Thermal-Hydraulic Issues in Cold Dielectric Cables: Over-Pressure Protection & Code Compliance

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HTS Solutions for a New Dimension in Power

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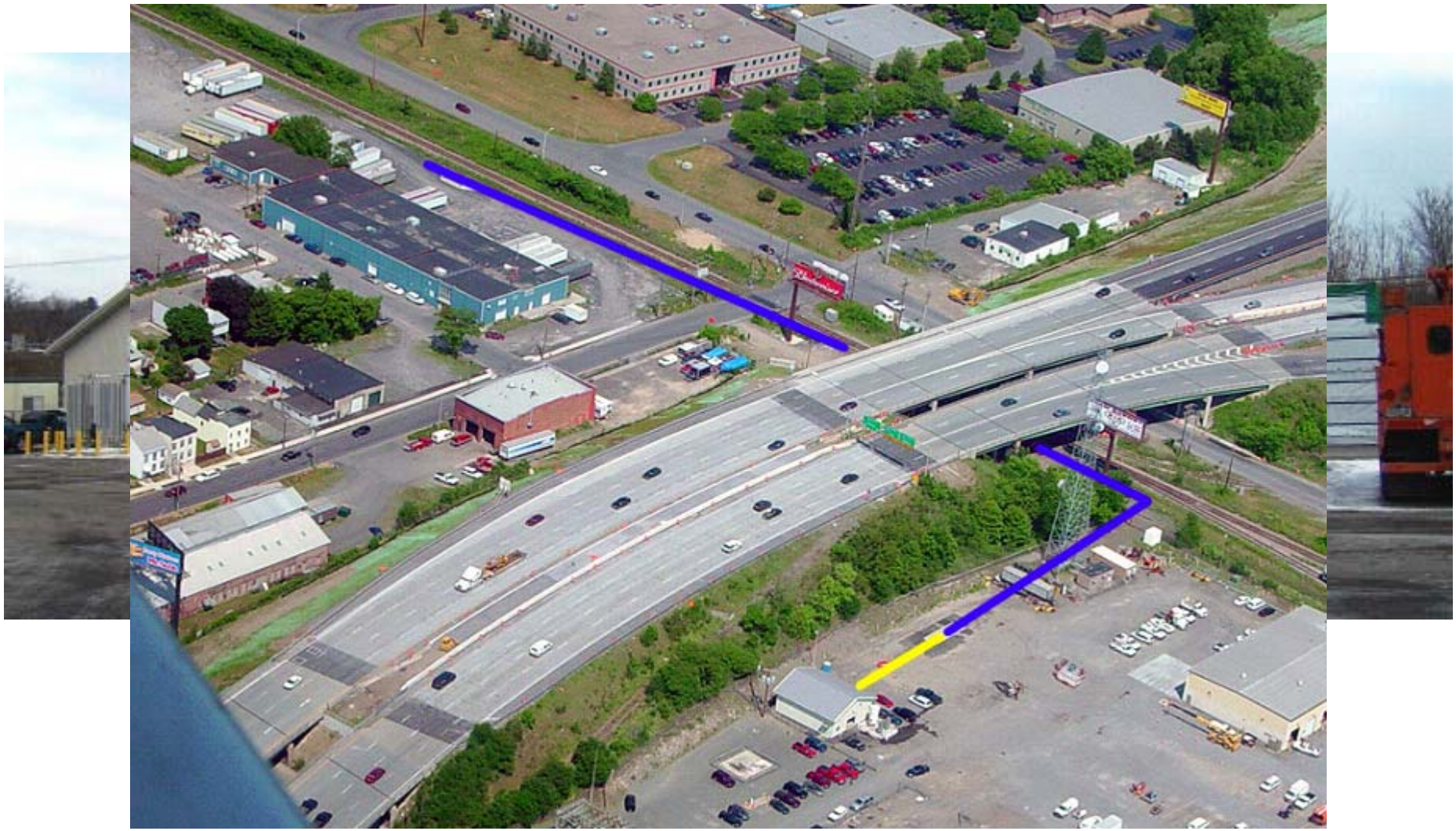
Program Overview

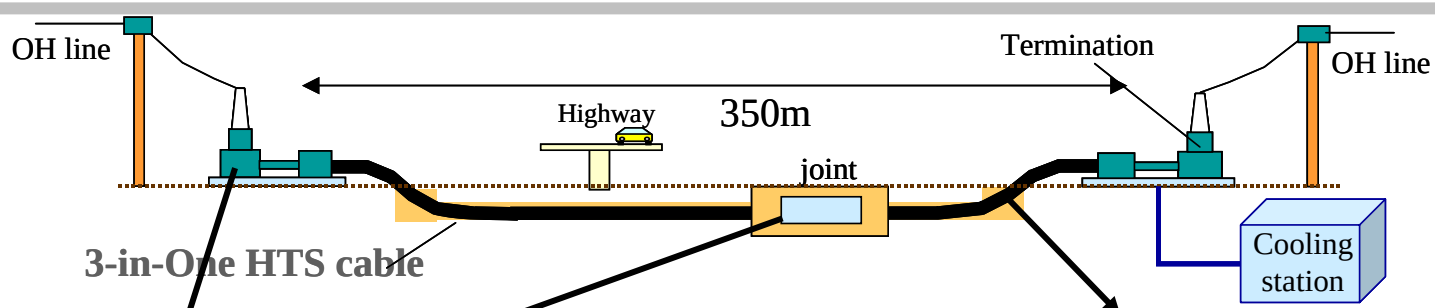
- 350m long - 34.5kV - 800A_{rms} - 48MVA
- Cold dielectric, 3 phases-in-1 cryostat, stranded copper core design

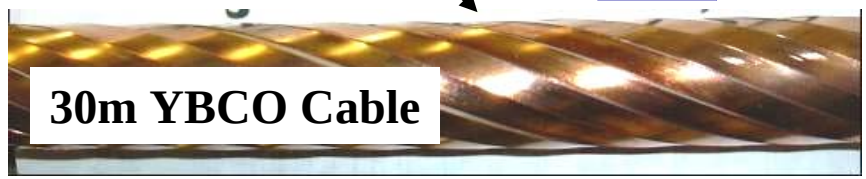
SuperPower Inc. A Subsidiary of Intermagnetics General Corporation	**Project Manager; Site Infrastructure, Manufacture of 2nd generation HTS conductor**
nationalgrid	**Host utility, conventional cable & system protection, system impact studies**
SUMITOMO ELECTRIC	**Design, build, install, and test the HTS cable, terminations, & joint**
BOC	**Design, construct and operate the Cryogenic Refrigeration System, and provide overall cable remote monitoring and utility interface**
NYSERDA, DEPARTMENT OF ENERGY, UNITED STATES OF AMERICA	**Supported by Federal (DOE) and NY State (NYSERDA) Funds**

Site Location

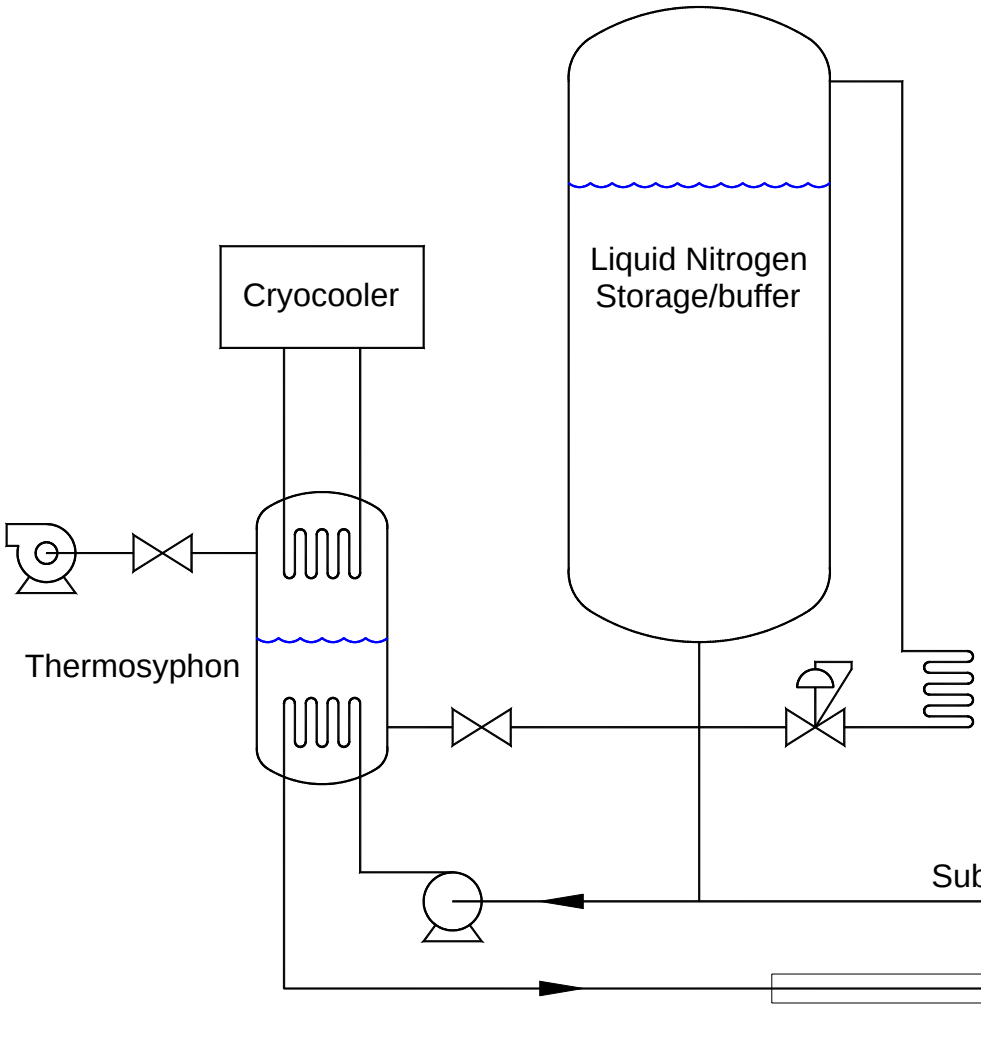


Cable System Layout & Design





Cryogenic Refrigeration System: Approach



Primary refrigeration: closed mechanical refrigeration
- Minimum 5 kW at 77 K total; 3.7 kW at 70 K (for cable)

Hybrid refrigeration arrangement for back-up and maintenance
- Bulk liquid nitrogen combined with vacuum pump
- Thermosyphon provides common heat exchange interface between cable and open or closed refrigeration sources

Remote monitoring and control
- Entire cable system to be monitored through BOC Remote Operations Center (ROC) in Bethlehem, Pa
- CRS operation will be controlled directly through ROC
- Formal interface between ROC and National Grid Eastern Regional Control Center for cable status and connect/disconnect

Code Compliance

CRS System –

- All piping systems designed and fabricated to ASME B31.3
- All pressure vessels designed and fabricated in accordance with ASME Section VIII Div 1

Terminations –

- Inner cryostat vessels designed and fabricated in accordance with ASME Section VIII Div 1

Cable & Return Pipe Cryostats –

- Fall under the category of piping components (not pressure vessels)
- Area of concern after Conceptual Design Readiness Review meeting
  - Cable & CRS response during overcurrent situations
    - Gas formation in LN_2 during fault current situations
    - Fluid dynamics during fault current situations

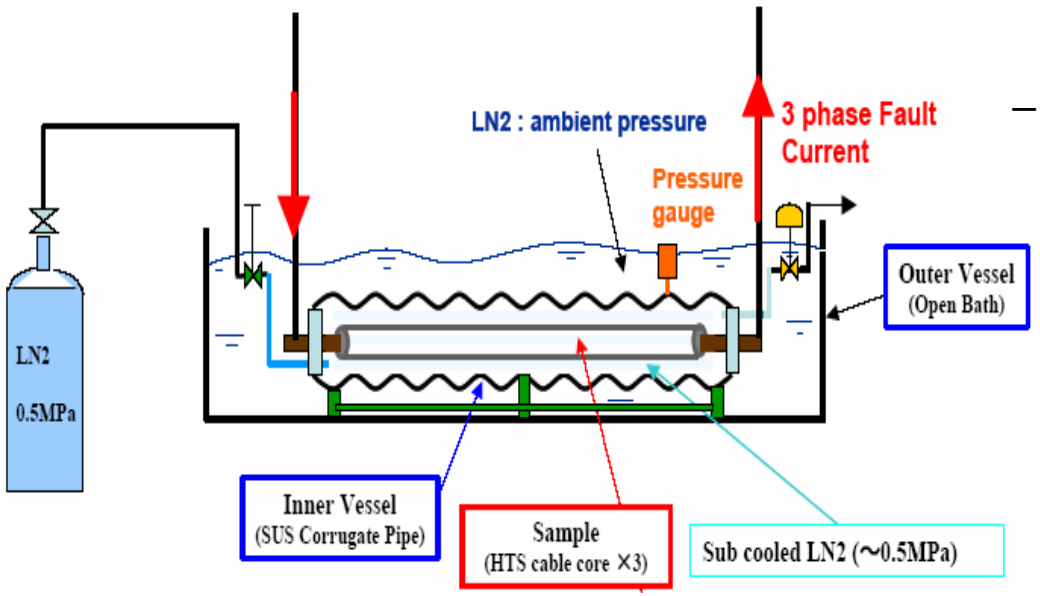
Fault Current Testing of Cable & Cryostat

Fault Current Conditions

- 23 kA_{rms} (58kA_{peak}) maximum
- 1st Contingency = 8 cycles (133 ms)
- 2nd Contingency = 38 cycles (633 ms)

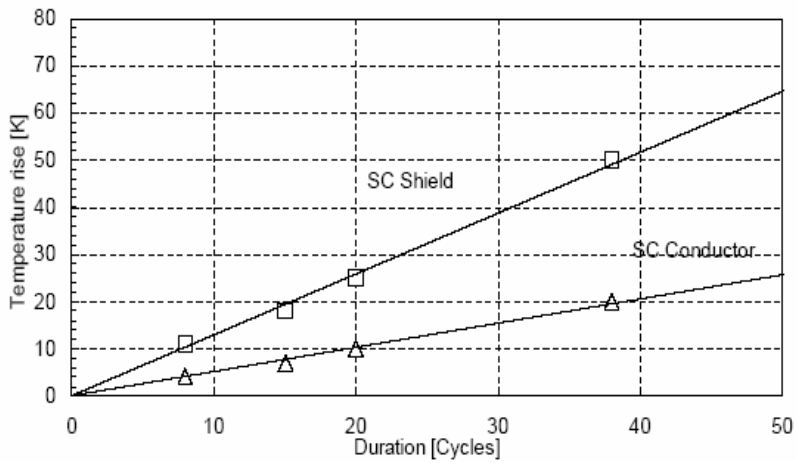
Through Fault Conditions

- 9 kA for 25 cycles (417 ms)
- 2.7 kA for 55 cycles (917 ms)

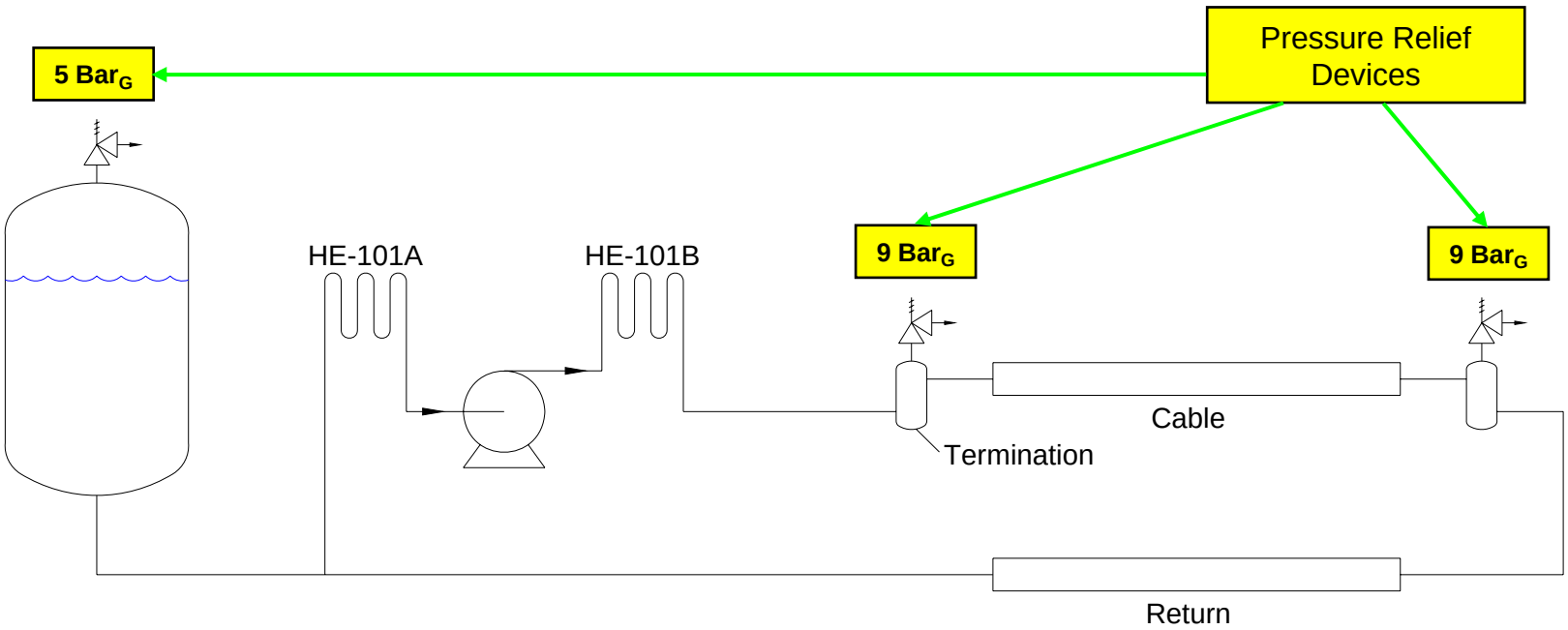


Test Results

- No damage to the HTS tapes or electrical insulation
- No degradation of critical current
- Temperature Rise
  - 8 cycles
    - 4 K Conductor layer
    - 11 K Shield layer
  - 38 cycles
    - 20 K Conductor layer
    - 50 K Shield layer
  - ΔT very small for through fault conditions



Over-Pressure Protection



Fault Current Condition: Pressure Implications

Second contingency fault of 23kA for 38 cycles

Liquid expansion during fault condition: 90 liters (max 21 liter/sec)

Maximum potential pressure rise: 57 bar

- Pressure reliefs on terminations (9 barg) and liquid nitrogen tank (5 barg)
- Pressure rise in cable will be greatest at furthest distance from terminations
  - Bounded by pressure relief setting at termination and maximum potential pressure rise

Cryostat burst pressure

- 120 bar (room temperature)
- 260-270 bar (at operating temperature)
  - Factor of Safety – Greater than 4