Superconducting Lines for the Transmission of Large Amounts of Power over Great Distances

Garwin-Matisoo Revisited 40 Years Later!

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Generational Axioms of History

- There is nothing new under the sun

  Ecclesiastes 1:9-14
- What's past is prologue

  The Tempest, by Bill S.
- Those who cannot remember the past are bound to repeat it

  George Santayana
- History is more or less bunk

  Henry Ford
- I can't think about tomorrow...I'm as lost as yesterday

  Tomorrow, by Bob Seger

PROCEEDINGS

THE INSTITUTION OF ELECTRICAL ENGINEERS

Volume 113 Power

Prospect of employing conductors at low temperature in power cables and in power transformers

K. J. R. Wilkinson, D.Sc., C.Eng., M.I.E.E.

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- ac Cables: 760 MVA (3ϕ), 275 kV, 1600 A
  - Be 77 K
  - Al 20 K
  - Nb 4 K (a "soft" superconductor!)
- *Objective: Efficiency, not increased capacity!*

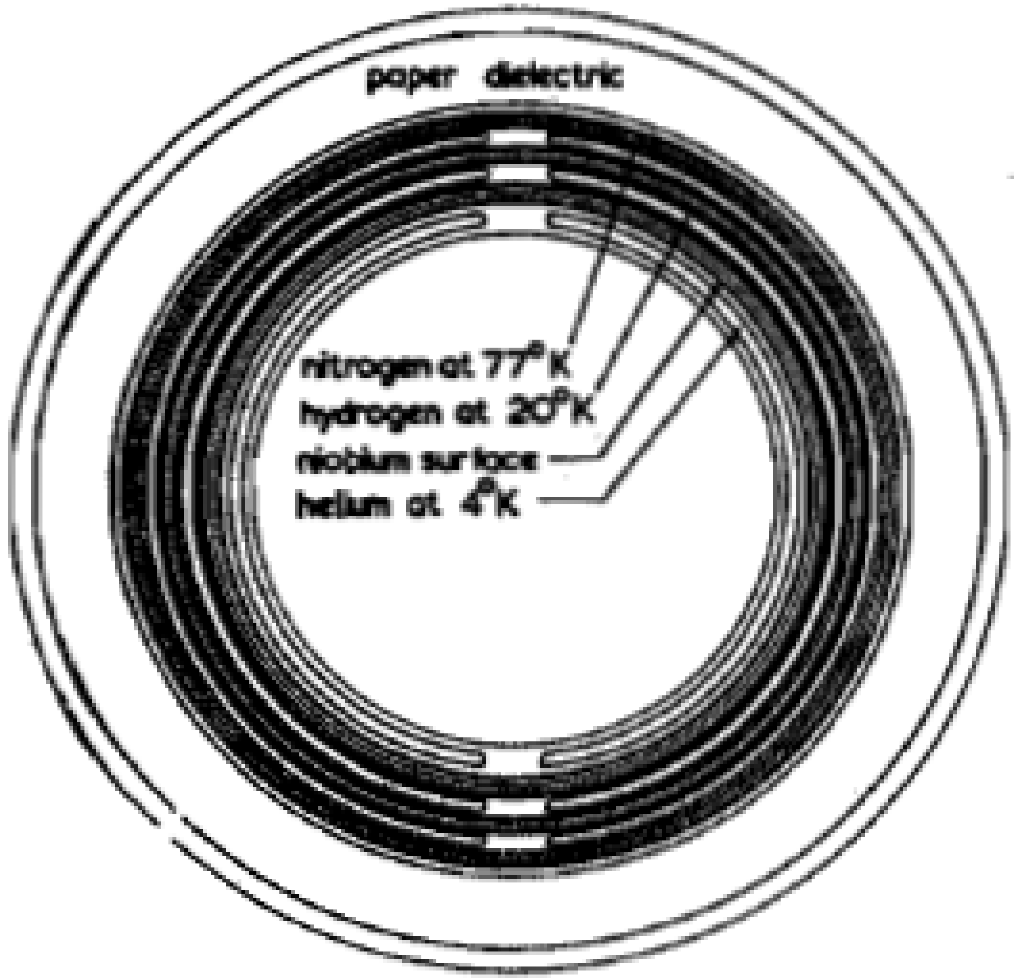

Fig. 2

Superconducting thin-walled niobium core cooled internally by liquid He and protected externally by liquid H_2 and liquid N_2

Cable Properties

H_{C1} = 0.16 T
Fault I = 40 kA

Metal	T (K)	ρ (Ω×cm)	Outer Diameter (cm)	Loss (W/km)
Cu	340	2×10^{-6}	6.0	46,500
Be	77	2×10^{-8}	6.0	460
Al	20	3×10^{-9}	6.0	470
Nb	4	0	10.4	0

Table 7

A COMPARISON OF COSTS, EXCLUDING CONSTRUCTION AND LAYING, BUT INCLUDING THOSE OF LOSSES, REFRIGERATION PLANT, AND CONDUCTOR MATERIAL

Core	Refrigerant	Capitalised costs of cable			
		I^2R loss	Plant and drive power	Conductor material	Approximate total
		£/km	£/km	£/km	£/km
Cu	—	3200	—	10000	13000
Al	H_2, N_2	17	21 260	3000	24000
Be	N_2	62	5170	800000	800000
Nb	He, N_2	—	9203	3000	12000

Cost of "Extra" Generation to Offset I^2R Losses (CEGB, 1965): 220 £/kw

Wilkinson's Conclusion (1966)

- "...only niobium has any hope of defraying its refrigeration costs by savings in conductor material"
- "But its impracticably large core diameter" (10.4 cm rules out Type I superconductors)
- A Type II superconductor with $J_C = 10^6$ A/cm^2 at a diameter of 6 cm would quench under a fault current of 40 kA
- "Such a hazard is clearly unacceptable."

Superconducting Lines for the Transmission of Large Amounts of Electrical Power over Great Distances

R. L. GARWIN AND J. MATISOO

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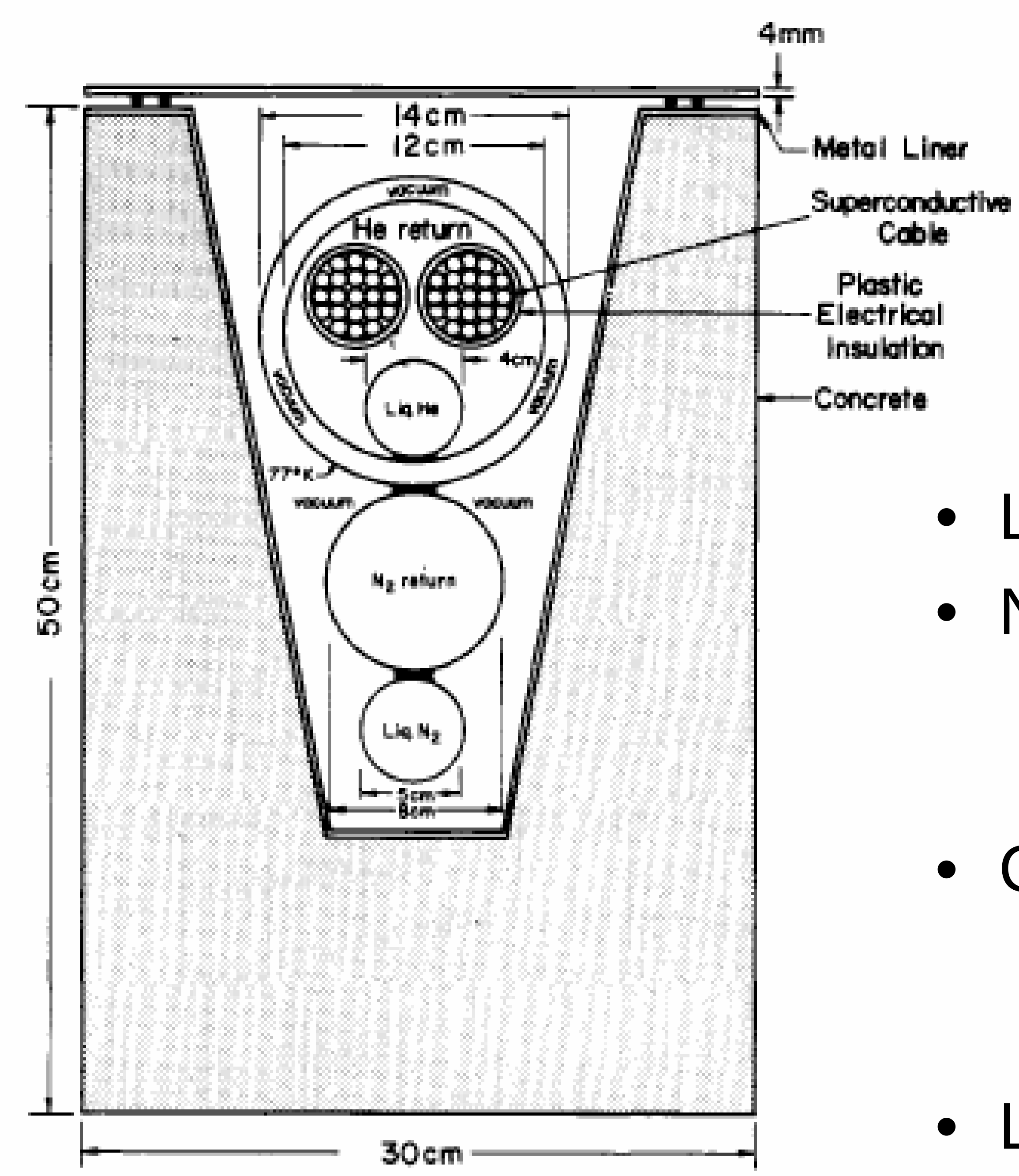
Rationale: Huge growth in generation and consumption in the 1950s; cost of transportation of coal; necessity to locate coal and nuke plants far from load centers.

Furthermore, the utilities have recently become aware of the advantages of power pooling. By tying together formerly independent power systems they can save in reserve capacity (particularly if the systems are in different regions of the country), because peak loads, for example, occur at different times of day, or in different seasons. To take advantage of these possible economies, facilities must exist for the transmission of very large blocks of electrical energy over long distances at reasonable cost.



Specs

- LHe cooled
- Nb_3Sn (T_C = 18 K)
  - J_C = 200 kA/cm^2
  - H* = 10 T
- Capacity = 100 GW
  - +/- 100 kV dc
  - 500 kA
- Length = 1000 km

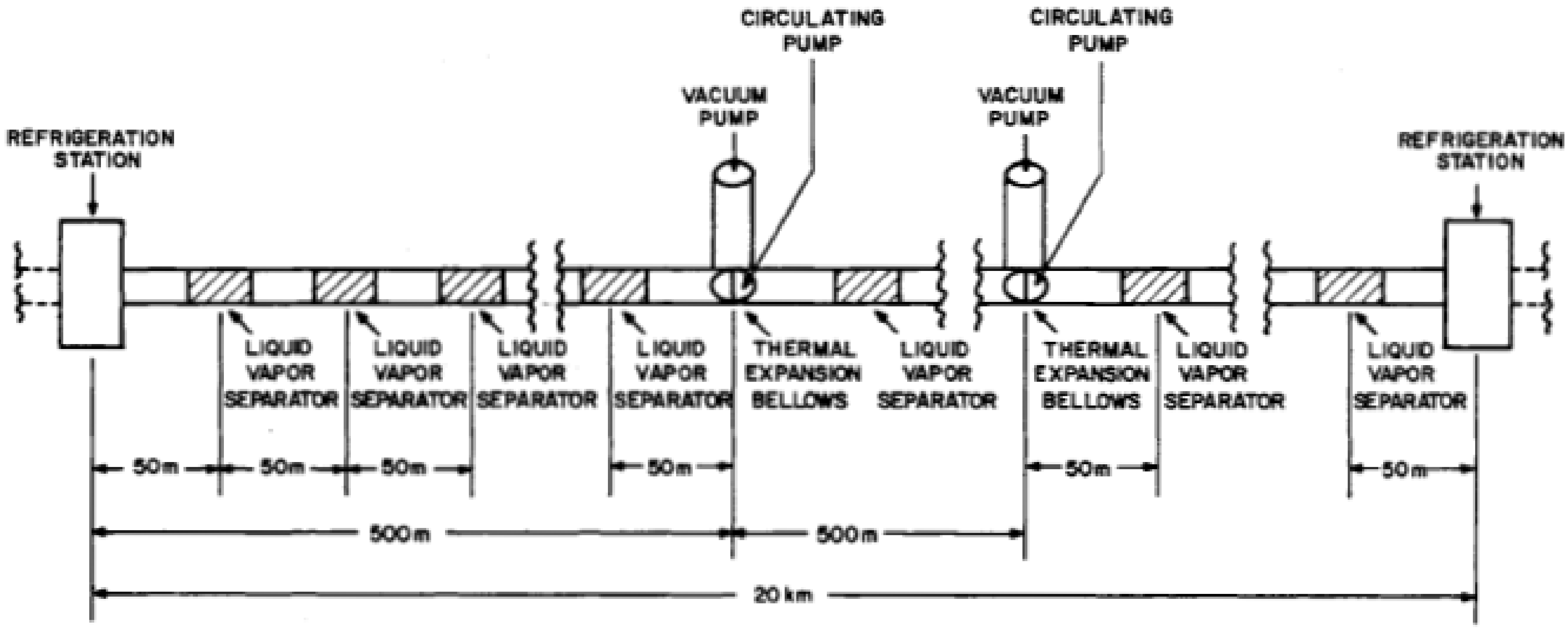
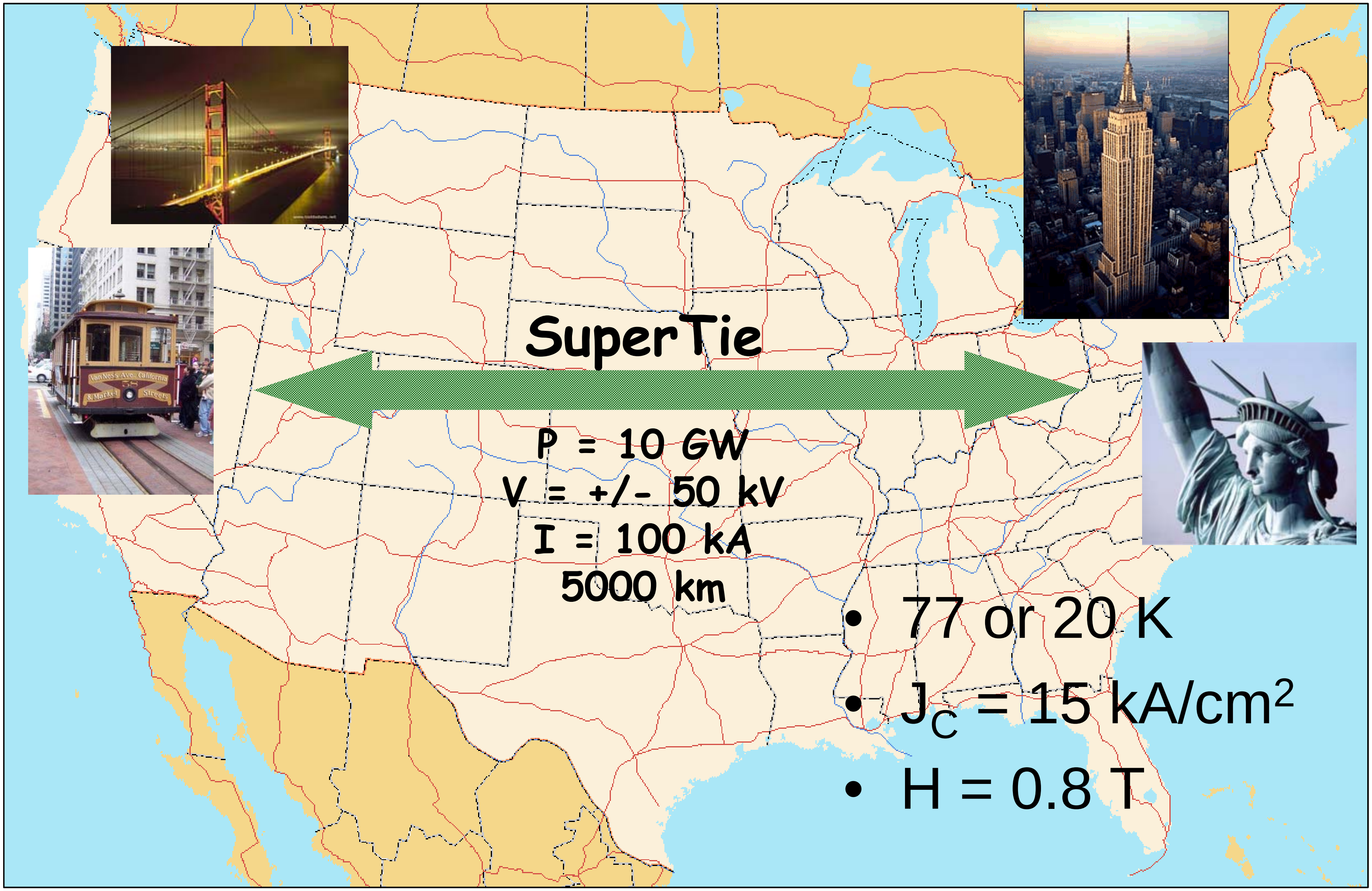


Fig. 2. A 20-km module of the 1000-km, 100-GW line.

• Refrigeration Spacing	20 km
• G-L Separator Distance	50 m
• Booster Pump Intervals	500 m
• Vacuum Pump Spacing	500 m

SuperTie



- 77 or 20 K
- J_C = 15 kA/cm^2
- H = 0.8 T

High-Amplitude Transient (ac) Losses According to Bean

$$W_H(n) = 2 \times 10^{-9} I_n^2 f$$

Where:

I_n = current amplitude for harmonic n, and
f = frequency for harmonic n (<u>here 60 Hz</u>)

I_n (kA)	W_H (W/m)
500 (G-M)	6,000,000
100 (SuperTie)	240,000

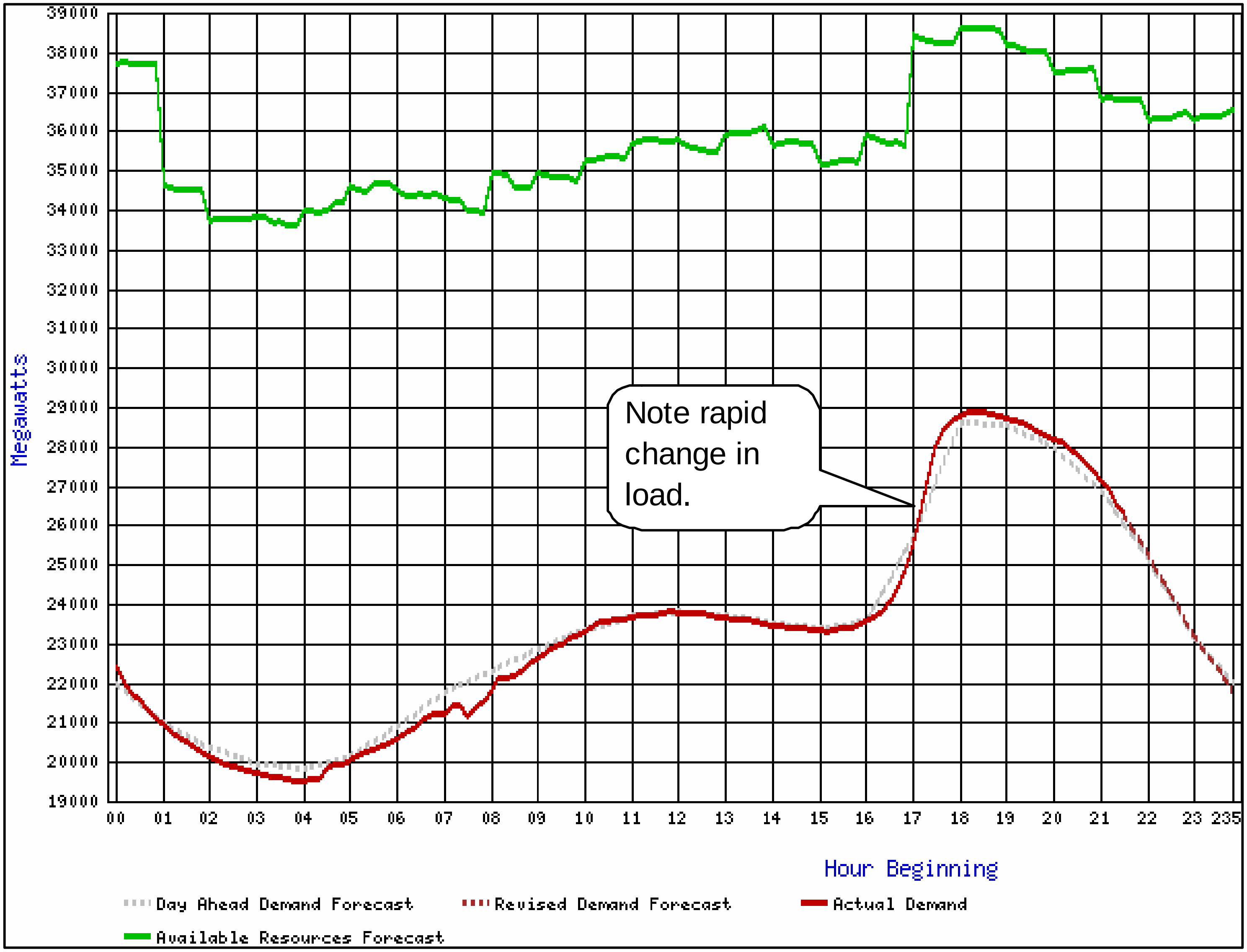
Low-Amplitude Transient (ac) Losses According to Bean

$$H = \frac{4 \times 10^{-10} (\Delta I)^3 F}{J_c R^2} \quad \mathrm{W/cm}$$

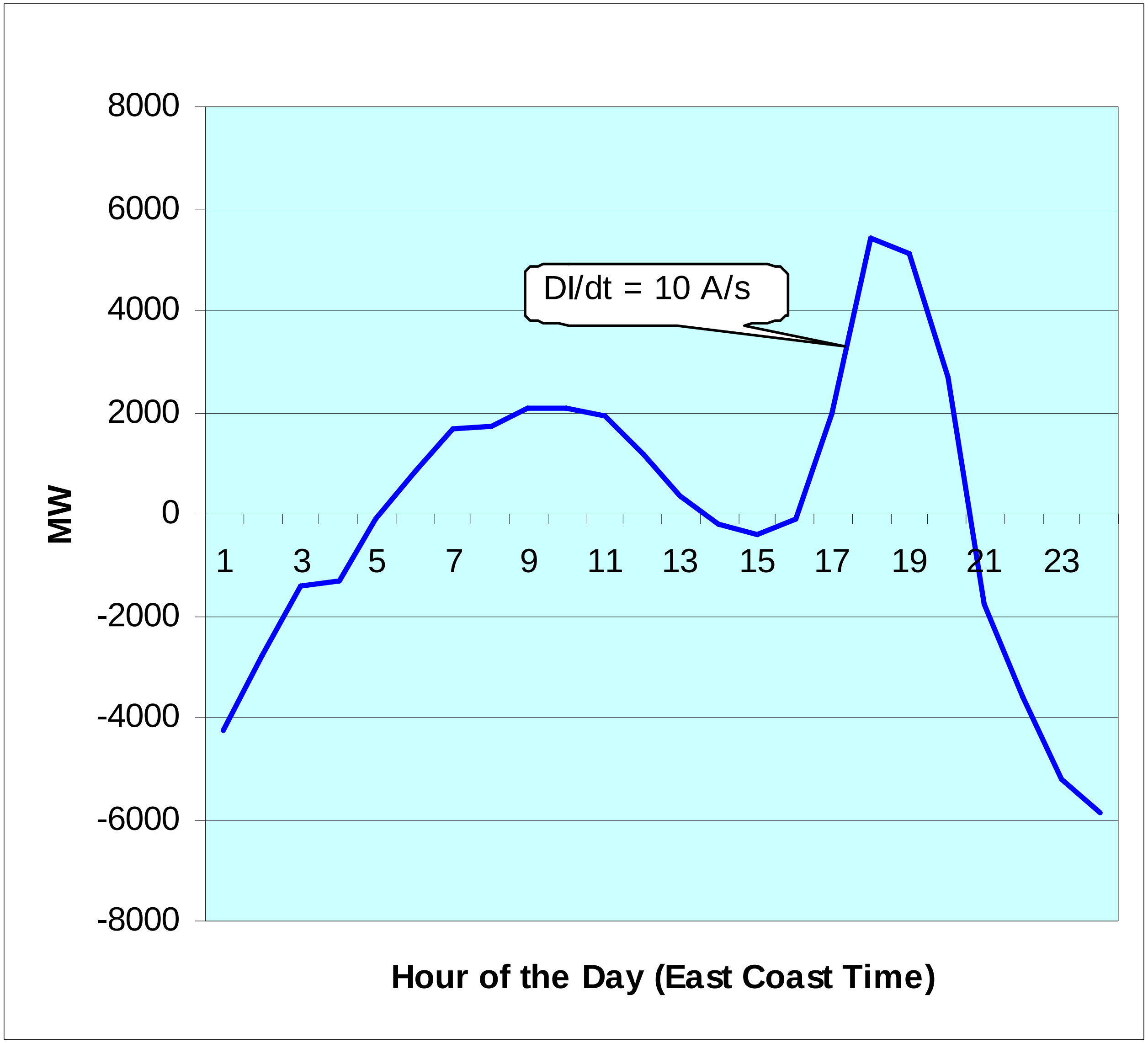
1% Ripple

J_C(kA/cm^2)	R (cm)	ΔI (A)	F (Hz)	H (W/m)
15	1	1000	360	1

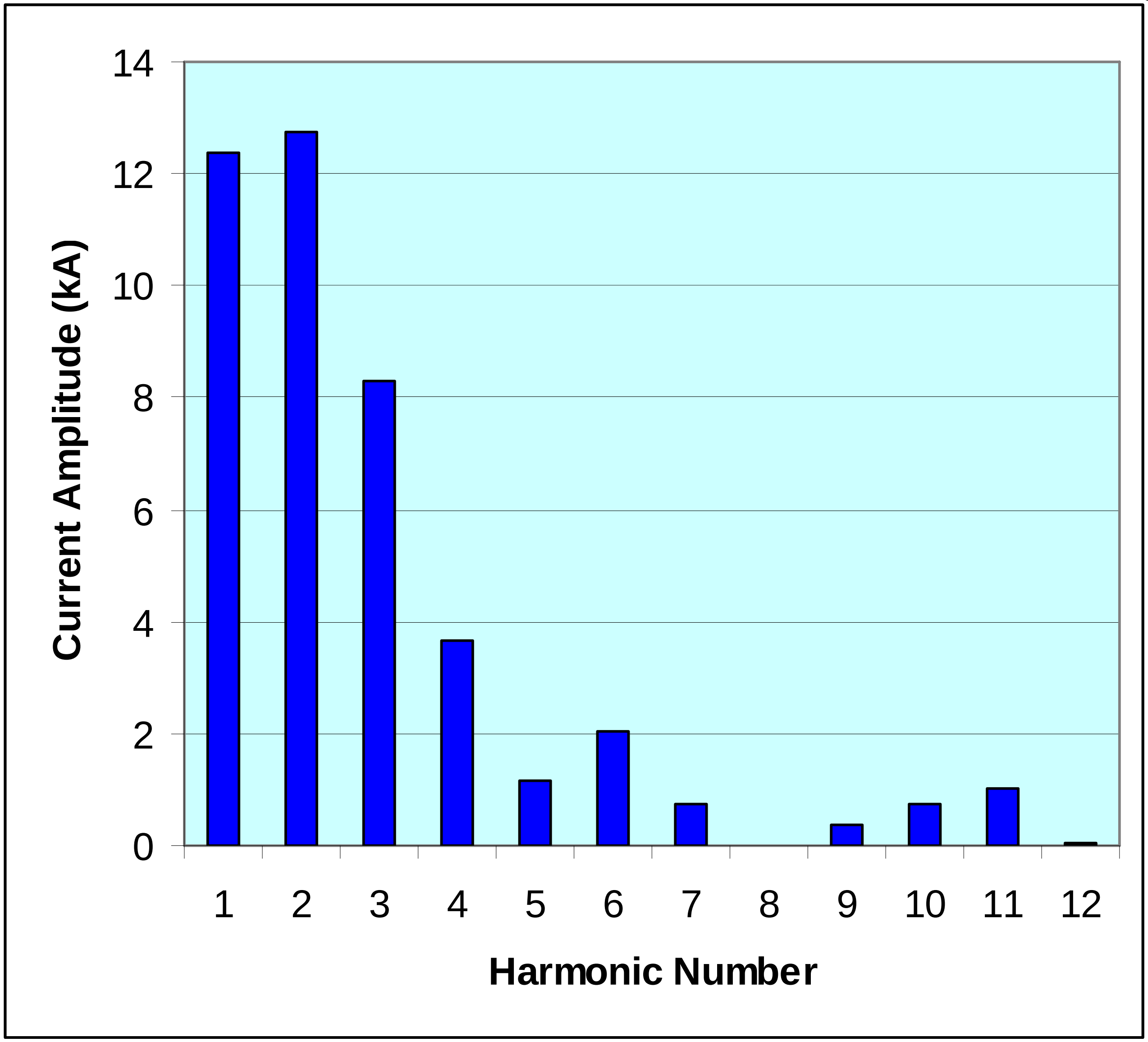
Hotel California, 8 January 2006



“Twin Californias”



Current Harmonics for “Twin Californias” Diurnal Trading



"Twin California" Trading Losses

Harmonic, n	I_n (kA)	f (μHz)	W_H (kW/5000 km)
1	12.4	11.6	1.8
2	12.8	23.2	3.8
3	8.31	34.7	2.4
4	3.67	46.3	6.2
		Total	8.7

No Problem!

“Sanity Check”

- Worst Case: Assume a “toleration loss” no larger than 1 W/m, then the entire SuperTie could be reversed in only 2 hours.
- The “fastest” change would be ~ 10 A/s between 5 and 6 PM EST. Compare with 1% ripple on 100 kA at the 6th harmonic of 60 Hz which is 720,000 A/s!

5000 km SuperTie Economics

Base Assumption: C/P "Gen X" = $50/kA×m

Cost of Electricity ($/kWh)	Line Losses in Conventional Transmission (%)	Annual Value of Losses on 10 GW Transmission Line @ 50% Capacity (M$)	Additional Capital Costs for HTSC and Refrigeration (M$)	FRB Discount Rate (%)	Period for ROI (Years)
0.05	5 %	110	52,574	5.5 %	62

"Deregulated Electricity" will <u>not</u> underwrite this ROI, only a "public interest" investment analogous to the Interstate Highway system makes sense

Garwin-Matisoo Bottom Line

This is not an engineering study but rather a preliminary exploration of feasibility. Provided satisfactory superconducting cable of the nature described can be developed, the use of superconducting lines for power transmission appears feasible.

Whether it is necessary or desirable is another matter entirely!