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HVDC Generator Outlet Transmission System Issues with Wind Generation

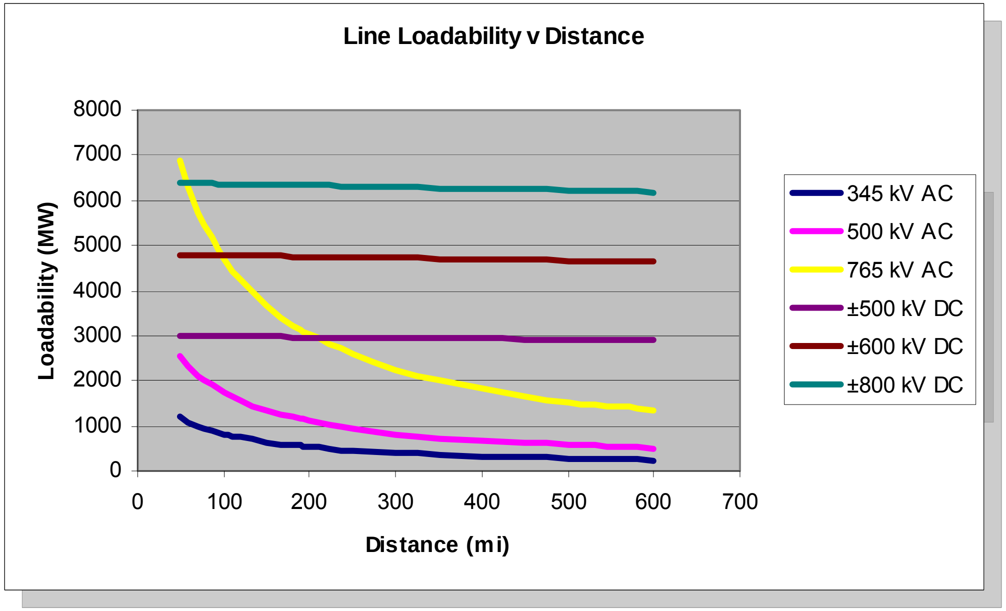
Topics

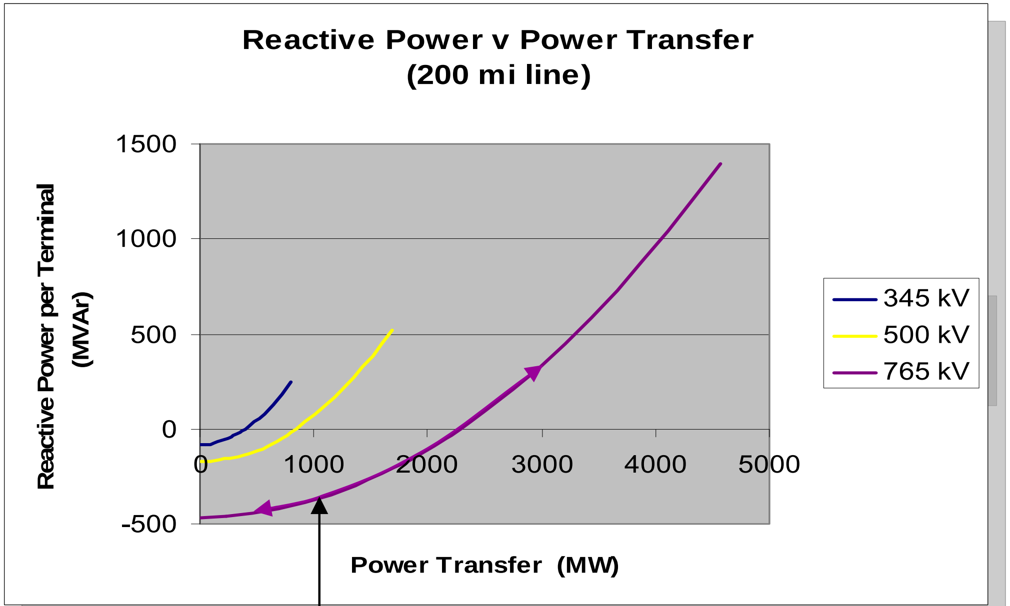
- Transmission characteristics
- HVDC technology
- Reactive power compensation
- Short circuit levels and voltage support
- Transmission alternatives
- Operability & coordination
- Station layouts
- Conclusions

Characteristics of HVDC transmission

- Controllable power flow – firm
- Facilitates integration of remote diverse resources, less impact on existing grid, no parallel flow issues
- Higher power, fewer less-expensive lines
- No stability distance limitation
- Reactive power demand of conventional HVDC is limited to terminals independent of distance
- Lower losses
- Asynchronous, ‘firewall’ against cascading outages
- Up to 6400 MW on a bipolar (double circuit) line
- Up to 1000 MW on a cable circuit
- No limit to underground or sea cable length

Transmission line delivery capability v distance
AC line capacity diminishes with distance*





Reactive power variation of 800 MVAr per 100 mi, 0.2-1.3 SIL

AC line distance effects:

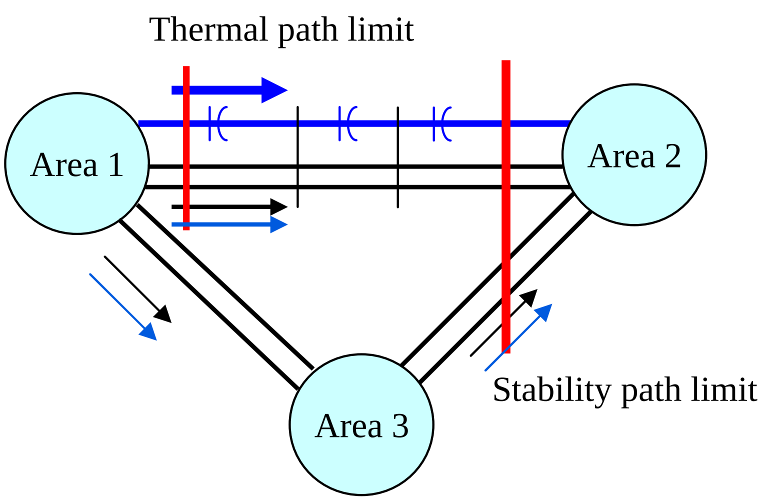
- Intermediate switching stations, e.g. every ~200-250 mi max segment due to TOV, TRV, RPC, voltage profile
- Lower stability limits (voltage, angle)
- Increase stability limits & mitigate parallel flow with FACTS: SVC & SC
- Reactive demand varies with line loading
- Parallel flow issues more prevalent

DC line distance effects:

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

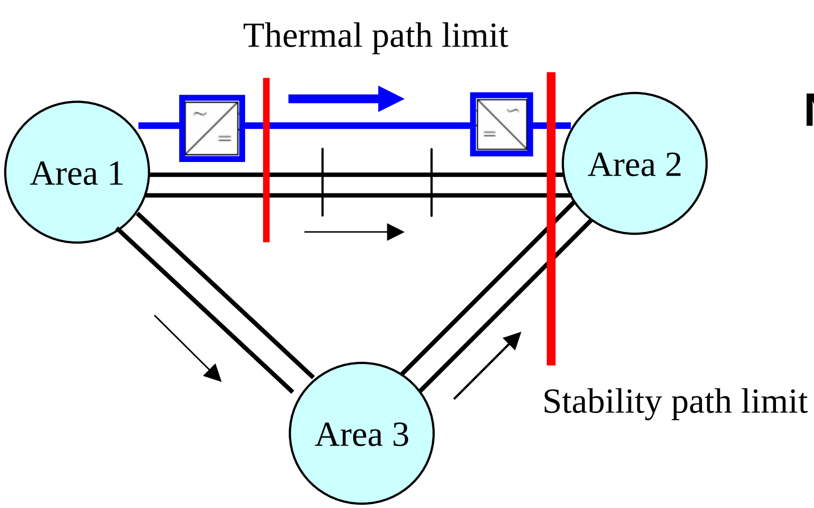
* St Clair Curve

Distance effects



New AC line:

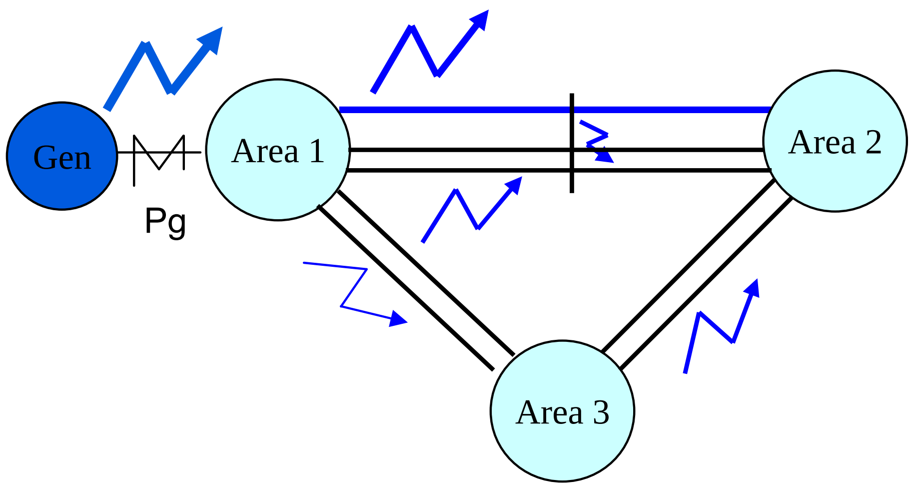
- Need for intermediate switching stations – the longer the line the more intermediate S/S (TOV, TRV, voltage profile)
- Lower stability limits with longer distance
- Reactive power demand variation with loading
- Parallel flow issues more prevalent and widespread for longer transmission
- Increase stability limits & mitigate parallel flow with series compensation (FACTS)
- Thermal limit remains the same

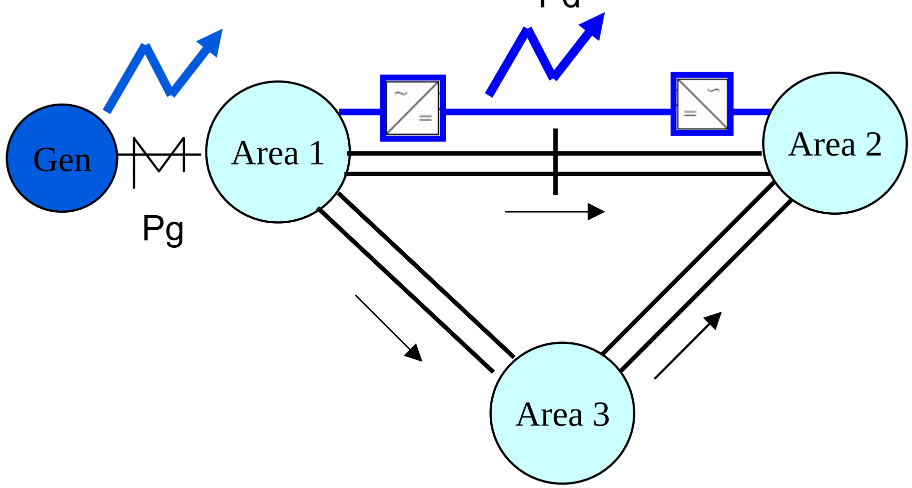


New DC line:

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

Indirect v direct control – AC v DC





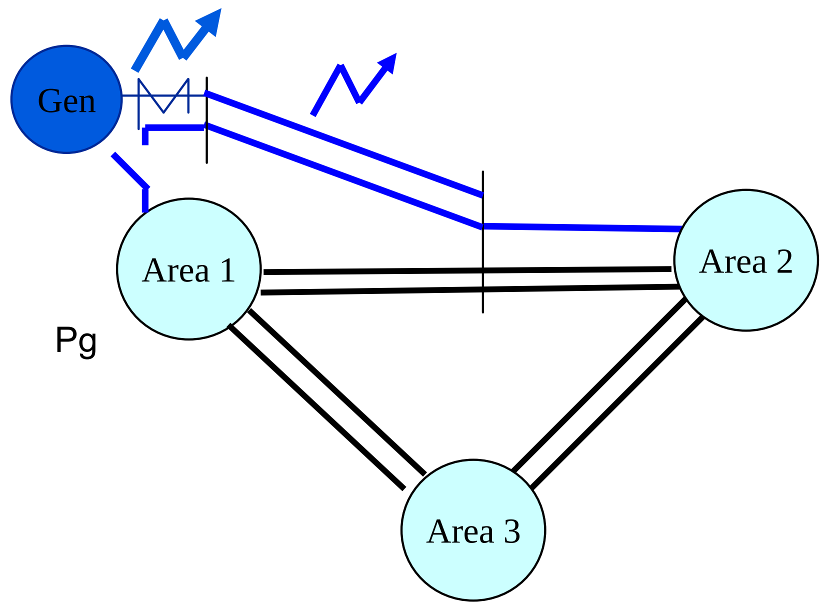
AC Transmission:

- 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:

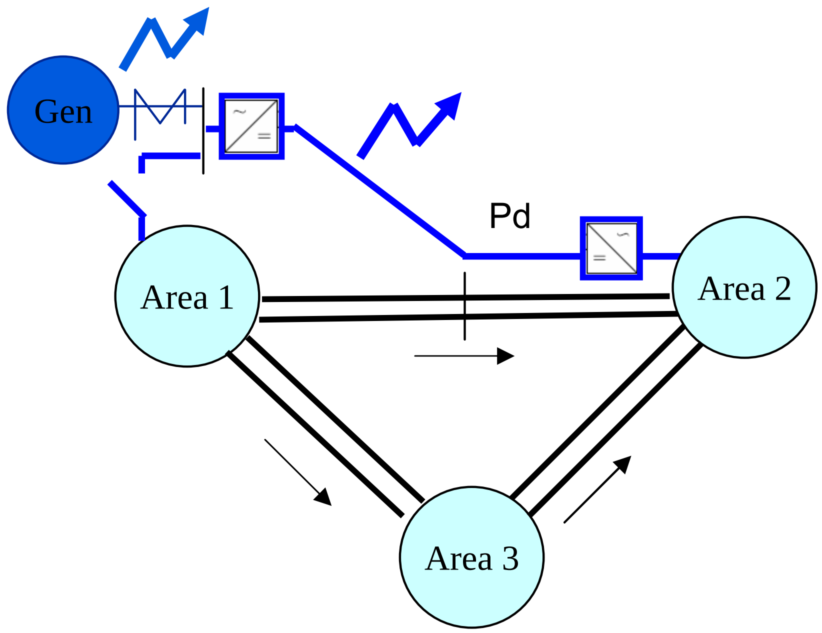
- Controlled power flow adds flexibility
- Pd = Σ Pg + P schedule or k * Pg
- Transfers do not burden underlying grid
- Permits optimum power flow
- Bypasses congestion
- More firm

Isolated or Radial Operation – AC v DC



AC Transmission:

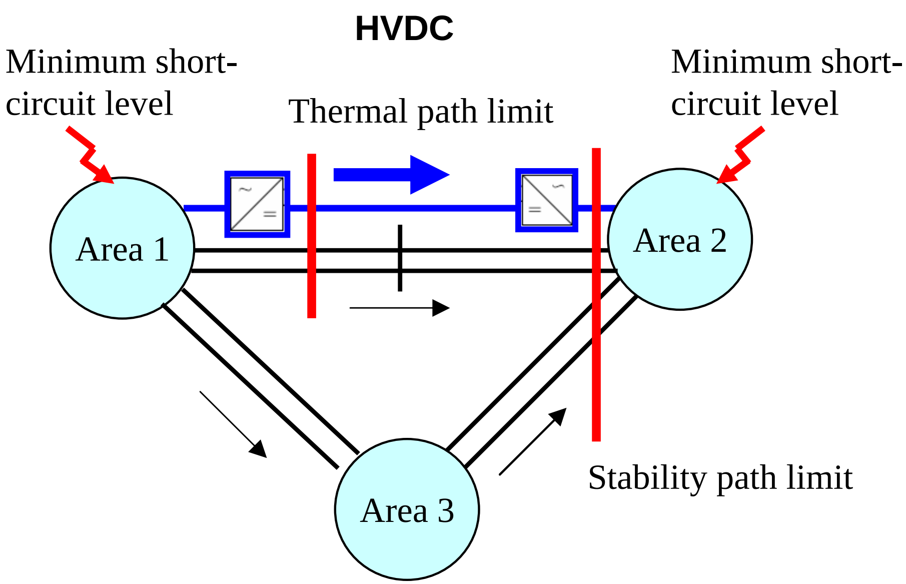
- Isolated operation may present stability problem
- More generator outlet lines may be required for stability
- SSR/SSTI more likely if series compensation used, requires mitigation
- Auto-reclosing problematic due to transient torque fatigue stress



HVDC Transmission:

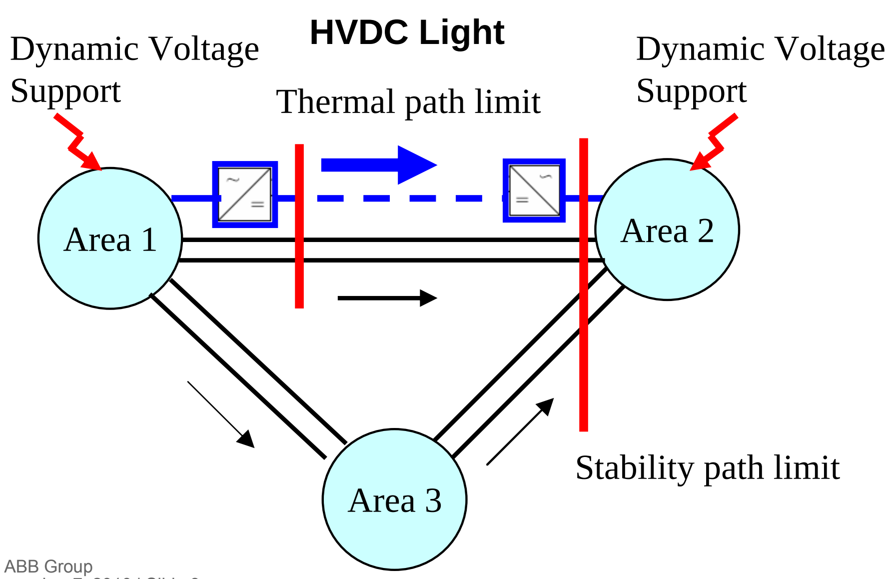
- Isolated operation OK, may require SSTI mitigation for some generators - control
- Bipolar line provides two circuits
- Auto-reclosing reduced risk of transient torque amplification – soft restarts possible
- Synchronous or asynchronous operation – some issues with wind generation with conventional HVDC but not VSC HVDC

Converter Technology
HVDC v HVDC Light



Conventional HVDC – LCC/CSC:

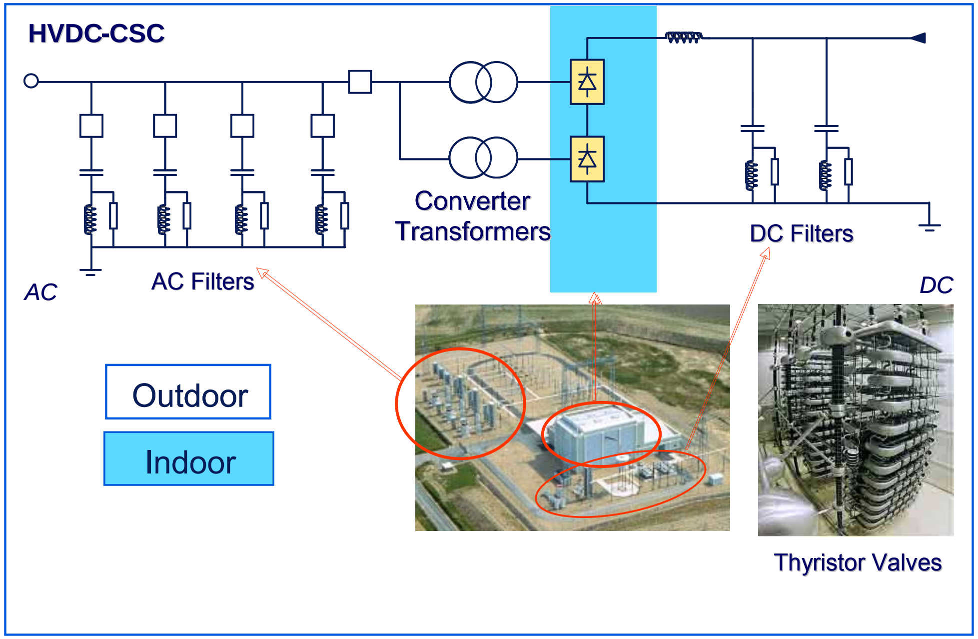
- Minimum short circuit level restriction (S_{MVA} > 2 x Pd)
- Induction wind generation contribution to short circuit and voltage support limited
- Reactive power demand at terminals (Q ~= 0.5 x Pd)
- Reactive compensation at terminals
- Higher ratings, greater economies of scale

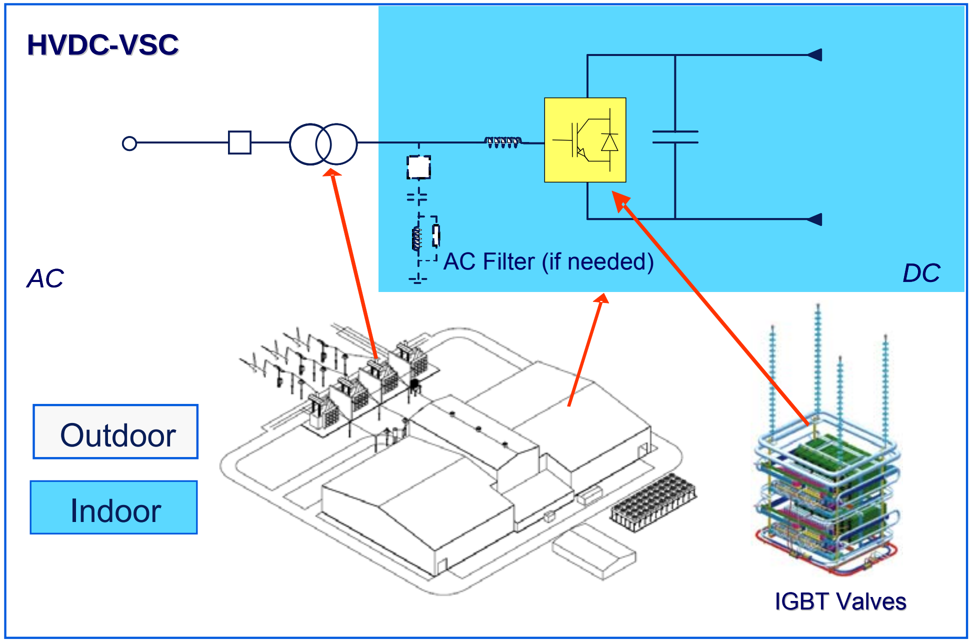


HVDC Light - VSC:

- No minimum short circuit levels
- No filters or reactive power demand
- Dynamic reactive voltage support (virtual generator, Q ~= ± 0.33 x Pd)
- Leverage ac capacity by voltage support
- Conducive for but not limited to underground cable transmission

Core HVDC technologies





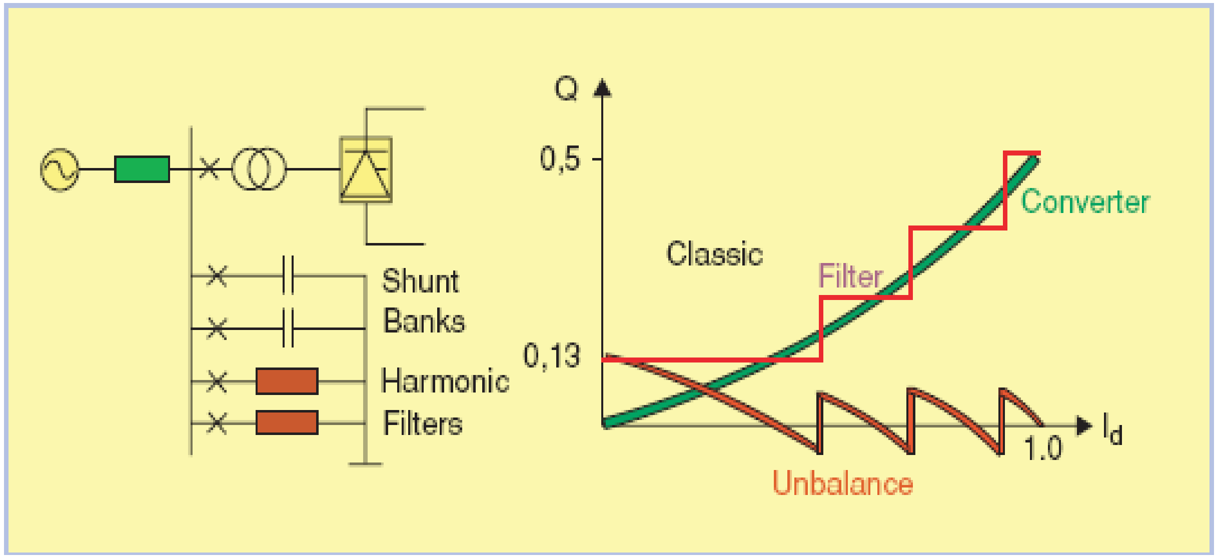
HVDC Classic

- Current source converters (CSC)
- Line-commutated converter (LCC) with thyristor valves
- Requires 50% reactive compensation (35% HF)
- Converter transformers
- Minimum short circuit capacity > 2 x Pd, > 1.3 x Pd with capacitor commuted converter (CCC)

HVDC Light 4G

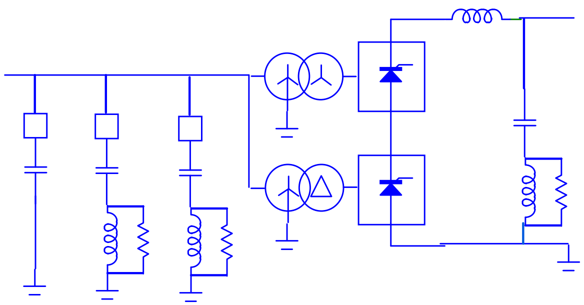
- Voltage source converters (VSC)
- Self-commutated with IGBT valves
- Cascaded two level converters (CTL)
- Requires no reactive power compensation (~0-15% HF as required)
- Virtual generator at receiving end: P,Q
- Standard transformers
- Weak system, black start
- Radial wind outlet regardless of type of wind T-G, off-shore or isolated from grid
- U/G or OVHD

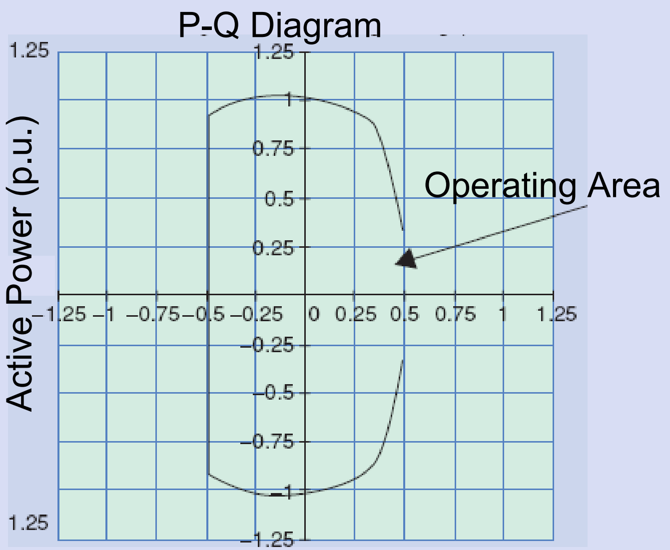
Comparison of Reactive Power Characteristics



HVDC Classic:

~ reactive compensation by switched filters and shunt capacitor banks

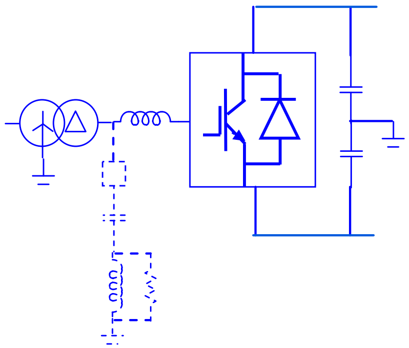




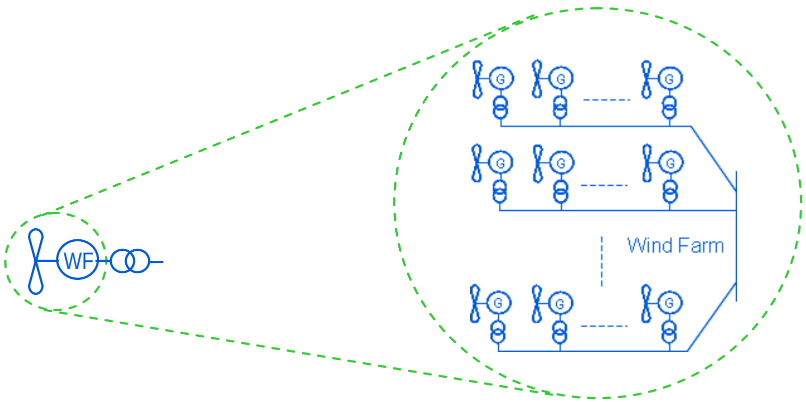
HVDC VSC Operating Range

HVDC Light:

No reactive compensation necessary, STATCOM with dynamic range ~ 0.5Pd/+0.5Pd MVAr @ 90% p.f.

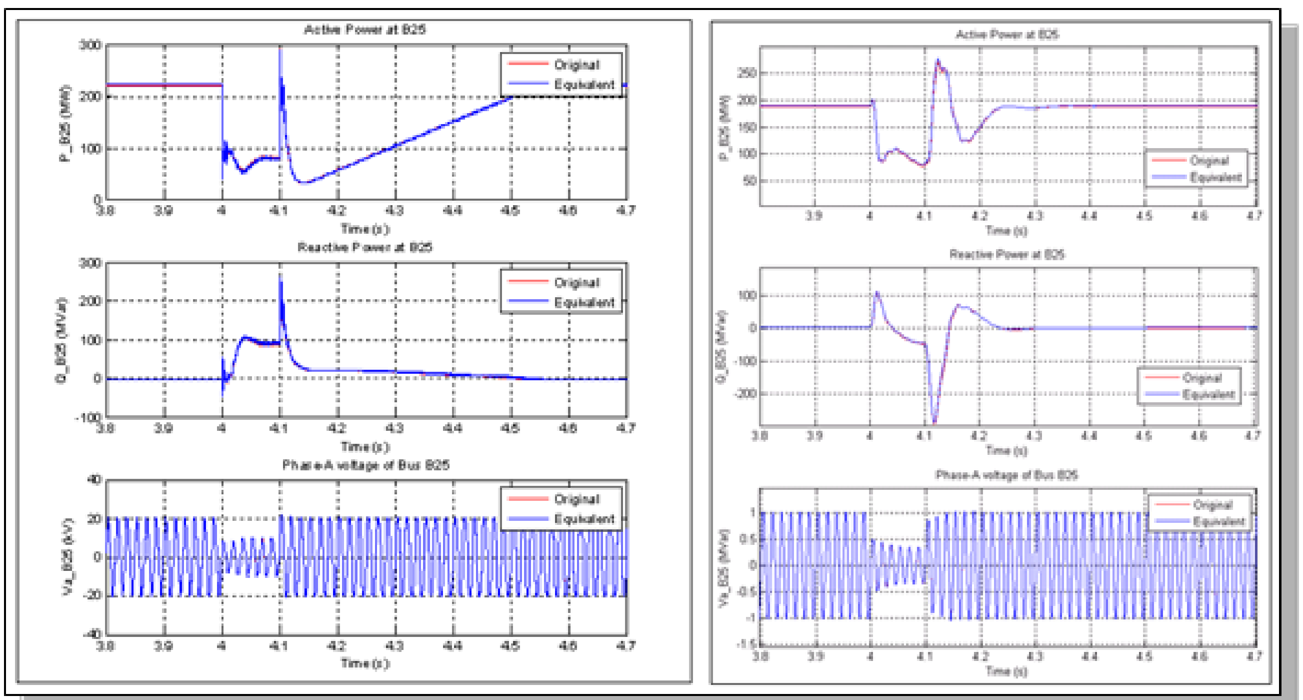


Wind Generation
Contribution to short circuit capacity & voltage support



- Relatively small contribution to short circuit levels compared to synchronous machines
- Limited voltage support from Types 3 & 4 machines relative to synchronous machines
- Limited by collector system impedance

FPC Type 4 WTG **DFIG Type 3 WTG**



Short Circuit Ratio (SCR) – “rule of thumb”
Definitions & system impacts

$S = S_N + S_{SC} + S_G + S_{WF}$

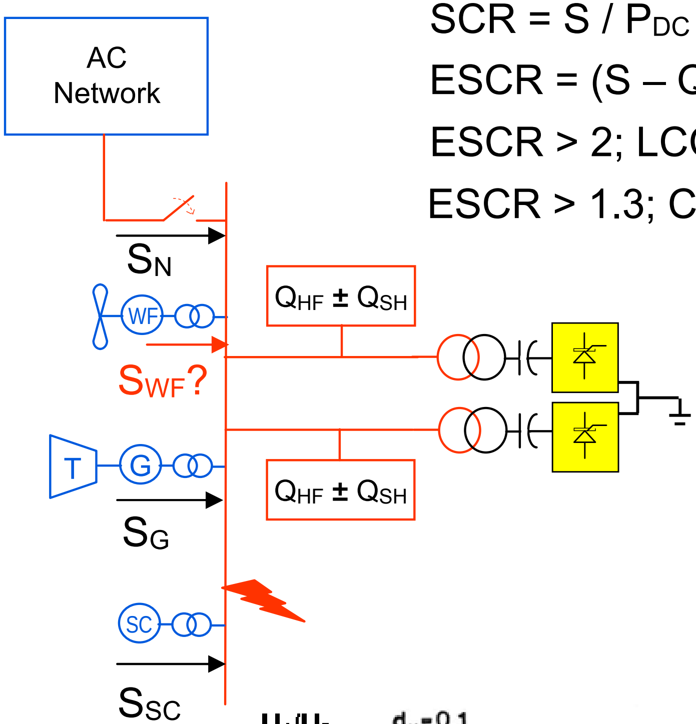
$Q = Q_{HF} \pm Q_{SH}$

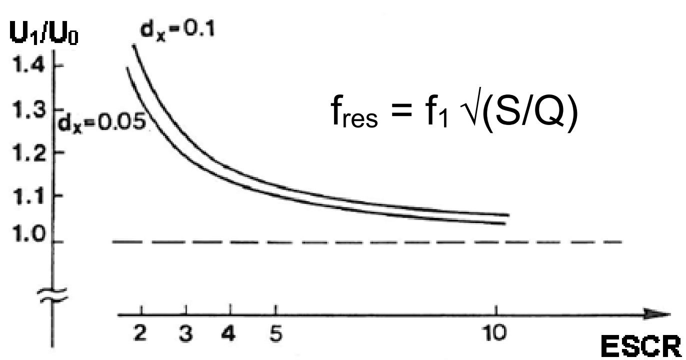
$SCR = S / P_{DC}$

$ESCR = (S - Q) / P_{DC}$

ESCR > 2; LCC

ESCR > 1.3; CCC

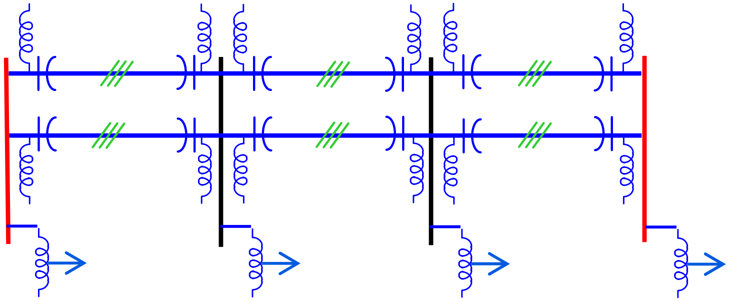




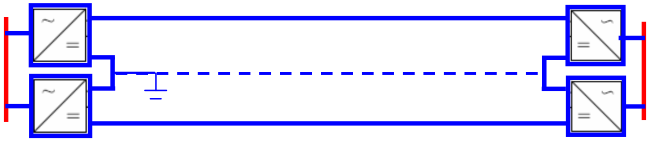
DOV at full load rejection

- S = short circuit contribution from synchronous machines local or embedded in network
- Limited contribution to short circuit ratio and voltage support from wind generation
- Q = reactive compensation
- Short circuit ratio (SCR) is an indication of ac voltage stability
- Effective short circuit ratio (ESCR) takes into account the destabilizing influence of shunt capacitive compensation (Q)
- Low short circuit ratios result in smaller filter banks, higher load rejection dynamic over-voltage and lower resonance frequencies
- Lower short circuit ratios with CCC, less shunt compensation
- Not a big issue with VSC

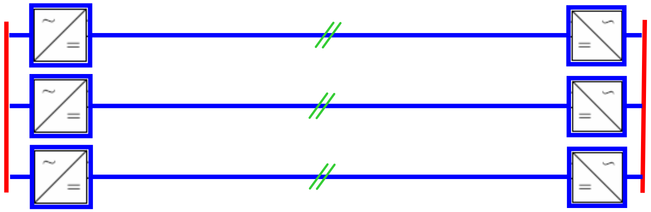
Transmission Alternatives
3000 MW capacity



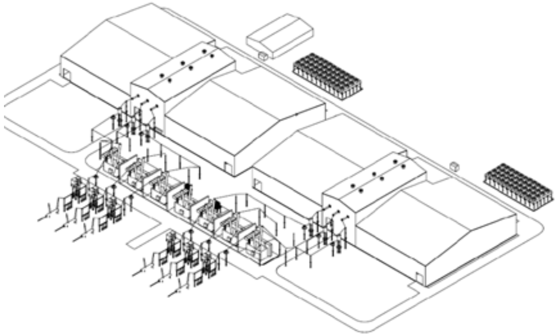
2 x 500 kV circuits with series comp



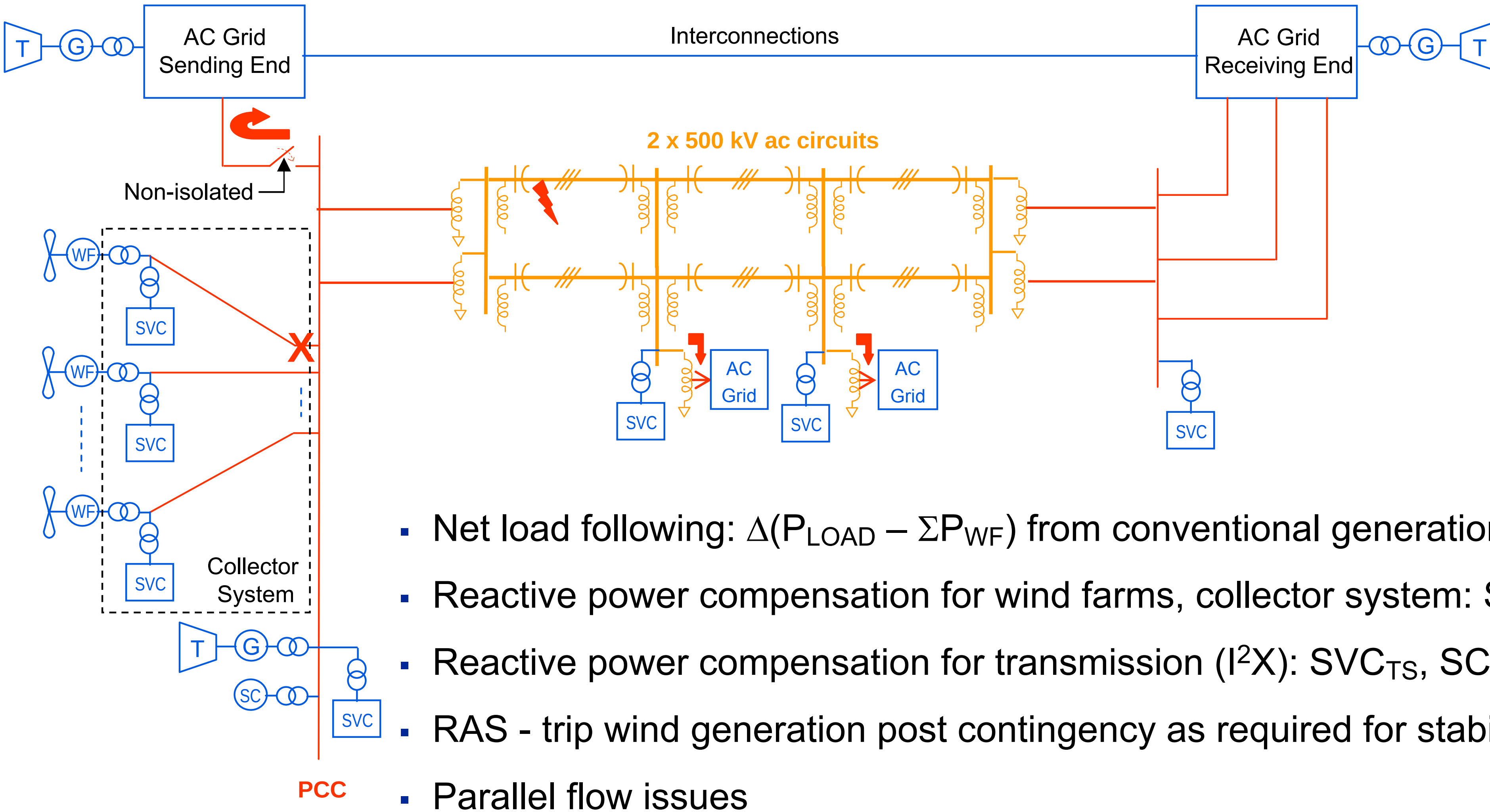
±500 kV HVDC bipole



3 x ±320 kV HVDC Light tripole

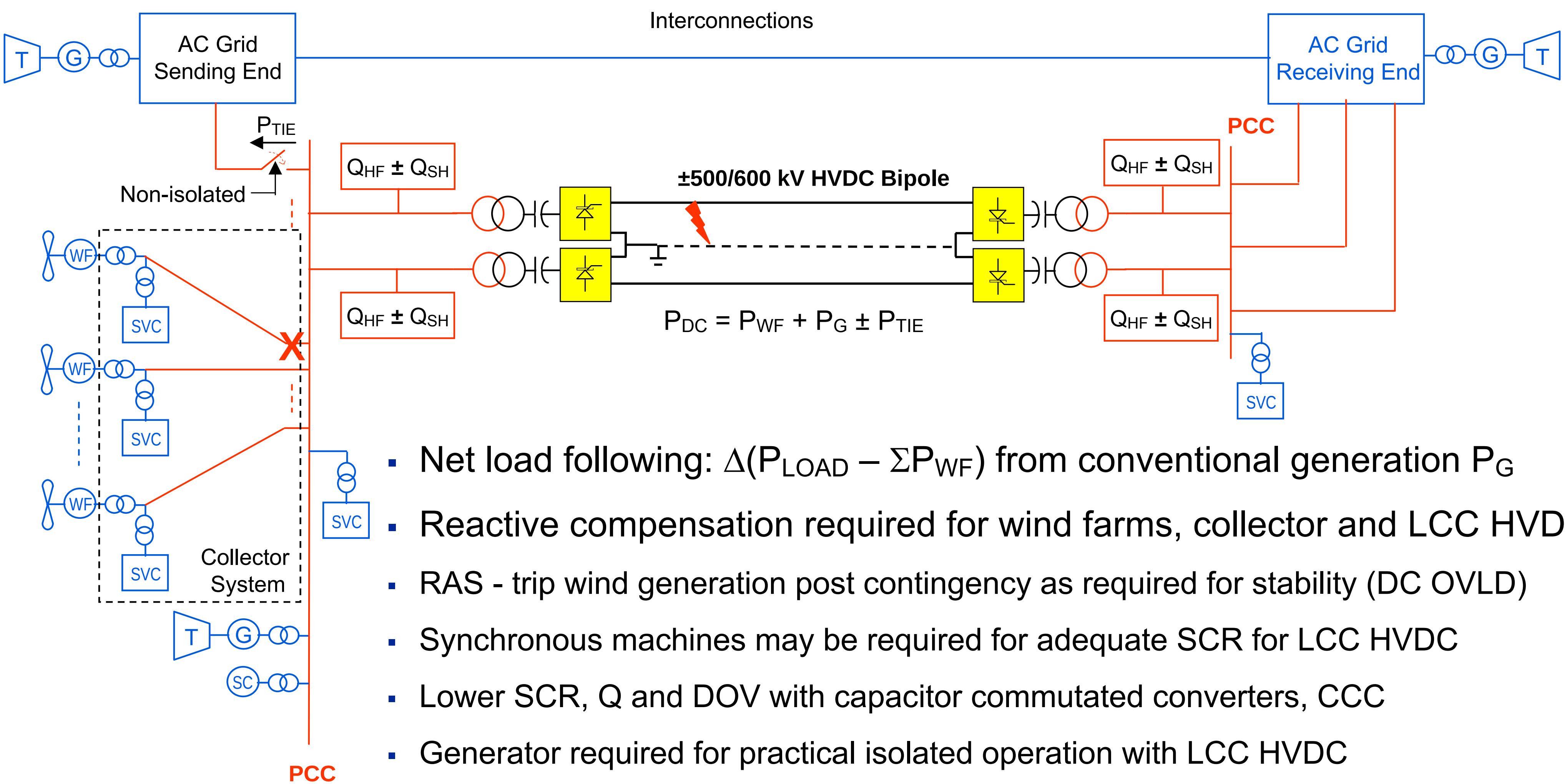


AC Outlet Transmission from 3000 MW Wind Farm
2 x 500 kV lines with series and shunt compensation



- Net load following: $\Delta(P_{LOAD} - \Sigma P_{WF})$ from conventional generation P_G
- Reactive power compensation for wind farms, collector system: SVC_{WF}
- Reactive power compensation for transmission (I^2X): SVC_{TS}, SC, P_G
- RAS - trip wind generation post contingency as required for stability
- Parallel flow issues
- Subsynchronous issues, i.e. SSR, SSTI mitigation may be required
- Cost allocation issues

HVDC Outlet Transmission for 3000 MW Wind Farm
Bipolar LCC HVDC Link



- Net load following: $\Delta(P_{LOAD} - \Sigma P_{WF})$ from conventional generation P_G
- Reactive compensation required for wind farms, collector and LCC HVDC
- RAS - trip wind generation post contingency as required for stability (DC OVLD)
- Synchronous machines may be required for adequate SCR for LCC HVDC
- Lower SCR, Q and DOV with capacitor commutated converters, CCC
- Generator required for practical isolated operation with LCC HVDC
- Controllable - no parallel flow issues, asynchronous or synchronous op OK
- No (simplified) cost allocation issues

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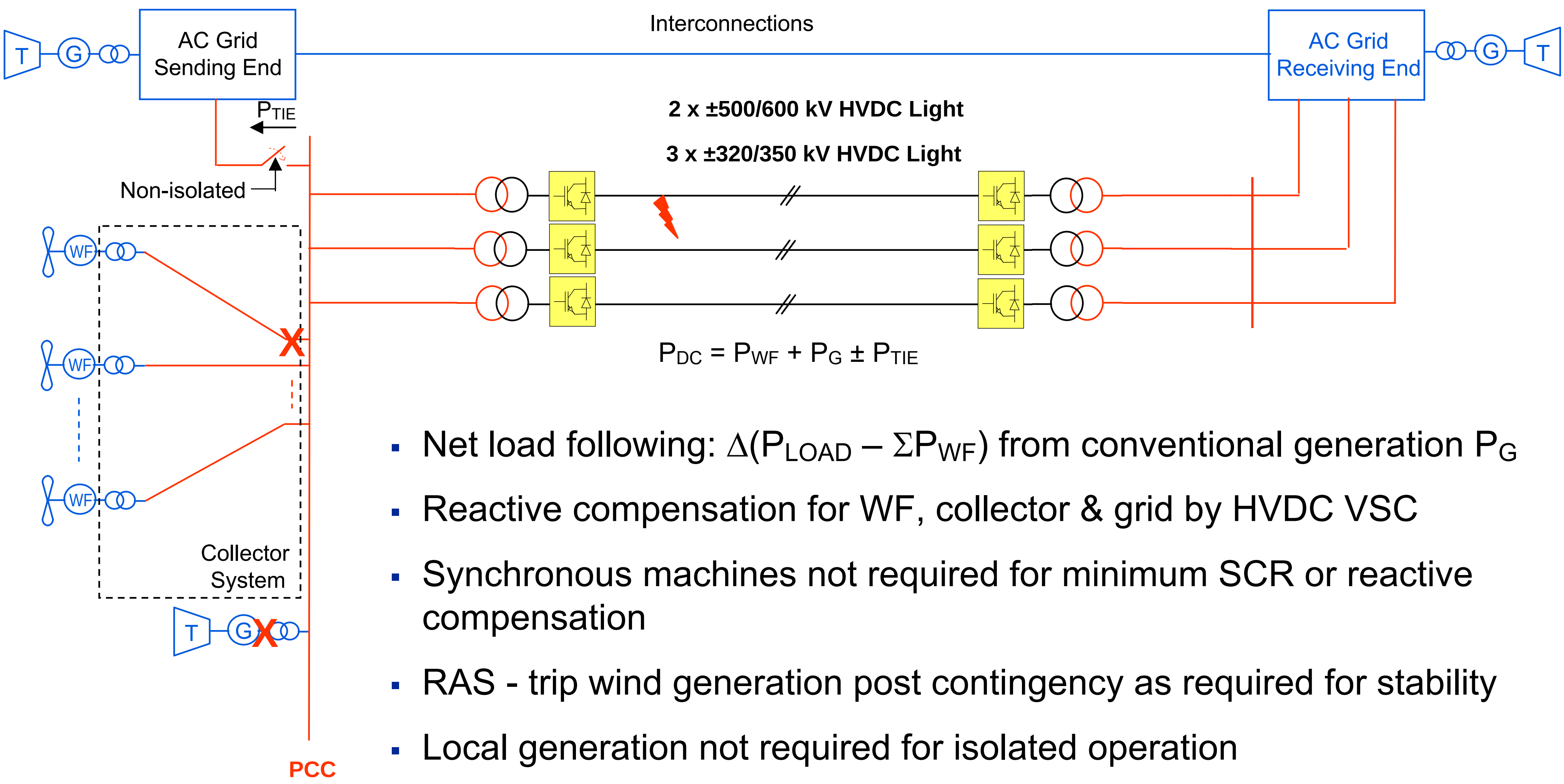
HVDC Light outlet transmission for 3000 MW wind farm
2 or 3 x HVDC Light (VSC) circuits



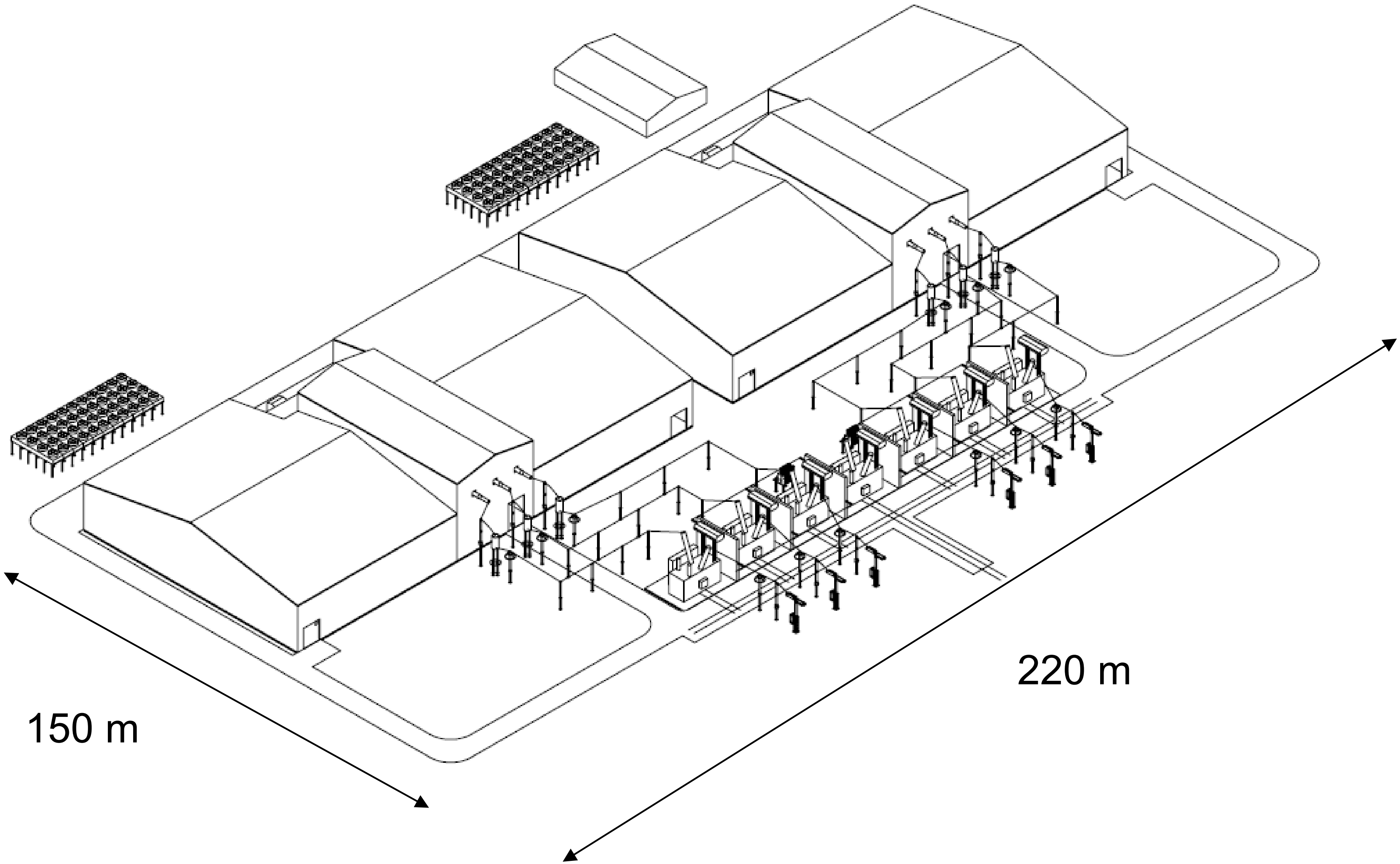
- Net load following: $\Delta(P_{LOAD} - \Sigma P_{WF})$ from conventional generation P_G
- Reactive compensation for WF, collector & grid by HVDC VSC
- Synchronous machines not required for minimum SCR or reactive compensation
- RAS - trip wind generation post contingency as required for stability
- Local generation not required for isolated operation
- Controllable, no parallel flow issues, asynchronous or synchronous operation OK, set $P_{TIE} = 0$ for 'virtual isolation'
- No (simplified) cost allocation issues

How big is an HVDC converter station?

Walmart Supercenter
~ 31.5 acres
~12.8 hectares

2000 MW HVDC Station
~ 26.2 acres
~10.6 hectares

HVDC Light Generation 4
Station layout 2 x 1000 MW ± 320 kV



Conclusions

- Variability of wind requires active and reactive power regulation for both AC, DC or mixed transmission
- Controllability of HVDC provides operational flexibility, mitigates parallel flow issues and firms up transfer capacity
- Isolated operation with conventional HVDC requires local reactive power compensation and ac voltage support some of which is derived from synchronous machines
- Isolated operation with conventional HVDC without local generation is impractical, especially with variable, intermittent resource
- HVDC with voltage source converters demands no reactive power compensation, provides dynamic voltage support to wind farms, collector system and ac grid in both non-isolated and isolated configurations

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