Medium Voltage DC Solid State Circuit Protection

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PJM CV

- **Aerospace & Defense Industry** (RCA, GE, Ford Aerospace, LORAL, Lockheed)
  - Technical Program Management
  - Business Planning & Marketing
  - Business Development
  - Strategic Planning
  - Mergers & Acquisitions
- **Navy Machinery Systems R&D**
  - Power Semiconductors
  - Power Converters
  - Hybrid Electric Drive
  - Ocean Renewable Energy
  - Solid State Circuit Protection

Floating Micro-Grids

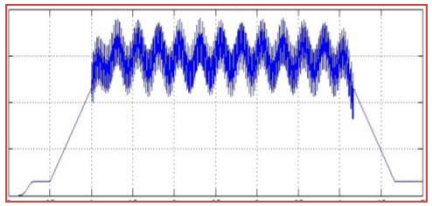
Littoral Combat Ship
TIGC – 2.3 Mw @ 480 VAC 3Ø

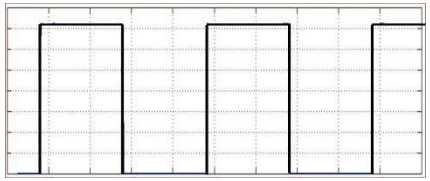
Destroyer
II-TIGC – 9 Mw @ 480 VAC 3Ø
IIIA-TIGC -12 Mw @ 4160 VAC 3Ø

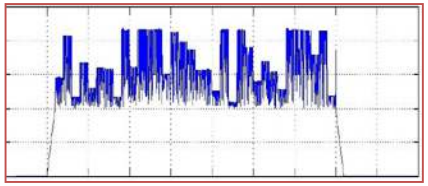
Aircraft Carrier
TIGC – 108 Mw @13.8k VAC 3Ø

Driving to DC Power

Emerging Mission Load Power Profiles







- **CHARACTERISICS:**
  - **DC Power Based**
  - **Highly Dynamic Load Profiles**
  - **Stochastic In Nature**
  - **Intermittent Usage**

- **IMPLICATIONS:**
  - **Highly Stressful to AC Generators**
  - **Potential Instabilities & Resonance**
  - **Currently < 1Mw But Will Increase**
  - **Requires Robust DC Fault Protection**

2 Pronged Approach

Generate AC – Distribute DC

Supplement w/Energy Storage

Point Source Loads In Zone

- 1kV supply.
- Point source AC conversion as required.
- Point source breakers for coordination & fault protection.

System Wide Zone to Zone

- 12kV supply.
- Traditional zonal architecture.
- Utilize breakers for inter-zonal bus ties and zone isolation.
- Utilize converter current limiting and no-load disconnects for intra zonal distribution protection.
- Switchboard level coordination & fault protection logic.

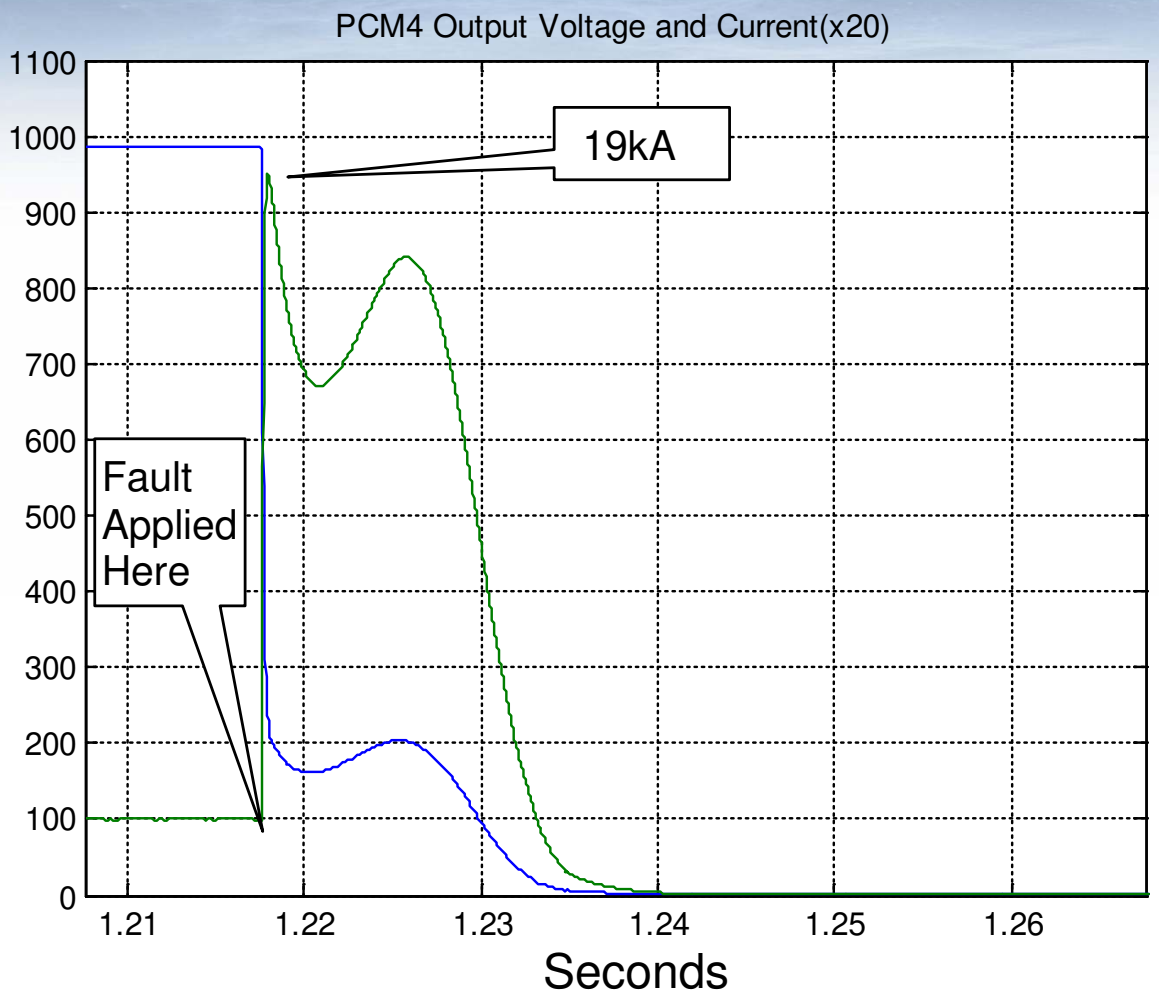
	HVDC Risk Title
HVDC #01	High Voltage DC Breaker/ Protection and Isolation System

DC Fault Clearing Challenges

- DC fault clearing technical challenges:
  - No zero crossing as in AC systems.
  - High di/dt, values.
  - High magnitude of fault currents.
  - Arc suppression & containment.
  - Voltage spike if arc is not employed to clear fault.

Notional DC Fault Example

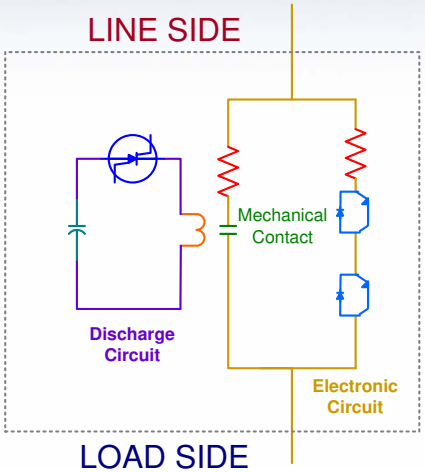
- Power converter output bolted fault.
- High di/dt.
  - 65A/µs
  - Large filter capacitance
  - Rapid rise time
- Ringing on the decay.



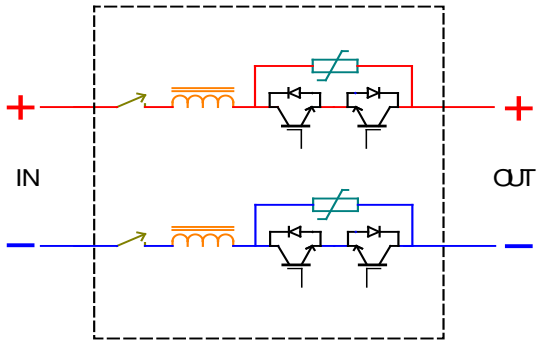
Potential Solutions

- Traditional electromechanical

- Hybrid (solid state & mechanical)



- Pure solid state (stand alone or embedded into power converter)

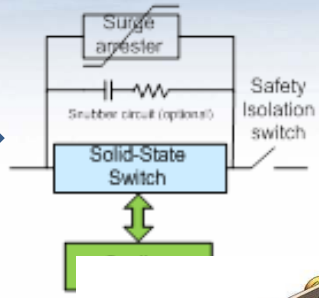


Electro-Mechanical Breakers

- 5000 amps @ 935 VDC
- Big
- Heavy
- Complicated (swiss watch)
- Expensive ($$$$$)
- Long lead time
- Maintenance & Reliability Headache (zillions of moving parts & tight tolerances)

Solving the 1 kV Problem

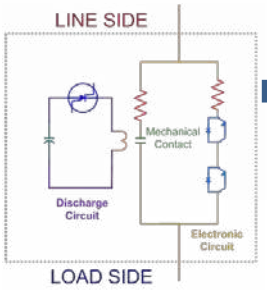
Develop three independent solutions based on the available options

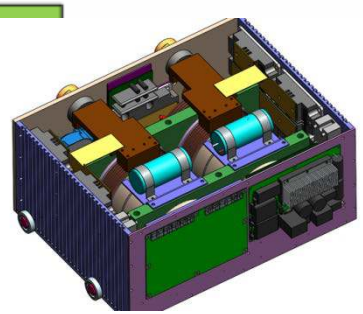


DEVELOPMENT ITEMS

Coordination Schemes

Cooling Concepts





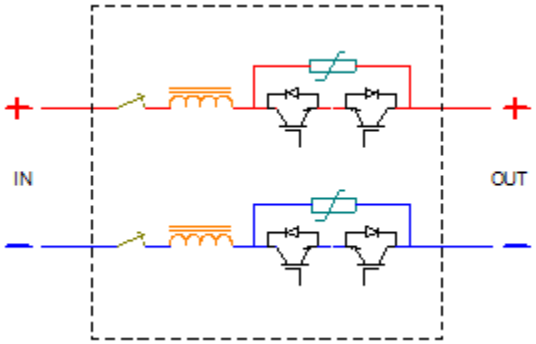
Packaging

Voltage Withstand

Safety & Maintainability

Leakage Current

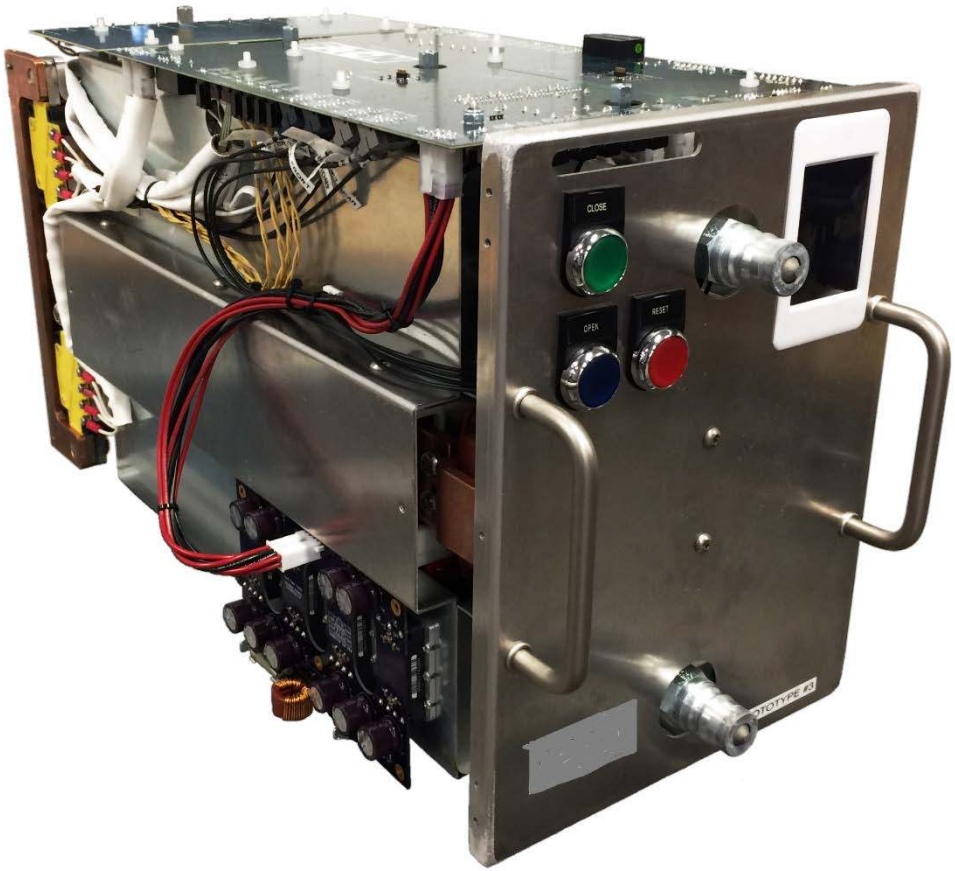
Expanded COTS Device SOA



1 kV Solution Metrics

Attribute / Parameter	Phase 1 Metrics	Note
Response Time (ms)	< 1 ms	Includes detection through complete response
Power Density (MW/m^3)	> 18 MW/m^3	
Efficiency	> 99.5%	Overall device
Maximum Fault Current (Amps)	> 80,000 A	
Continuous Current Range (Amps)	> 1,000 A	
Voltage Range (kVDC)	> 1 kVDC	
False (Nuisance) Trips	< 5%	
Safety Isolation	Open-Dry Contact	
Shunt Trip Capability	Yes	5 - 30 Volt Control signal or Optical signal
Conduction / Break Capability	Bi-directional / Both poles	Both poles need to break full voltage and current
Source Operation	Generators, Converters, Energy Storage	Transformer rectifier, voltage source converter; Batteries and capacitors

1kV Breaker Prototype



- 1000 amps @ 1000 VDC
- Smaller (just)
- Lighter (a little)
- Simpler (a lot)
- Cheaper ($)
- Shorter Lead Time
- Fewer Components (8 moving mechanical parts)

1kV Prototype Testing

- Voltage Rating
- Current Rating
- Dielectric
- Bi-directionality
- Fault clearing time
- Open on Fault
- Close on Fault
- Coordination
- Loss of Coolant
- 80,000 Amp Fault Current Potential
- Life-Cycle

MEETS ALL REQUIRED METRICS

Moving Forward

- Transition 1kV to shipboard application.
- Finalize development of 12kV 2000A prototype.
- Demonstrate 12kV system level protection.
- Transition 12kV to shipboard application.
- Deploy to next generation of Navy ships.

Future Research Areas

- Wide-band gap semiconductors.
- On state resistance.
- Current sharing among parallel devices.
- Voltage clamping techniques.
- Gate drive synchronization.

QUESTIONS?

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