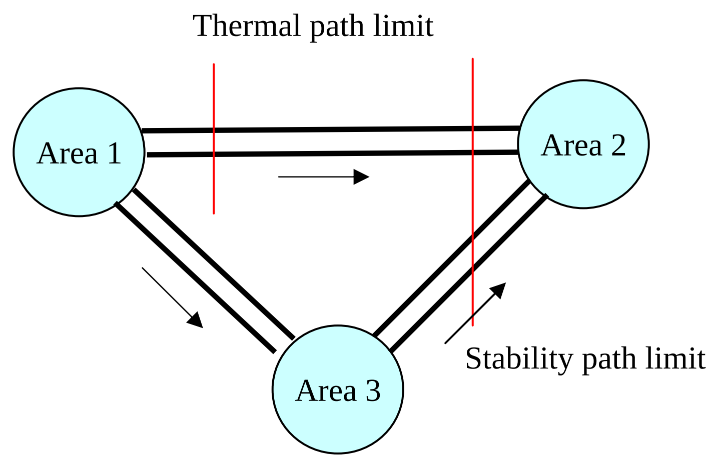
Topics

- Comparison of HVDC & EHV Transmission
  - Conceptual HVDC & EHV Comparison
  - Example Economics: Capital Costs, Losses

Transmission Constraints

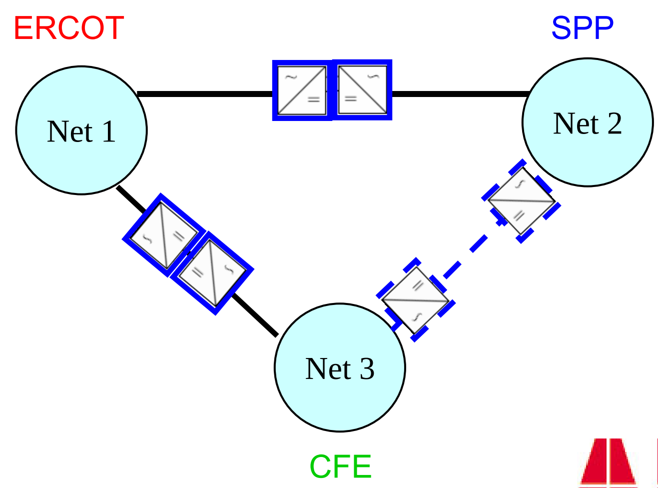
Network path limits:

- Thermally constrained
- Stability constrained (voltage, angle)
- Parallel flow issues
- Constraints result in sub-optimal dispatch

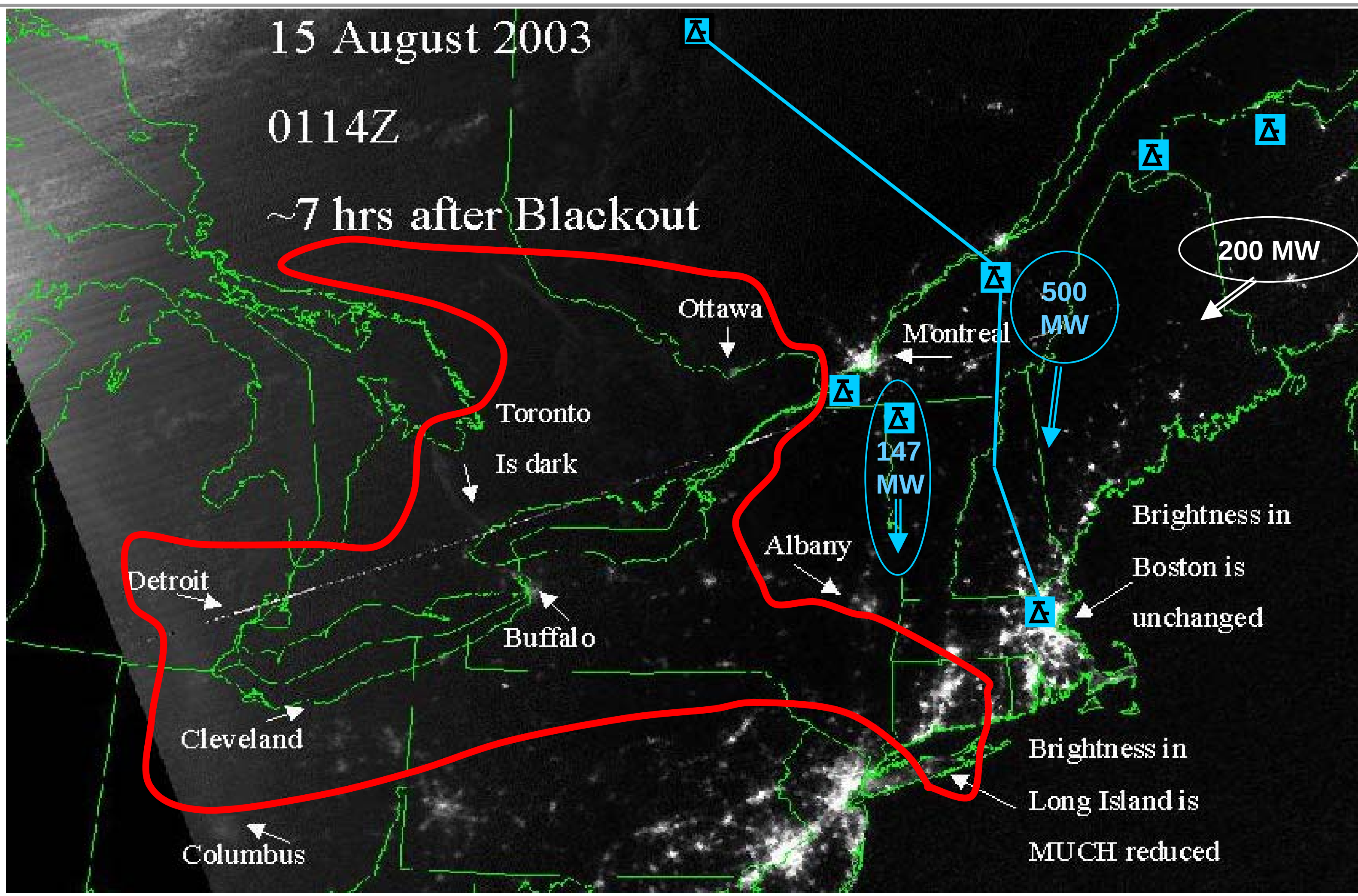


Asynchronous Ties:

- Limited by converter capacity and local network characteristics
- Provide mutual assistance
- Prevent cascading outages, 'firewall'
- Allow incremental interconnections
- No inadvertent flow
- Improve reliability



Blackout Aug 14, 2003 – Power flow to Northeastern USA



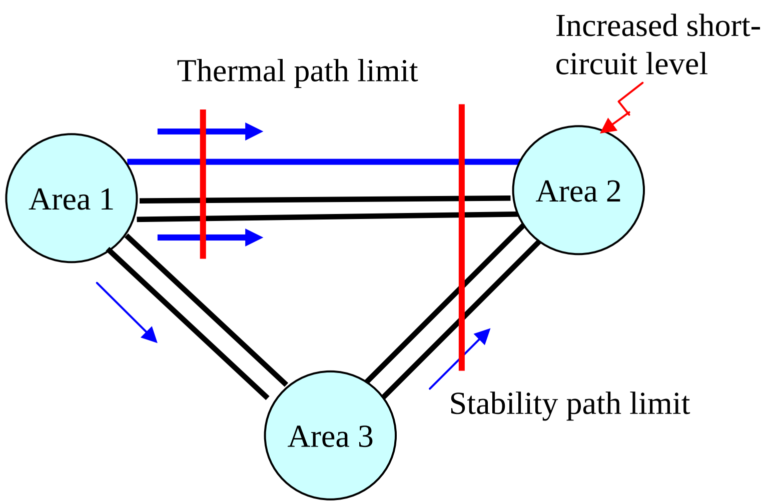
Source: Public Power Weekly, August 25, 2003

Blackout ‘book-ended’ by strong grid to south (back-stop), weak grid to east (shear pin) and asynchronous grid to the northeast (firewall) – no SPS or RAS

Transmission Expansion – EHV v HVDC

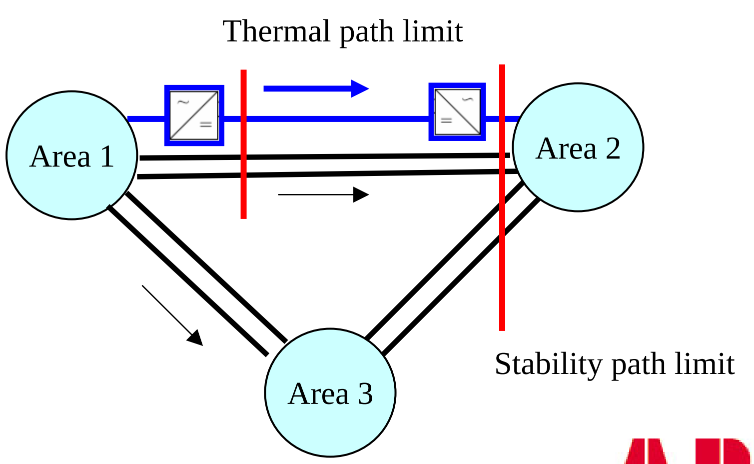
Raise path limits by new AC line:

- No direct flow control (generation dispatch)
- Raise thermal limit
- Raise stability limit (voltage, angle)
- Parallel flow issues
- Increased short circuit levels
- Distributed reactive power demand
- Single circuit or double circuit configuration
- Corona & audible noise issues with higher voltages at altitude



Raise path limits by new DC line:

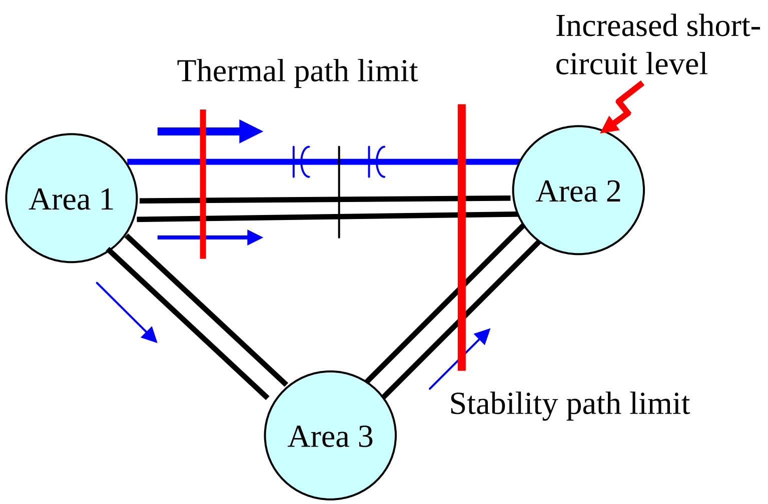
- Flow control adds operational flexibility
- Raise thermal limit
- Raise stability limit (voltage, angle)
- No parallel flow issues due to control
- No increase in short circuit levels
- Lumped reactive power demand at terminals
- Double circuit (bipolar configuration)



Distance Effects

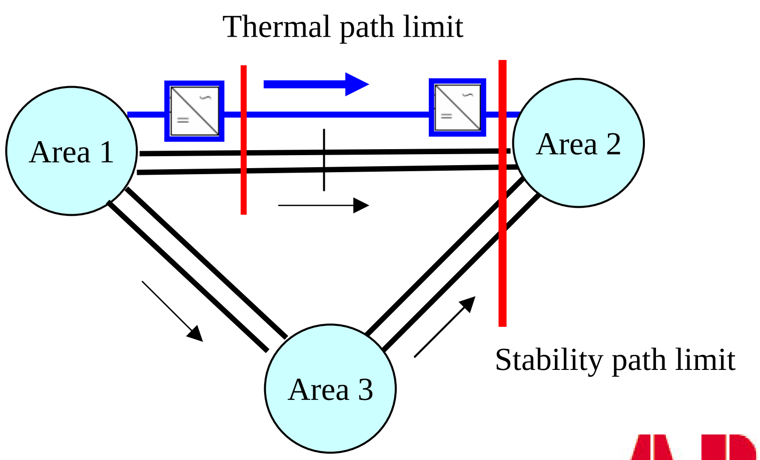
New AC line:

- Need for intermediate switching stations
- Lower stability limits (voltage, angle)
- Higher reactive power demand with load
- Higher charging at light load
- Parallel flow issues more prevalent and widespread
- Increase stability limits & mitigate parallel flow with series compensation (FACTS)
- Thermal limit remains the same



New DC line:

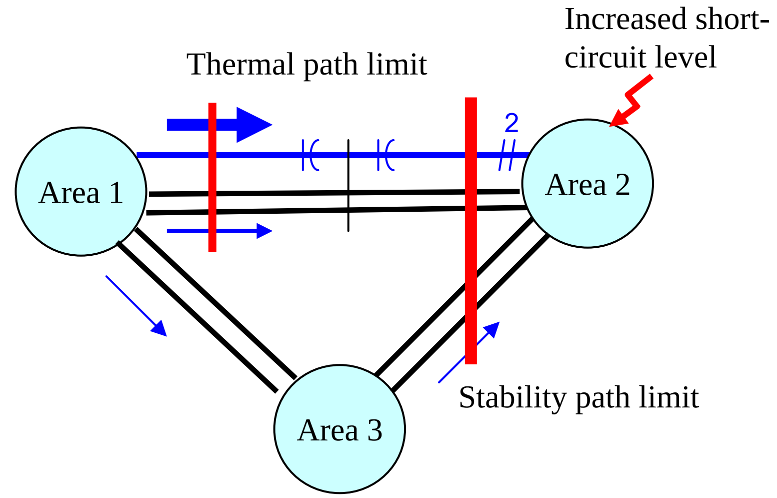
- No distance effect on stability
- Raise stability limit (voltage, angle)
- No need for intermediate station
- No parallel flow issues due to control
- No increase in short circuit levels
- No increase in reactive power demand



Staged Transmission Expansion

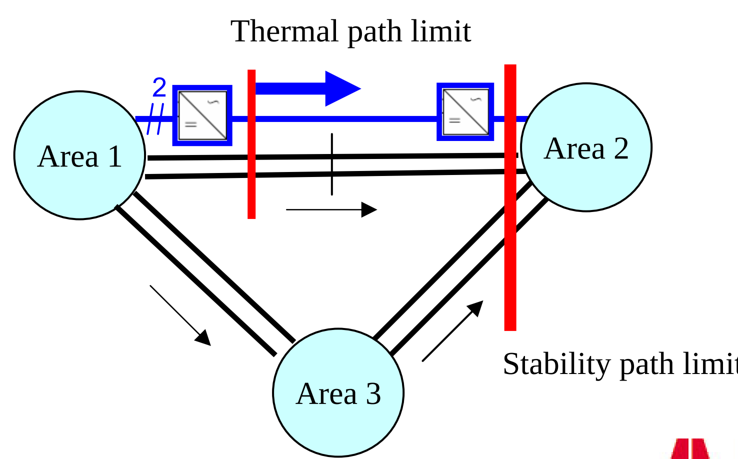
Add second AC line:

- Increases thermal limit
- Increases stability limits (voltage, angle)
- Increase stability limits & mitigate parallel flow with series compensation (FACTS)
- Higher short circuit levels
- Improves reliability
- Two circuits



Add second DC line:

- Increases thermal limit
- Increases stability limits (voltage, angle)
- Improves reliability
- Four circuits (bipolar configuration)
- Add converter capacity as complement or alternative to new line (higher current or voltage)



Staged Transmission Expansion HVDC

Stage 1:

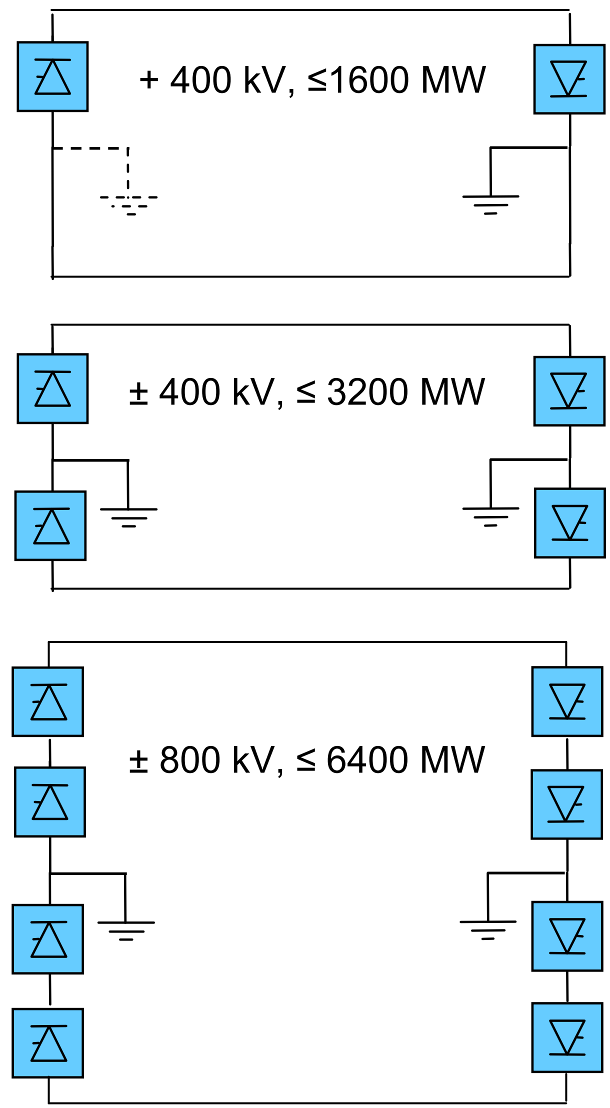
- Build bipolar transmission line
- Insulate one pole to 400 kV, second pole as neutral
- Add up to 1600 MW converter at each end

Stage 2:

- Raise insulation on second pole to 400 kV
- Add up to 1600 MW converter at each end on second pole

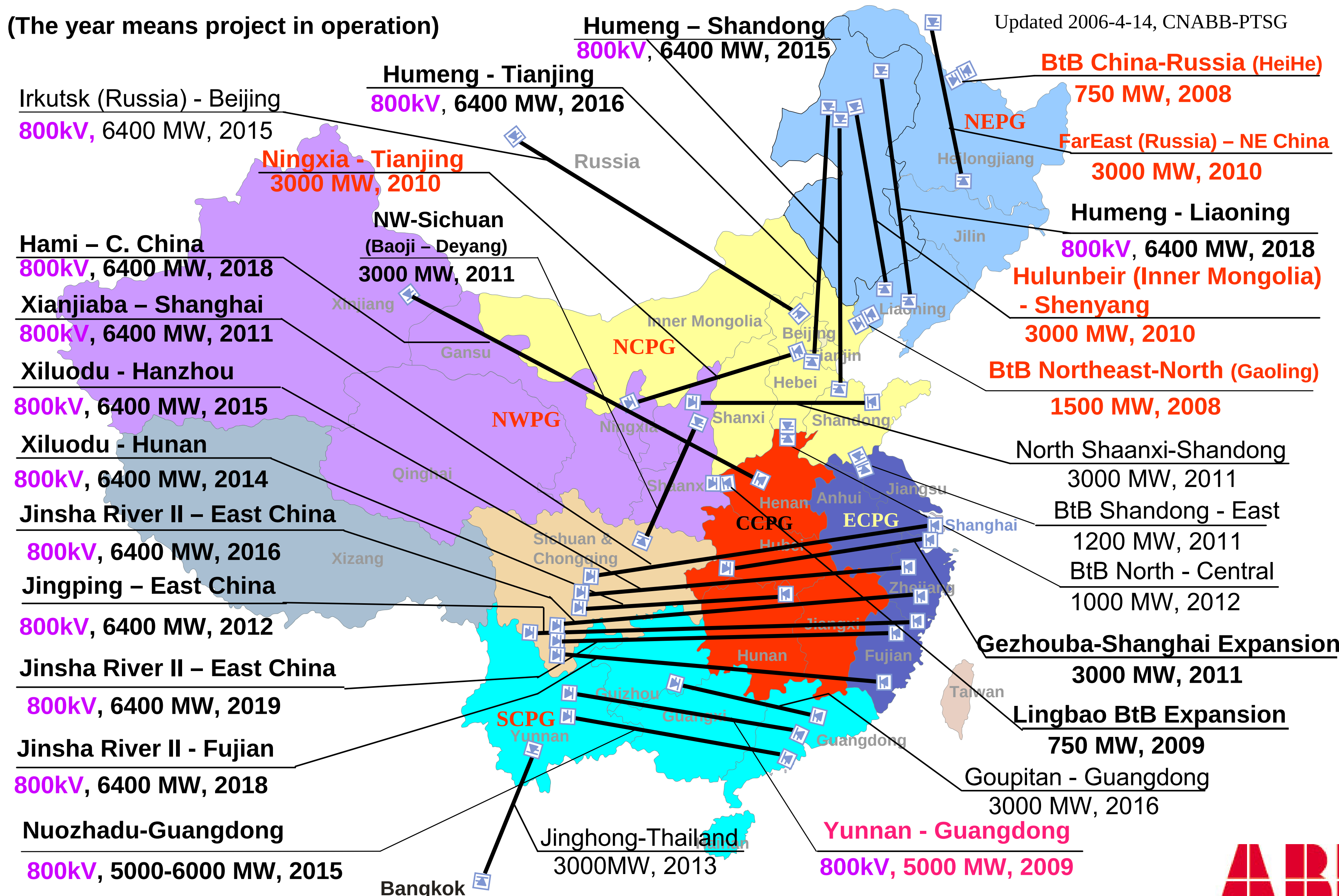
Stage 3:

- Raise insulation on both poles to 800 kV
- Add up to 1600 MW series-connected converter at each end on each pole
- Power doubled, no increase in losses



Planned HVDC Projects by 2020 in China

(The year means project in operation)

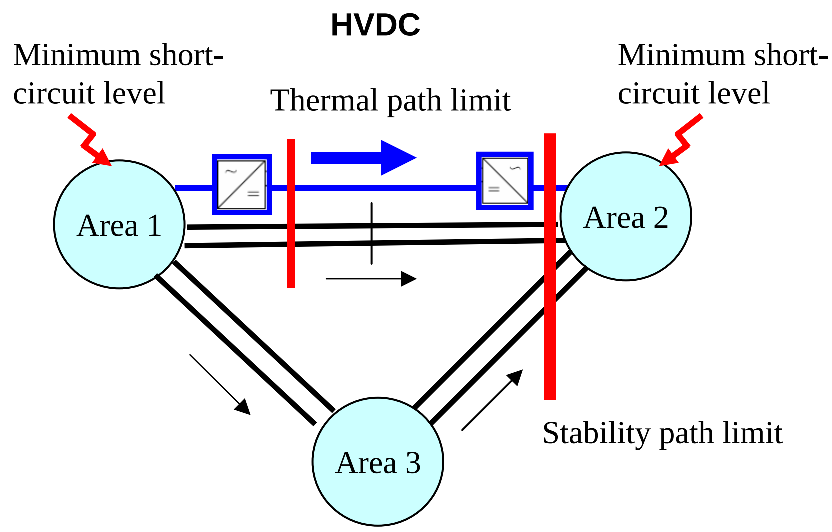


ABB

Transmission Expansion – HVDC v HVDC Light

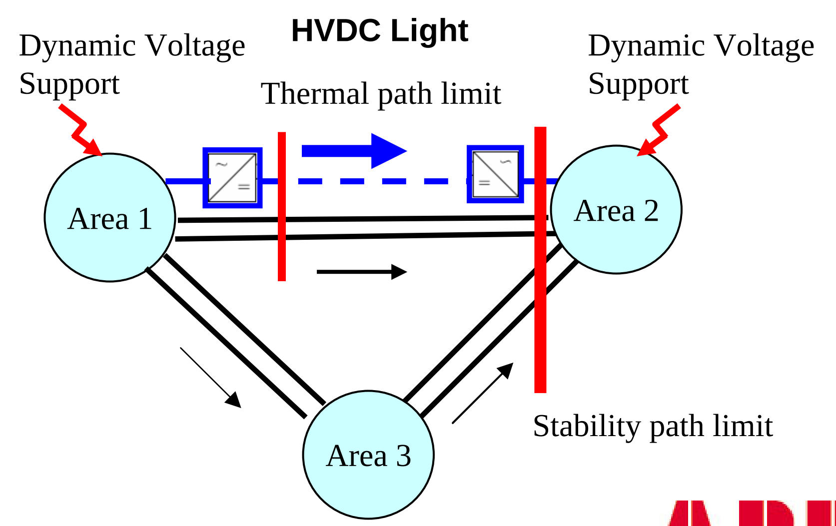
Conventional HVDC:

- Minimum short circuit level restriction (S > 2 x Pd)
- Reactive power demand at terminals (Q = 0.5 x Pd)
- Reactive compensation at terminals
- Higher ratings possible
- Greater economies of scale



HVDC Light:

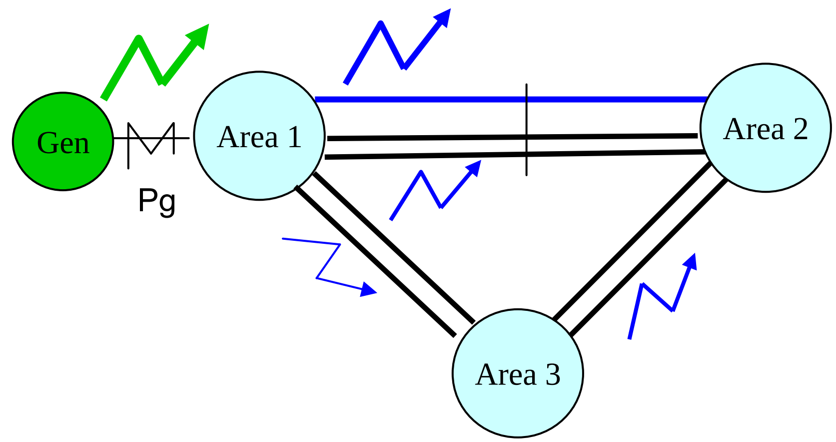
- No minimum short circuit levels
- No reactive power demand
- Dynamic reactive voltage support (virtual generator)
- Leverage ac capacity by voltage support
- Conducive for but not limited to underground cable transmission



Indirect v Direct Control – AC v DC

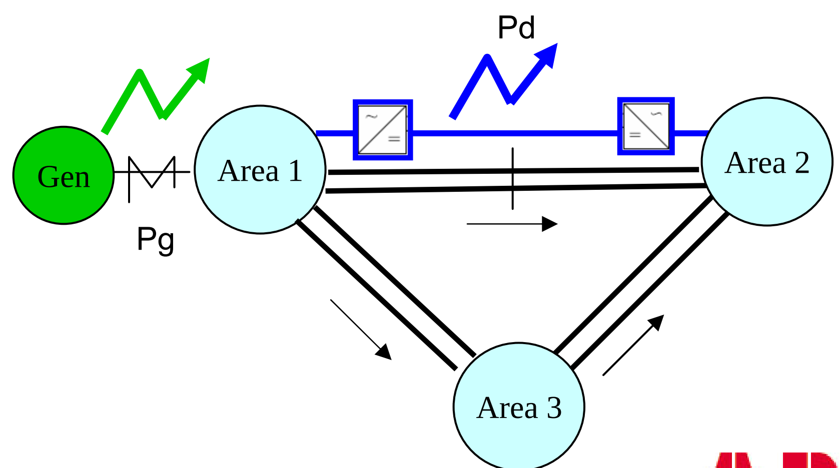
AC Transmission:

- Power flow from generation distributes per line characteristics (impedance) & phase angle (generation dispatch)
- Variable generation gives variable flow on all paths
- May be limited due to congestion
- New resources add cumulatively clogging existing paths
- Flow controlled indirectly by generation dispatch



HVDC Transmission:

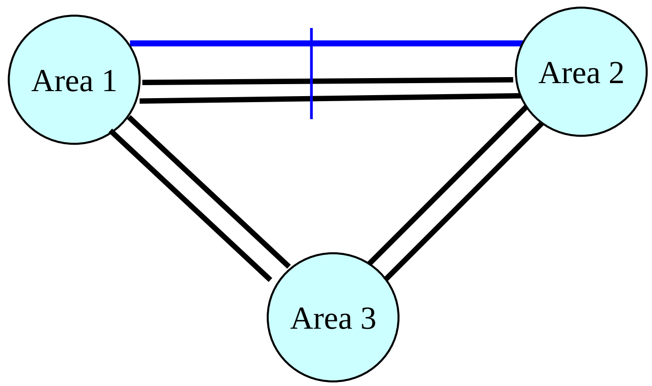
- Controlled power flow adds flexibility
- Pd = P schedule or by Σ generation
- Pd = Pg or,
- Pd = Pg + P schedule or,
- Pd = k * Pg
- Permits optimum power flow
- Bypasses congestion



Tapping – AC v DC

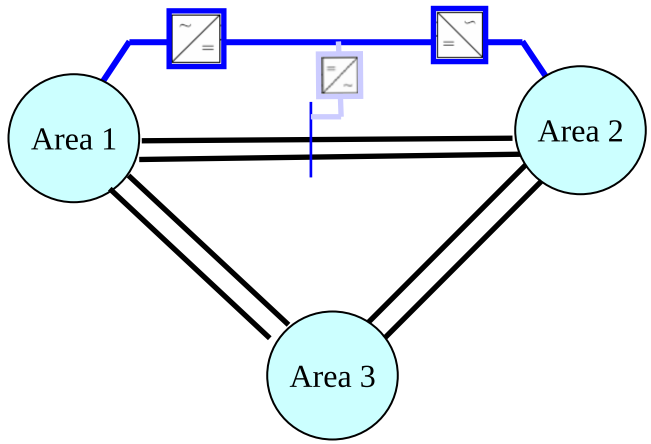
AC Tap

- Add transformer & substation equipment
- Exacerbate parallel flow issues



HVDC Tap

- Electronic clearing of dc line faults
- Fast isolation of faulty converters
- Reactive power compensation
- Momentary interruption due to ac fault at tap
- Limitations on tap rating, location and recovery rate due to voltage stability



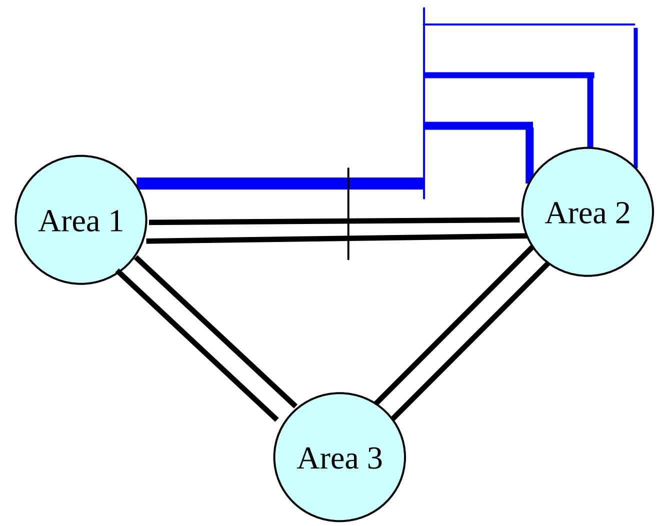
HVDC Light Tap

- No momentary interruption to main power transfer due to ac fault at tap
- Less limitations on tap rating and location
- No reactive power constraints
- Improved voltage stability

Off-ramps

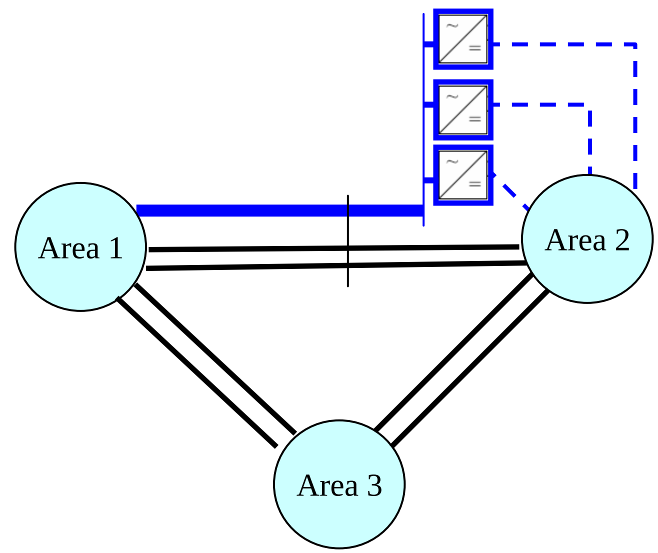
AC off-ramps:

- No control of power injection
- Potential for unequal utilization and local congestion
- Reactive power compensation required for light & heavy load conditions
- No voltage support
- Increases fault current duties
- Increased right-way-requirements



HVDC Light off-ramps:

- Delivers bulk power allocation to selected distribution substations in congested area
- Provides dynamic voltage support (virtual generator)
- Doesn't increase fault current duties
- Allows shared use of narrow rights-of-way
- Stealthy and healthy

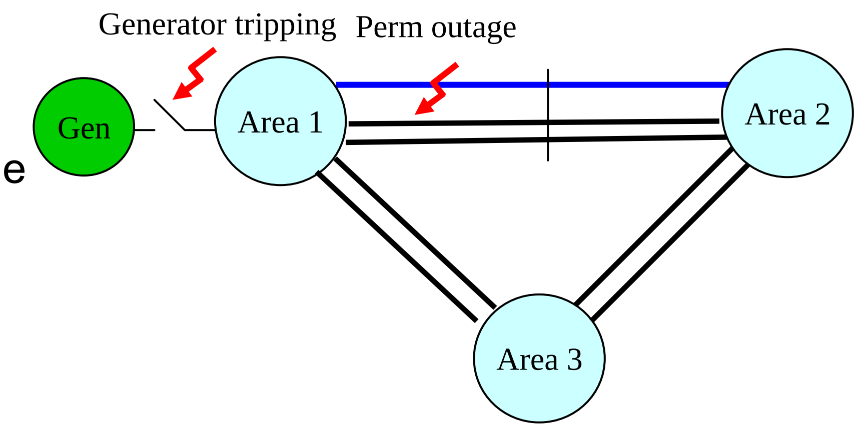


ABB

Contingency Response – AC v DC

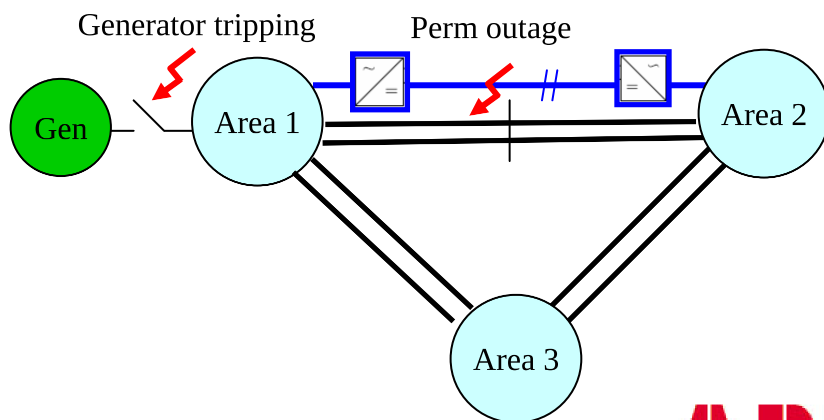
AC Transmission:

- Capacity of new line v reserve margin (stability, thermal) in parallel paths
- Reserve margin v remedial action
- Severity v probability – single circuit, double circuit or corridor outage, circuit reliability
- Capacity factor, spinning reserve (amount & location), restoration speed
- No control



HVDC Transmission:

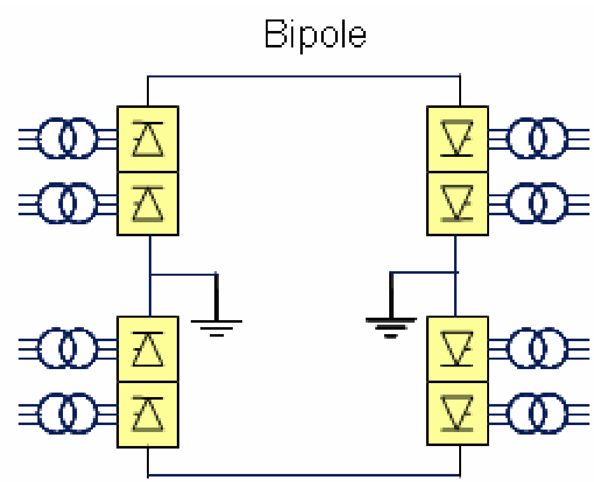
- Capacity of new path v reserve margin (stability, thermal) in parallel paths
- Reserve margin v remedial action
- Severity v probability - monopole, bipole or corridor outage
- Reliability of line & terminals (outage probability - monopole or bipole)
- Capacity factor, spinning reserve (amount & location), restoration speed
- Control – preposition or post-contingency

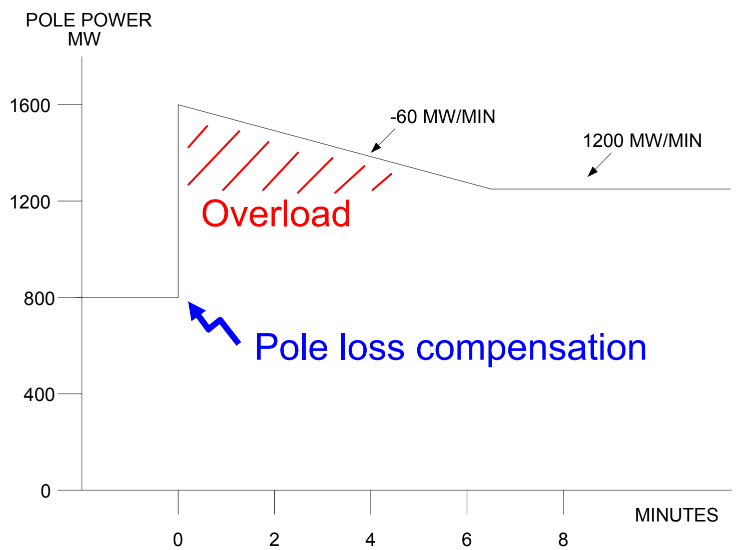


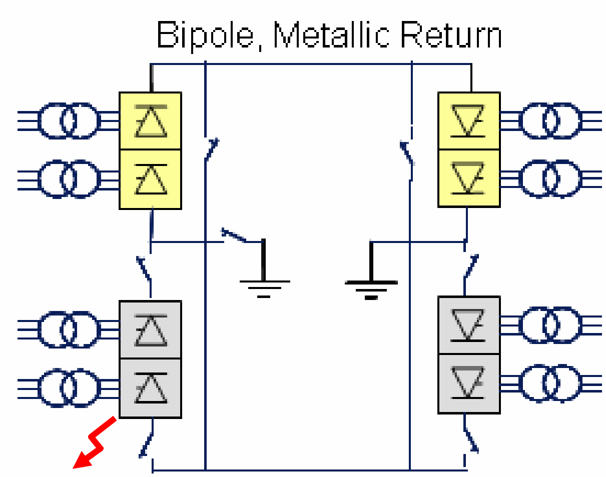
HVDC Bipole – Contingency Operation

DC Transmission:

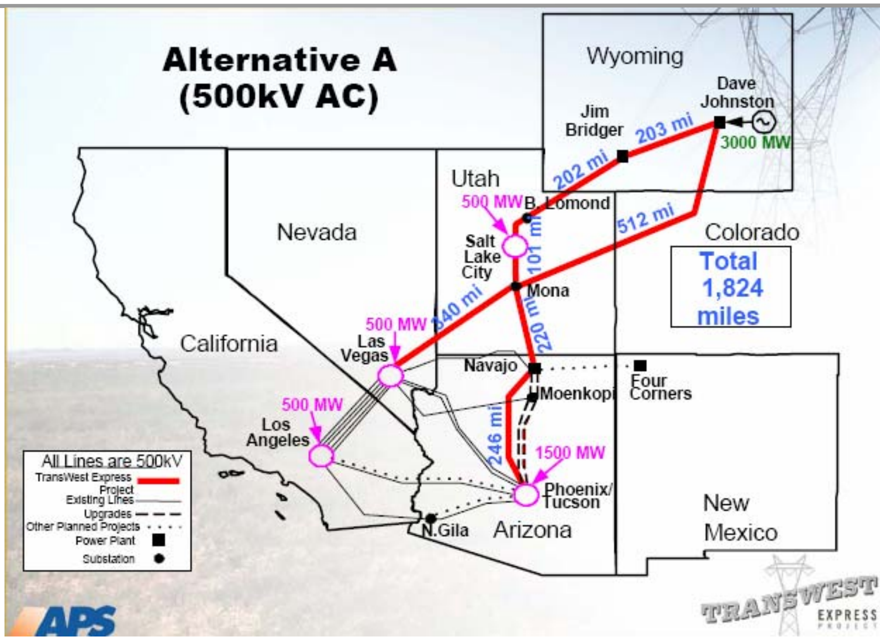
- Firm capacity
- High utilization possible
- Can operate with reserve capacity
- Similar to double circuit ac line
- Expandable
- More power on fewer lines with lower losses

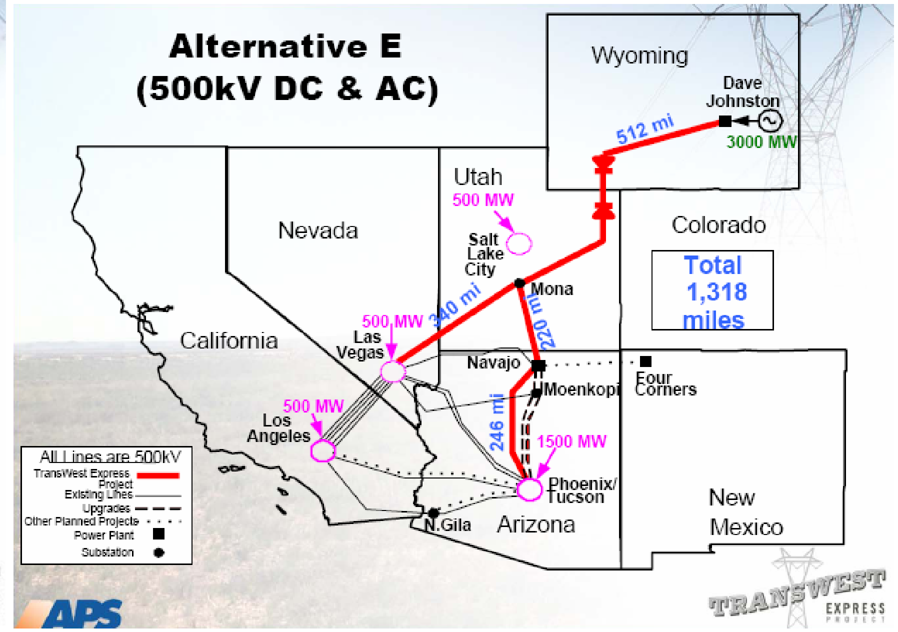


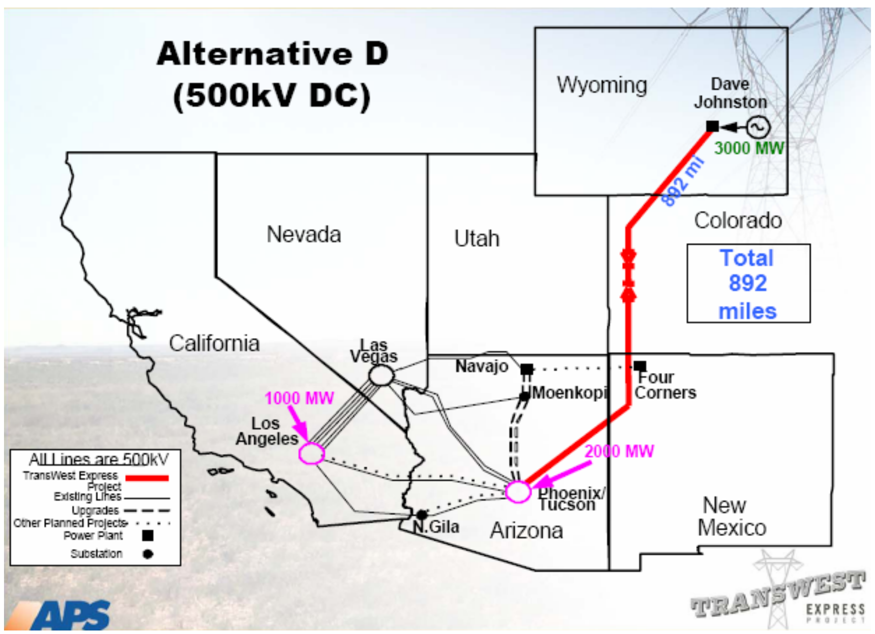




TransWest Express – 500kV AC, ±500kV HVDC Alternatives





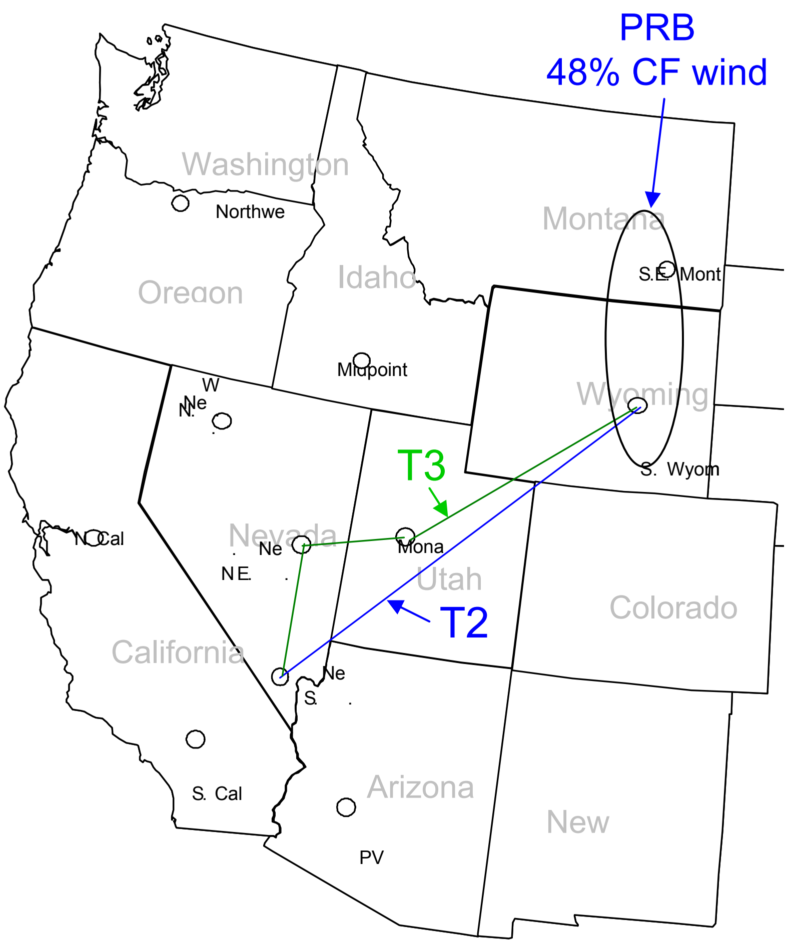


Transmission Losses and Estimated Project Cost

Transmission Alternatives	Increase in WECC System Losses	Project Cost ($ Million)
Alternative A	245 MW	4,335
Alternative B	256 MW	4,897
Alternative C	308 MW	4,589
Alternative D	124 MW	2,347
Alternative E	182 MW	3,190

Source: http://www.oatioasis.com/azps/

Frontier 3000 MW – Benefit : Cost Ratios



		T2	T3
Scenario			
Source	Coal - PC		
	Coal - CCS	1,000	1000
	Wind	2,700	2,700
Sink	Gas CC		
	Coal - PC	2,500	2500
Line Capacity	MW	3,000	3,000
Line Segments		1 x 500 KV (DC)	2 x 500 KV (AC)
Line Segment Costs	$ Million	$2,200	$4,200
Line Losses		6.2%	9.9%
Financing		Utility	Utility
GHG Adder		$40	$40
Dependable Capacity		Yes	Yes
GWH		18,361	18,361

	T2	T3
Results		
B/C Ratio	3.59	1.85
Benefits ($MM)	$800	$765
Costs ($MM)	$223	$414
Savings ($MM)	$577	$351
Value ($/MWh)	$31.44	$19.11

- Who pays the higher cost ($2B) of not building the most economic transmission?
- What's the value of firm transmission v cost of congestion?
- What's the net value of tapping?
- Is hybrid AC/DC (T2 + T3) the natural choice for 6000 MW?