iMOD Inc

Some thoughts on….

The Future of Electric Power Transmission

Enhancing Capacity of today's Systems:

Improve Capacity thru

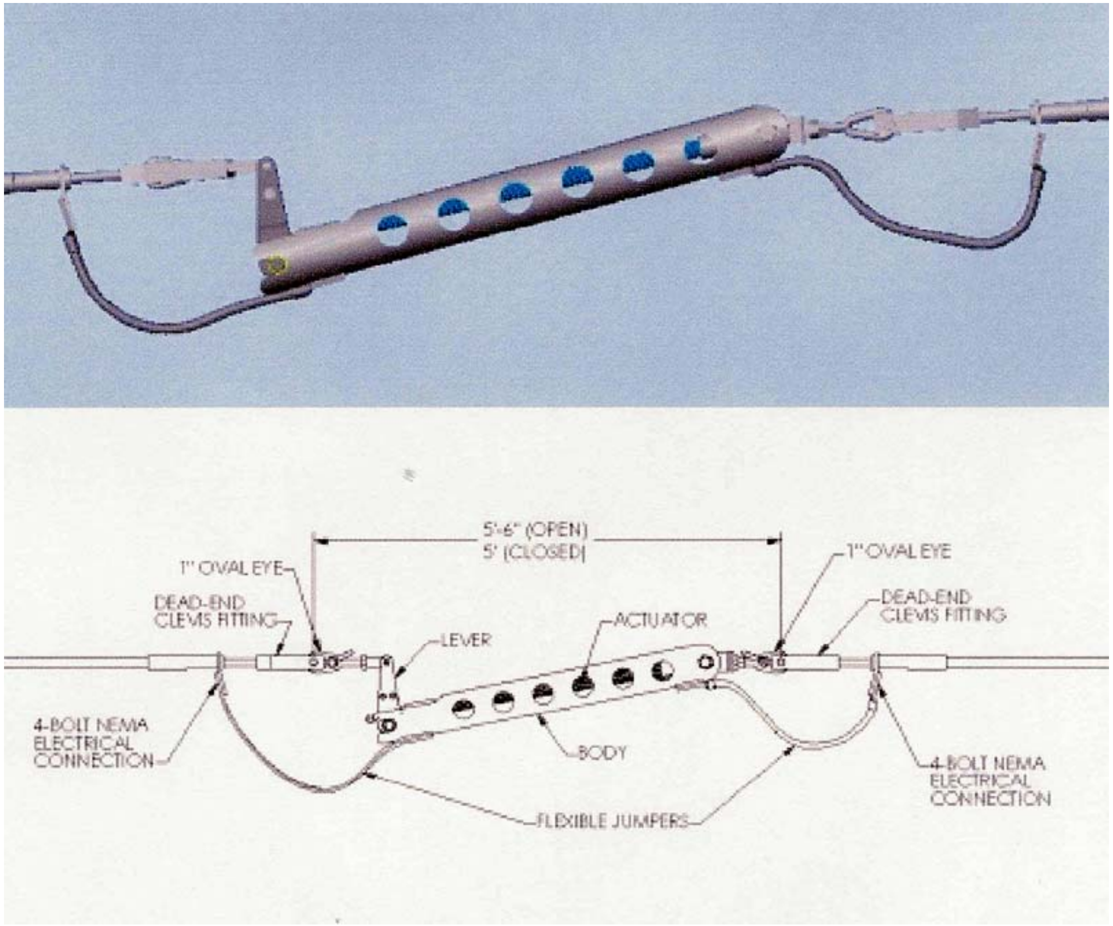
1. Better using intrinsic characteristics of transmission lines

2. Adding equipment to achieve greater flows

   Series compensation
   Reactive power sources
   Phase angle shift

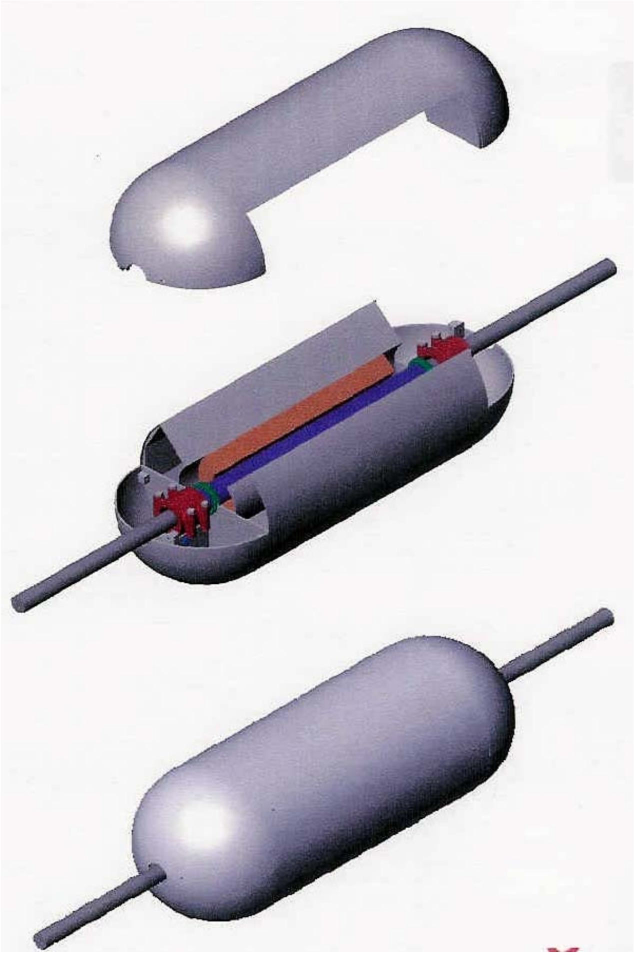
Increasingly dependent on power electronics ….“FACTS”

Current-activated Tension Adjuster



Distributed Reactive Drop Compensation

Series quadrature voltage adjuster:



Enhancing Capacity of todays System:

Improve Capacity thru

1. Better using inherent characteristics of transmission lines

2. Adding equipment to achieve greater flows

    Series compensation
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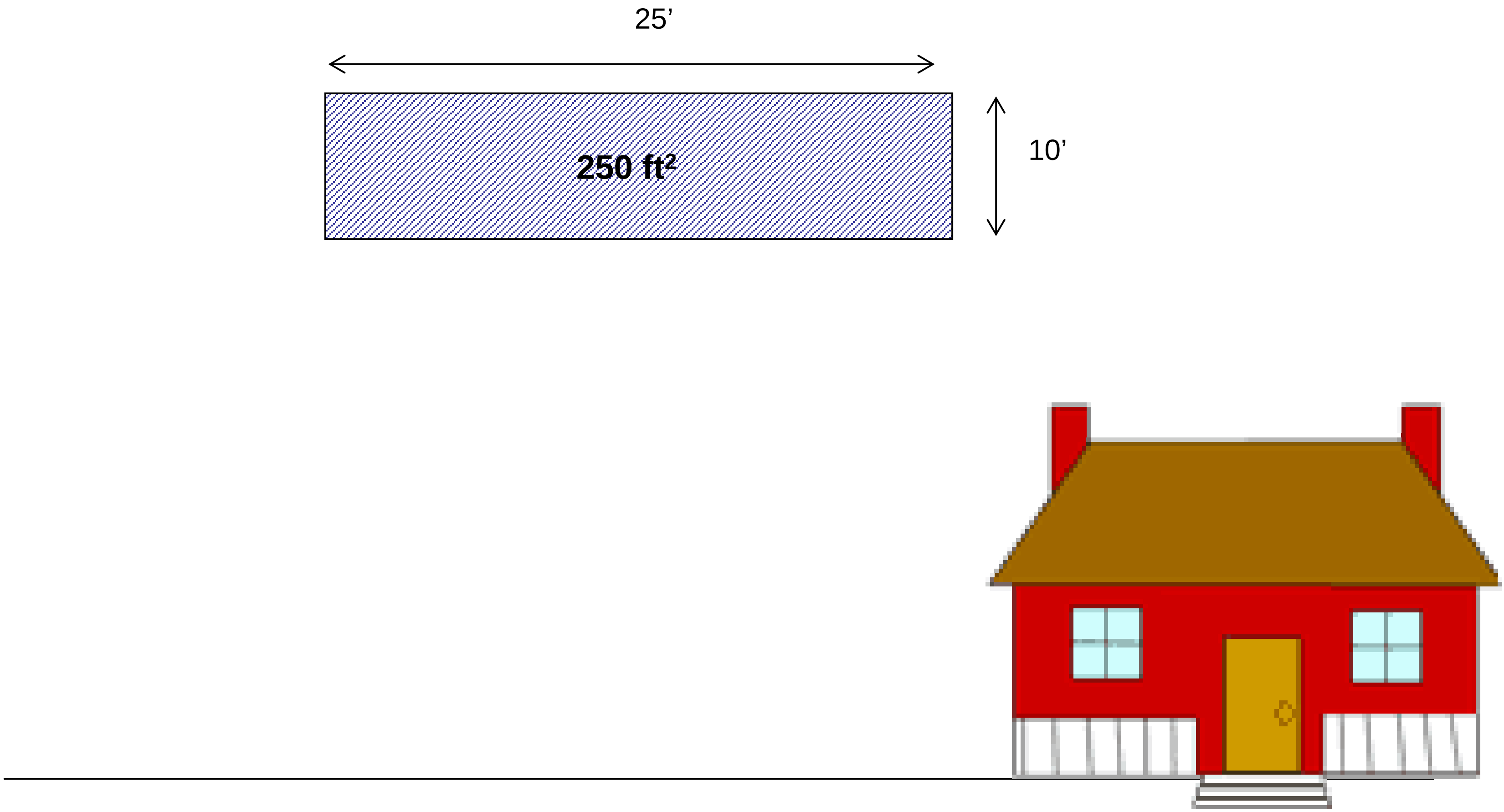
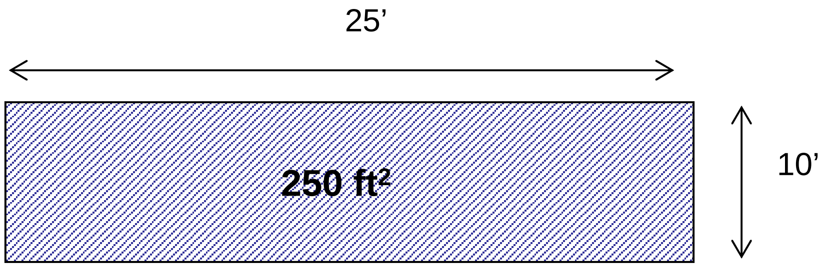
How many MW/ft^2?



Poynting Vector Analysis

$$\bar{S} = \bar{E} x \bar{H}$$



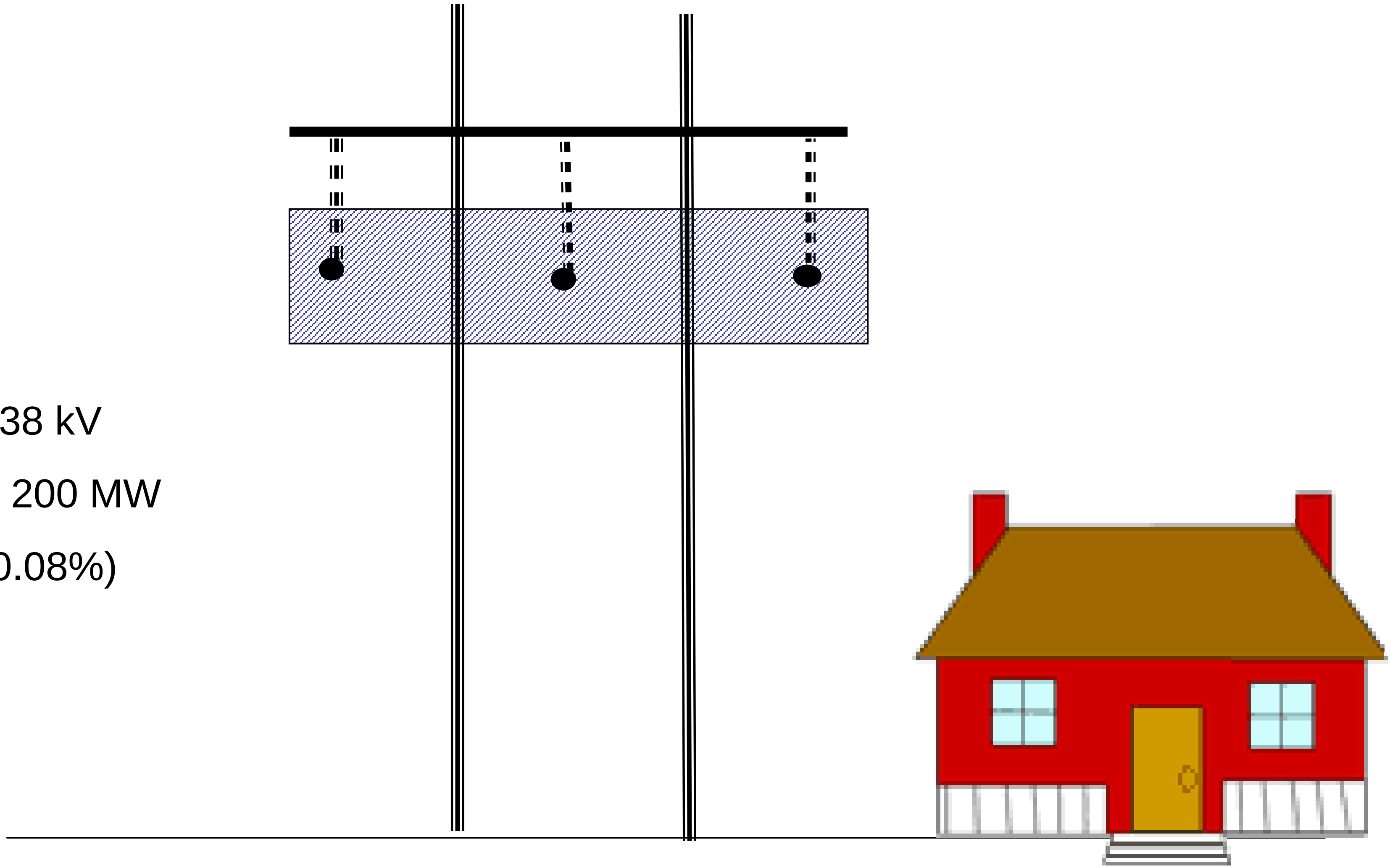
$$S_{\max} = \frac{E_{\max}^2}{Z_i}$$

$$E_{\max} = 30 \frac{kV}{cm}$$

$$S_{\max} = 12{,}000 \frac{MW}{m^2} = 1{,}115 \frac{MW}{ft^2}$$

$$P = 278{,}810 MW$$

How are we doing?

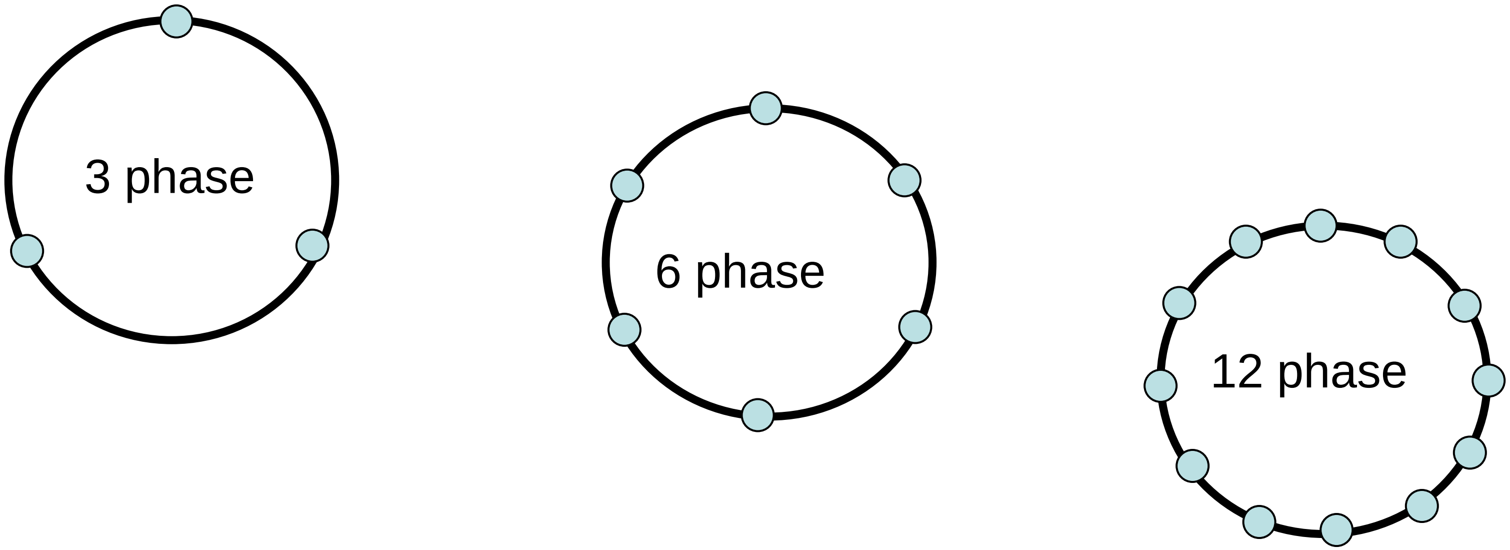


138 kV

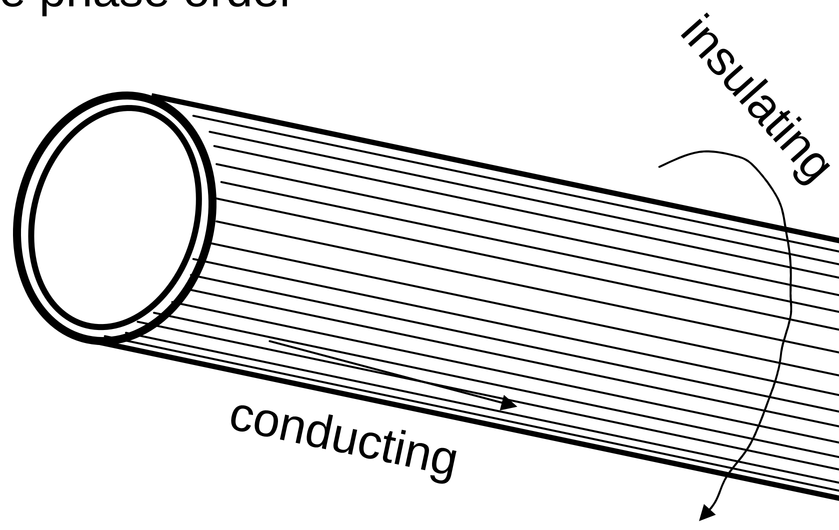
~ 200 MW

(0.08%)

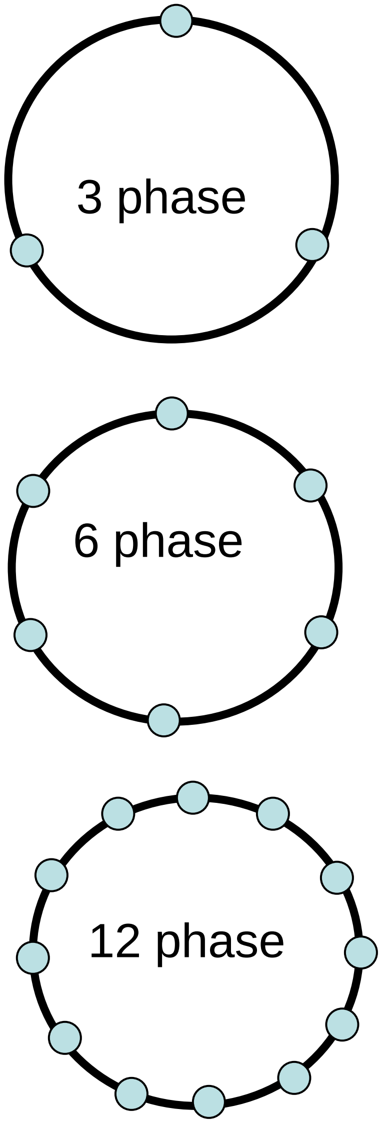
High Phase Order Transmission

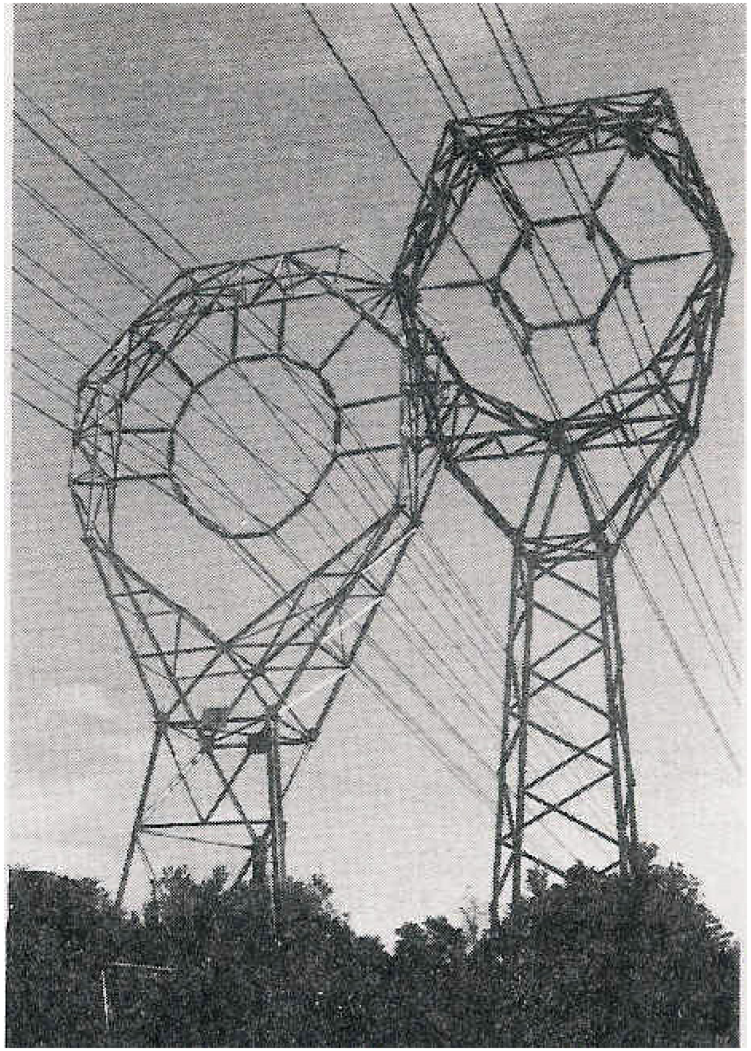


Infinite phase order



It Works….but imagine the substation!

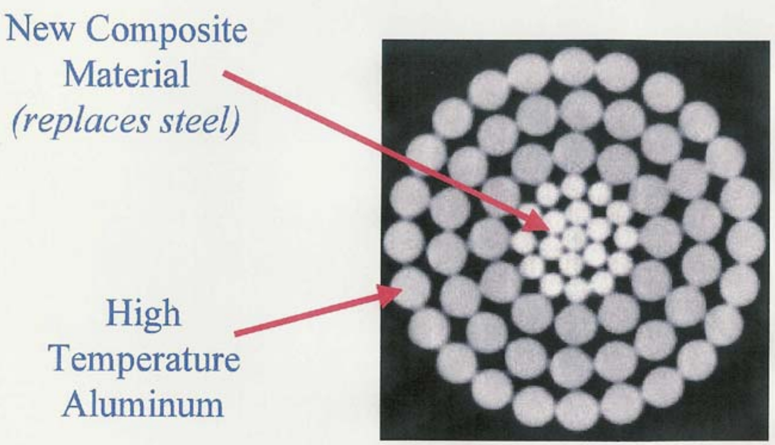




1. ACCR

3 Composite Conductor (ACCR)

A Materials Innovation



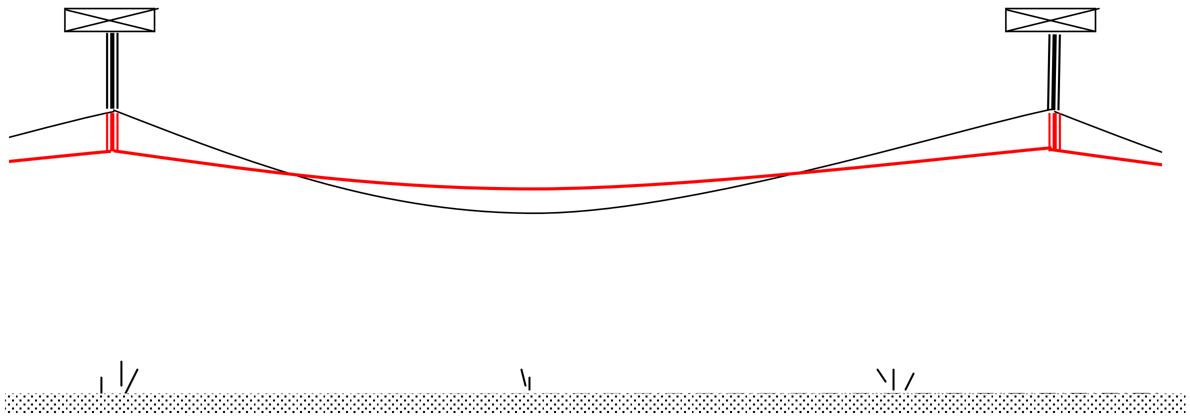
High Performance

- Lightweight – High Strength
- Low Sag at High Temperature

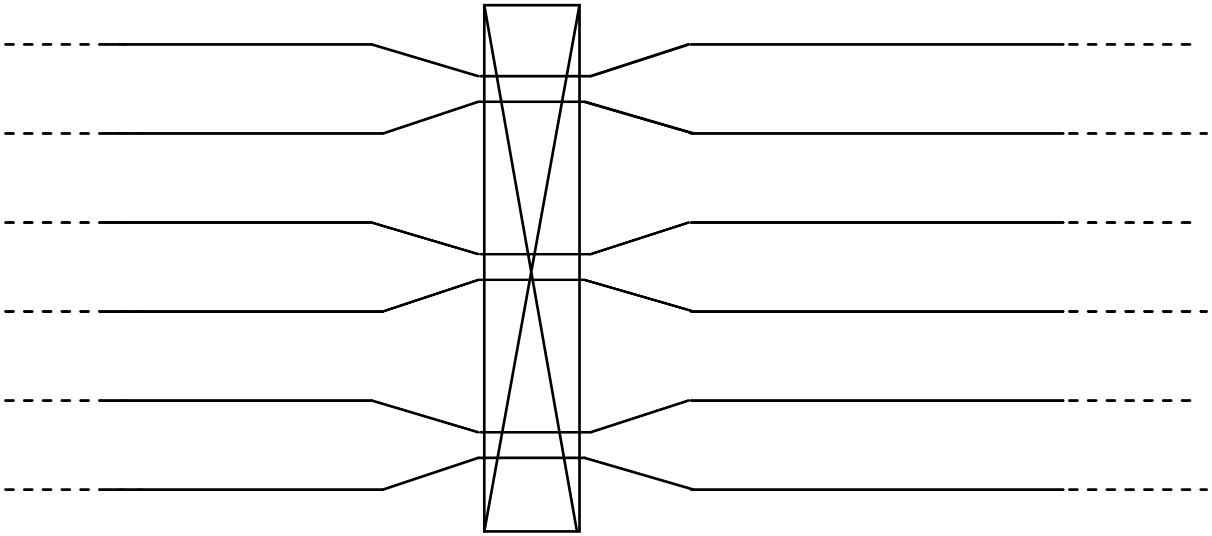
Potential for Current & Voltage Uprating

Reconductoring allows:

1. Current uprating by reducing sag
2. Voltage uprating by creating extra clearance and room for more insulators. (Light weight allows bundling)

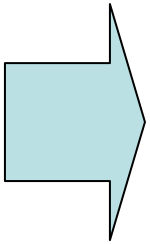


2. High Surge Impedance Loading Construction



X reduced

C increased



Voltage (kV)	SIL (MW)	
	Normal	HSIL
69	9-12	10-40
138	40-50	50-120
230	120-130	130-440
500	950-1,000	1,000 - 2,000

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3. HVDC Conversion

Advantages:

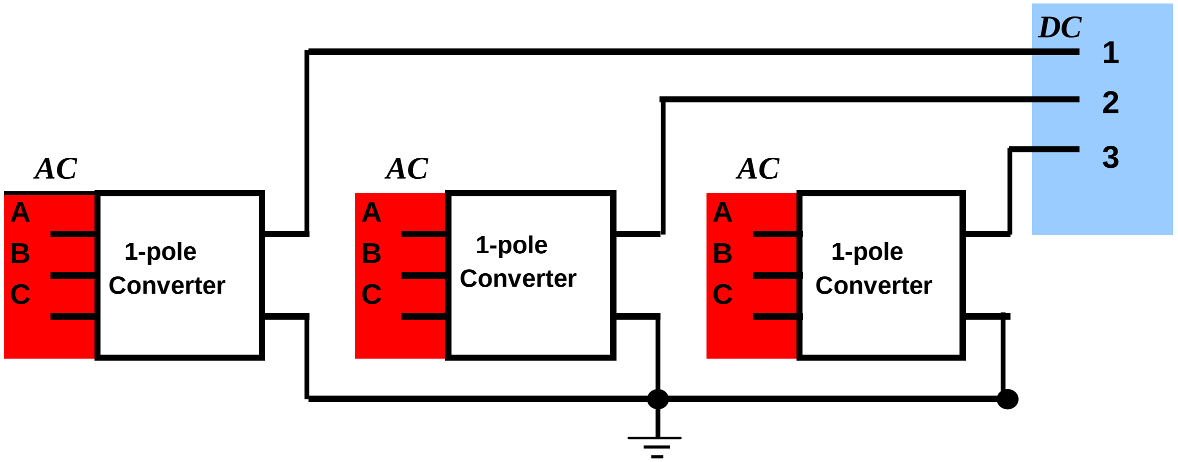
1. Full time-utilization of insulation
2. DC Operating advantages

Obstacles:

1. High cost per ***incremental*** kW
2. Bi-pole system leaves 1/3 of a valuable line investment idle

3. Tri-pole HVDC

An extra conductor….. Why not an extra bridge?

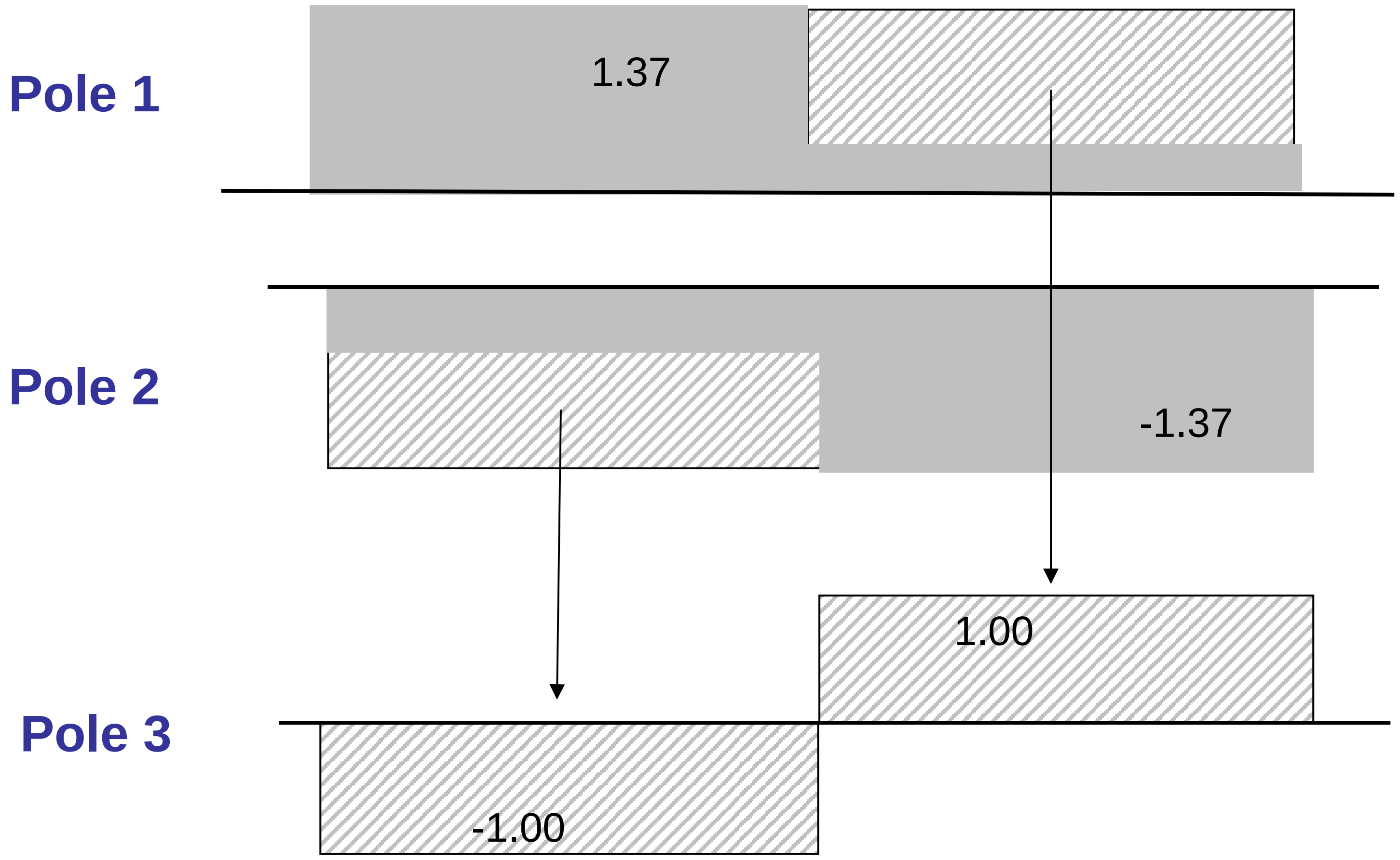


Bi-Pole HVDC

Conductor 3 is idle except in emergencies

Current- Modulated HVDC

One pole reversible, in current & voltage:



Pole 3 alternately relieves current from pole 2…then pole 1

Asymmetrical Modulation

One reversible pole:

Po

Po

Po

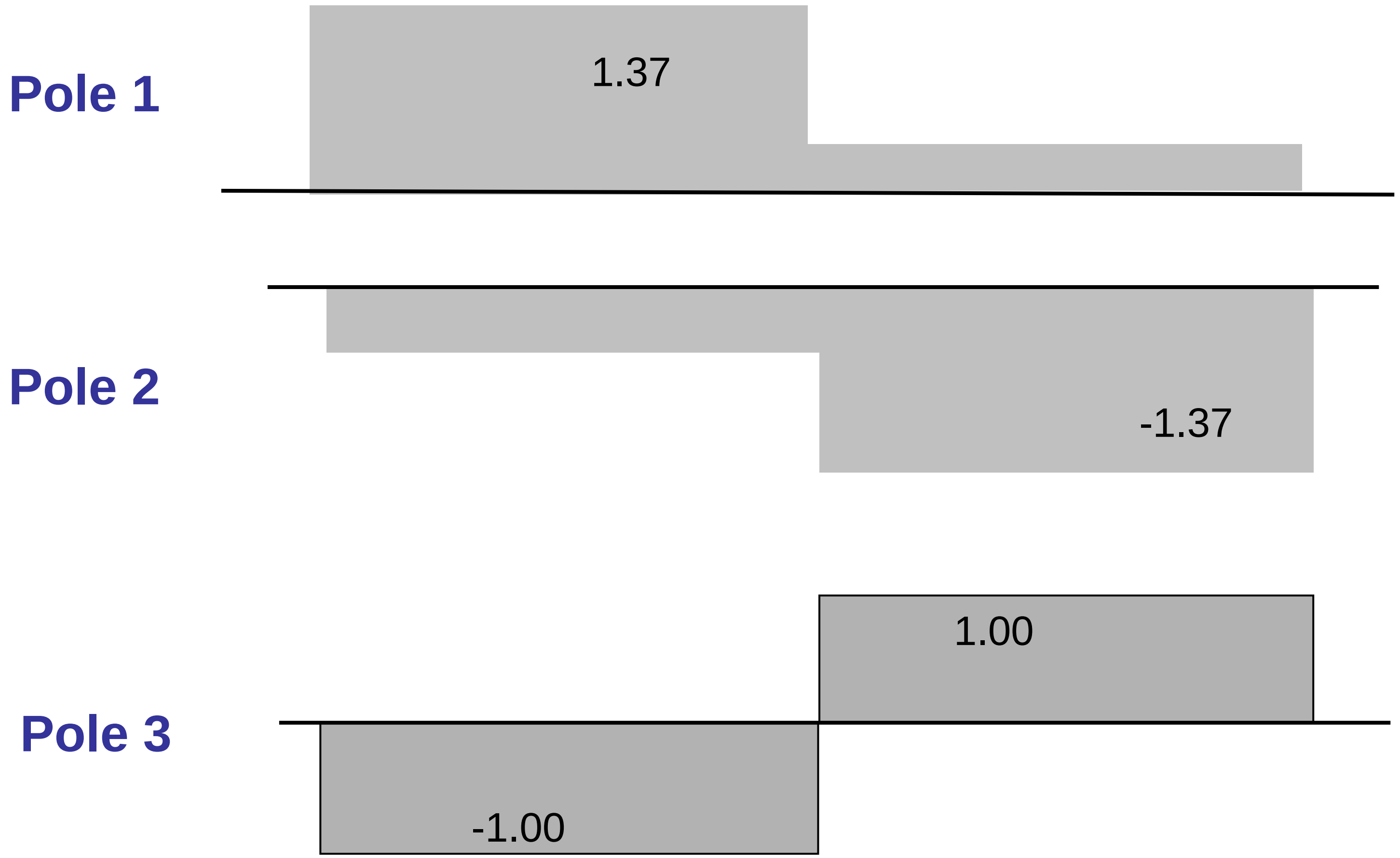
The tri-pole system:

1. **Carries 37% more power than a bi-pole on the same 3-conductor system.**
2. **Reduces losses, for the same power, by 20%**
3. **Can loose any conductor or pole, act like a bi-pole, and still transmit 73% of its maximum power.**
4. **Needs no ground return.**

-1.00

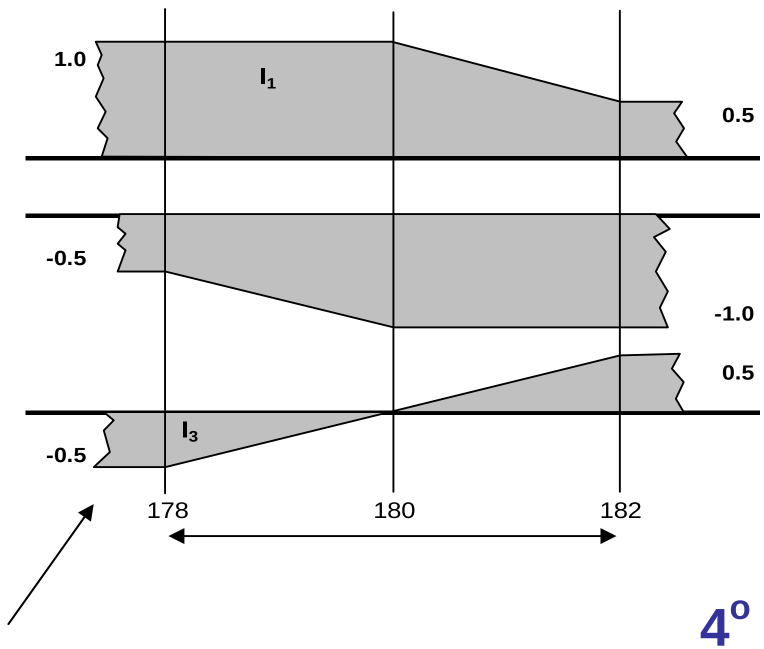
Pole 3 alternately relieves current from pole 2…then pole 1

Current- Modulated HVDC



Transitional Ramps

Ramp holds constant DC Power

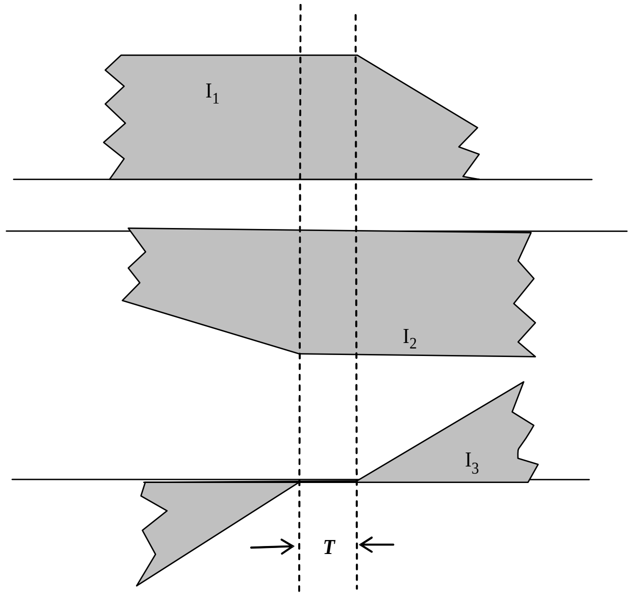


Modulating Pole regulated to hold neutral current to zero

4^o of a 6 minute period = 4 seconds

Transitional Ramps

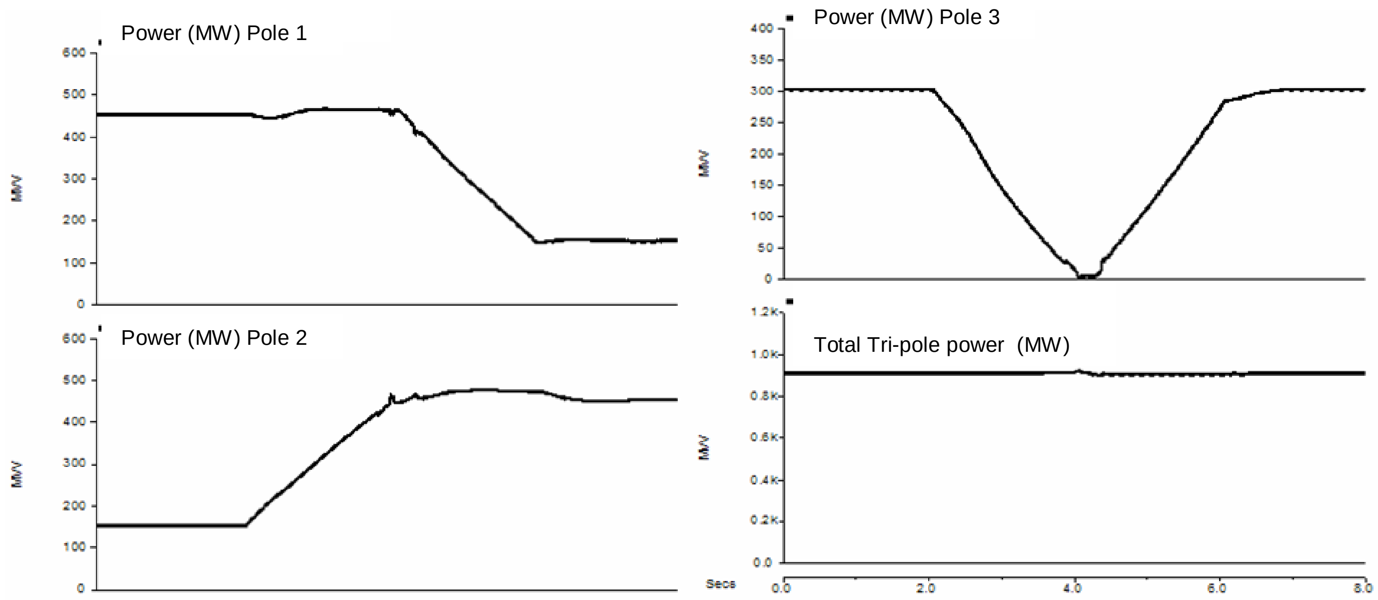
Constant-polarity currents overlap. providing time to reverse modulating pole polarity



(Detailed control simulation demonstrated by Dennis Woodford)

Transitional Ramps

Simulation (By Dennis Woodford) of the transition with example control logic:



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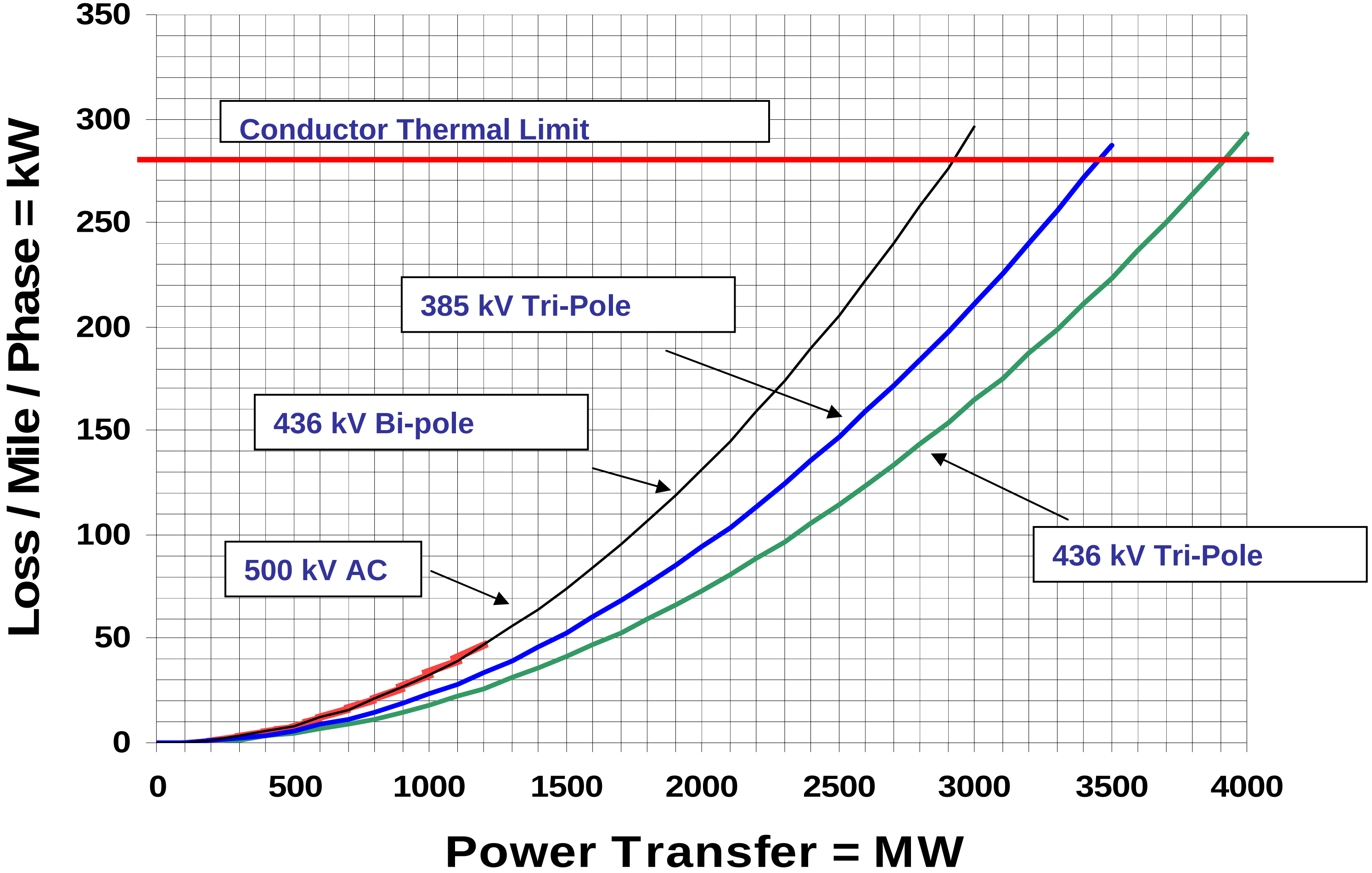
Economics - AC Conversion

Issues:

1. **Tri-pole terminals are 10% to 20% more expensive per kW**
2. **This premium is offset by higher DC/AC power ratio…lower cost per incremental kW**
3. **Tri-pole makes 37% better use of prior transmission line investment**
4. **Tri-pole losses are lower**
5. **Tri-pole has 50% higher redundancy.**

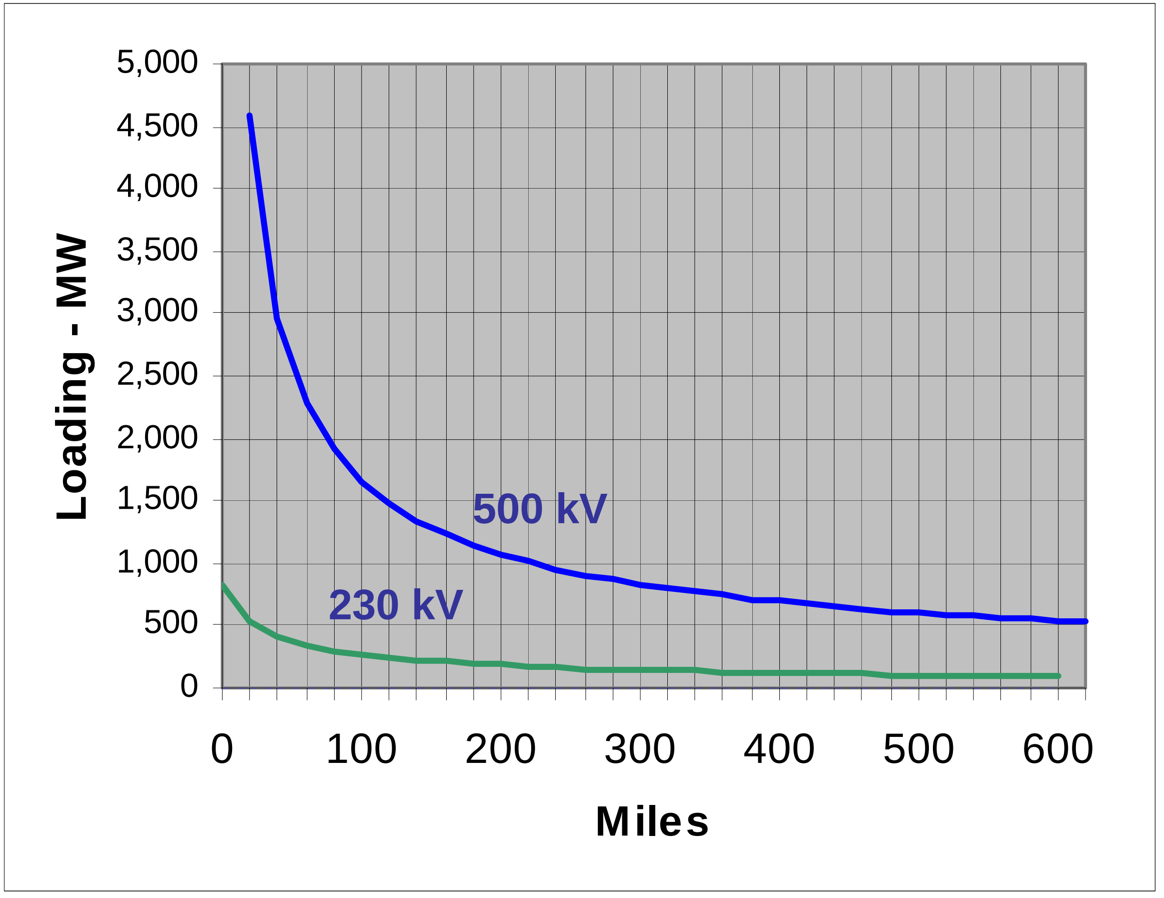
A 500 kV Conversion Example

Different ways to bring loading up to thermal capacity



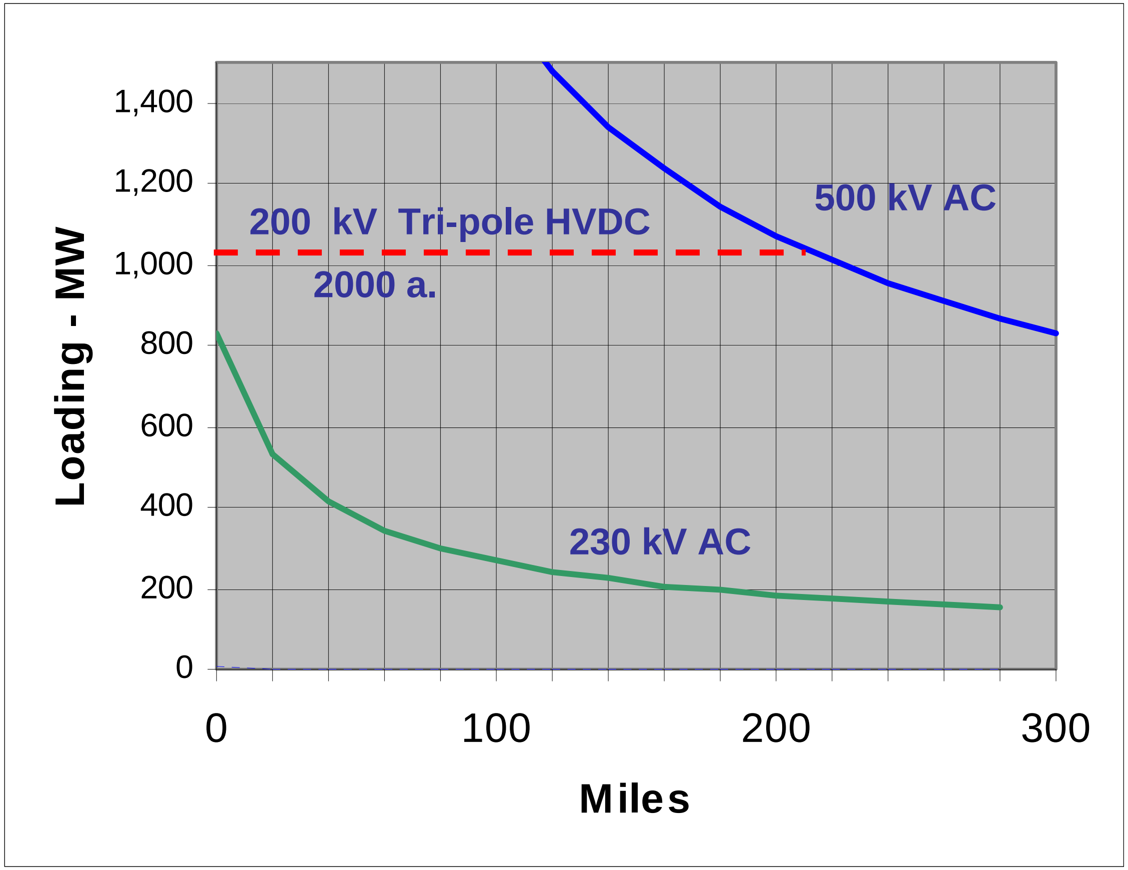
The case for "promoting" 230 kV

St. Clair Curve for 500 kV and 230 kV:

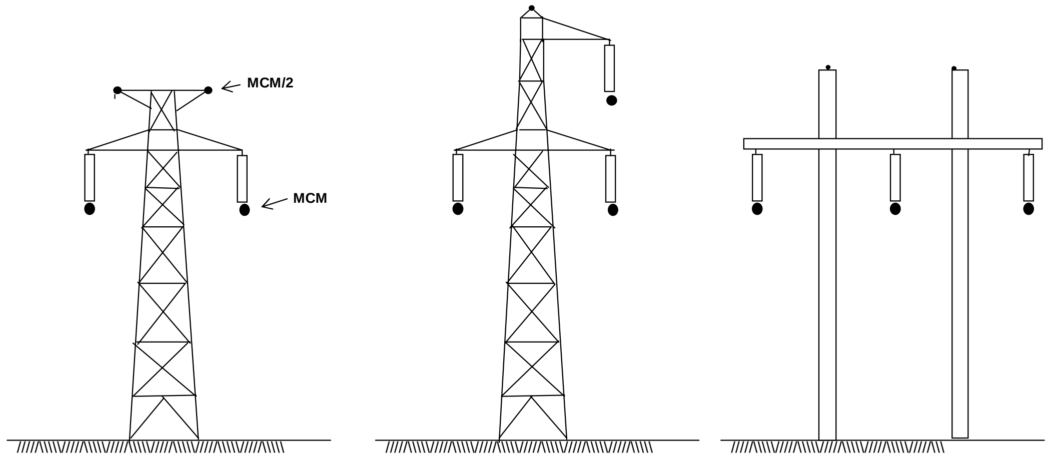


230 kV Promotion

Convert the 230 to tri-pole HVDC, feed terminals from the 500 kV Bus (If the 230 kV can be spared from its own network)



What about new HVDC circuits?

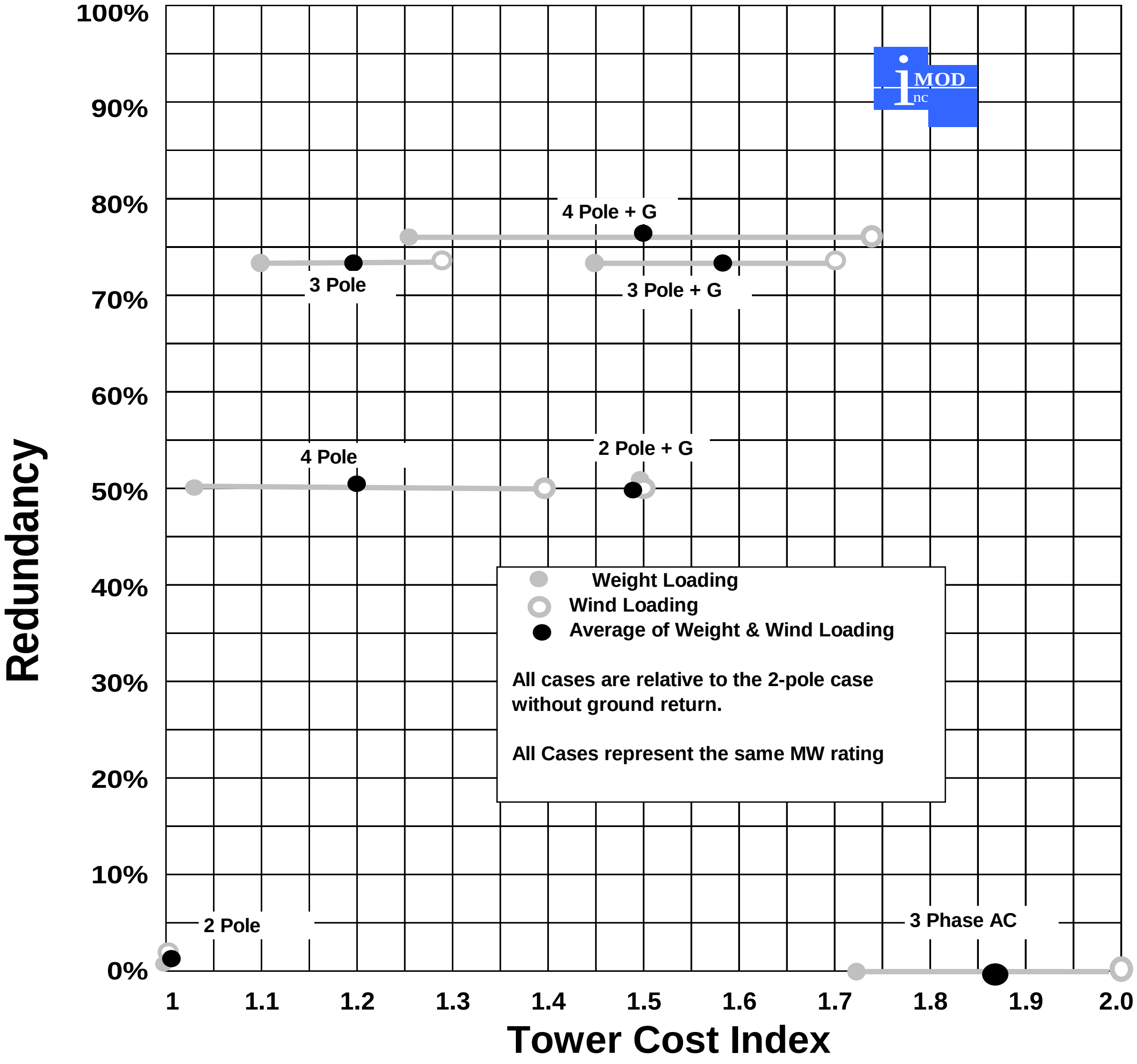


Bi-pole w Ground Return **Tri-pole without Ground Return**

MW = 1.00 R = .5 **MW = 1.37 R = .78**

All towers have approximately equal wind & weight loading….approximately the same cost in $/mile

HVDC options – all equal MW



All options suspended from a single tower.

Conclusion

- It's worthwhile reviewing the basics of conductor configuration and use…e.g. "bundled circuits"
- DC will play a bigger role in future systems. Tri-pole appears to have cost and reliability advantages both for conversion and for new lines where metallic ground return is used.
- Higher voltage bi-directional valves are needed both multi-terminal and tri-pole applications.
- Reliability criteria need to better accommodate internal circuit redundancy.