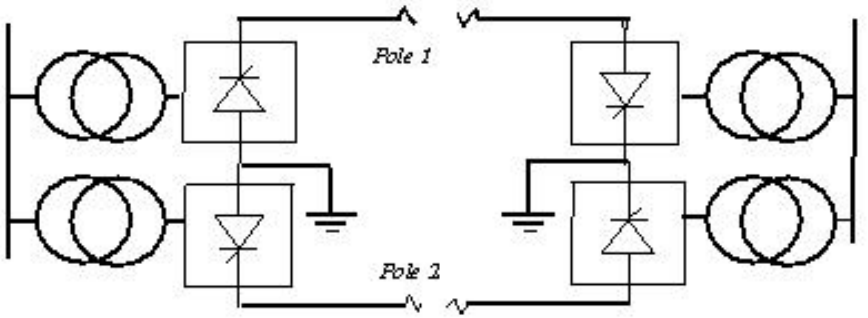
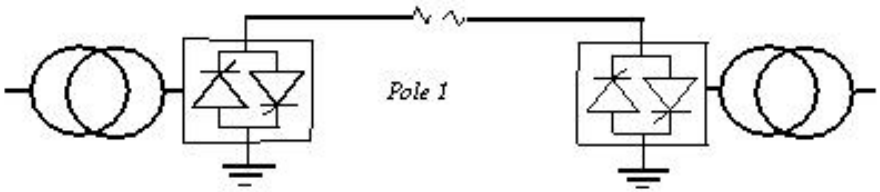
Tripole Configuration

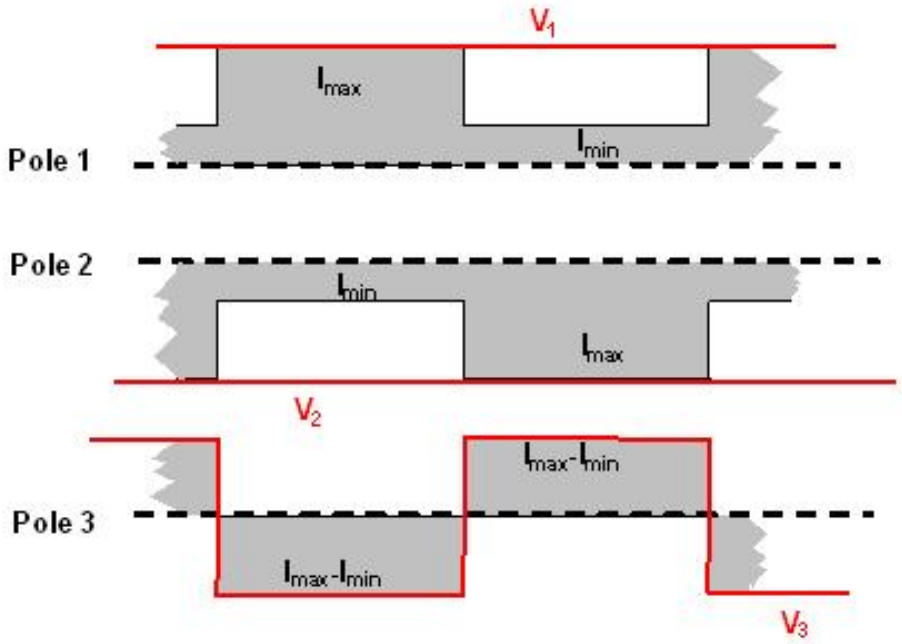
A conventional bipole for conductors 1 & 2 ….



A Monopole with back-to-back valves in pole 3



Asymmetrical Modulation

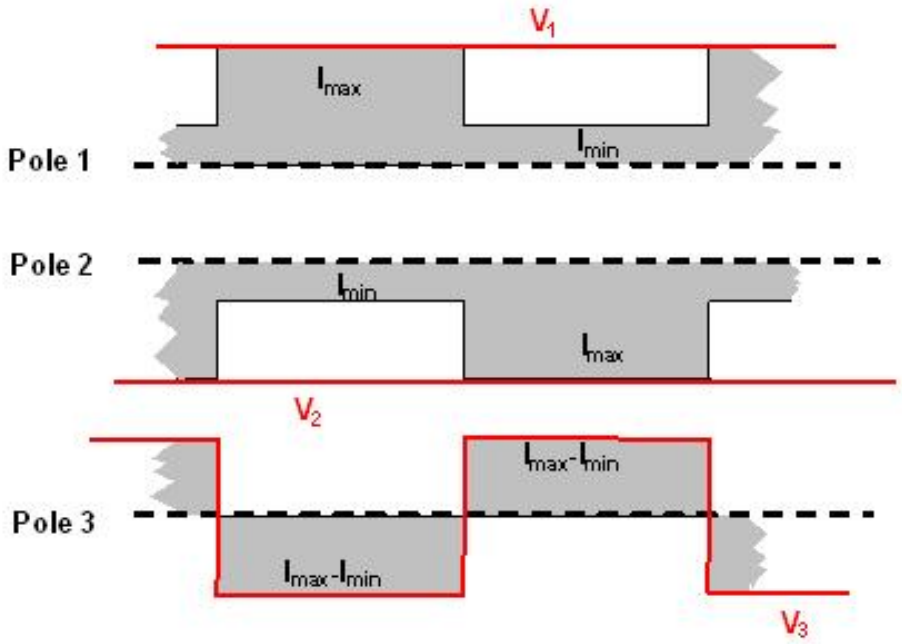


$$\frac{P_{tripole}}{P_{bipole}} = 1.37$$

$$R = .73$$

$$R' = .84$$

Asymmetrical Modulation



$$\frac{P_{tripole}}{P_{bipole}} = 1.37$$

$$R = .73$$

$$R' = .84$$

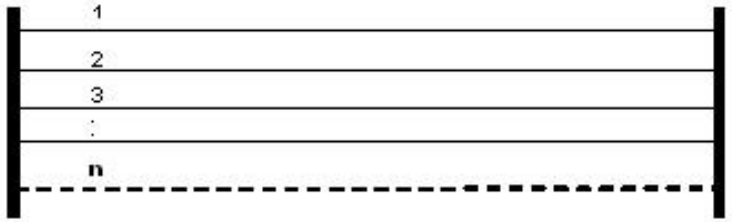
System (n-1) context is a critical to dc conversion economics

$$\text{DC Effectiveness} = \frac{\text{Increase in path loading (MW)}}{\text{DC Terminal Rating}}$$

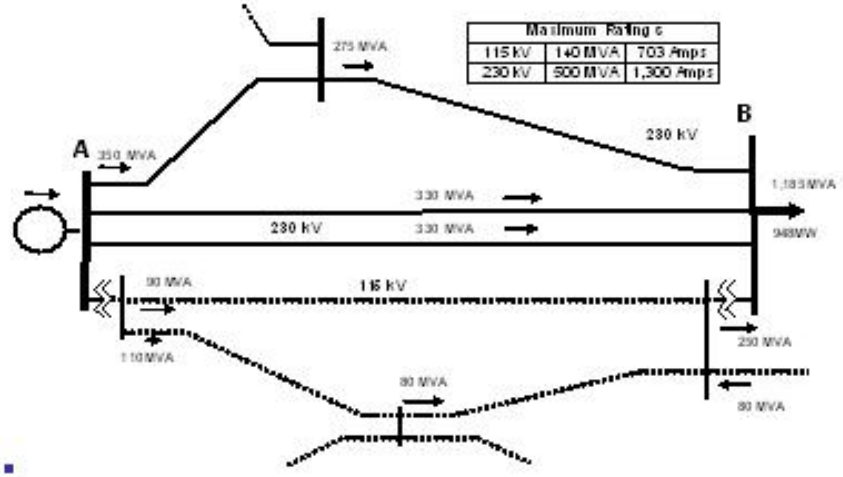
AC to DC Conversion Leverage

Preliminary Studies on:

1. An idealized n-circuit configuration



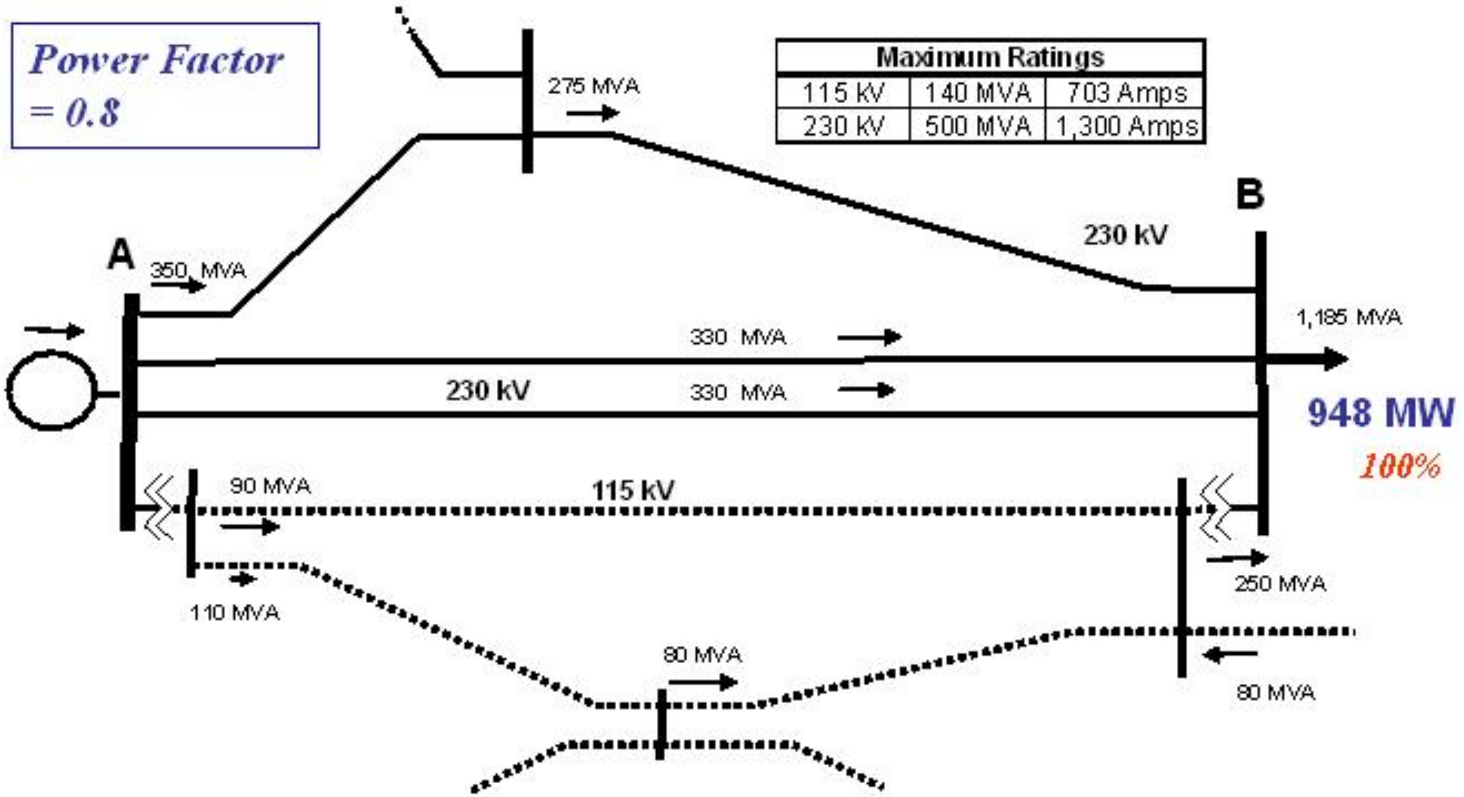
2. A simplified system segment



Show the following:

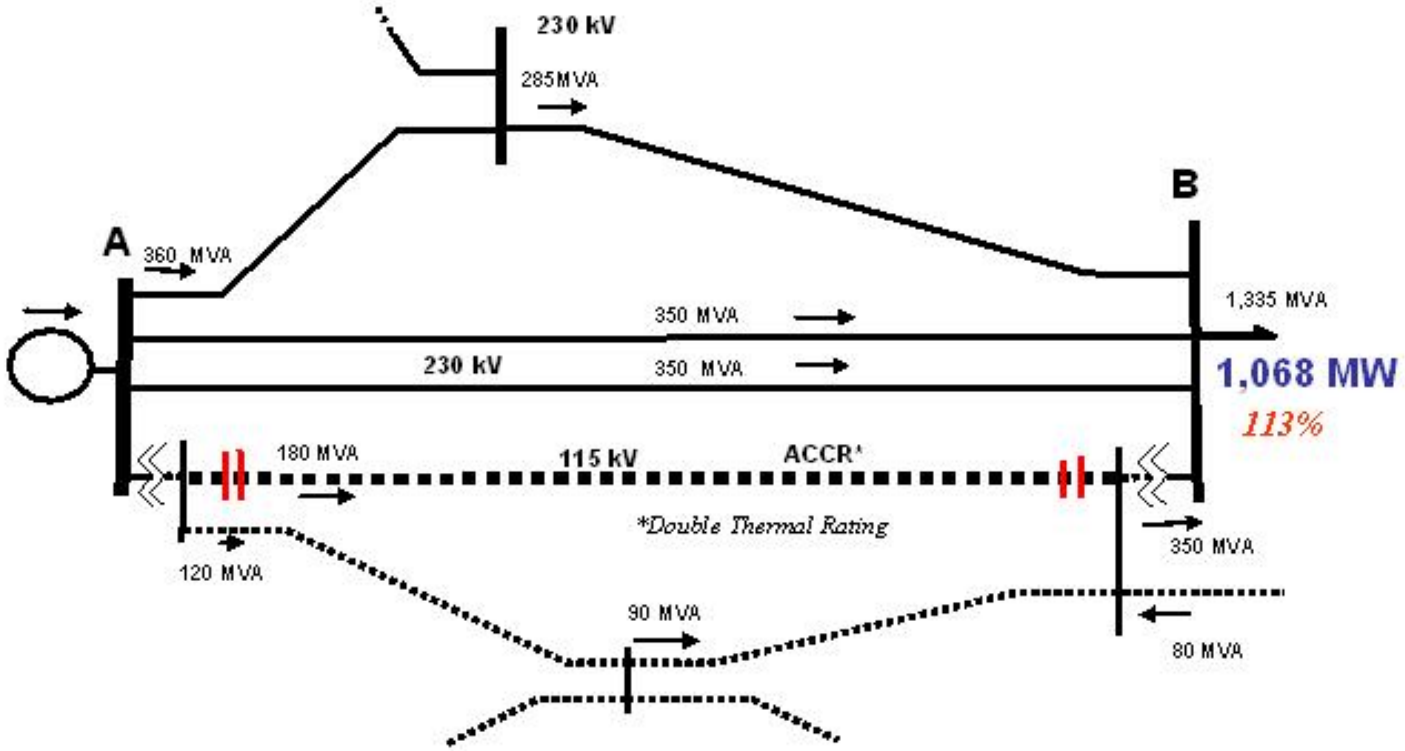
Leveraging Ampacity Increase

Challenge: Maximize MW transfer from A to B, respecting (n-1) criterea



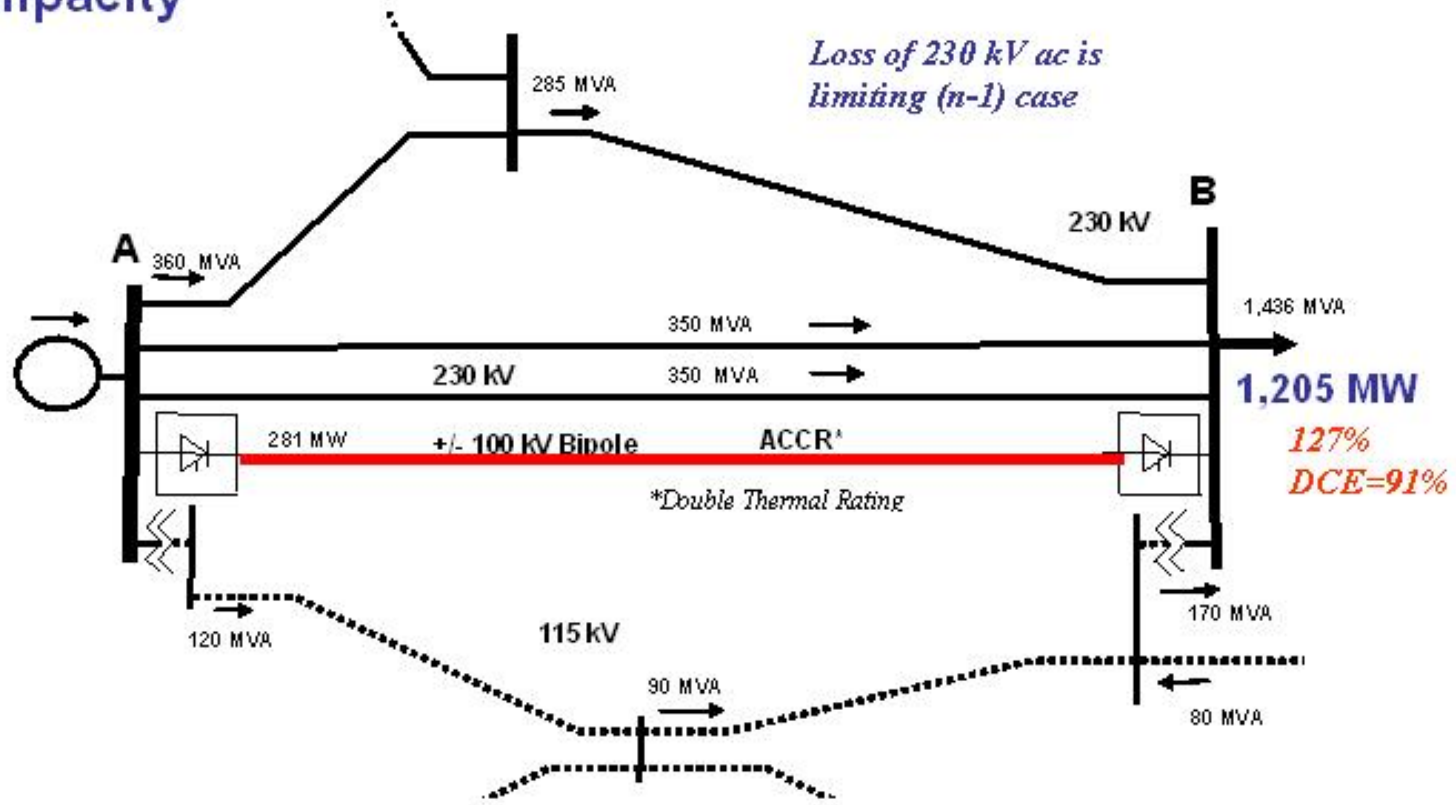
Leveraging Ampacity Increase

FACTS can bring the ACCR up to the same fraction of full rating as before…not more.



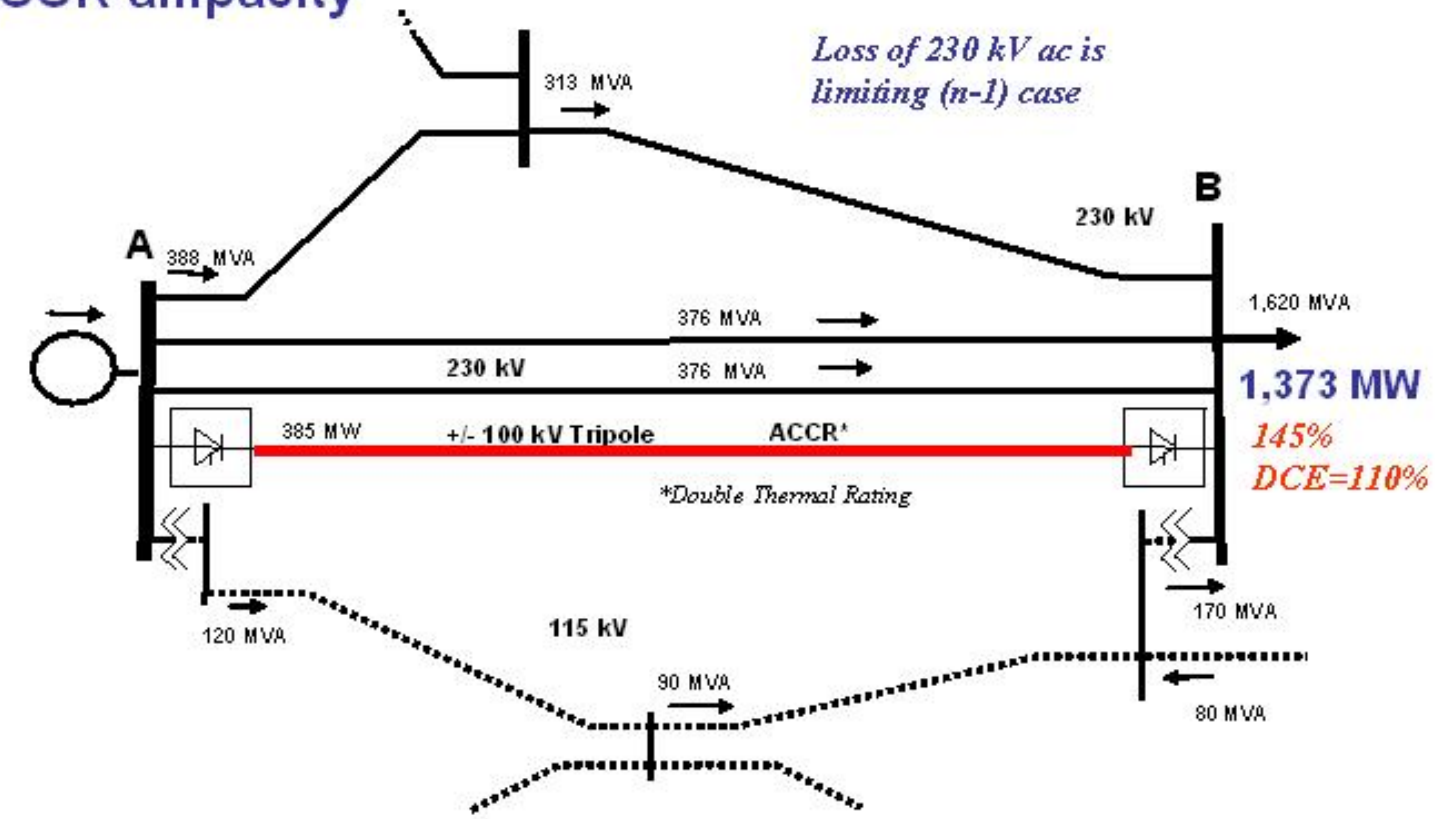
Leveraging Ampacity Increase

Conversion of the 115 to Bipole HVDC uses full ACCR ampacity



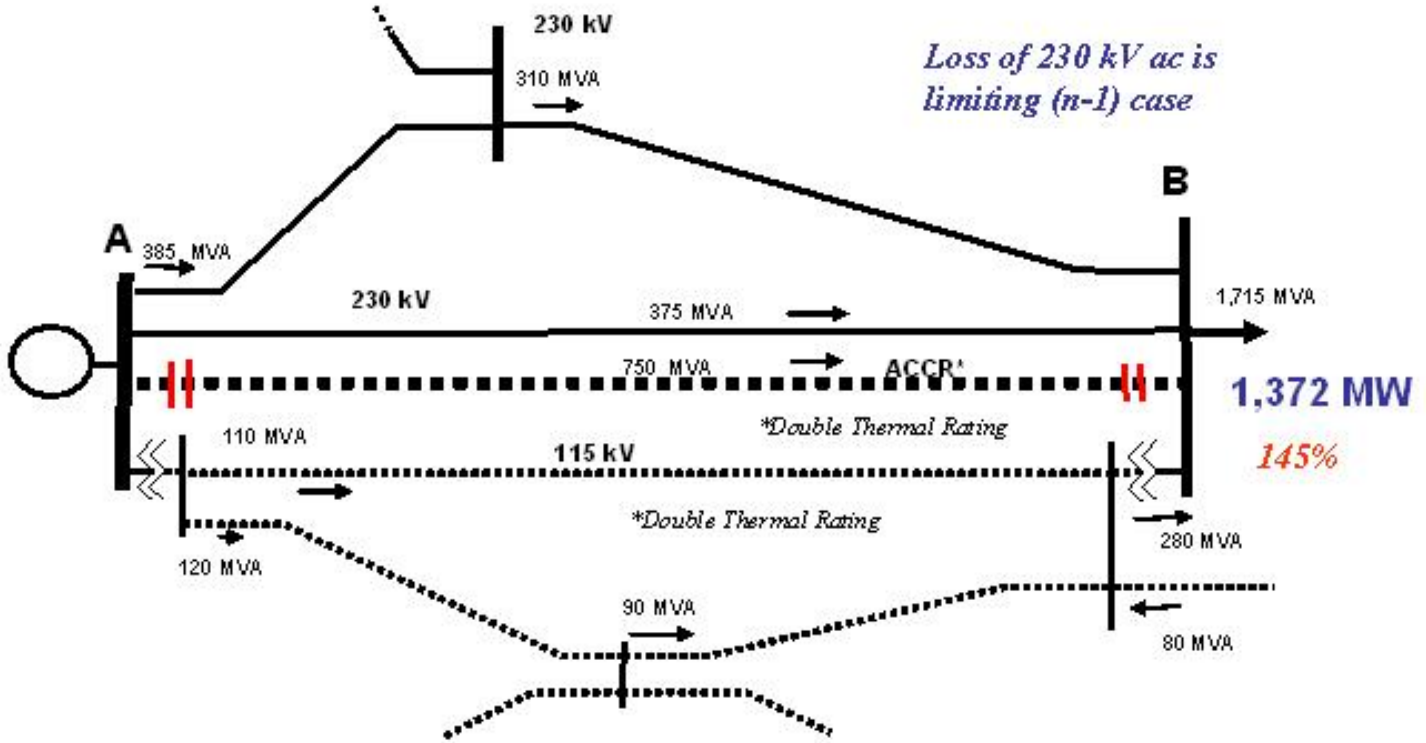
Leveraging Ampacity Increase

Conversion of the 115 to Tripole HVDC, again using full ACCR ampacity



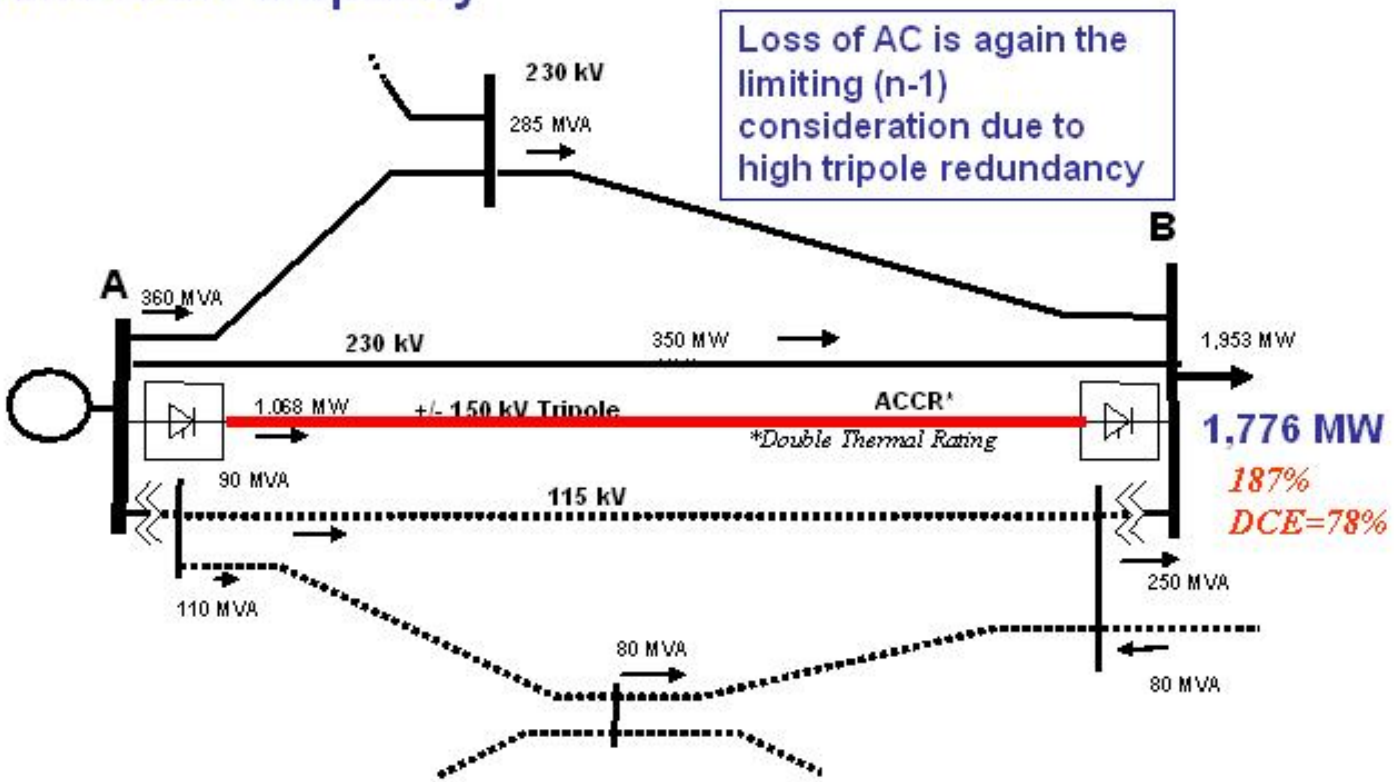
Leveraging Ampacity Increase

FACTS again allow doubling the rating of the 230 kV line



Leveraging Ampacity Increase

Conversion of the 230 kV to Tripole HVDC, again using full ACCR ampacity



AC to DC Conversion Leverage

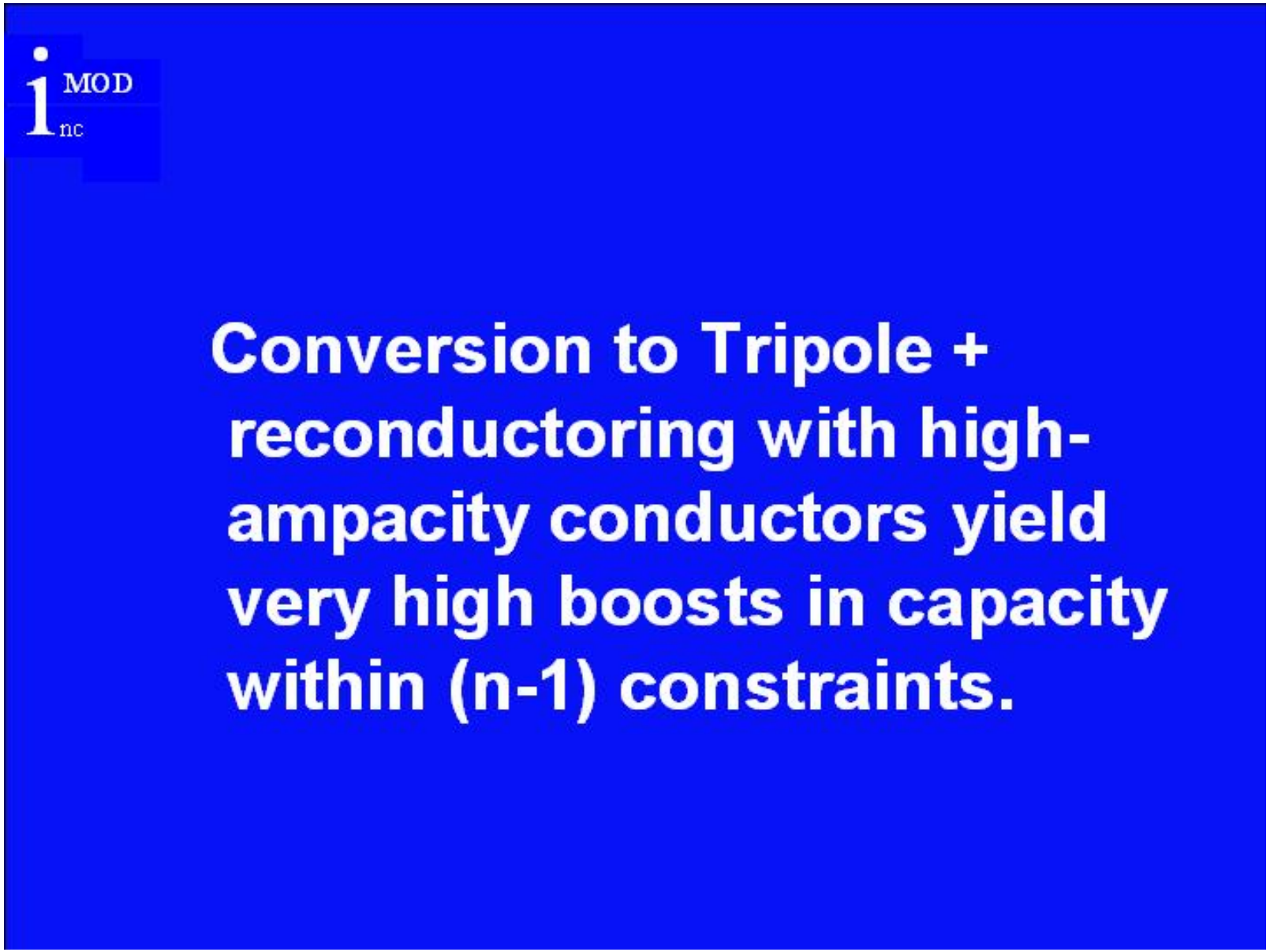
1. For conversion of circuits which are weak compared to parallel lines, e.g. a 230 kV line underlying a 500 kV interconnection

- *X% increase in DC overload rating will usually offset an X% reduction in base rating*
- *DC overload capacity is helpful only if controls automatically call on overload rating*
- *DC Conversion can achieve substantially higher path increase than FACTS solutions.*
- *DCE for tripole is in the range of 80%*

AC to DC Conversion Leverage

2. For conversion of circuits which are strong compared to parallel lines, e.g. a 345 kV line overlying a 138 kV system

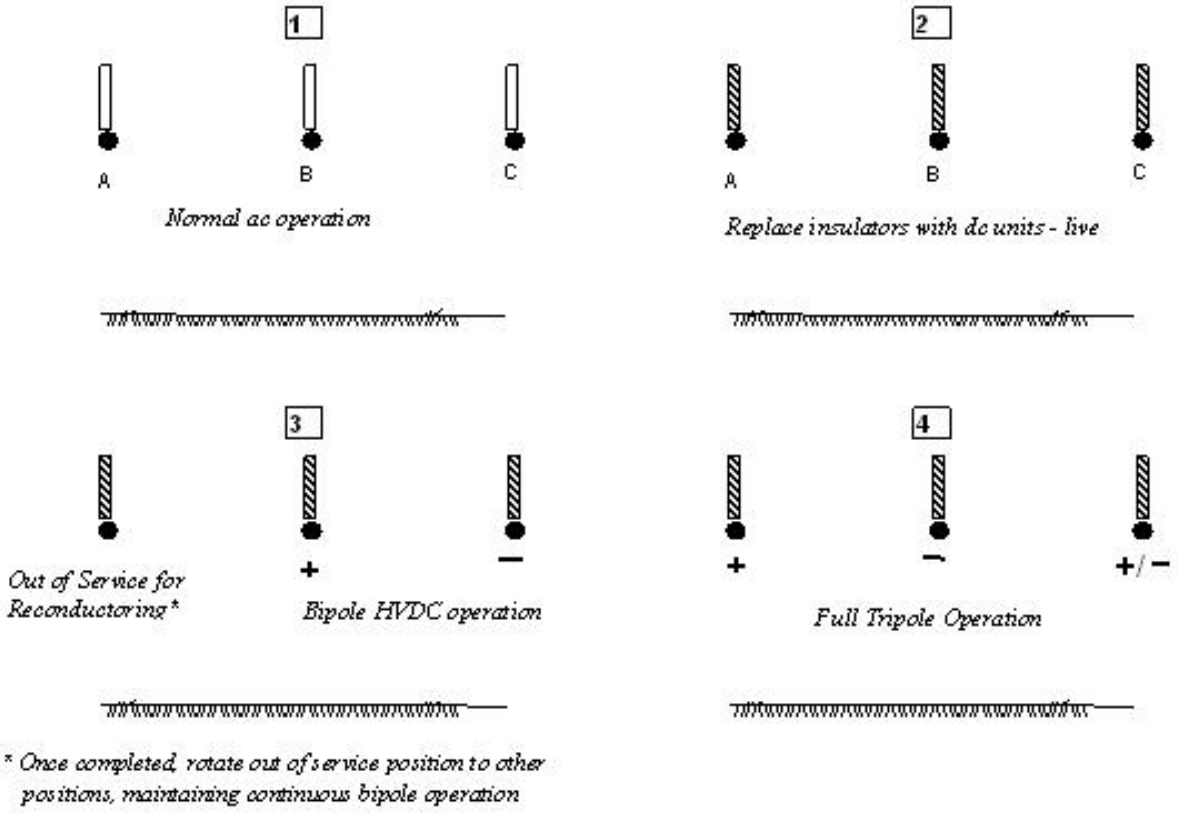
1. *Redundancy is of primary importance in (n-1)-limited transfer*
2. *X % increase in redundancy will offset –X% reduction in dc rating.*
3. *Tripole's high redundancy allows substantially higher ratings than bipole, while still satisfying (n-1) criteria*
4. *DCE for tripole is typically ~85% … for bipole ~55%*


MOD
nc
Conversion to Tripole + reconductoring with high-ampacity conductors yield very high boosts in capacity within (n-1) constraints.

Tripole and Reconductoring

1. *FACTS devices exploit ampacity advantage only up to prior % margin between operating and maximum rating.*
2. *DC conversion multiplies the advantages of ampacity improvement and ac-to-dc transfer increase…within (n-1) constraints*
3. *The tripole /composite option can achieve a total path MW flow increase several times greater than an ac FACTS-based solution*
4. *Tripole's redundancy advantage is critical to high DCE. The latter, combined with reconductoring, can exceed 100%*
5. *Over one third of the net path flow increase may be by virtue of higher allowable loading of parallel circuits.*

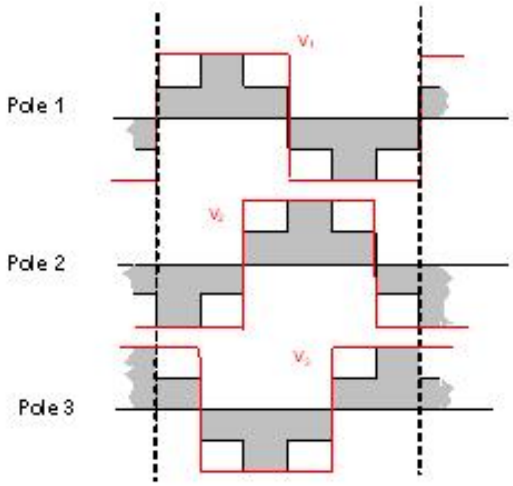
Non-disruptive conversion to DC

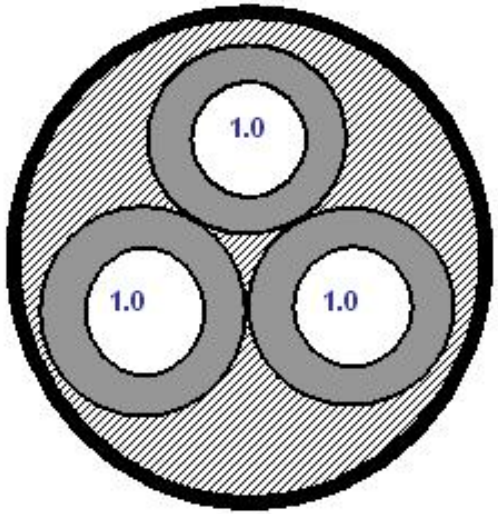



MOD
nc
Tripole Cable
Applications

MOD inc

Cable Conversion





Symmetrical Modulation allows dc loading of all three conductors at full thermal rating

Power = 1.414 time that achieved with bipole conversion

Redundancy = .71 to .90, depending on overload capability

MOD inc

DC on AC-designed xlpe cable?

XLPE:

The voltage reversal period of tripole HVDC (like 60 Hz) is very short compared to ion migration time…yet essentially dc insofar as void ionization is concerned.

Tripole HVDC may allow standard xlpe cable to operate at kV/mm stress levels typical of dc.

Configuration Comparison

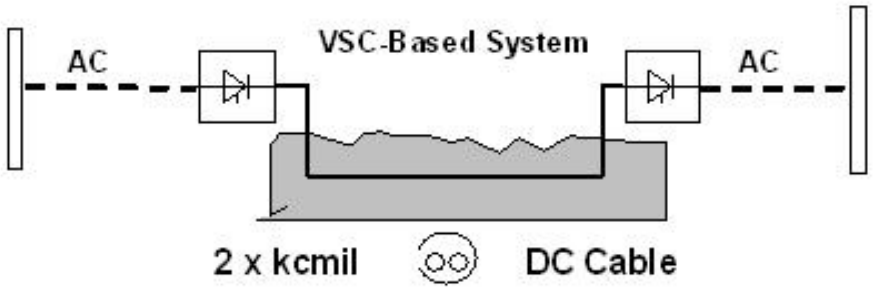
Power = 1

Redundancy = 0

Total kcmils = 1.00

Dead Load Pickup? Yes

Transition to OH? No



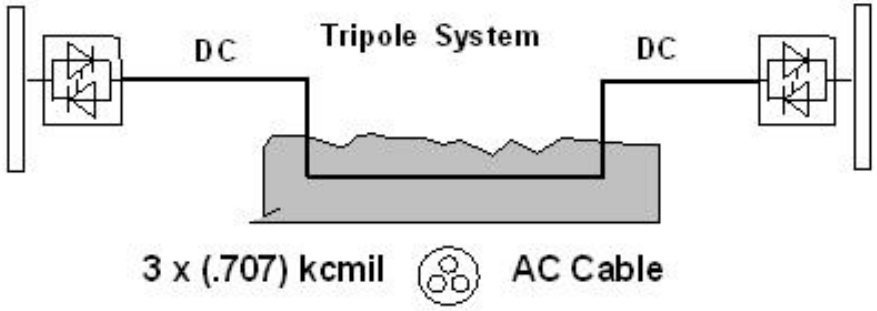
Power = 1

Redundancy = 70%

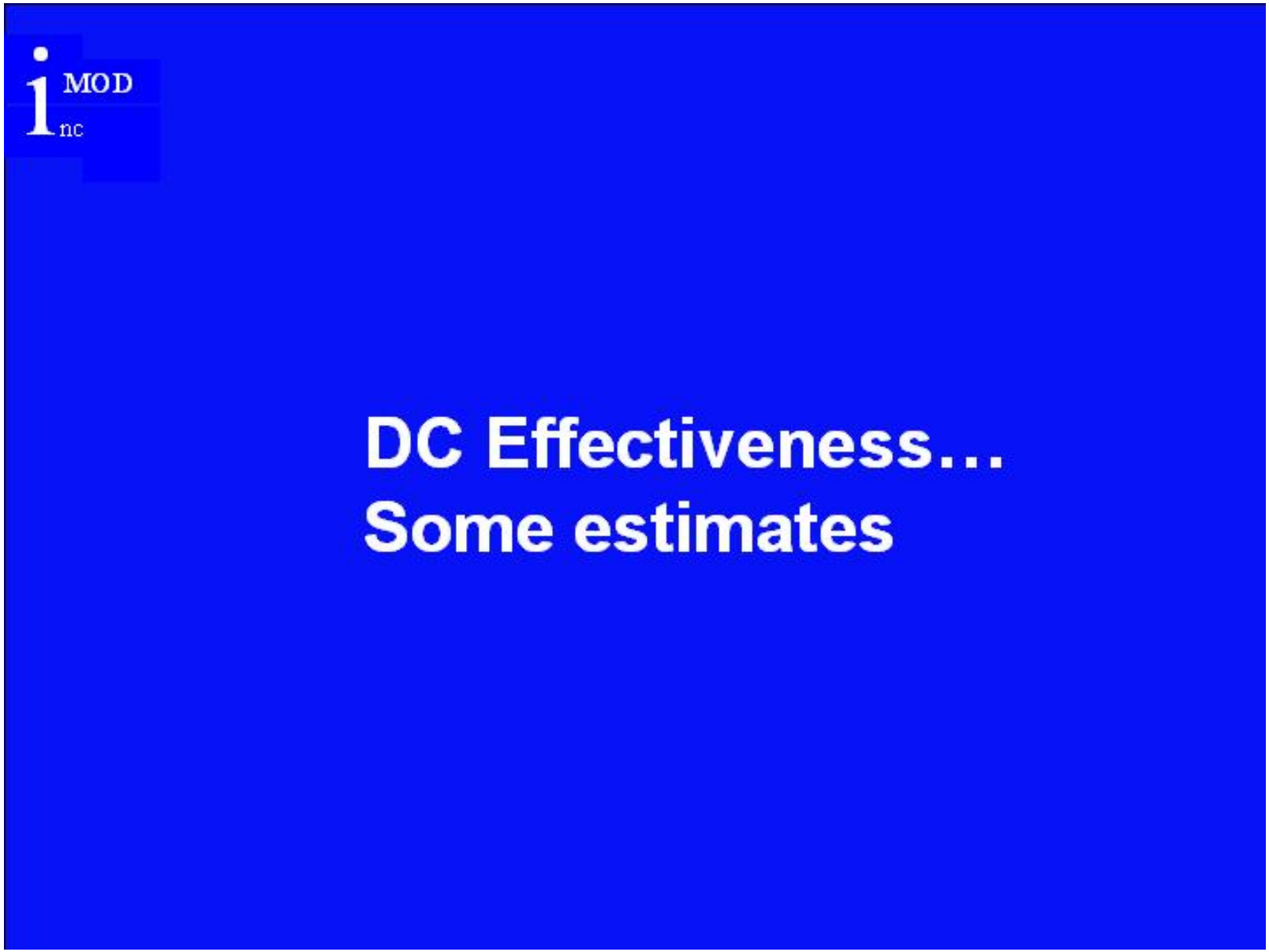
Total kcmils = 1.06

Dead Load Pickup? Maybe

Transition to OH ? Yes



Relative Cost ?

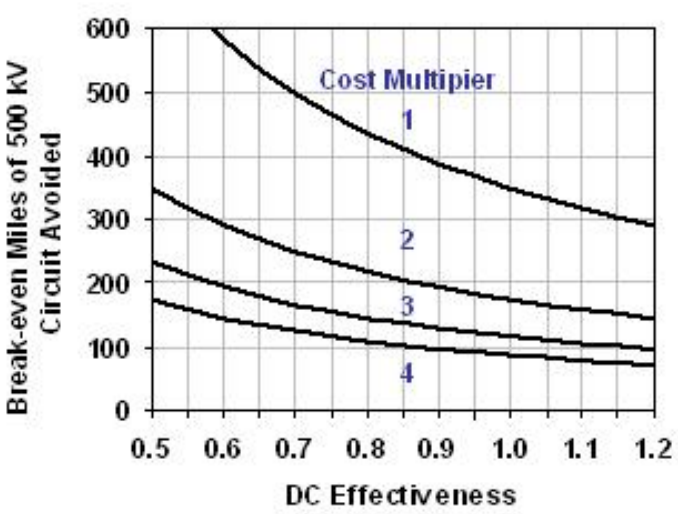

iMOD
Inc
DC Effectiveness…
Some estimates

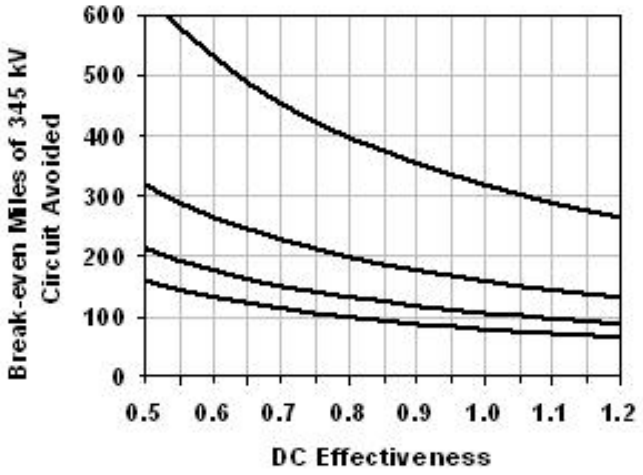
Assumptions:

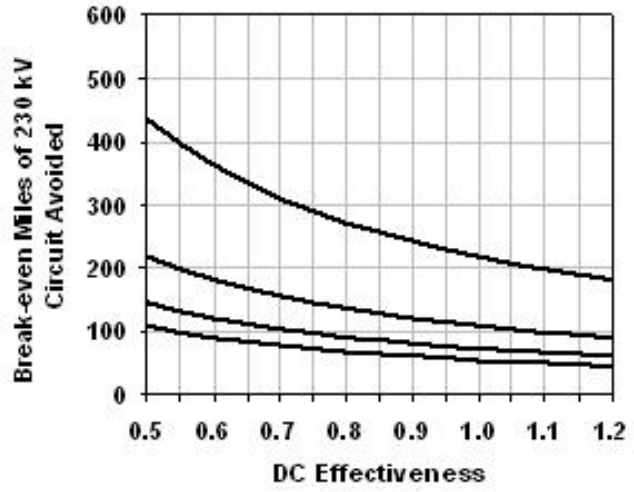
Ratio of allowable to Max loading	70%
Power Factor	80%
Cost per MW for two terminals	$300,000

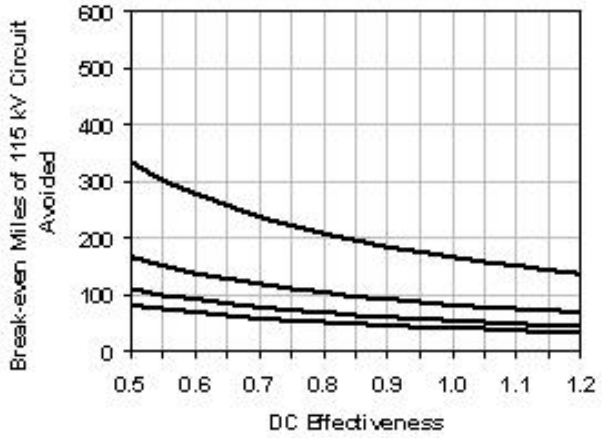
1	2	3	4	5	6	7
kV	Base Cost $(000)/mile	Max Amperes	Max MVA	Oper MVA	Oper MW	2/6 $/MW-Mi
500	$1,000	2,400	2078	1,455	1,164	$859
345	$600	1,900	1135	795	636	$944
230	$400	1,300	518	363	290	$1,379
115	$200	1,000	199	139	112	$1,793

Consider Multiples of 1, 2, 3, and 4 against the above cost


Break-even Miles of 500 kV Circuit Avoided
600
500
400
300
200
100
0
Cost Multipier
1
2
3
4
0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2
DC Effectiveness


Break-even Miles of 345 kV Circuit Avoided
600
500
400
300
200
100
0
0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2
DC Effectiveness


Break-even Miles of 230 kV Circuit Avoided
600
500
400
300
200
100
0
0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2
DC Effectiveness


Break-even Miles of 115 kV Circuit Avoided
600
500
400
300
200
100
0
0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2
DC Effectiveness

Summary

1. System context is critical in economic assessment of dc line conversion and in optimizing station design.
2. The rating increases achievable by reconductoring and by DC conversion multiply and can yield very high boosts in capacity within (n-1) constraints
3. A substantial fraction of total path increase may be on circuits other than the one that's reconductored
4. DC conversion may be economic in high transmission cost regions.

Summary

5. An ac line may be reconductored and converted to dc with minimum disruption to service.
6. In conversion of a three phase cable to dc, the tripole achieves 41% more transfer than a bipole
7. Symmetrical tripole may allow use of standard xlpe cable to be used at dc stress levels