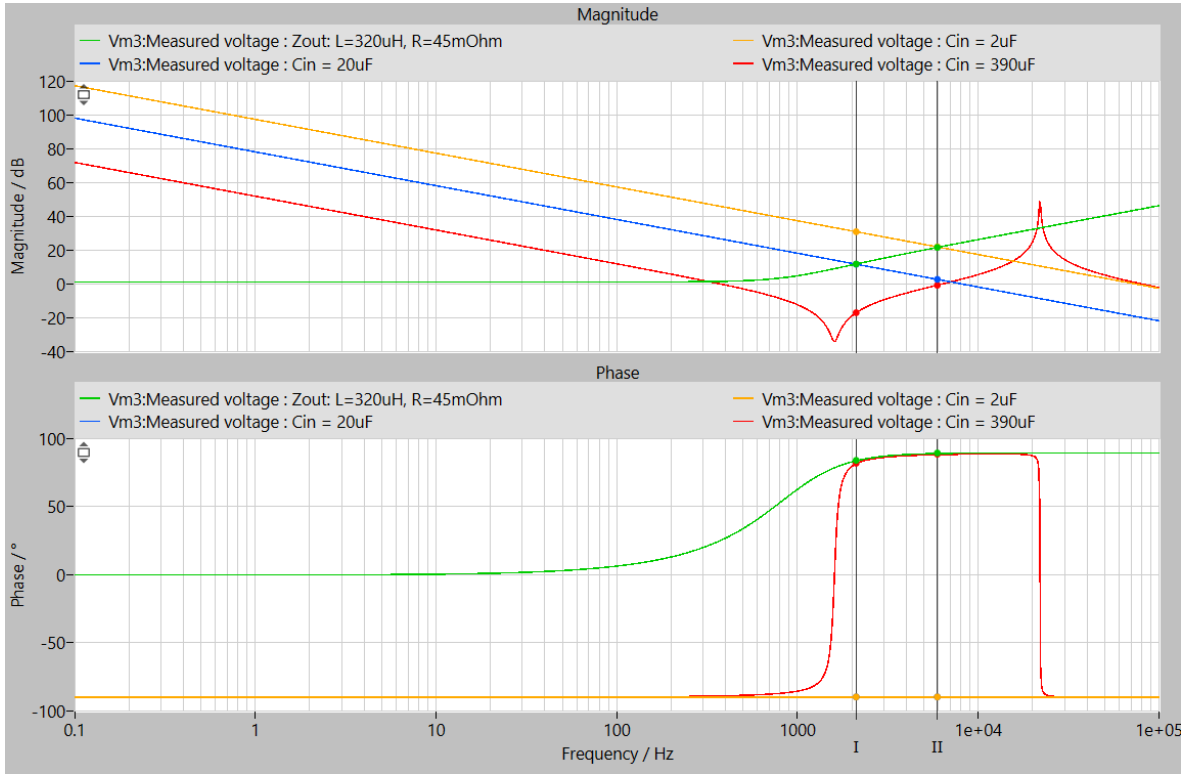



Front time: $T_r = 8\mu s \pm 20\%$
Time to half-value: $T = 20\mu s \pm 20\%$



# Modeling and Stability

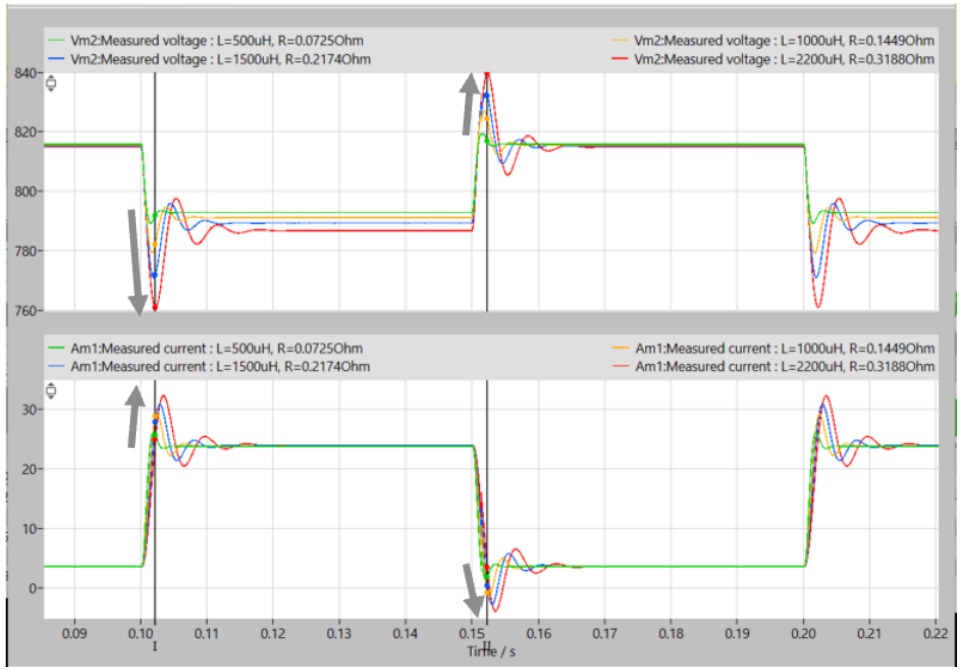


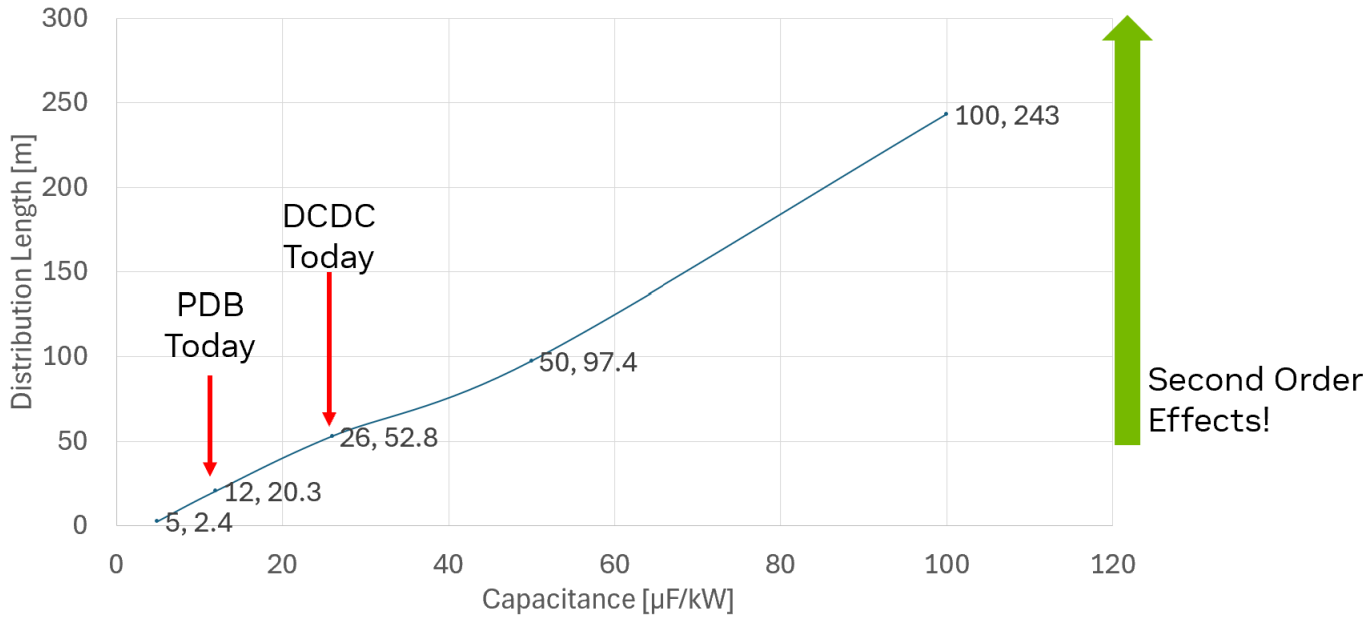



# 800 VDC Distribution Requirement

Distribution Minimums

| Value | Unit | Value | Notes |
|---|---|---|---|
| Typical Equivalent Input Capacitance Requirement | µF/kW | 26 | |
| Minimum Input Capacitance Stability | µF/kW | 12 | @62.4 µH distribution |
| Maximum Distribution Inductance Stability | µH | 250 | Per 125A/800V whip |
| Maximum Distribution Inductance Stability | µH | 5 | Per 1 MW block |
| AC Busway Resistance Required Corner Frequency | Hz | 500 | |



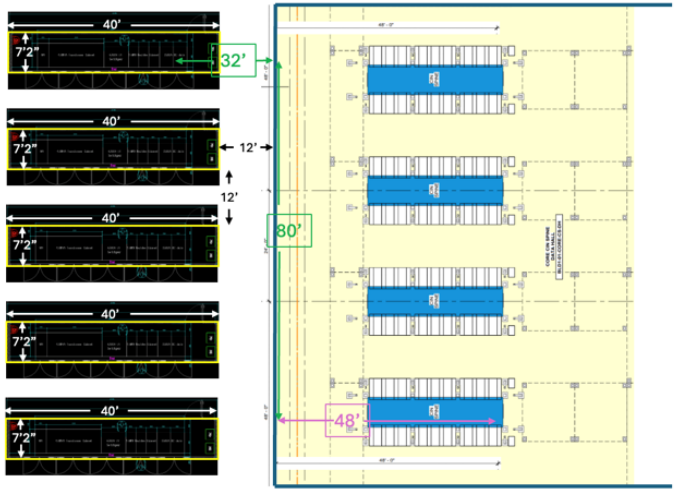



# Distribution Model

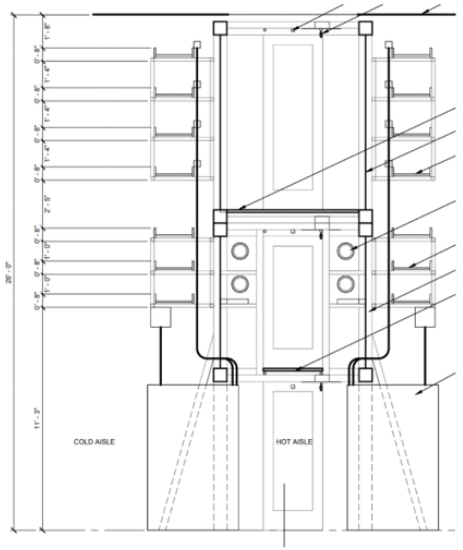
Lumped L/R Ratio is what is important for model

| Distribution Type | | | A | | B | | C | | N+N C | | Cabled non-coax C | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | min | max | min | max | min | max | min | max | min | max |
| Bus Duct | 6000A | m | 0 | 0 | 0 | 0 | | 34.1 | 24.4 | 32.5 | 0 | 0 |
| Busway | 1250A | m | 0 | 0 | 1 | 8 | 3.7 | 14.6 | 0 | 0 | 0 | 0 |
| Whip Length | 125A | m | 1.5 | 3.1 | 10.7 | 17.7 | 5.2 | 7.0 | 5.2 | 5.2 | 30.5 | 84.0 |
| | | m | 1.5 | 3.1 | 11.7 | 25.7 | 8.8 | 55.8 | 29.6 | 37.7 | 30.5 | 84.0 |
| | µH/m lumped | | min | max | min | max | min | max | min | max | min | max |
| Inductance Bus Duct | **0.077** | | 0 | 0 | 0 | 0 | 0 | 3 | 1.878 | 2.505 | 0 | 0 |
| Inductance Busway | **0.060** | | 0 | 0 | 0.060 | 0.477 | 0.218 | 0.872 | 0 | 0 | 0 | 0 |
| Inductance Cable | 0.377 | | 0.5655 | 1.150 | 4.036 | 6.666 | 1.954 | 2.644 | 1.960 | 1.960 | 11.494 | 31.681 |
| Total Inductance | µH | | **0.566** | **1.150** | **4.095** | **7.143** | **2.172** | **6.145** | **3.838** | **4.465** | **11.494** | **31.681** |
| | mΩ/m send | | min | max | min | max | min | max | min | max | min | max |
| Resistance Bus Duct | 0.006 | | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.382 | 0.273 | 0.364 | 0.000 | 0.000 |
| Resistance Busway | 0.027 | | 0.000 | 0.000 | 0.054 | 0.429 | 0.196 | 0.784 | 0.000 | 0.000 | 0.000 | 0.000 |
| Resistance Cable | 0.521 | | 1.563 | 3.178 | 11.154 | 18.426 | 5.401 | 7.307 | 5.418 | 5.418 | 31.768 | 87.563 |
| Total Resistance | mΩ | | **1.563** | **3.178** | **11.208** | **18.854** | **5.597** | **8.474** | **5.692** | **5.783** | **31.768** | **87.563** |
| Voltage Drop | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.3 | 1.6 | 2.2 | 0.0 | 0.0 |
| Voltage Drop | | | 2.0 | 4.0 | 13.9 | 23.0 | 6.8 | 9.1 | 6.8 | 6.8 | 39.7 | 109.5 |
| Voltage Drop | | | 0.2 | 0.4 | 1.4 | 2.4 | 0.7 | 1.1 | 0.7 | 0.7 | 4.0 | 10.9 |
| Voltage Drop Total | | | 2.1 | 4.4 | 15.3 | 25.4 | 7.5 | 12.5 | 9.1 | 9.7 | 43.7 | 120.4 |
| Dist Losses Total | 6000 | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 13767.8 | 9834.1 | 13116.3 | 0.0 | 0.0 |
| Dist Losses Total | 1250 | | 0.0 | 0.0 | 83.8 | 670.0 | 306.4 | 1225.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| Dist Losses Total | 125 | | 24.4 | 49.7 | 174.3 | 287.9 | 84.4 | 114.2 | 84.7 | 84.7 | 496.4 | 1368.2 |
| Dist Losses Total | | | 1172.3 | 2383.6 | 8767.9 | 17035.2 | 5521.2 | 25130.8 | 13897.9 | 17180.1 | 23826.2 | 65672.3 |
| Dist Efficiency | | | **100.0%** | **100.0%** | **99.8%** | **99.6%** | **99.9%** | **99.5%** | **99.7%** | **99.6%** | **99.5%** | **98.7%** |

6000A Busduct Run: 6' (Vertical) + 32' + 80' = 118'
1250A Busway Run: 48'




125A Power Whip Length: 23'



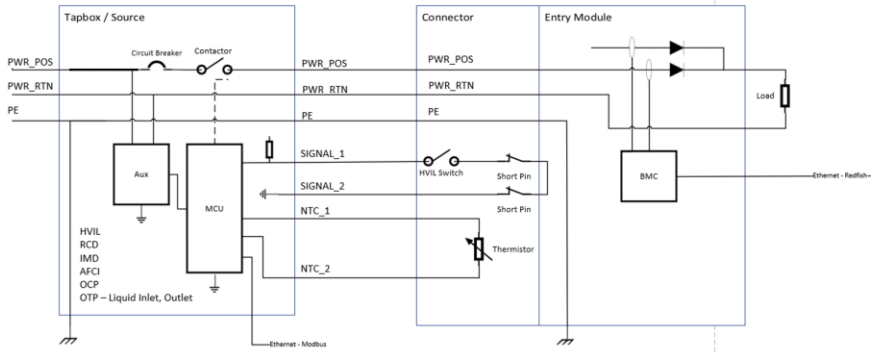

Requires separate ground bond for hard tied ground

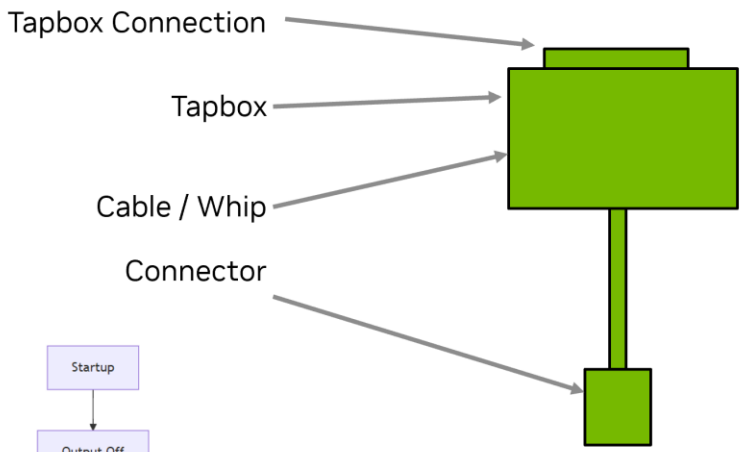
Larger wire gauge required

# Validation

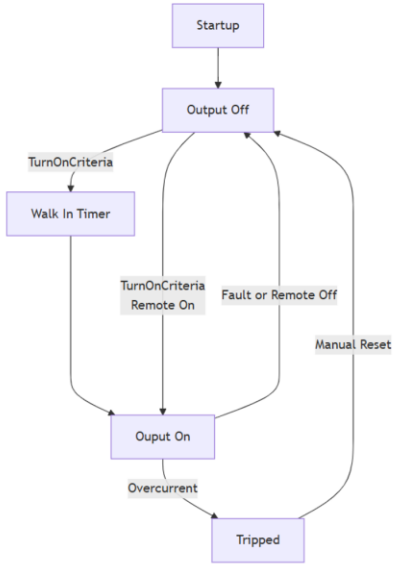
- Simulation is the first step
  - Small signal stability check w/ distribution impedance
  - Large signal distribution check
  - Stability margin check
  - DC Time / Voltage withstand curve check at load
- Single component validation
  - Single SST Module
  - DC/DC Power Shelf
  - Simulated max designed distribution impedance
- Pilot builds and system bringup

# Rack Standardized Startup Sequence




| State Change | Criteria | Threshold |
|---|---|---|
| **TurnOnCriteria** | Input Voltage | 800 VDC ±5% |
| | Insulation Monitoring Device | Greater than TBD Ω |
| | High Voltage Interlock | Engaged |
| | Liquid Inlet Temperature | < 45 °C |
| | Liquid Outlet Temperature | < 85 °C |
| | Connector Temperature | < TBD °C |
| **Fault** | Over Temperature Protection (Any) | |
| | Arc Fault Current Interruption | |
| | Residual Current Monitoring | Greater than TBD mA imbalance |
| | Insulation Monitoring Device | Greater than TBD Ω |
| | Break in High Voltage Interlock | |
| | Current Backfeed | negative current for more than 100 µs |
| **Walk In Timer** | Time | 10 seconds with a minimum of 1024 steps |
| **Remote Off** | Modbus command | TBD |
| **Remote On** | Modbus command | TBD |



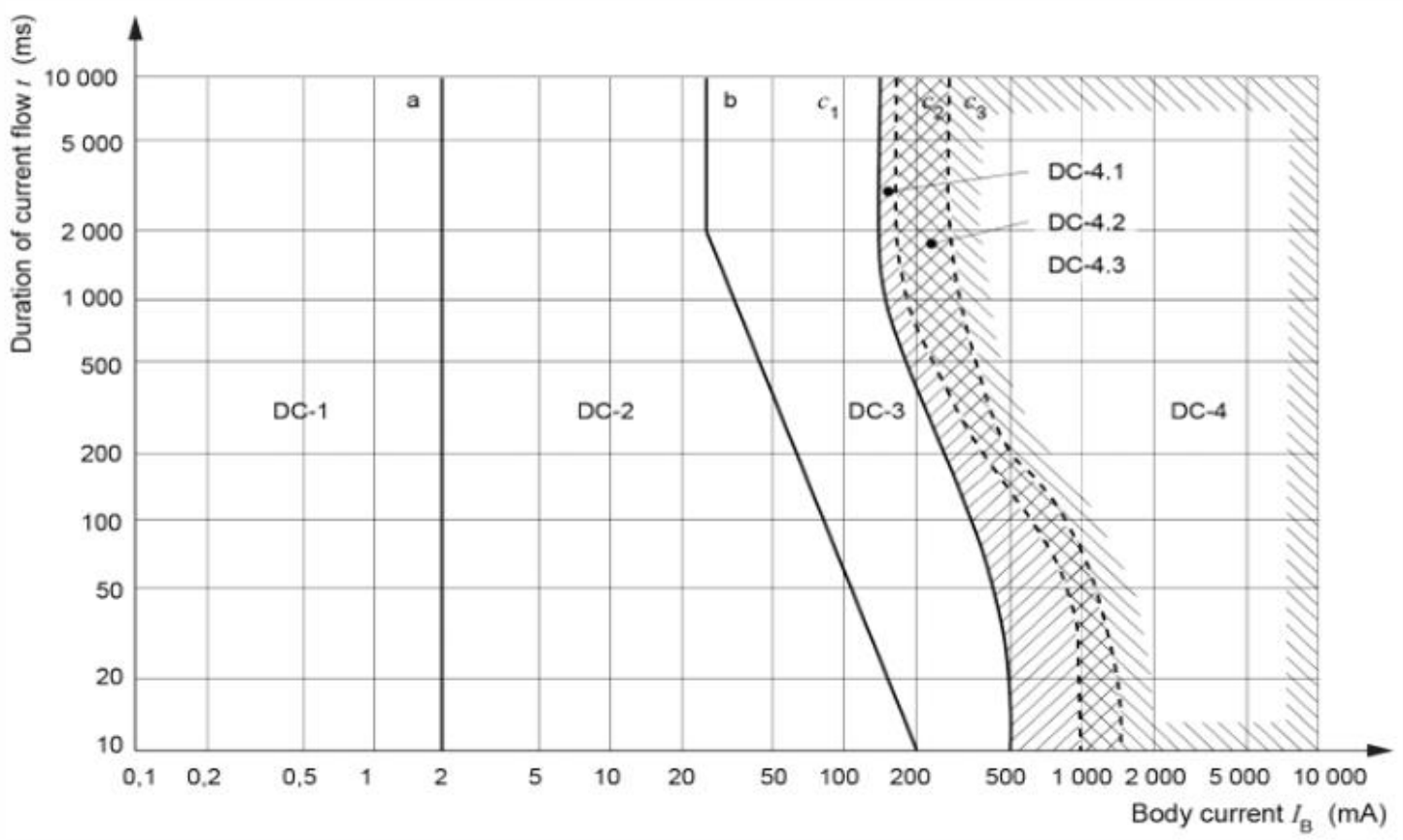
# 800 VDC Arc Fault Protection

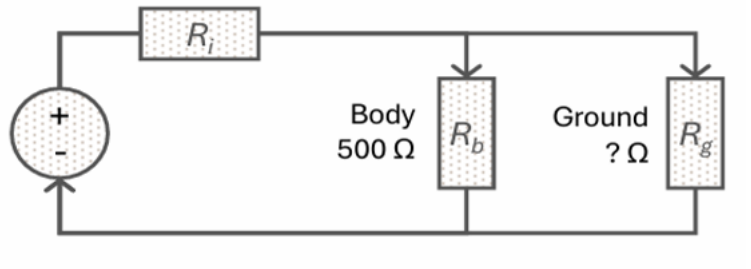
$$E_1| = k\frac{E_{\text{arc}}}{a^2 + d^2}.$$

| Category | Protective Clothing | Incident Energy |
|---|---|---|
| 0 | No melting, Flammable Materials with Weight >= 4.5 oz/sq yd | 0.0 - 1.2 cal/cm$^2$ |
| 1 | Arc-rated FR Shirt & Pants | >1.2 - 4.0 cal/cm$^2$ |
| 2 | Arc-rated FR Shirt & Pants | >4.0 - 8.0 cal/cm$^2$ |
| 3 | Arc-rated FR Shirt & Pants & Arc Flash Suit | >8.0 - 25.0 cal/cm$^2$ |
| 4 | Arc-rated FR Shirt & Pants & Arc Flash Suit | >25.0 - 40.0 cal/cm$^2$ |
| DANGEROUS! | No FR Category Found | >40.0 - 999.0 cal/cm$^2$ |

PPE CATEGORIES – based on 2012 NFPA 70E
(no Cat 0 in 2015)

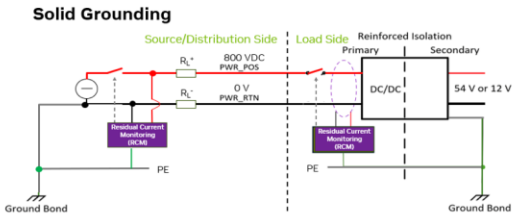
# 800 VDC Personnel Protection

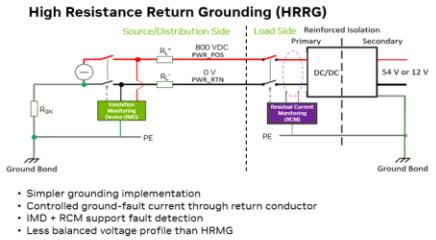


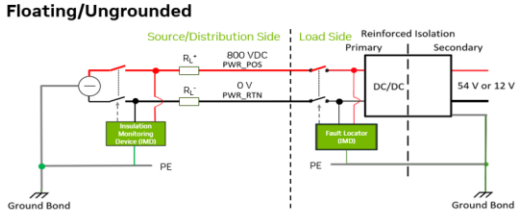




$$R_g \leq \frac{I_{threshold} \times R_b \times R_{int}}{V_{source} - I_{threshold}(R_b + R_{int})}$$

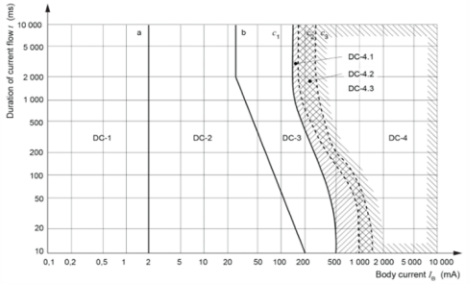
# Grounding

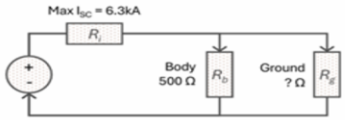



| | | Solid Ground | High Resistance Midpoint | Floating |
|---|---|---|---|---|
| **Protection** | Main Feed | High Side and Low Side | High Side and Low Side | High Side and Low Side |
| | Tapbox / Branch | High Side | High Side and Low Side | High Side and Low Side |
| | Compute Rack | High Side | High Side - IMD for return fault | High Side and Low Side |
| | Protection Requirements | Ground Bonding Reliant (< 7 mΩ)<br>Residual Current Monitor (RCM)<br>2*RCM/Breaker current PE < 2.5V | Insulation Monitoring Device (IMD)<br>Residual Current Monitor (RCM) | Insulation Monitoring Device (IMD) |
| **Faults** | Incident Energy | High | Resistor Controlled | Very Low |
| | Detection | Simple | Difficult | Difficult |
| | Fault Transient Overvoltage | Low | Medium | High |
| **Reliability** | Leakage Current (Galvanic Corrosion) | High | Low | Very Low |
| **Challenges** | | Limits maximum busway to about 26m<br>7 mΩ from rack to source<br>Provision for grounding bolts on rack and busway | | Signal integrity / noise |



# Call to Action

- Update DC Voltage Withstand curve to allow for SSCB / IEC Surge
- Standardize on rack startup sequence and checks
- Minimum filter requirements
- Small signal and large signal modeling is required to ensure stability
- Open models should be published with specifications
- Impedance vs. frequency plots for cables and busways and inductance will be limiting factor for dynamic loads

# Thank You!

