Life Long Learning

- **Professional development: seminars, workshops, conferences, summer courses, PE license**
- **Literature resources**
  - Reference books, i.e. McGraw Hill “Standard Handbook for Electrical Engineers”
  - Magazines, i.e. IEEE “Power & Energy”, CIGRE “Electra”
  - Journals, i.e. IEEE “Transactions on Power Delivery”, also on line http://ieeexplore.ieee.org/
  - Standards and Engineering Practices (Guidelines), i.e. IEEE 1547 “Standard for Interconnecting Distributed Resources with Electric Power Systems”
- **Professional societies**
  - Institute of Electrical and Electronic Engineers IEEE http://www.ieee.org/
  - International Council of Large Electrical Systems CIGRE http://www.cigre.org/
- **Government agencies**
  - US Department of Energy http://www.doe.gov/

Life Long Learning

- **Additional online resources**
  - Power Globe - an international listserv for power engineers http://powerglobe.powerquality.com/
  - PowerSurf - a search engine for peer ranked power engineering education sites http://ceaspub.eas.asu.edu/powersurf/login.asp
  - IEEE PES Pathfinder - reference guide on selected web sites on power engineering http://www.ieee.org/pes_pathfinder
  - Power Learn - an educational web site on power engineering course material from Iowa State http://powerlearn.ece.iastate.edu/asp/
  - Prof. C. Indulkar's web site on links to power engineering http://www.geocities.com/cindulkar/links.html

Contemporary Issues

- **Keeping up to date with regulatory changes**
  - For example, restructuring of the utility sector with new regulations has significantly changed the utility working environment within the last 10 years
    - Open generation to economic competition (initially to promote renewable energy sources, FERC Order No. 888 and 889, April 1996)
    - Splitting of transmission and generation businesses
    - Investor owned transmission operators
  - Federal Energy Regulatory Commission FERC http://www.ferc.gov/
    - Is an independent agency that regulates the interstate transmission of natural gas, oil, and electricity. FERC also regulates natural gas and hydropower projects.
  - North American Electric Reliability Council NERC http://www.nerc.com/
    - Ensures that the bulk electric system in North America is reliable, adequate and secure
  - State Regulatory Bodies, i.e. Florida Public Service Commission http://www.psc.state.fl.us/
    - Regulates electric utility pricing

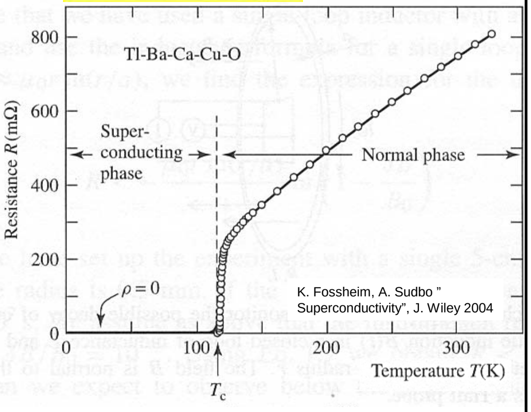
Contemporary Issues

- **Keeping up to date with new technology development**
  - New energy resources
    - Wind and ocean waves
    - Tidal hydro
    - Photovoltaic
    - Hydrogen fuel cells
    - See also national Renewable Energy laboratory (NERL) http://www.nrel.gov/
  - Power electronics
    - Variable speed drives for motors
    - Solid state DC-AC power converters for solar and fuel cells
    - High voltage DC transmission systems (HVDC)
  - Superconductivity
    - High temperature superconductors (HTS) reduce conduction losses and increase current densities
    - Cables (increase power density, specifically for dense urban areas)
    - Refurbishing rotors of large turbine generators (reduce losses)
    - Fault current limiters (utilize highly non linear V-I curve of HTS)
    - High power density motors (e.g. ship propulsion)

High Temperature Superconductors HTS

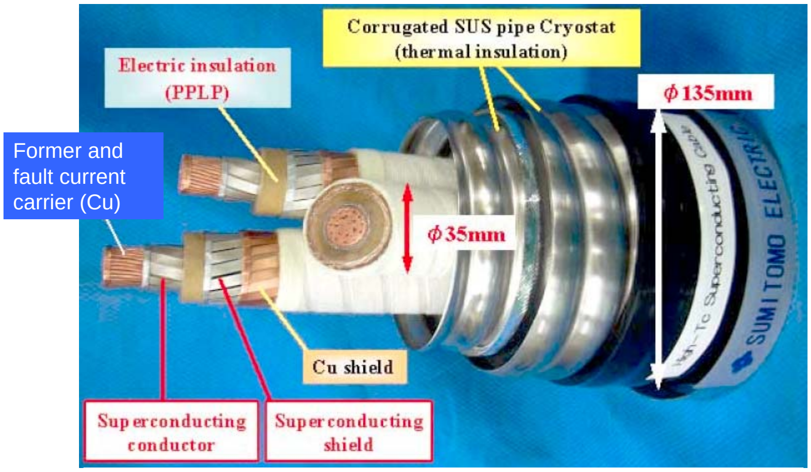
- **Superconductivity is a state of matter at low temperatures where the electrical DC resistivity becomes zero (immeasurable)**
  - Phenomenon first discovered by Kamerlingh Onnes 1911 (Leyden, Netherlands), e.g. Hg (mercury) below 4°K (-269.15°C, -452.47°F)
  - “High” Temperature SC discovered by Bednorz and Mueller 1987 (Zuerich, Switzerland), e.g. $Bi_2Sr_2Ca_2Cu_3O_{10}$ (BSCCO2223) below 110°K (nitrogen liquefies at 77°K)
  - Allows for near losses AC current flow in HTS conductors with low cost LN_2 refrigeration systems

Photo: American Superconductor Corp.



K. Fossheim, A. Sudbo ” Superconductivity”, J. Wiley 2004

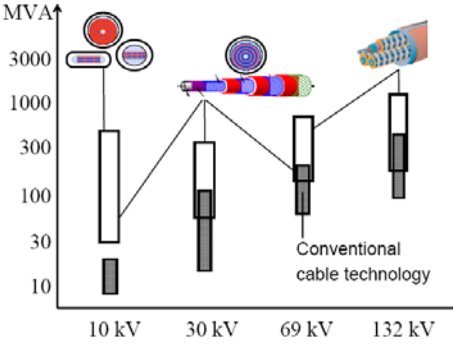
HTS Cable Design



Hiroyasu Yumura, ” Design, Manufacturing and Testing Overview of the Albany HTS Cable System”, presentation, EPRI SC Conference, Sep 2005

HTS Cable Advantages

- **Higher power at lower voltages**
  - Reduction of voltage classes – smaller substations, relocate transformers, simplify permitting process
- **Thermally independent from surroundings**
- **Low impedance, longer cables**
  - Enables control of load flow on AC network
  - Longer distance between phase transposition
- **Enable the integration of renewables and distributed generation**
  - Avoid transformation steps for connections of new sources



David Lindsay, " Superconducting Cable Systems", presentation, EPRI SC Conference, Sep 2005

HTS Cable Projects Worldwide

Sumitomo/TEPCO	66 kV, 115 MVA, CD, 100 m
Sumitomo/IGC/Albany	35 kV, 350 m, 2003-2006
Southwire/DOE	12 kV, 26 MVA, CD, 30 m
Ultera/SW/AEP	13 kV, 69 MVA, CD, 200 m
nktcables/ELKRAFT/ELTRA	30 kV, 104 MVA, WD, 30 m
Furukawa/Super ACE	66 kV, CD, 500 m, 1 phase
LG Cables/KERI/Korea	23 kV, 50 MVA, CD, 30 m, '02-04
KEPCO/Korea	100 m demonstrator
InnoPower/Yunnan/PRC	30 kV, WD 30 m, '02-04
Condumex/Mexico	30 m demonstrator 2003-2005
AMSC/Keyspan/NY	138 kV, 600 m, US-DOE, '03-06
Pirelli/Detroit	24 kV, 100 MVA, WD, 120 m

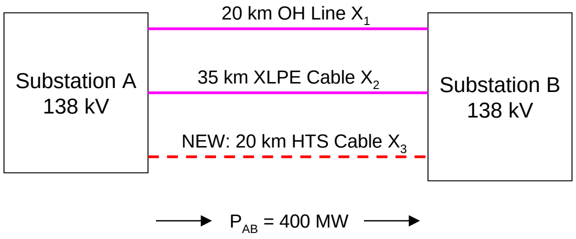
David Lindsay, " Superconducting Cable Systems", presentation, EPRI SC Conference, Sep 2005

Low impedance HTS cables – system imapct

A Comparison of Power Transmission Technologies				
Technology	Resistance (Ω/km)	Inductance (mH/km)	Capacitance (nF/km)	(MVAR/km)
Cold Dielectric HTS	0.0001	0.06	200	1.08
Conventional XLPE	0.03	0.36	257	1.4
Overhead Line	0.08	1.26	8.8	0.05

John Howe, et.al., "Very Low Impedance Cables", white paper, Nov 2003 (lead American Superconductor Corporation)

Near perfect containment of B-field within cable due to HTS shield



Substation A
138 kV

20 km OH Line X_1

35 km XLPE Cable X_2

NEW: 20 km HTS Cable X_3

Substation B
138 kV

P_{AB} = 400 MW

Low impedance HTS cables

$$P = \frac{3V_{A,L-N}V_{B,L-N}\sin(\delta)}{X} = \frac{V_A V_B \sin(\delta)}{X}$$

$X_1 = 9.5\ \Omega$
$X_2 = 4.75\ \Omega$
$X_3 = 0.45\ \Omega$
$V_A = V_B = 138$ kV

Without HTS cable

$$X_{1,2} = 3.17\ \Omega \longrightarrow \delta = \sin^{-1}\left(\frac{400\cdot 3.17}{138^2}\right) = 3.8°$$

$$P_1 = \frac{138^2\sin(3.8°)}{9.5} = 133\,MW \quad P_2 = \frac{138^2\sin(3.8°)}{4.75} = 266\,MW$$

With HTS cable

$$X_{1,2,3} = 0.39\ \Omega \longrightarrow \delta = \sin^{-1}\left(\frac{400\cdot 0.39}{138^2}\right) = 0.47°$$

$$P_1 = \frac{138^2\sin(0.47°)}{9.5} = 16\,MW \quad P_2 = \frac{138^2\sin(0.47°)}{4.75} = 33\,MW \quad \boxed{P_3 = \frac{138^2\sin(0.47°)}{0.45} = 347\,MW}$$

HTS cable requires series reactance or phase angle regulator (PAR) for power flow control