SYMPOSIUM ON HTS CABLE APPLICATIONS
June 24, 2004 Kunming

Installation and Trial Operation of 35kV/121MVA HTS ac Power Cable

Ying Xin, Innopower Superconductor Cable

Key Participants of the Project

- Innopower
- Yunnan Electric Power Group
- Institute of Plasma Physics, Academia Sinica
- Tsinghua University
- InnoST
- Vacree
- Shanghai Cable Works
- Huazhong University of Science and Technology

Acknowledgement

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- China's Ministry of Science, Hi-tech Development Plan (863 plan)
- Beijing Municipal Government
- Yunnan Provincial Government

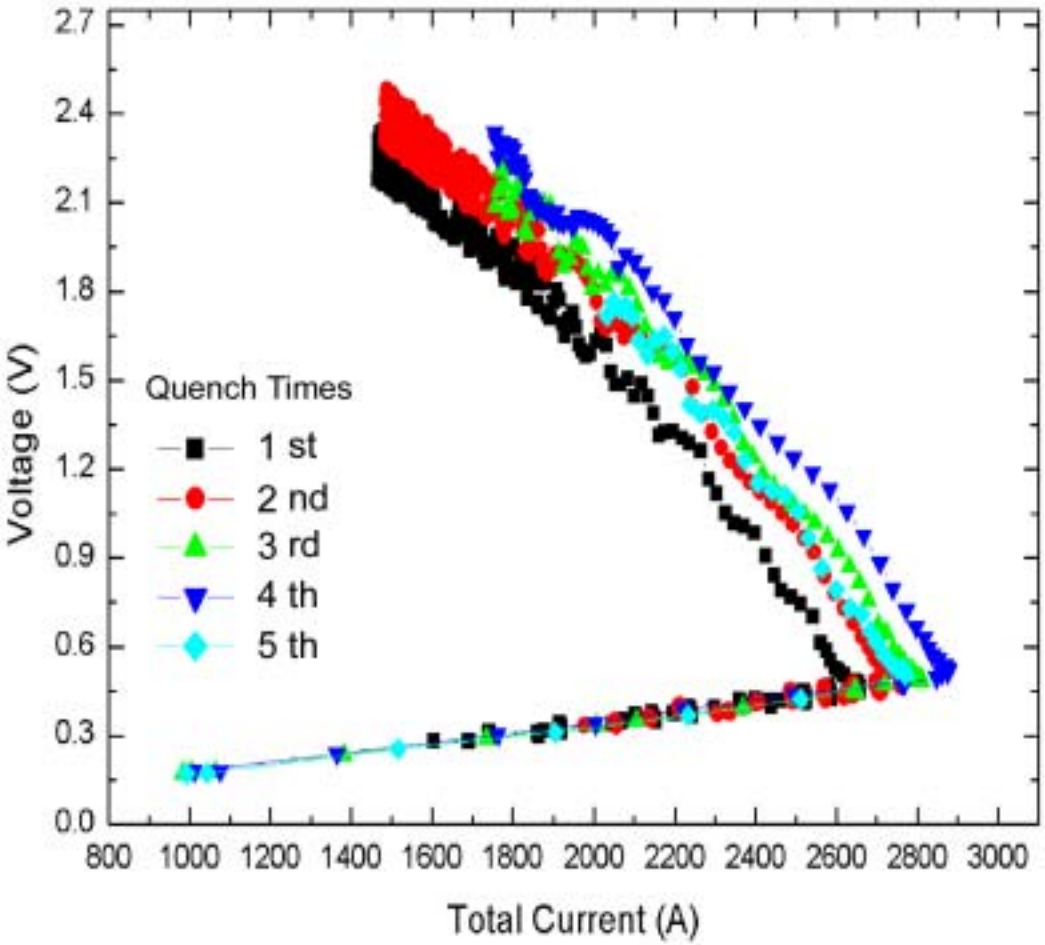
System Parameters(final):

Subject	Specification	Subject	Specification
Mode of Cable	Three single phase, Outdoor	**Operation Altitude**	1,900m
Length	33.5m (flange to flange)	**Outer Diameter of Cable**	112mm
Rated Voltage	35kV	**Cooling Fluid**	LN_2
Rated Current	2kA(rms)	**Cooling Capacity**	2,000W at 75K
Shortcut Current	20kA/2S	**Inlet Temperature**	70~72K
Dielectric Type	Warm	**Outlet Temperature**	74~76K
Installation Bending Angle	90^o	**Reliability Requirement**	>20000 hours

Project Chronicle

Subject	2002	2003			2004
	8-12	1-4	5-8	9-12	1-4
Design of cable conductor					
Design and tests of short cable model					
Optimization of cable design and fabrication techniques					
Fabrication of cable					
Design and tests of terminations					
Fabrication of terminations					
Design of cooling system					
Integration of cooling system					
Installation and field trial of the system					

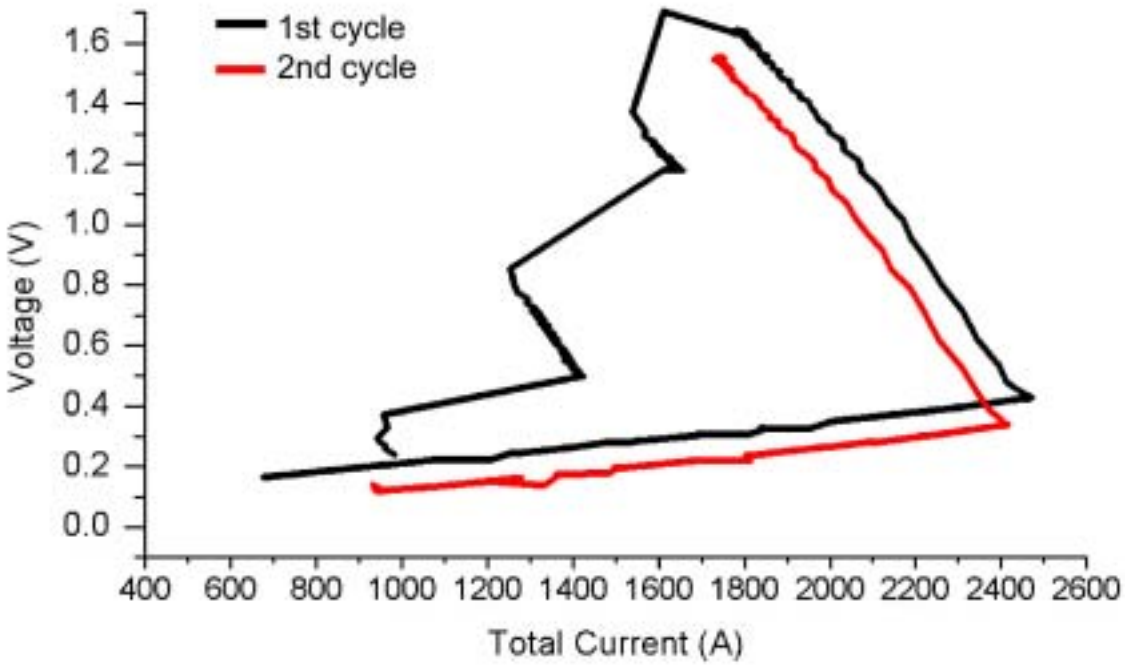
AC Current Carrying Capacity of a Cable vs Ic of tapes



- A 2 layer, 3m cable consists of 37 (18，19) BSCCO tapes. The Ic's of tapes are 70~80A.
- The start ac effective critical current of the cable was 2642 A, the max. was 2897 A.
- The results indict:

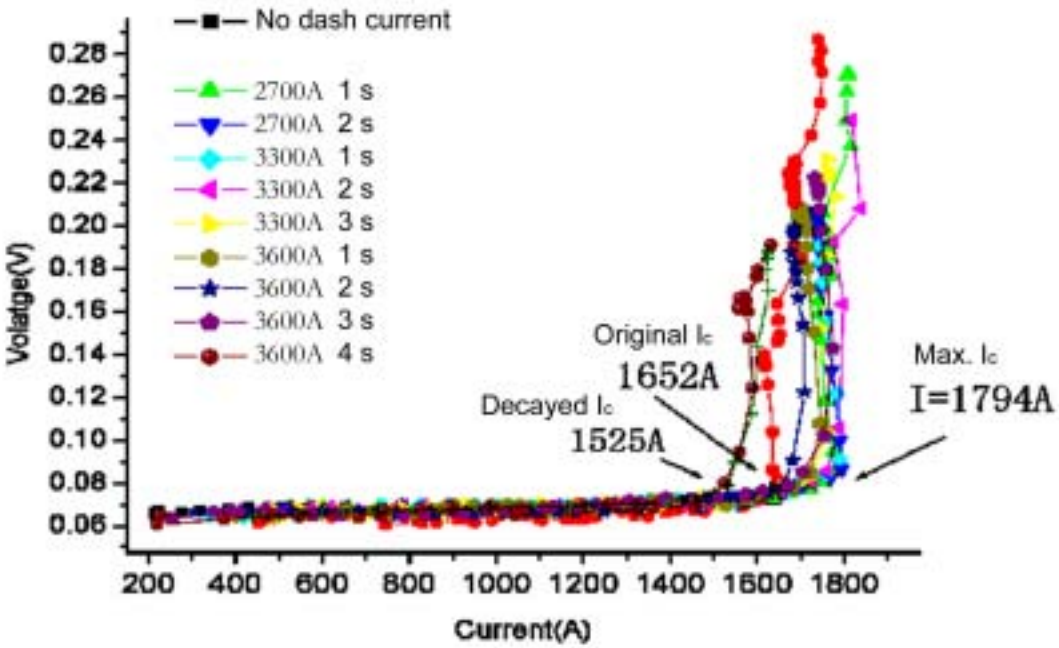
1. The critical current of the cable does not decline after a quench;
2. The effective ac critical current of the cable > $\Sigma Ic/1.141$.

Superconductivity Restoration Characteristic



- A 2 layer, 3 m cable consists of 40 (20，20) BSCCO tapes.
- The effective critical current of the cable was 2500 A.
- After superconductivity quenched, V↑,I↓ as the transformer setting unchanged.
- After reducing the output of the transformer, V ↓, saw small I↑.
- When I < 900 A, the cable restored superconductivity, and a new cycle began.

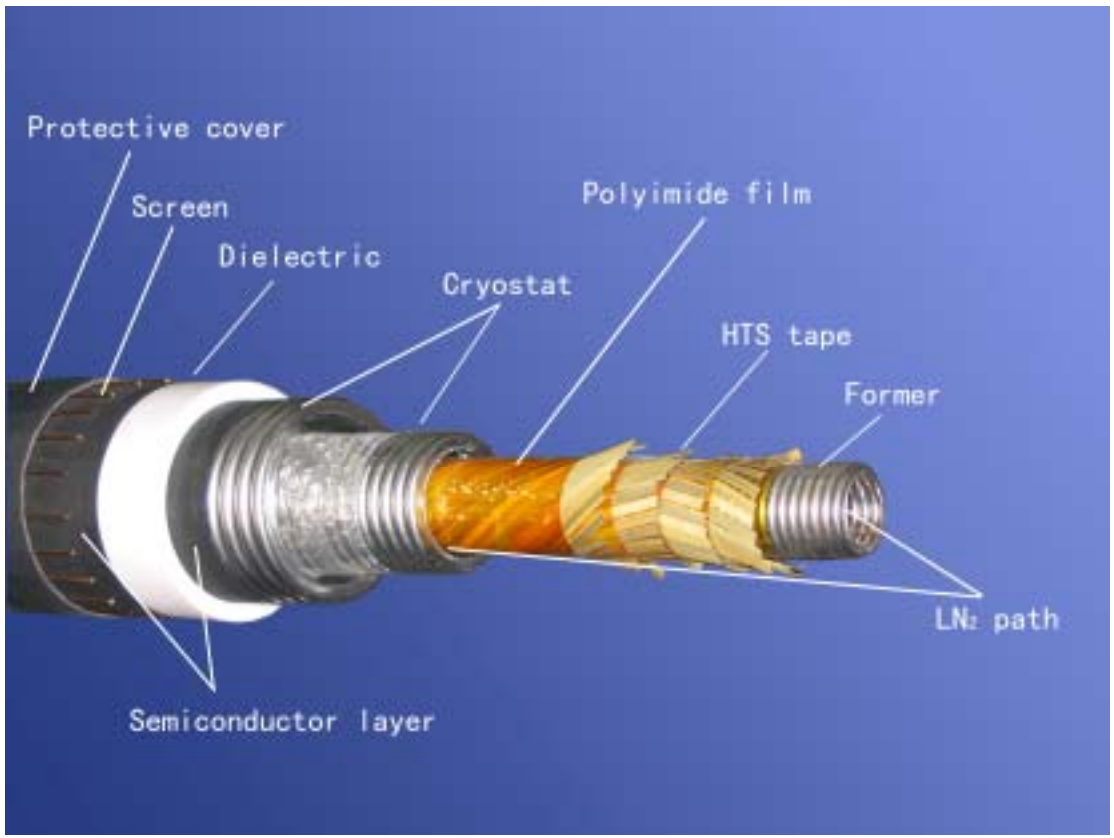
Large Current Exercise Test for Cable Shortcut Current Capacity



- A 1 layer, 1 m cable consists of 18 BSCCO tapes.
- AC current of 2700-3600A was applied to the sample for a time period of 1-4S.
- Each time after applying the current, the I-V curve was measured.
- The I-V curves were compared.
- The results indict:

1. There is no meaningful change in I-V curve in the first 8 tests.
2. After applying 3600A for 4S, the critical current of the cable was decreased by 8%.

33.5 m Cable



Former ID/OD(with Braiding):
30/35 mm
Layers of HTS tape:
4
Number of HTS tape:
90(21,24,24,21)
Ic of HTS tape:
60-80 A (77K, self field)
ID/OD of cryostat:
43/70 mm
Dielectric material:
XLPE
Thickness of dielectric:
11.9mm
Overall linear specific weight:
9.2kg/m

33.5 m Cable

Electric Insulation

Factory sample test:

Partial discharge(ac 39 kV) ***<1 pc***

AC withstand voltage ***104 kV, 4h, passed***

Impulse voltage ***250 kV, 10+, 10-, passed***

Field AC withstand voltage(with terminations):

55 kV, 5 min, passed

33.5 m Cable

Delectric

Resistance:
Phase A > ***100000 MΩ***
Phase B > ***100000 MΩ***
Phase C > ***100000 MΩ***

Capacitance:
Phase A ***15060 pF***
Phase B ***15060 pF***
Phase C ***15080 pF***

Loss:
Phase A ***0.024%***
Phase B ***0.023%***
Phase C ***0.024%***

Protective layer resistance:
Phase A ***52300 MΩ***
Phase B ***52400 MΩ***
Phase C ***47600 MΩ***

33.5 m Cable

DC Resistance

Cable + terminations

at 300K:
Phase A ***10.6 mΩ***
Phase B ***10.1 mΩ***
Phase C ***10.2 mΩ***

at 74K:
Phase A ***85 μΩ***
Phase B ***84 μΩ***
Phase C ***84 μΩ***

33.5 m Cable

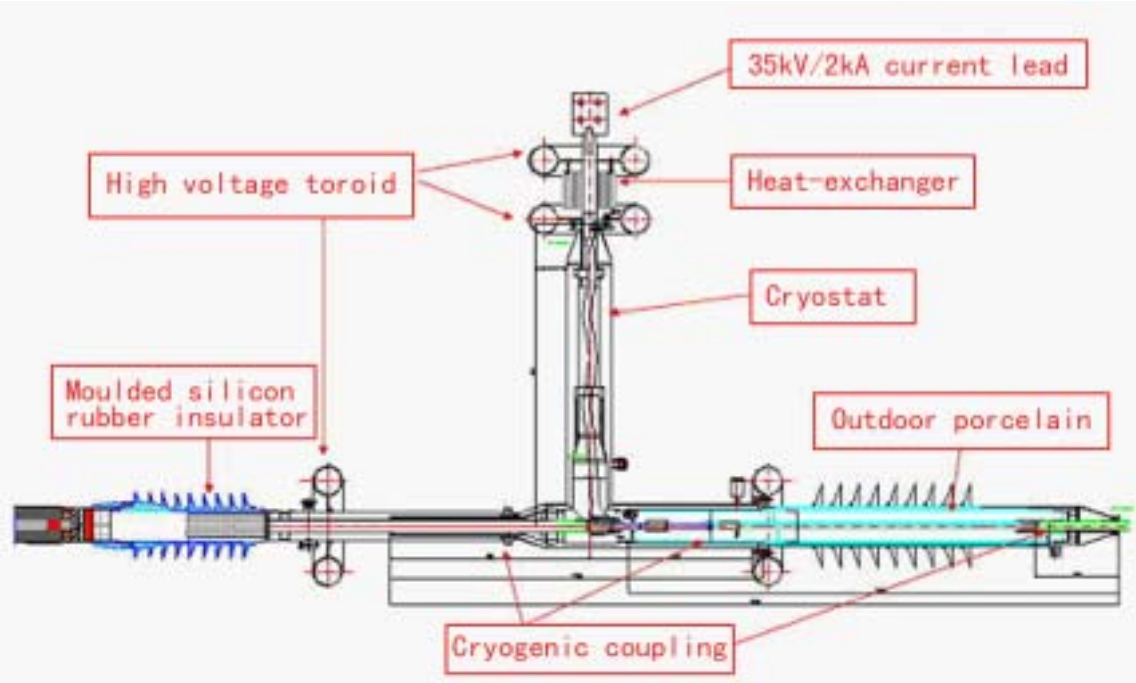
Phase

Phase shift between I and V at operation of 1500A at 74K:
Phase A ***83.0°***
Phase B ***84.6°(-95.4 °)***
Phase C ***85.1°***

AC loss

at 1500A, 74K:
26-30W/phase
Determined by caloric method.

Terminations



Dimension:
L 1812 mm; H 1468 mm
Weight:
30 kg
Dimension of current lead:
S 320 mm^2; L 860 mm
Optimized at 1220 A
Cryostat:
SS steel, evacuated
Insert LN_2 pipe:
Epoxy resin tube

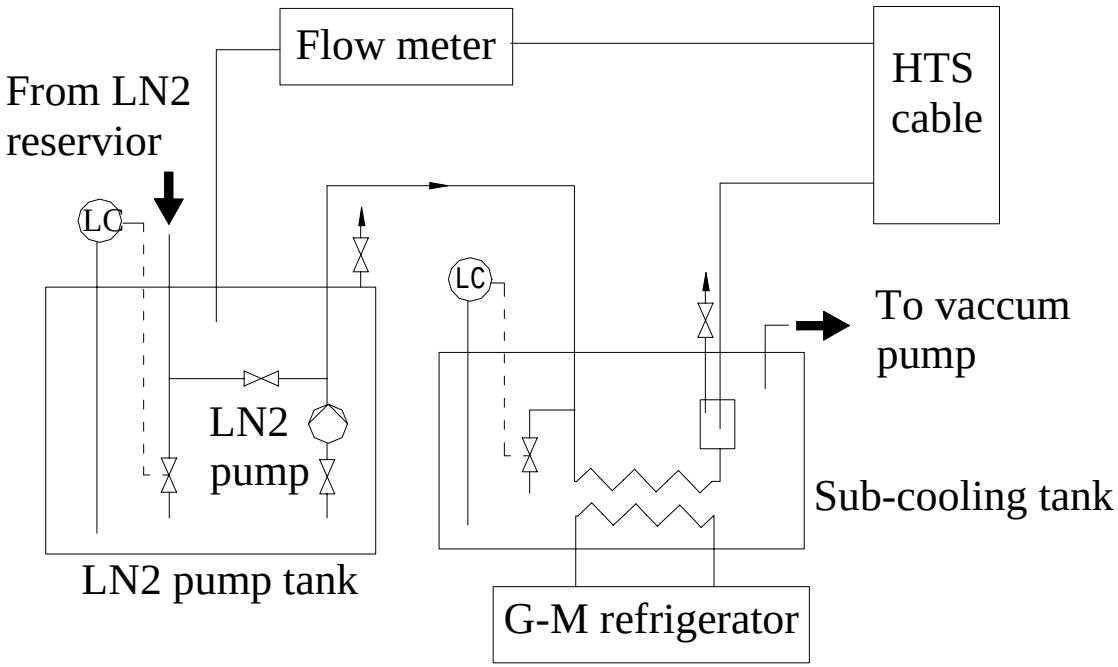
Terminations

Factory sample test:
Partial discharge(ac 39kV)
<10 pc
AC withstand voltage ***65 kV, 4h, passed***
Joule heat at 1220A at working:
52 W
Heat inleak:
38-42 W

Terminations

Resistance at 300K:
47 μΩ
Resistance at working:
40 μΩ

Cooling System



7 sets of G-M Cryorefrigerators operating in parallel

2000W cooling capacity at 75 K

Liability > 20000 hours

Energy saving by controlling the number of cryorefrigerators operating based on heat load

Cooling System

Purge (dry N_2 gas):
20-24 hours

Pre-cooling:
15-20 hours

Number of Cryorefrigerators working at normal load(800-1500A:
4-5

LN_2 flow rate:
600-900 L/h

Monitoring & Control

Parameters monitored

Temperatures:
In/out of each phase;
out of pump tank;
In/out of subcooling tank;
Coldhead of each cooler;
Cooling water

Pressure:
In/out of Pump tank;
In/out of each phase;
Subcooling tank
LN2 tank

LN2 flow rate:
Each phase;
Water

LN2 level:
Pump tank
Subcooling tank
LN2 tank

Current:
Each phase

Voltage:
Each phase

Monitoring & Control

Control parameters:
On/off for each cooler
LN_2 flow rate
Break/close for bus line breaker (send request to the substation main control)

Breaking/closing sequence:
For breaking
Close conventional bus line → Break HTS cable (<0.5 S)
For closing
Close HTS cable → Break conventional bus line (<0.5 S)

Project Highlights

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For live-grid trial operation, at 13:35 of April 19, 2004, the system was connected to the grid, at a load of 1600A, providing electricity to 4 industrial customers (including 2 metallurgical refineries) and about 100,000 residential population.

Prospect of Applications

Near Future Applications of HTS Cable

Replacing old cables in existing tunnels and trenches to increase capacity

From substation to large capacity refineries and plants

Prospect of Applications

Near Future Applications of HTS Cable

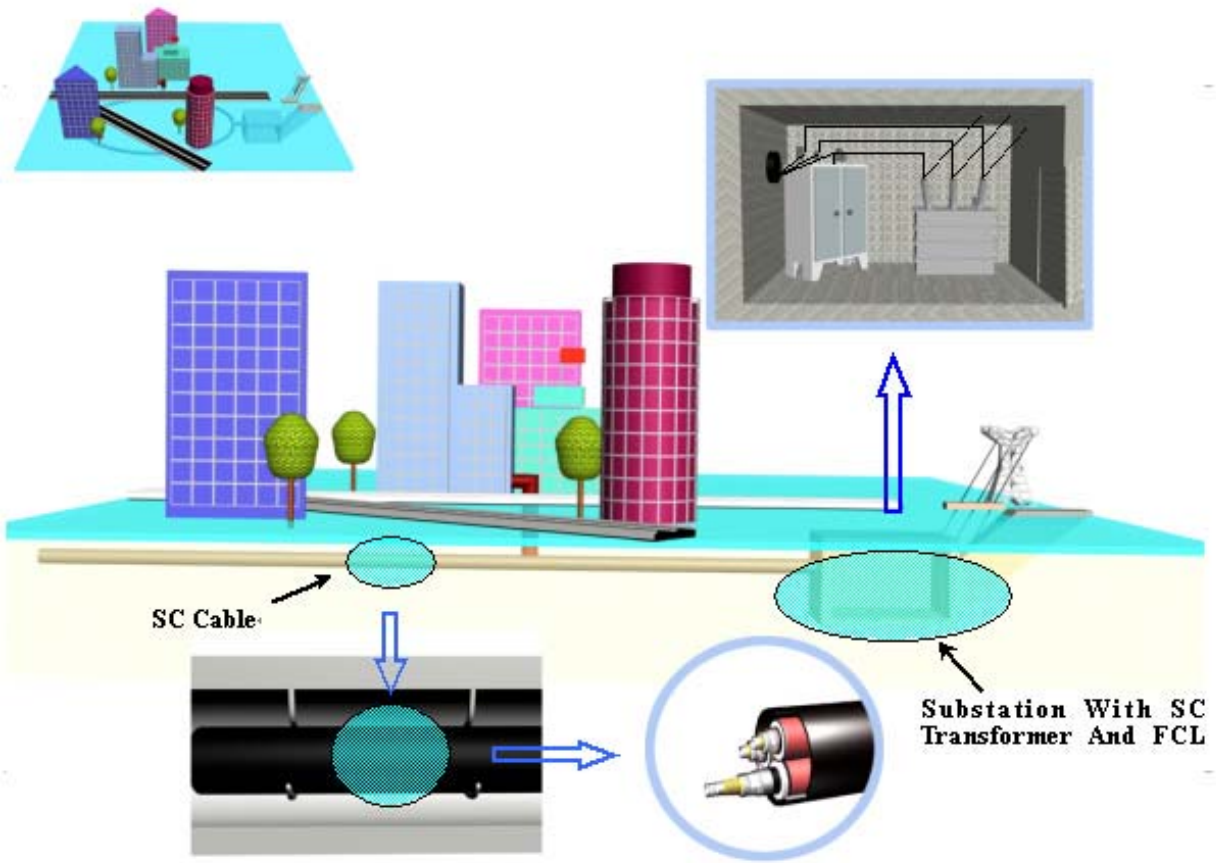
From generator to transformer, typically, 24kV/20-30kA, 20-200m

Metropolitan constant voltage network

Prospect of Applications

Future City's Main Electric Power Network

(underground transmission system)



Thanks, have a nice day!

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