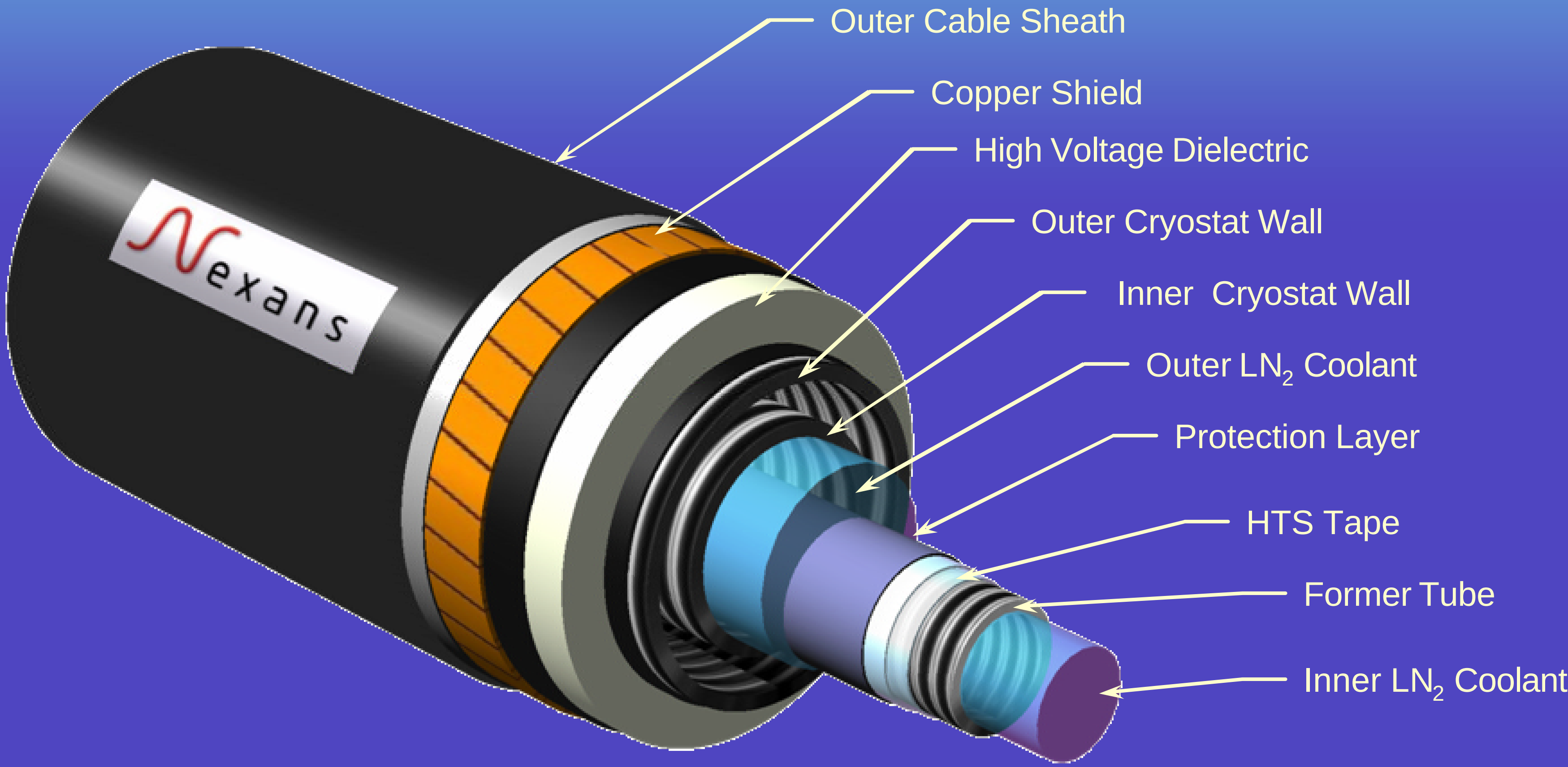
High Temperature Superconducting Cable for Power Transmission Applications

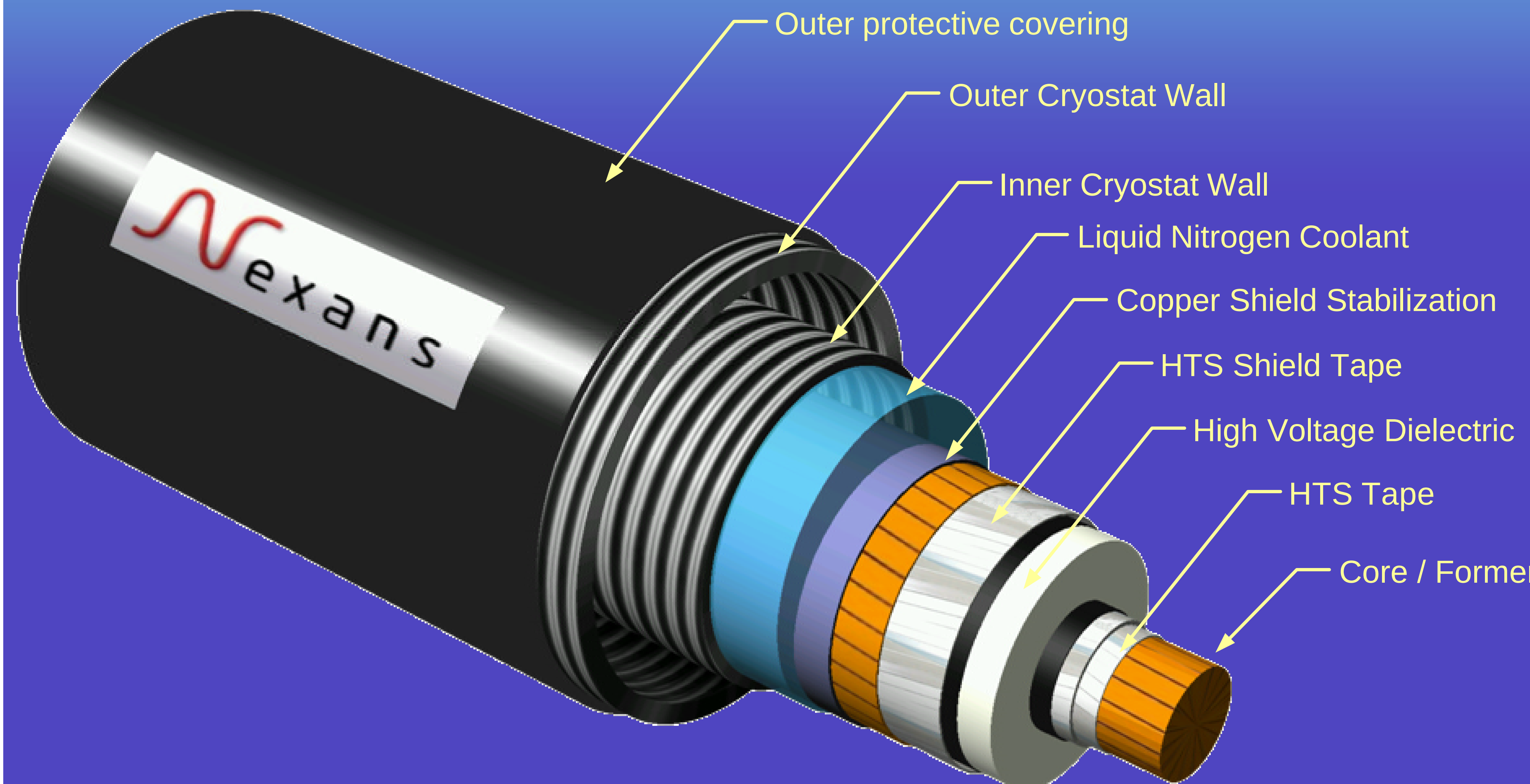
Contents

- Design possibilities of superconducting power cables
  - Warm and Cold dielectric concepts
  - Benefits and drawbacks
  - Grid operation of VLI (Very Low Impedance) cables
- Power cable development considerations
  - Design drivers and goals
  - Trade offs
- Projects
  - Major projects for power cables
  - Economical benefits

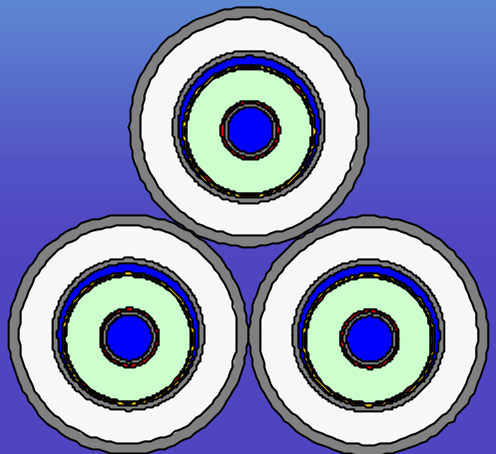
Warm Dielectric Cable Concept



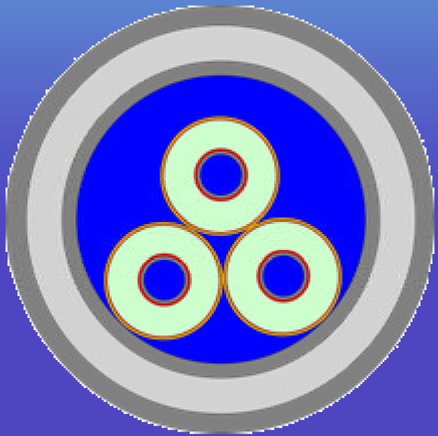
Cold Dielectric Cable Concept



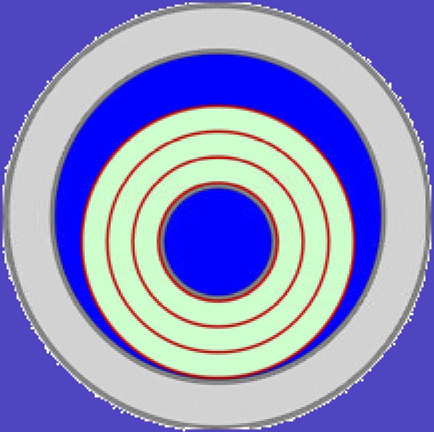
Cold Dielectric Alternatives



3 independent phases

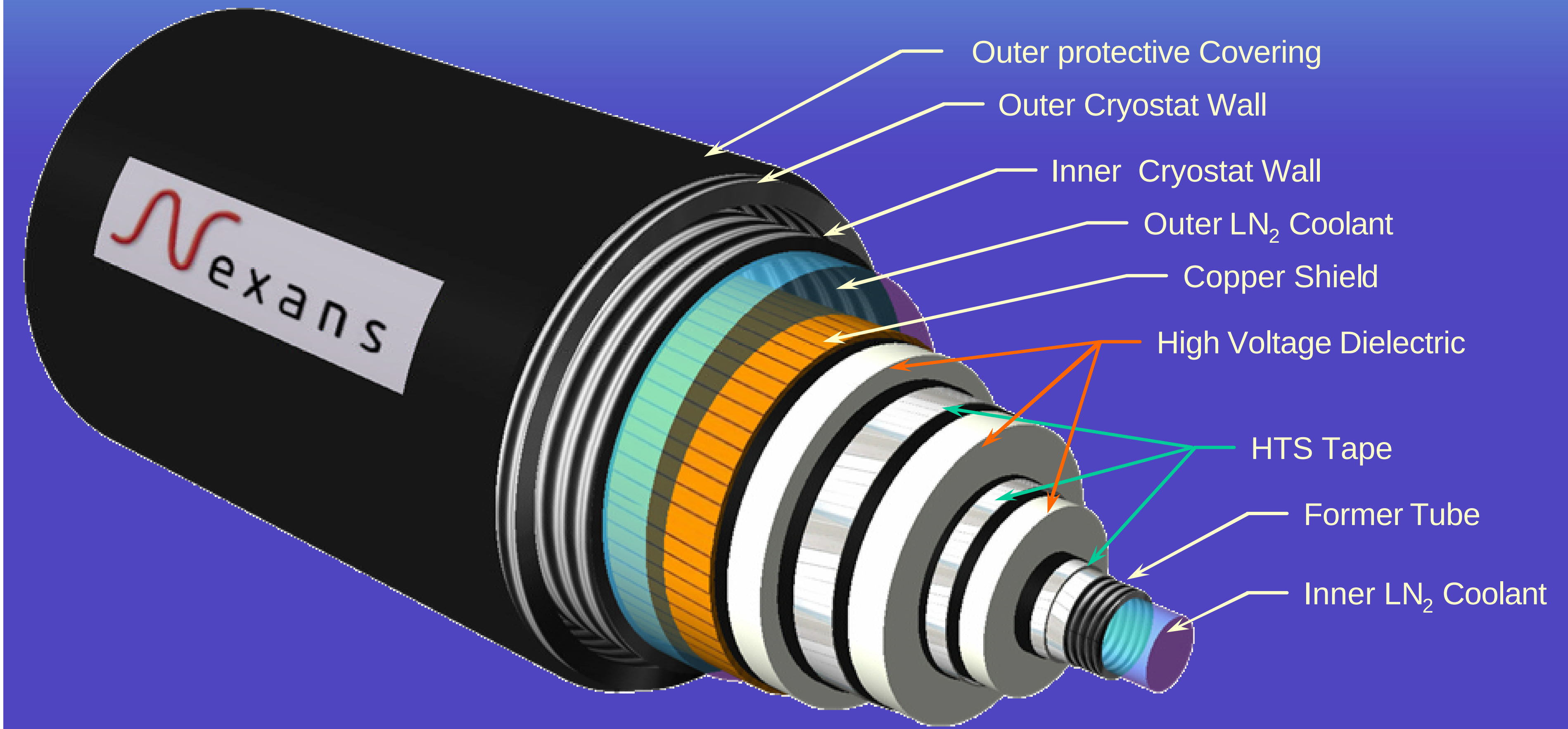


Three phases in one cryogenic envelope

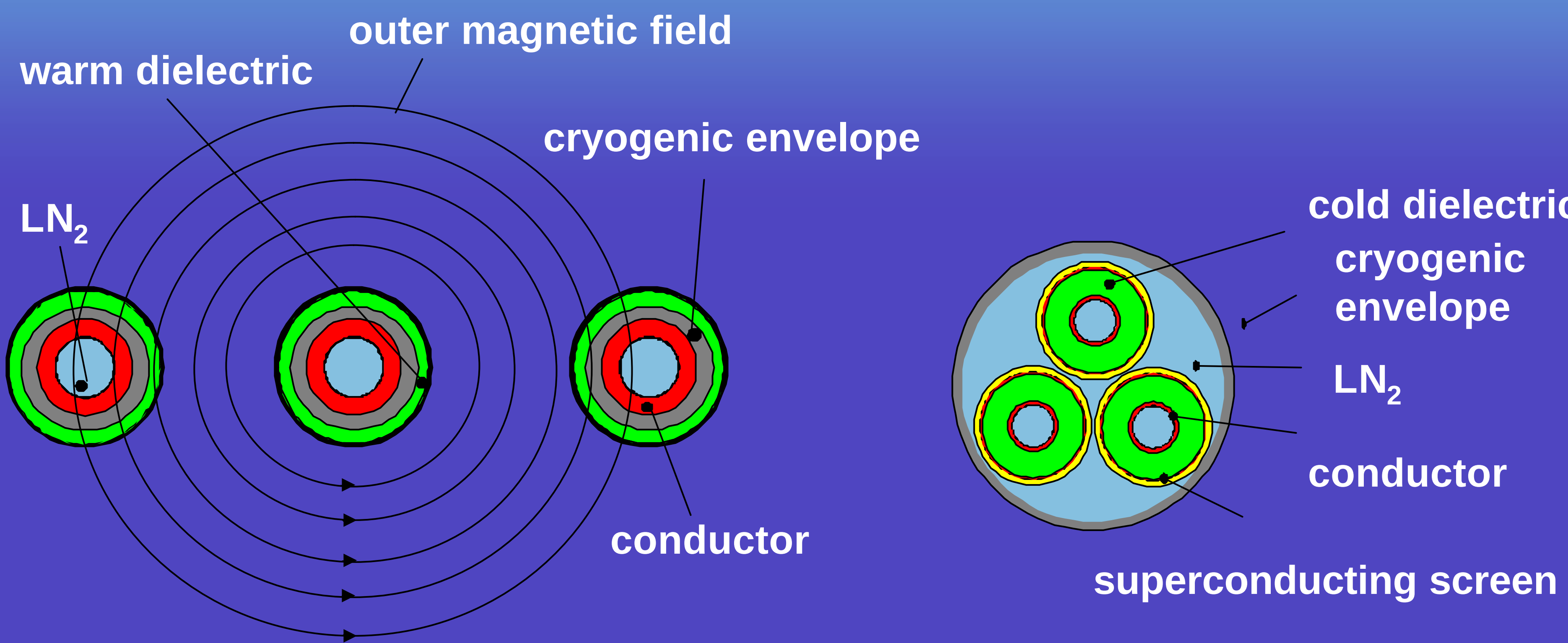


Concentric phases / Triaxial

Concentric (Triaxial) Concept



Comparison Cold and Warm Dielectric



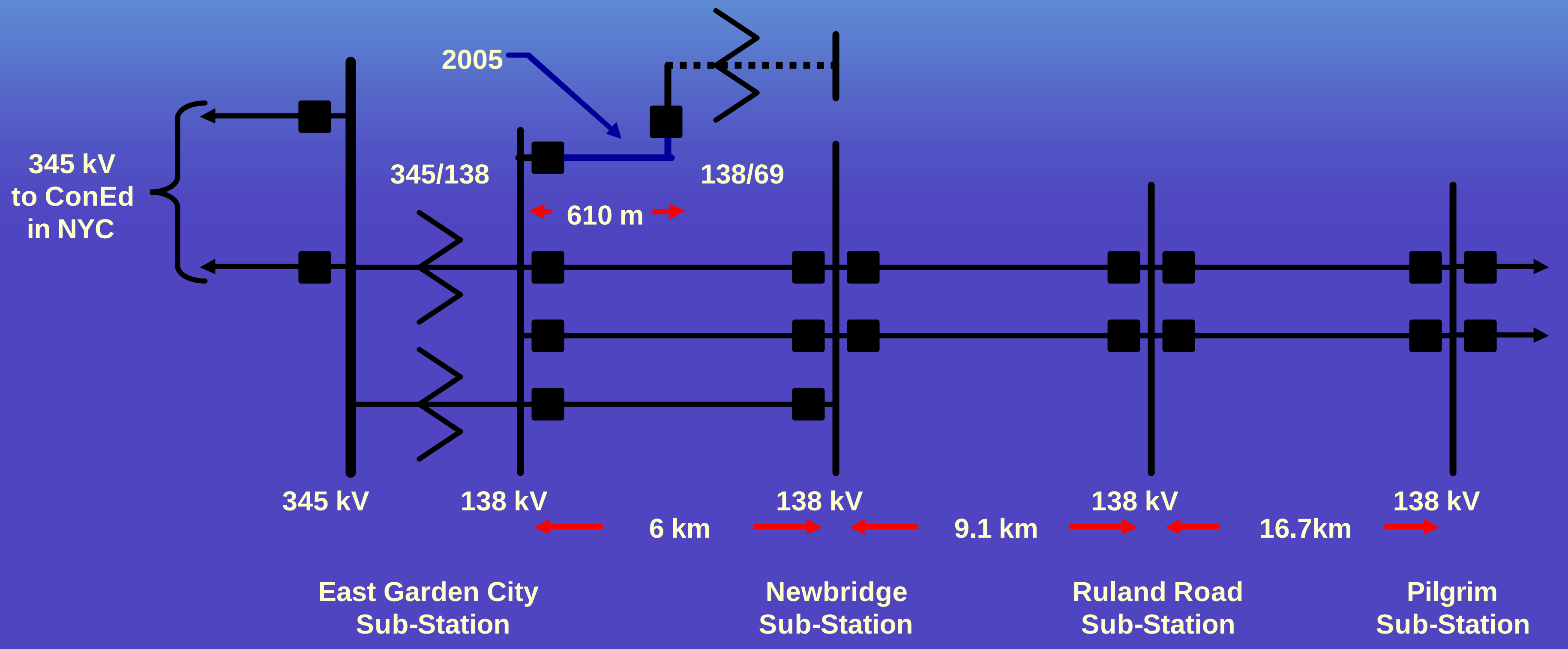
concept 1:
warm dielectric

concept 2:
cold dielectric

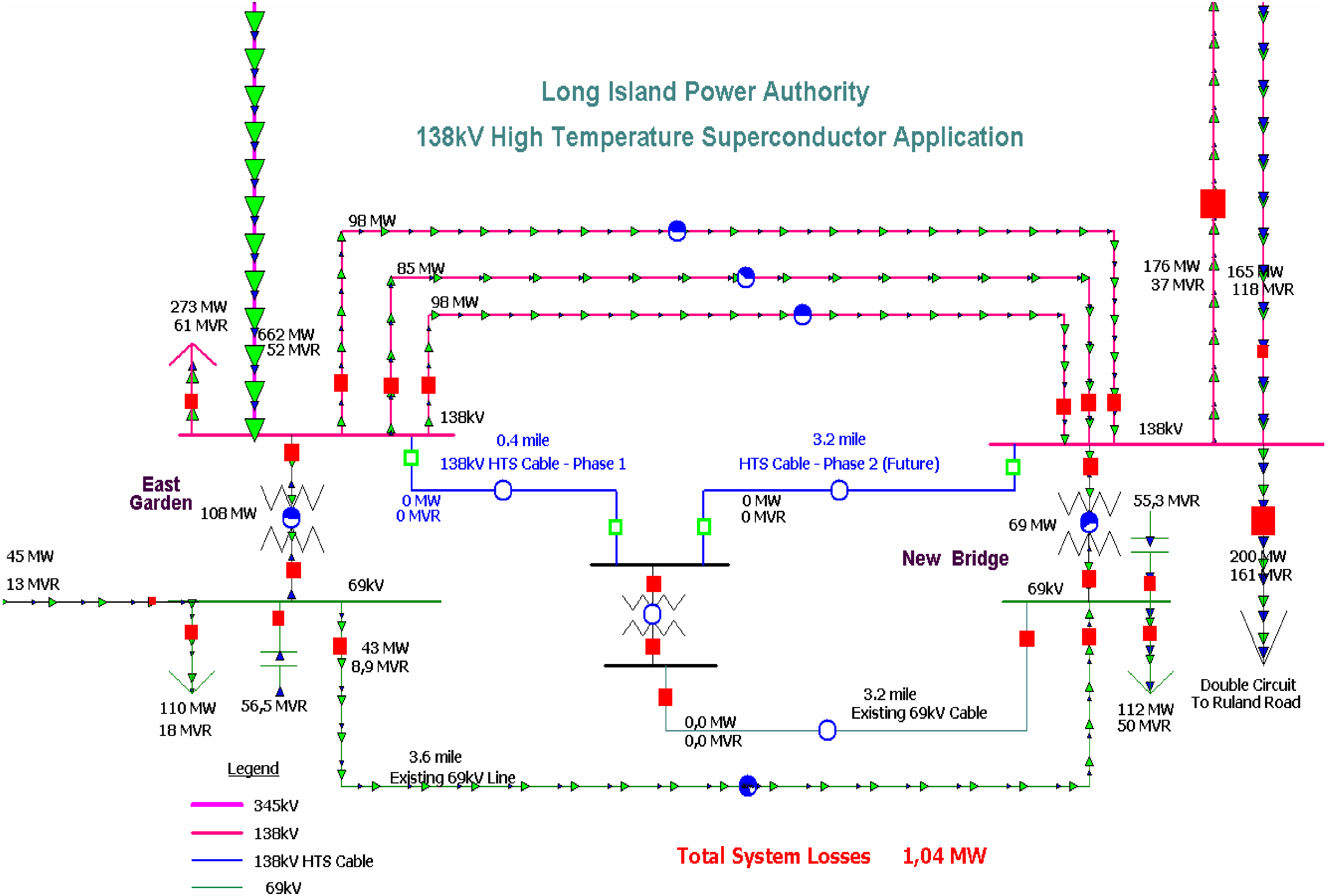
Design Comparison

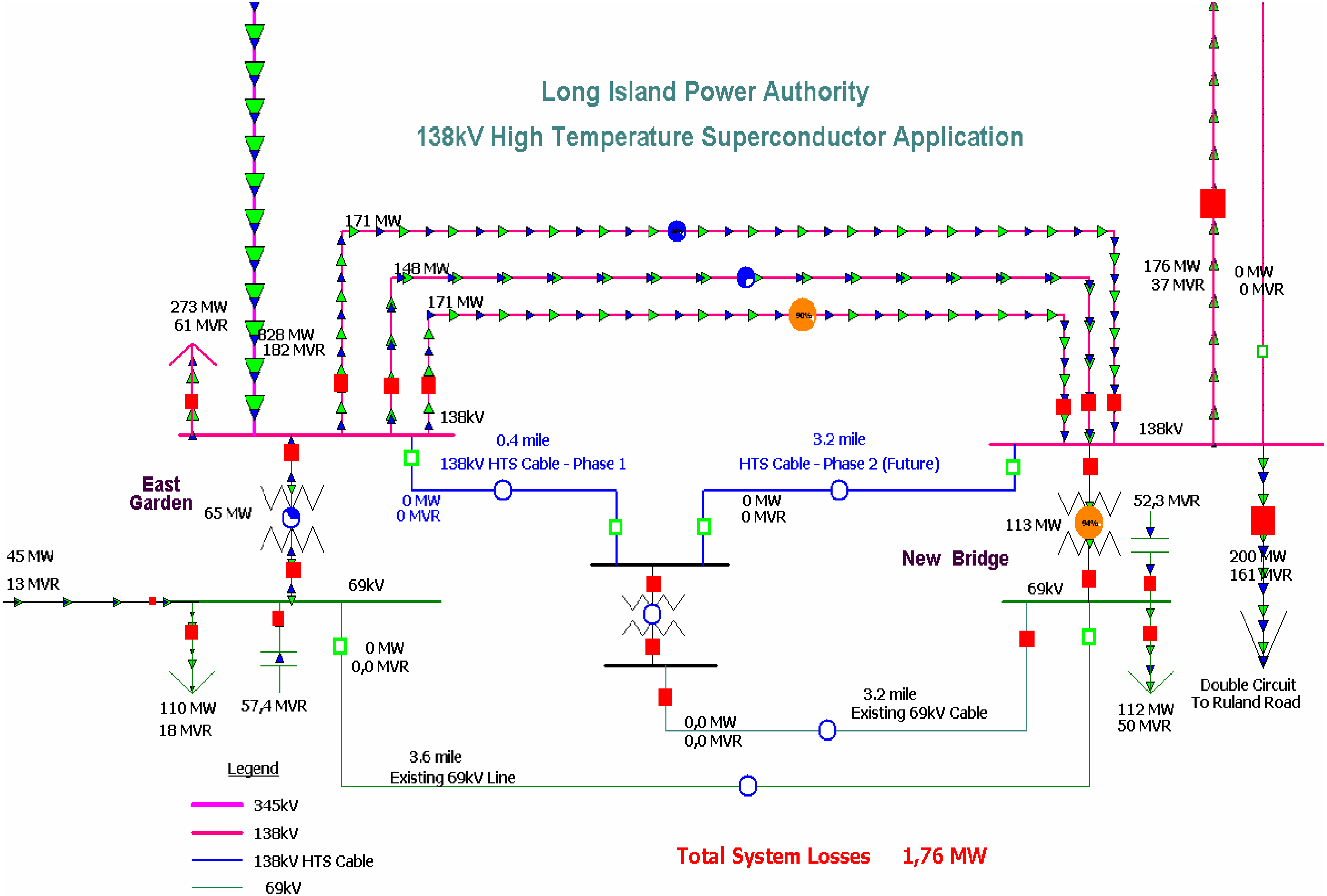
	warm dielectric	**cold dielectric**	**coaxial**
outer magn. field	yes	no	no
AC-loss	high	low	low
transport current	high	very high	very high
dielectric	conventional	new type (cold)	new type (cold)
cryostat	at high voltage (difficult to access)	at ground potential (easy access)	at ground potential (easy access)
HTS-tape amount	low	high (screen)	low
accessories	almost conventional	new design required	very difficult at high voltage levels
cable inductance	as conventional cables	**very low**	very low

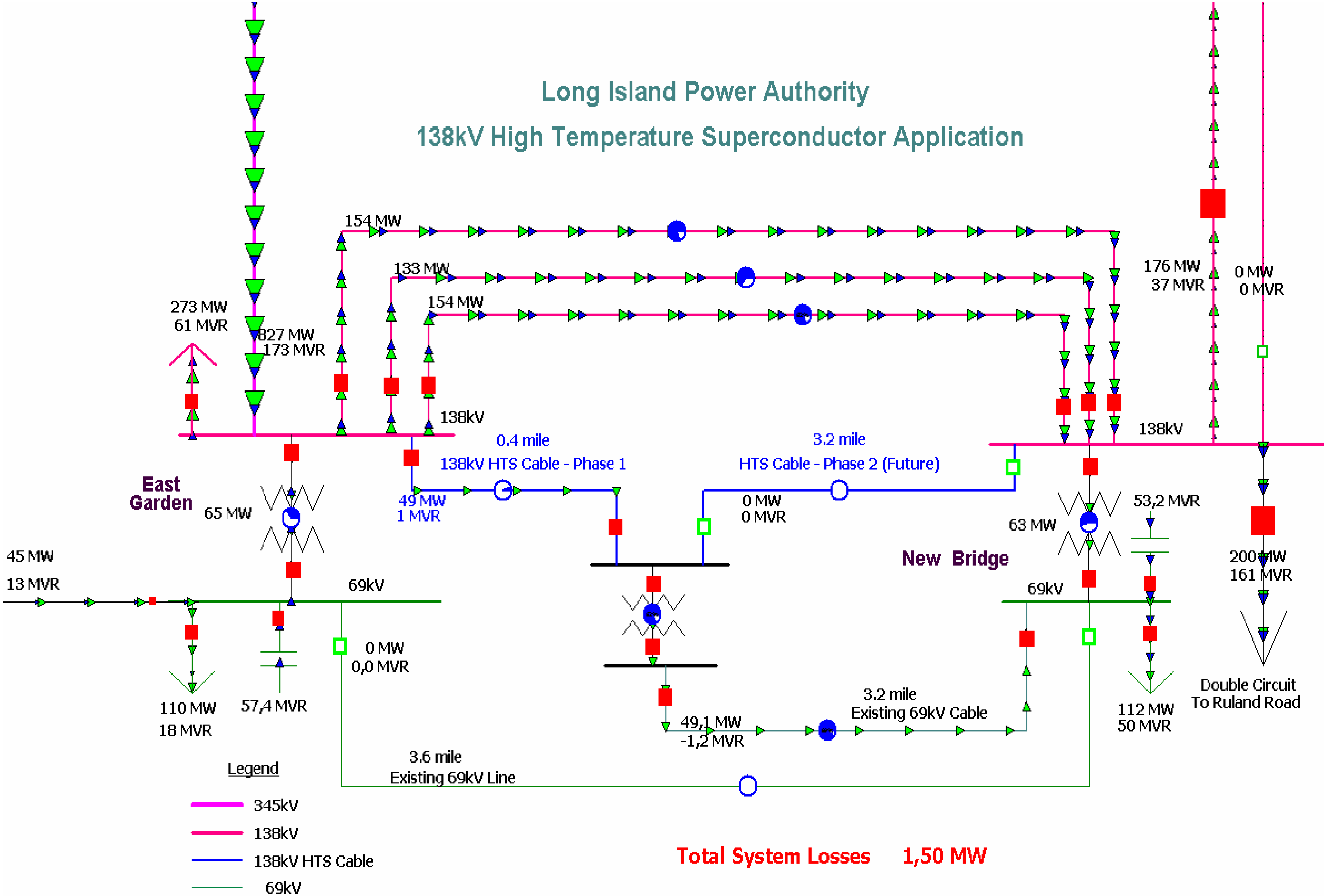
LIPA 138 kV HTS Cable Project – Phase 1



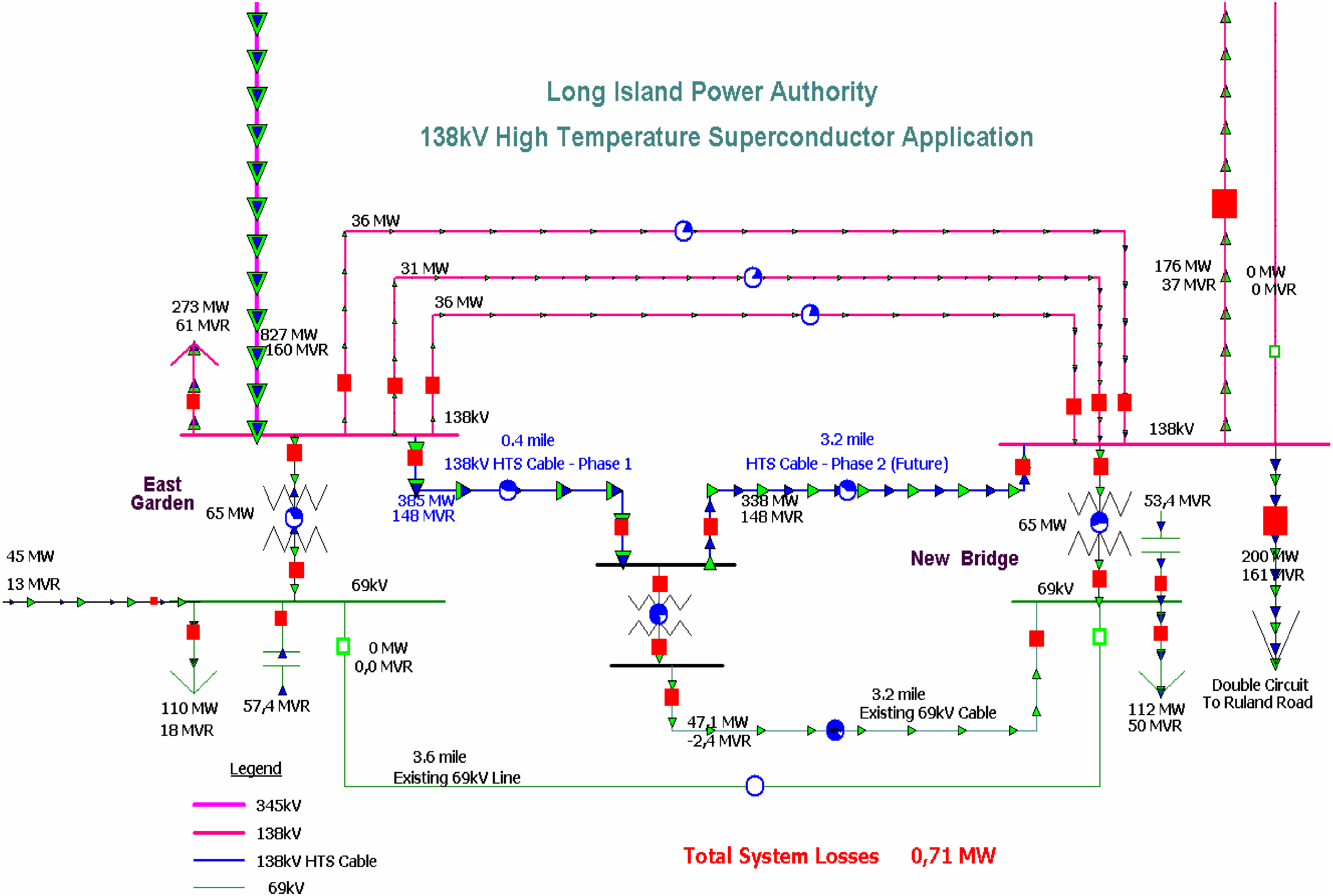
DOE Co-Funded – 610m 138kV 2400A HTS Cable


Long Island Power Authority
138kV High Temperature Superconductor Application
98 MW
85 MW
98 MW
273 MW
61 MVR
662 MW
52 MVR
138kV
176 MW
37 MVR
165 MW
118 MVR
138kV
0.4 mile
138kV HTS Cable - Phase 1
3.2 mile
HTS Cable - Phase 2 (Future)
East Garden
108 MW
0 MW
0 MVR
0 MW
0 MVR
55,3 MVR
69 MW
New Bridge
200 MW
161 MVR
45 MW
13 MVR
69kV
69kV
43 MW
8,9 MVR
110 MW
18 MVR
56,5 MVR
3.2 mile
Existing 69kV Cable
0,0 MW
0,0 MVR
112 MW
50 MVR
Double Circuit
To Ruland Road
3.6 mile
Existing 69kV Line
Legend
345kV
138kV
138kV HTS Cable
69kV
Total System Losses 1,04 MW


Long Island Power Authority
138kV High Temperature Superconductor Application
171 MW
148 MW
171 MW
273 MW
61 MVR
828 MW
182 MVR
138kV
0.4 mile
138kV HTS Cable - Phase 1
3.2 mile
HTS Cable - Phase 2 (Future)
176 MW
37 MVR
0 MW
0 MVR
138kV
East Garden
65 MW
0 MW
0 MVR
0 MW
0 MVR
52,3 MVR
113 MW
New Bridge
200 MW
161 MVR
45 MW
13 MVR
69kV
69kV
0 MW
0,0 MVR
110 MW
18 MVR
57,4 MVR
3.2 mile
Existing 69kV Cable
0,0 MW
0,0 MVR
112 MW
50 MVR
Double Circuit
To Ruland Road
3.6 mile
Existing 69kV Line
Legend
345kV
138kV
138kV HTS Cable
69kV
Total System Losses 1,76 MW



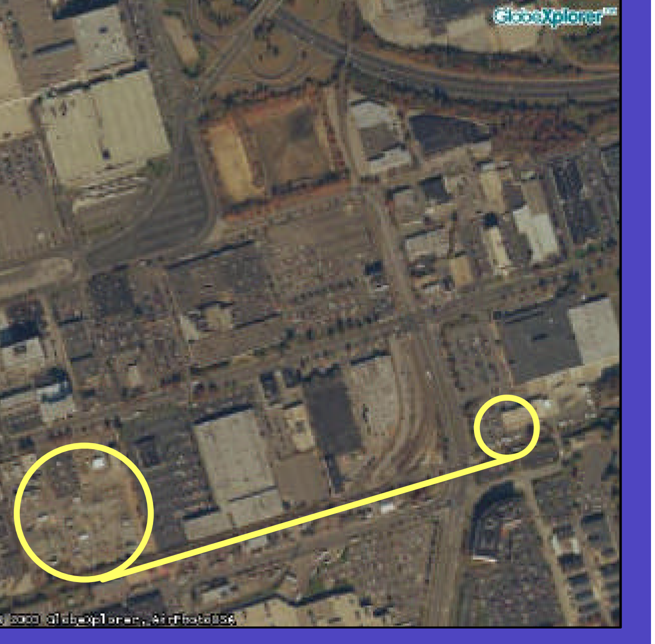
Long Island Power Authority
138kV High Temperature Superconductor Application
154 MW
133 MW
154 MW
273 MW
61 MVR
827 MW
173 MVR
138kV
0.4 mile
138kV HTS Cable - Phase 1
3.2 mile
HTS Cable - Phase 2 (Future)
176 MW
37 MVR
0 MW
0 MVR
138kV
East
Garden
65 MW
49 MW
1 MVR
0 MW
0 MVR
53,2 MVR
63 MW
New Bridge
200 MW
161 MVR
45 MW
13 MVR
69kV
69kV
0 MW
0,0 MVR
110 MW
18 MVR
57,4 MVR
3.2 mile
Existing 69kV Cable
49,1 MW
-1,2 MVR
112 MW
50 MVR
Double Circuit
To Ruland Road
3.6 mile
Existing 69kV Line
Legend
345kV
138kV
138kV HTS Cable
69kV
Total System Losses 1,50 MW



Long Island Power Authority
138kV High Temperature Superconductor Application
36 MW
31 MW
36 MW
273 MW
61 MVR
827 MW
160 MVR
176 MW
37 MVR
0 MW
0 MVR
138kV
138kV
0.4 mile
138kV HTS Cable - Phase 1
3.2 mile
HTS Cable - Phase 2 (Future)
East
Garden
65 MW
385 MW
148 MVR
338 MW
148 MVR
65 MW
53,4 MVR
New Bridge
45 MW
13 MVR
69kV
69kV
200 MW
161 MVR
0 MW
0,0 MVR
110 MW
18 MVR
57,4 MVR
3.2 mile
Existing 69kV Cable
47,1 MW
-2,4 MVR
112 MW
50 MVR
Double Circuit
To Ruland Road
3.6 mile
Existing 69kV Line
Legend
345kV
138kV
138kV HTS Cable
69kV
Total System Losses 0,71 MW

Nexans Cable design drivers - LIPA Project Fact Sheet

- Long Island Power Authority – east garden city substation
- Electrical operating characteristics
  - Operating voltage/current – 138kV/2400A ~ 574MVA
  - Design fault current – 69,000A @ 15 line cycles (250ms)
- Physical characteristics
  - Installation – one 12” pipe (11,7”/ 297mm ID)
  - Length – app. 610m
  - HTS tape length – 128km
  - Cold dielectric design with three individual cryogenic envelopes
- Hardware deliverables
  - Three ~ 610m long phase conductors
  - Six 161kV outdoor terminations
  - One 10kW refrigeration system at one end
  - Single joint to be tested in the lab

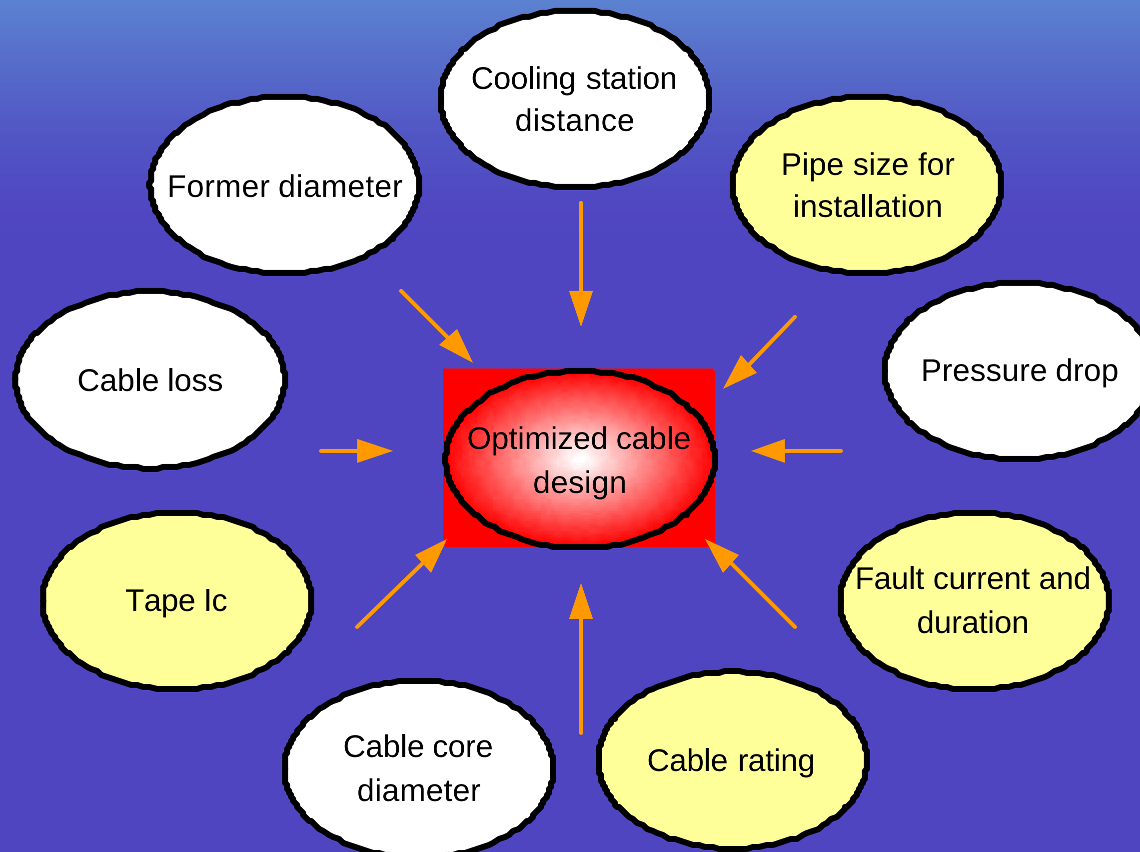


Worlds First Installation of a Transmission Voltage HTS Cable in the World

Cable Design Aspects

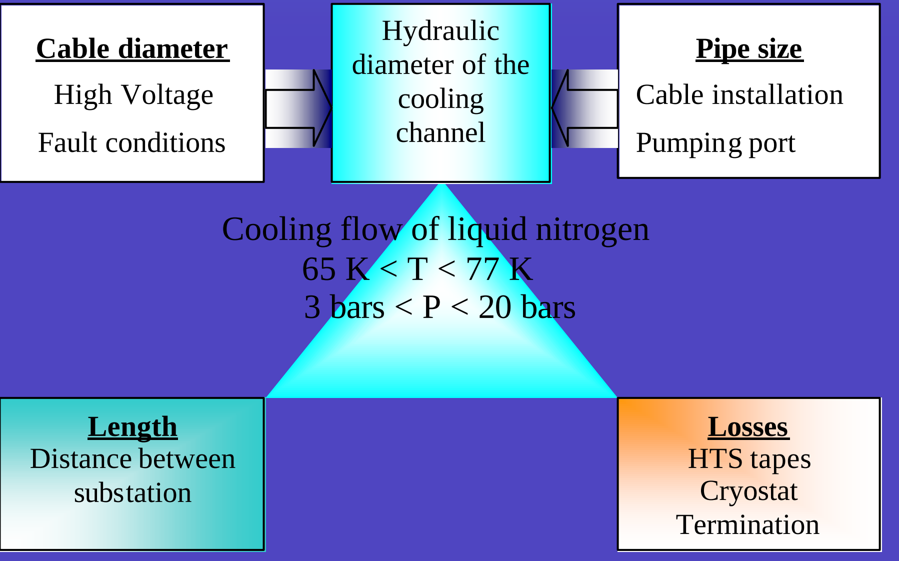
Various aspects of cable design need to be traded to reach the optimized design point during

- normal operation as well as
- fault current operation

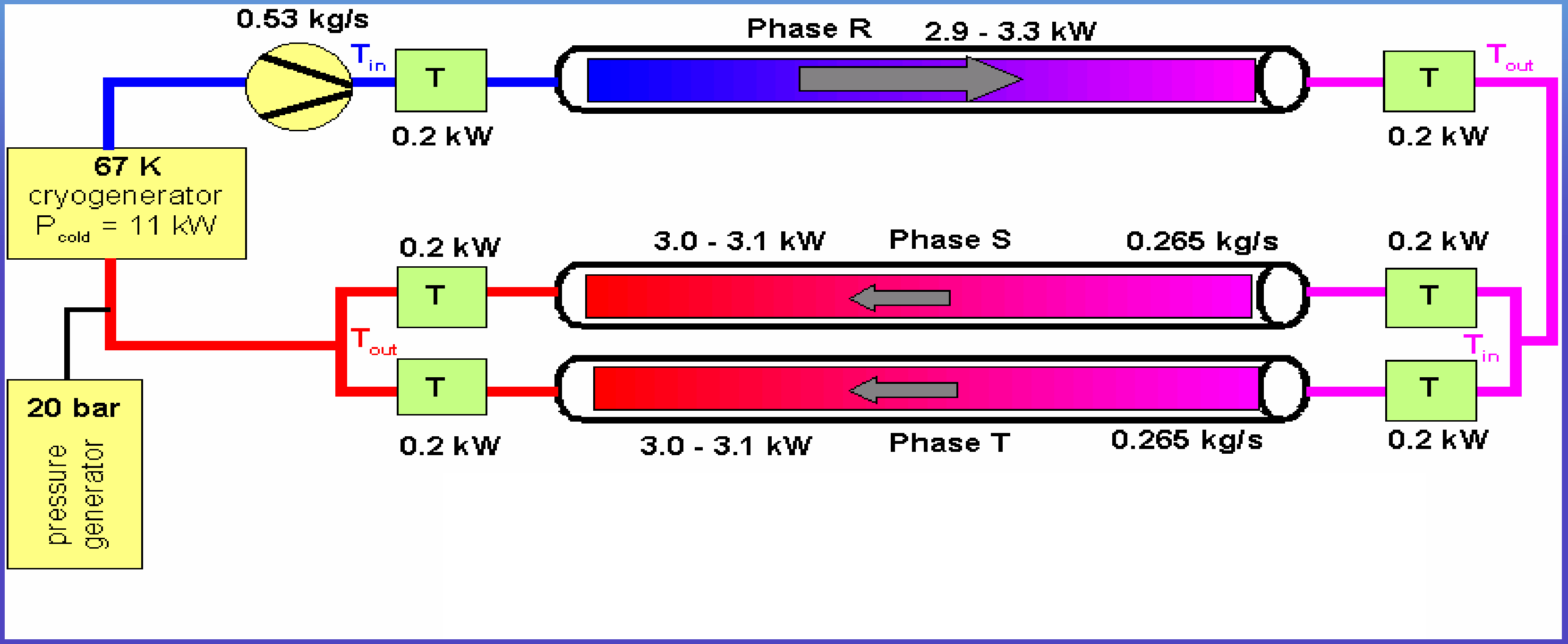


Technical Issue Cable Cooling

- Goal: cable temperature and pressure within specified range
- Trade off:
  - Hydraulic diameter determined by
    - Cable diameter
    - Pipe size
  - Distance between cooling stations (Length)
  - Cable losses determined by
    - HTS-tapes
    - Cryostat
    - terminations



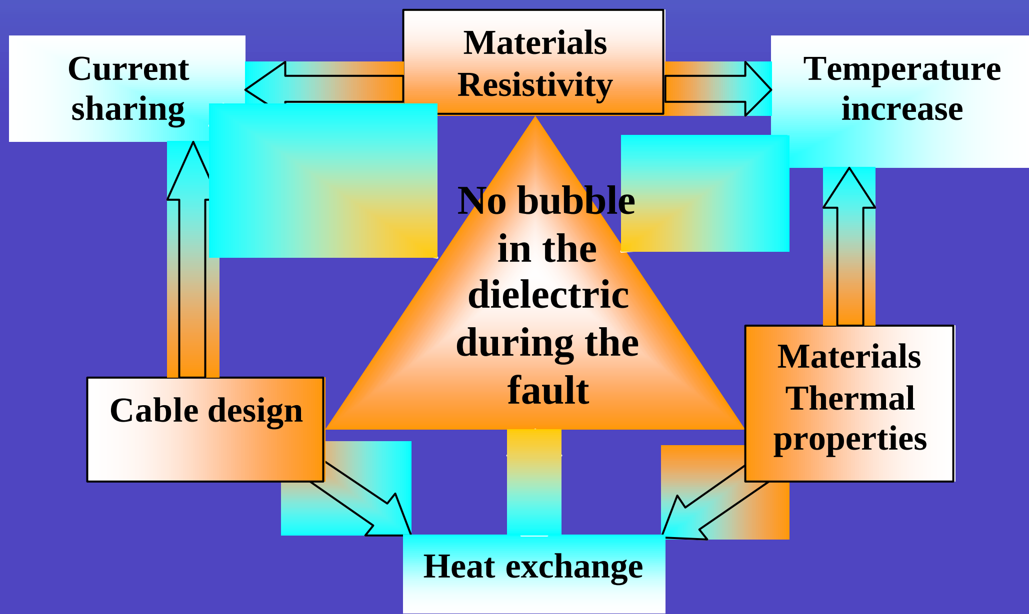
Cable Cooling Example LIPA Project



- Flow of LN_2 in single phase and back in two phases
- Effect of second pump and / or cooling station analyzed

Technical Issue Fault Current Operation

- Goal: no bubble formation during fault event to avoid dielectric breakdown
- Trade off:
  - Choice of materials
    - Resistivity
    - Thermal conductivity
    - Thermal capacity
  - Cable design
    - Current sharing properties
    - Heat exchange properties



Main HTS Cable Projects

Location	Main partners	Utilities	Cable			Use	Status
			Dielectric type	Number of phases	Characterictics		
U. S. A.	Pirelli / ASC		Warm	1	50 m / 115 kV / 2 kA	Demonstrator	Complete
Berlin	Pirelli (ex-Siemens) [1]		Cold	1	50 m / 110 kV / 2.1 kA	Demonstrator	Stopped
Italy	Pirelli / ASC	ENEL / Edison	Cold	1	30 m / 132 kV / 3 kA	Demonstrator	?
Detroit	Pirelli / ASC	Detroit Edison	Warm	3	120 m / 24 kV / 2.4 kA	Network	Cryostat Issue
Paris	Pirelli / ASC	EDF	Cold	1	50 m / 225 kV / 2.6 kA	Demonstrator	Complete
Tokyo	SEI	TEPCO	Cold		30 m / 66 kV / 1 kA	Demonstrator	Complete
Tokyo	SEI	TEPCO	Cold	3	100 m / 66 kV / 1 kA	Demonstrator	Complete
Albany (NY)	SEI / IGC	Niagara Mohawk	Cold	3	350 m / 34.5 kV / 0.8 kA	Network	Ongoing
Japan	Furukawa		Cold	1	500 m / 77 kV / 1 kA	Demonstrator	Ongoing
Carrollton (Ga)	Southwire / IGC	Southern California Edison	Cold	3 (rigid)	30 m / 12.5 kV / 1.25 kA	Plant supply	Complete
Copenhagen	NKT / NST [1]	Elkraft	Warm	3	30 m / 36 kV / 2 kA	Network	Complete
Columbus (Ohio)	Southwire	American Electric Power	Cold / (Tri)	3	300 m / 12.5 kV / 2.5 kA	Network	Ongoing
Kunming (China)	Innopower / Innova [2]	Yunnan Electric Power	Warm	3	30 m / 35 kV / 2 kA	Network	Ongoing
Long Island (NY)	ASC / Nexans	Long Island Power Authority	Cold	3	610 m / 138 kV / 2.4 kA	Network	Ongoing

[1] Cryogenic envelope supplied by Nexans.

[2] Cryogenic envelope and dielectric supplied by Nexans.

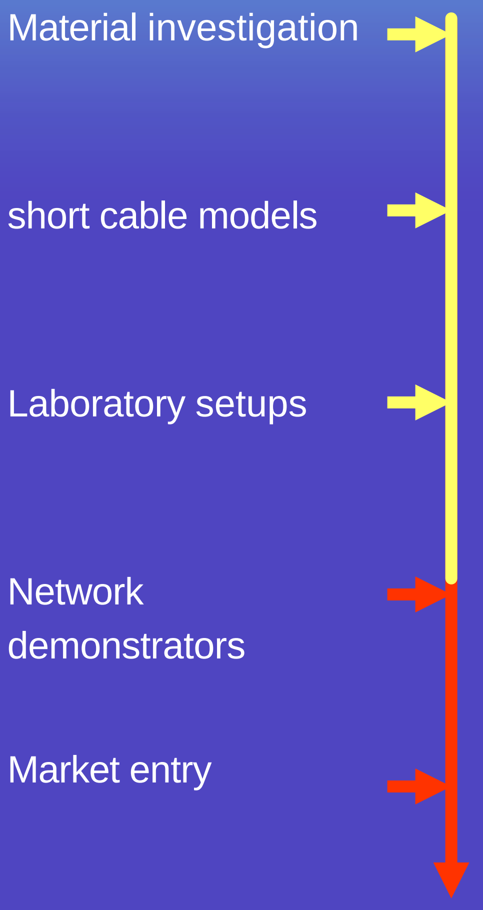
Economical Benefits

- Shorter lengths of insertion – no tying back to existing EHV backbone system (VLI)
- Lower voltage – benefit through cheaper auxiliary equipment
- Greater controlability with use of Phase Angle Regulator – control of power flow (VLI)
- Expanded generator siting options because of lower voltage drop (VLI)
- Reduced electrical losses

Superconducting power cables (particularly VLI) do not have to be cost competitive on a stand alone basis. Economical benefits of the „grid solution“ are of interest

Conclusion

- Different cable design concepts with their benefits and drawbacks are well understood
- Very low impedance characteristic of cold dielectric cables is of big interest to utilities
- Cable design tradeoffs driven by the specifications are to be managed
- Current ongoing projects enter the step from laboratory setups to grid installations
- The LIPA cable project is the first one on transmission voltage level so far



Thank you for your attention