HVDC Transmission

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IEEE PSCE
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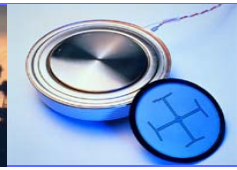
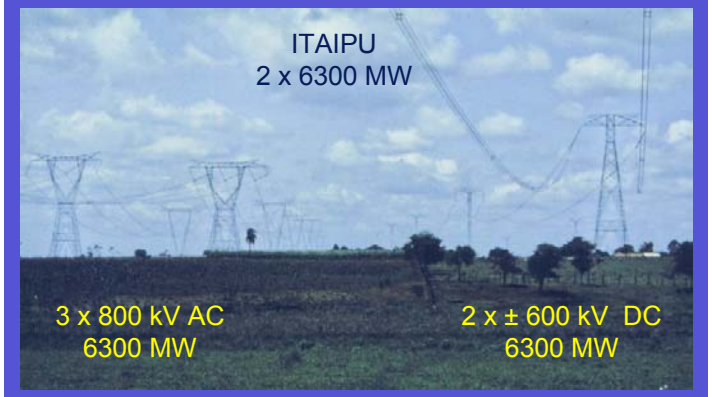
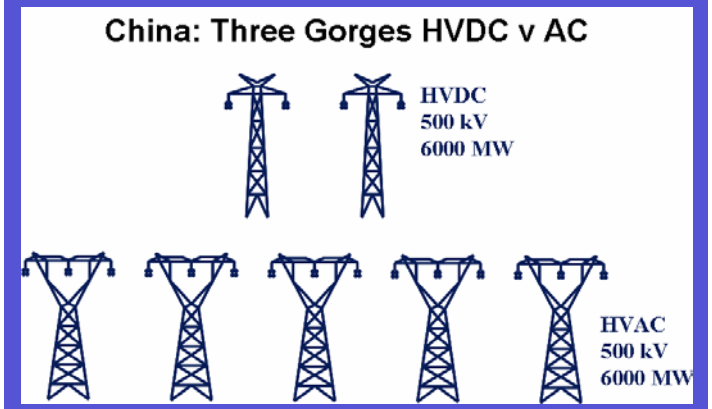


HVDC Transmission

- Applications
  - Long-distance, bulk-power OVHD transmission
  - Sea and land cable transmission
  - Asynchronous interconnections
  - Power flow control
  - Congestion relief
- Ratings
  - Power range up to 4000 MW at ± 500 kV
  - Power range up to 4800 MW at ± 600 kV
  - Voltage range increasing to ± 800 kV for 2009 operation
  - Power range up to 6400 MW at ± 800 kV
  - MIND Cables

Long-Distance Bulk Power Transmission





- Generator Outlet Transmission
  - More power on fewer lines
  - Improved stability
  - Lower installed cost
  - Reduced losses
  - Double circuit (bipolar line)
  - Reduced ROW
  - One line vs. two – e.g. IPP, CU, Square Butte
- Interconnections
  - Firm capacity
  - Bypass congestion
  - Avoid loop flow
  - No limit due to parallel paths
  - Interconnect diverse regions

Cost Comparison of 3000 MW Transmission Systems

Alternative	DC Alternatives				AC Alternatives			Hybrid AC/DC Alternative		
	± 500 kV Bipole	2 x ± 500 kV 2 Bipoles	± 600 kV Bipole	± 800 kV Bipole	500 kV 2 Single Ckt	500 kV Double Ckt	765 kV 2 Single Ckt	± 500 kV Bipole	500 kV Single Ckt	Total AC+DC
Capital Cost										
Rated Power (MW)	3000	4000	3000	3000	3000	3000	3000	3000	1500	4500
Station costs including reactive compenstation	$420	$680	$465	$510	$542	$542	$630	$420	$302	$722
Transmission line cost (M$/mile)	$1.60	$1.60	$1.80	$1.95	$2.00	$3.20	$2.80	$1.60	$2.00	
Distance in miles	750	1,500	750	750	1,500	750	1,500	750	750	1,500
Transmission Line Cost (M$)	$1,200	$2,400	$1,350	$1,463	$3,000	$2,400	$4,200	$1,200	$1,500	$2,700
Total Cost (M$)	**$1,620**	**$3,080**	**$1,815**	**$1,973**	**$3,542**	**$2,942**	**$4,830**	**$1,620**	**$1,802**	**$3,422**
Annual Payment, 30 years @10%	$172	$327	$193	$209	$376	$312	$512	$172	$191	$363
Cost per kW-Yr	$57.28	$81.68	$64.18	$69.75	$125.24	$104.03	$170.77	$57.28	$127.40	$80.66
Cost per MWh @ 85% Utilization Factor	$7.69	$10.97	$8.62	$9.37	$16.82	$13.97	$22.93	$7.69	$17.11	$10.83
Losses @ full load	193	134	148	103	208	208	139	106	48	154
Losses at full load in %	6.44%	3.35%	4.93%	3.43%	6.93%	6.93%	4.62%	5.29%	4.79%	5.12%
Capitalized cost of losses @ $1500 kW (M$)	$246	$171	$188	$131	$265	$265	$177	$135	$61	$196

Parameters:

Interest rate %	10%
Capitalized cost of losses $/kW	$1,500

Note:

AC current assumes 94% pf

Full load converter station losses = 0.75% per station

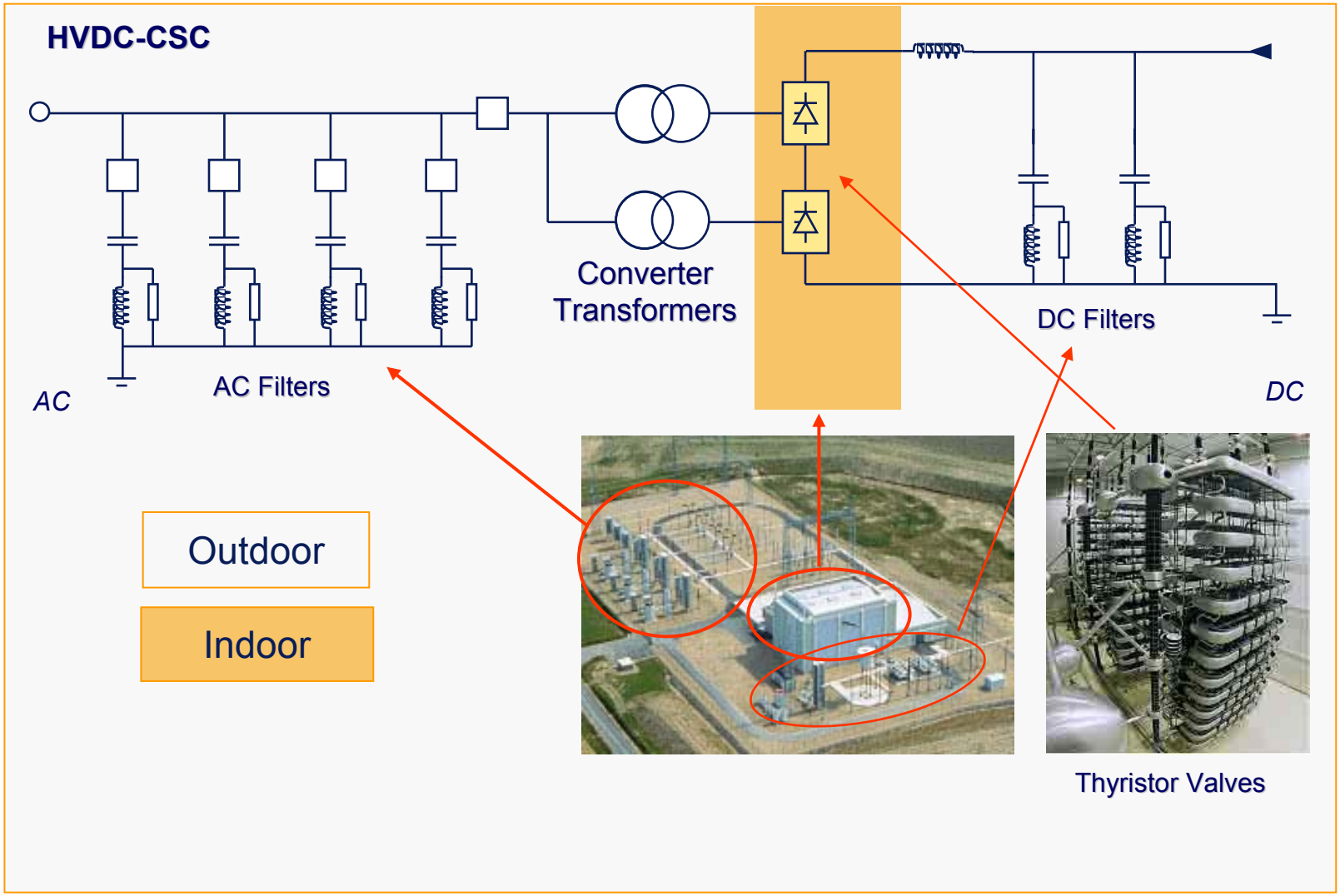
Total substation losses (transformers, reactors) assumed = 0.5% of rated power

Comparison to Rail Transport of Coal

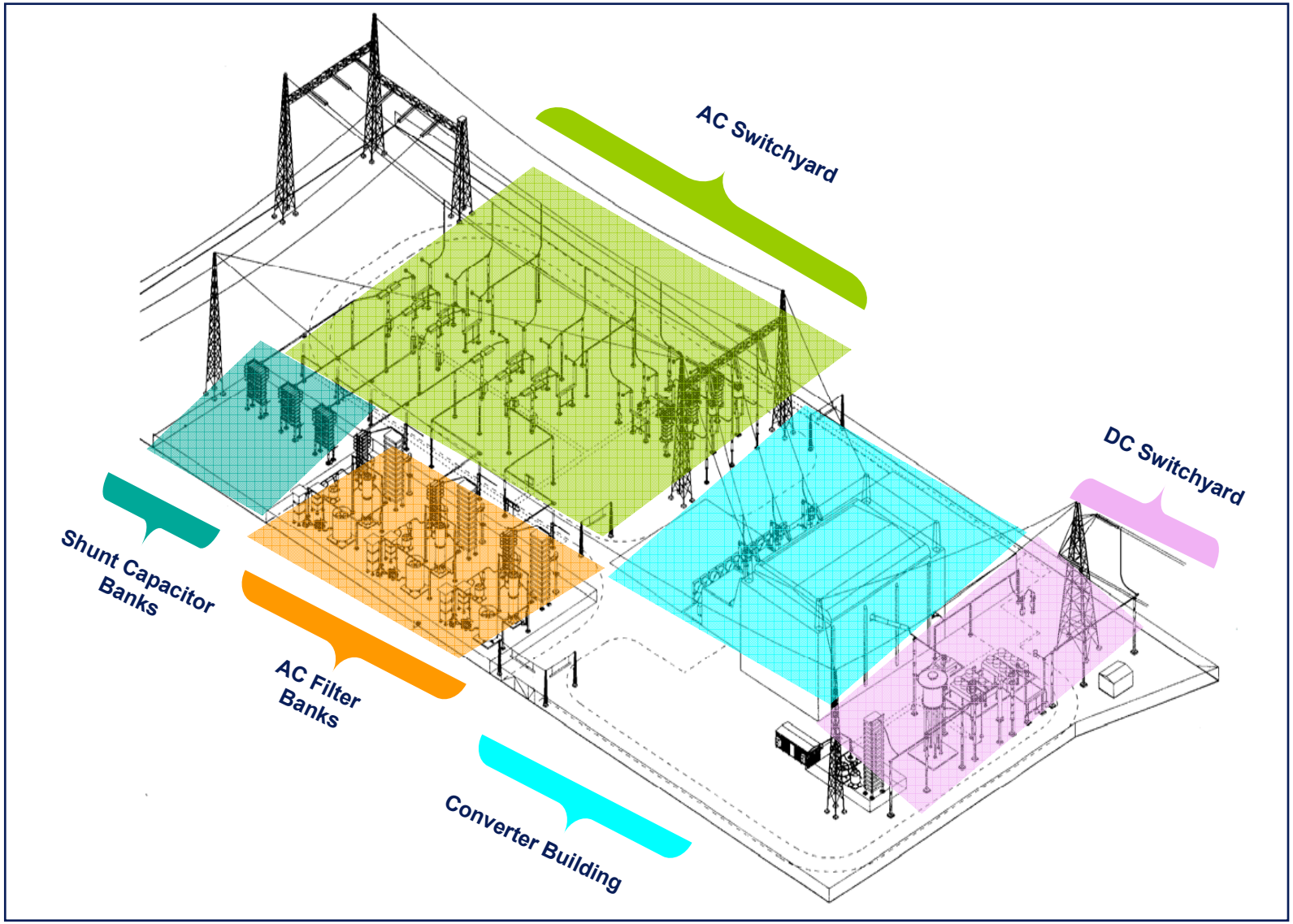
- 3000 MW power plant
- Coal haul distance 900 miles
- Fuel – sub-bituminous coal 8500 BTU/lb
- Plant heat rate – 8500 BTU/kWh, 85% load factor
- 3 unit trains per day (100, 100 ton cars/train)
- Annual hauling cost $560 M at $50 per ton
  - $186 per kW-yr
  - $25 per MWh
  - 20 million gallons of diesel fuel per year @ 500 net ton miles per gallon
- Subject to escalation, congestion
- Cannot deliver energy from renewable resources

The HVDC Classic Converter Station

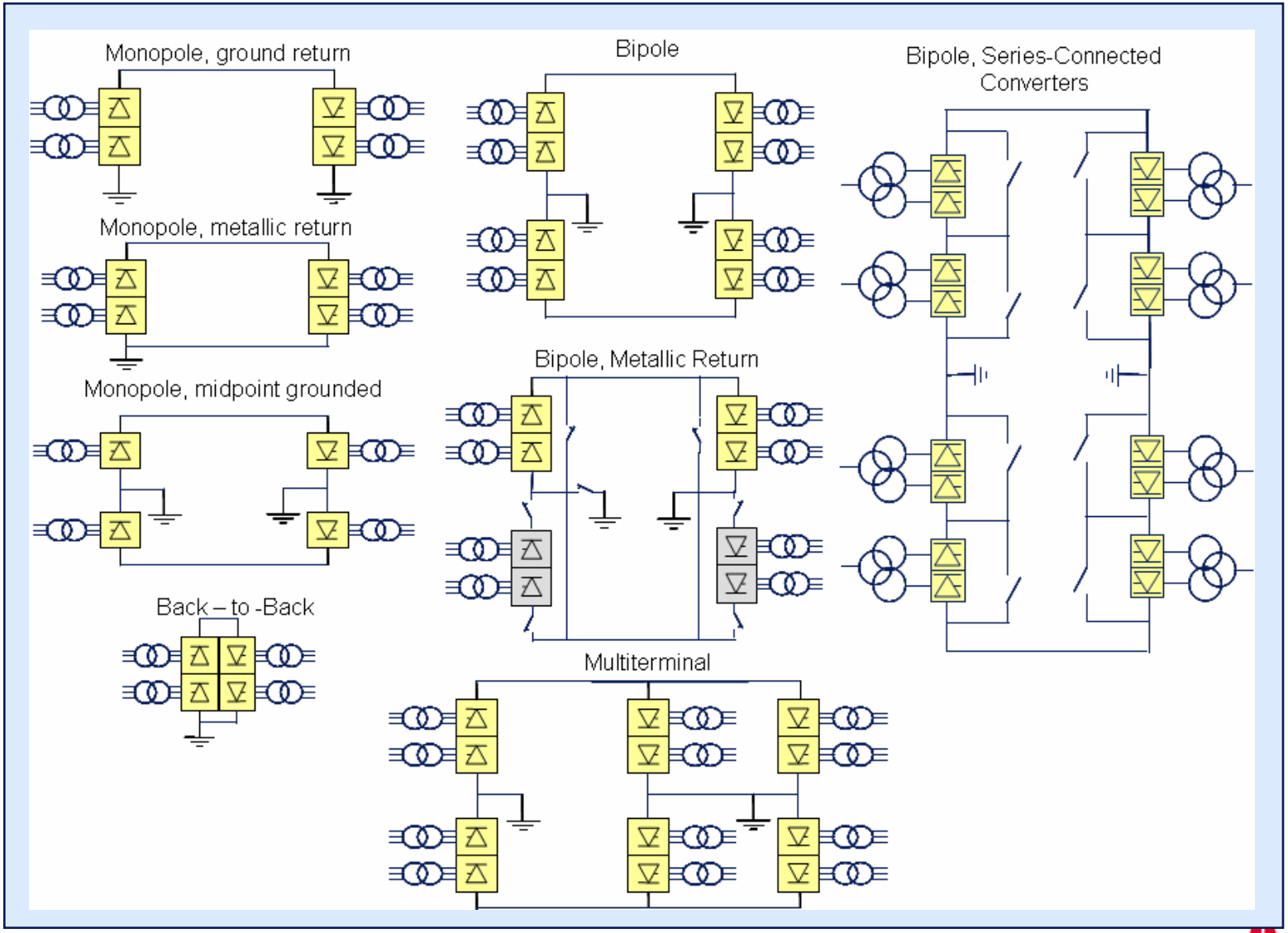
The HVDC Classic Converter Station



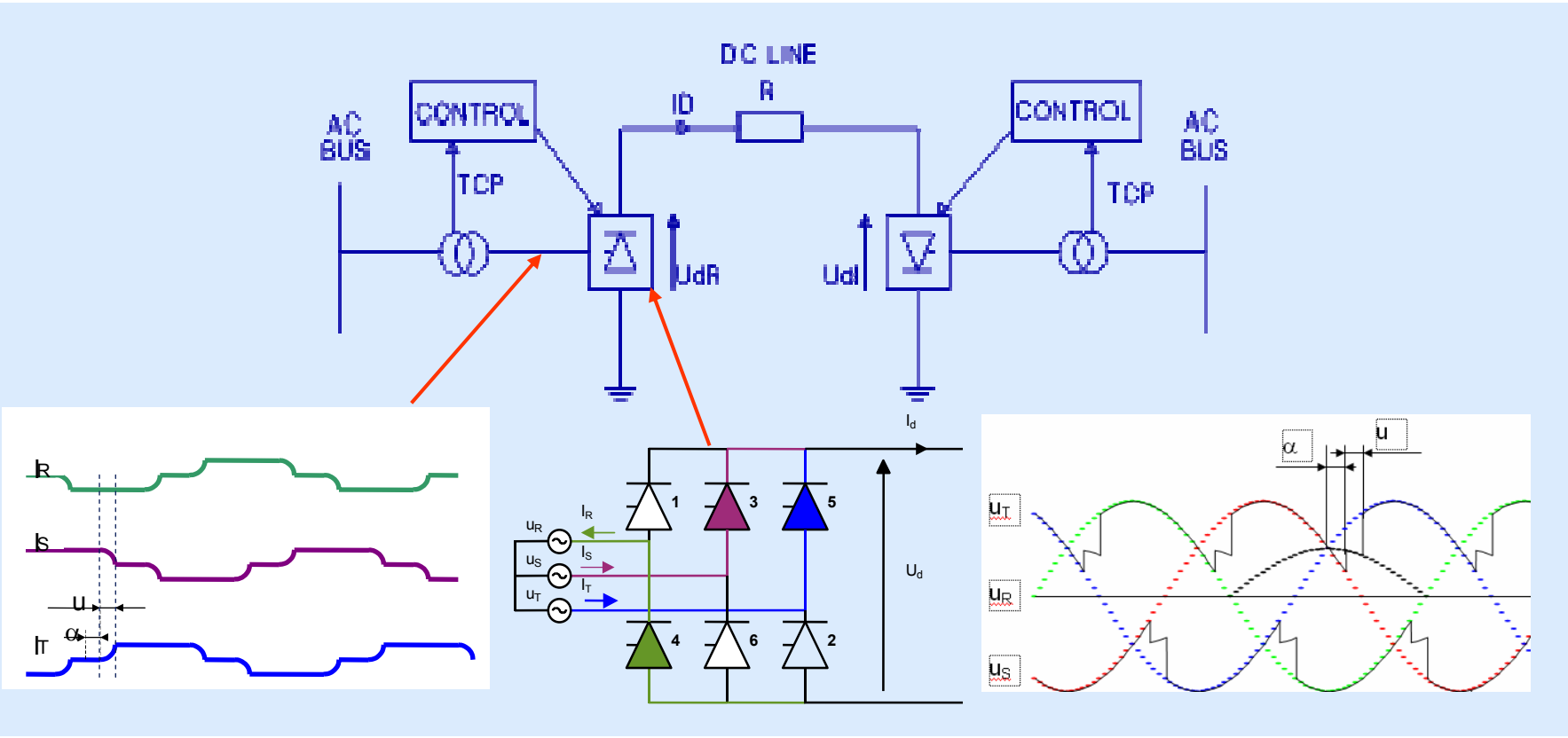
HVDC Converter Station Design



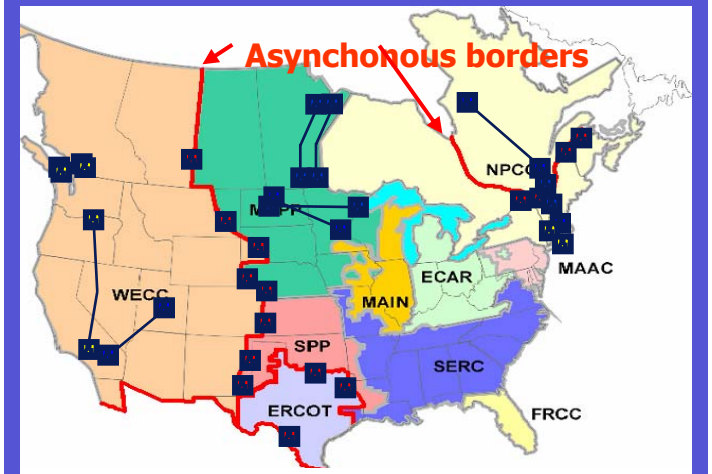
HVDC Operating Configurations and Modes



HVDC Classic Control



Asynchronous Interconnections



HVDC in North America

- Economic
  - Firm transactions
  - Shared reserves
  - Increase diversity
  - Economy energy trade
- Reliability
  - Emergency power support
  - Mutual assistance
  - Isolate disturbances
  - ‘Fire-wall’ against cascading outages
  - Reserve sharing

The CCC* Converter Station

*Capacitively-commutated converter station

Transmission
Line, Cable or Back-Back

Smoothing reactor

Converter

AC bus

Weaker Systems
Back-to-Back
100 - 550 MW

DC filter

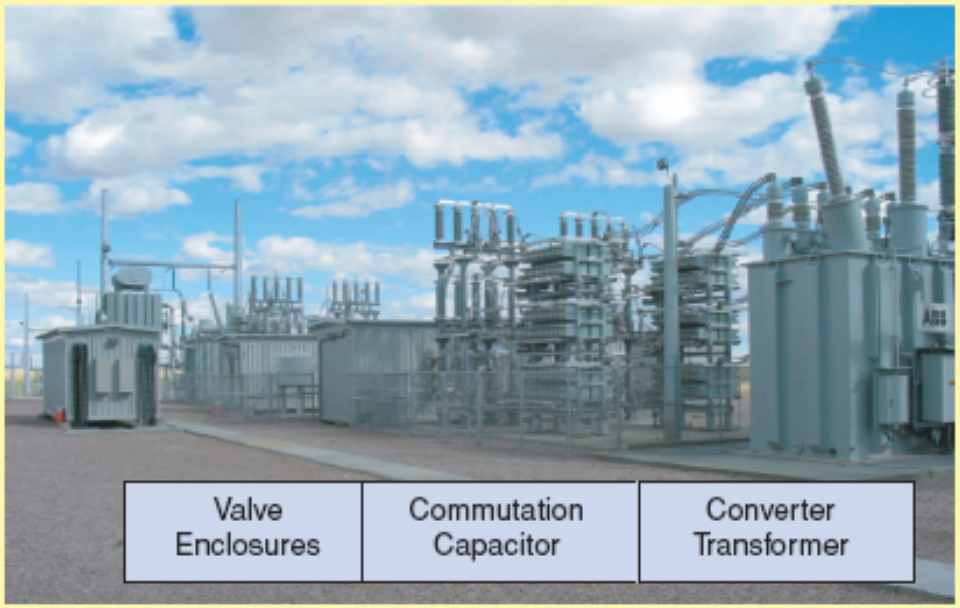
Commutation capacitors

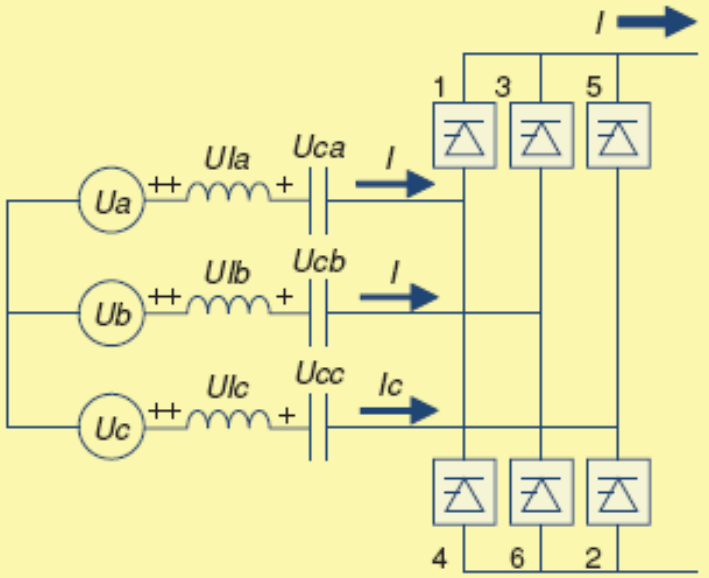
Contune AC filters

Telecommunication

Control system

Modular Back-toBack CCC Asynchronous Tie

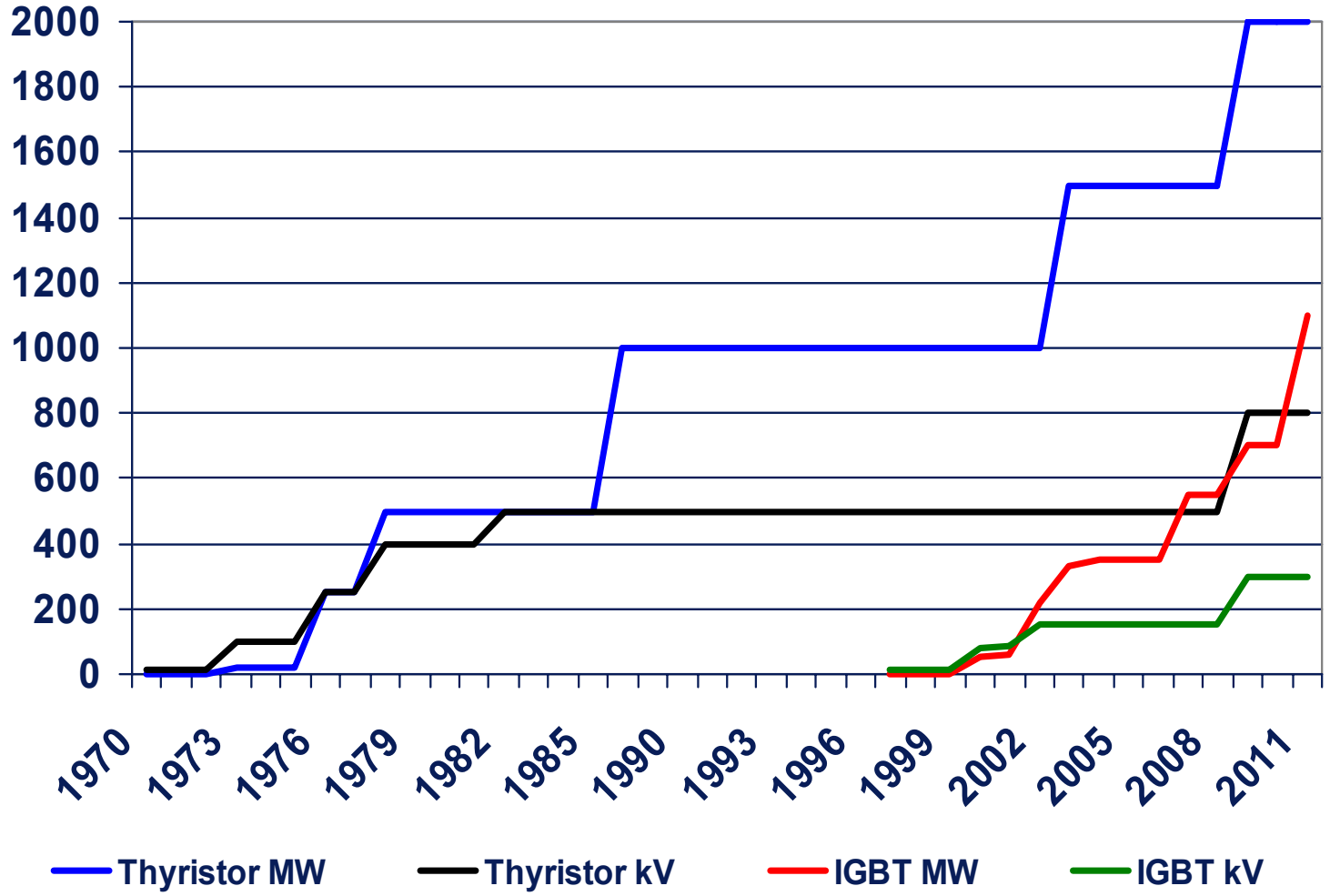




HVDC Light Transmission – Voltage Source Converters

- Applications
  - Underground and sea cable transmission
  - Off-shore - platforms, islands
  - Urban in-feed
  - Constrained ROW
  - Virtual generator for replacement of RMR generation
  - Integration of remote renewable generation
  - Improved voltage stability
- Ratings
  - Power range 50-1100 MW
  - Voltages ± 80, ± 150 and ± 300 kV
  - Extruded cables with prefabricated joints

HVDC Solid State Converter Development



HVDC Light Station

Strong or Weak Systems
Dynamic Voltage Control
Underground Transmission
Up to ±150kV, 550MW
Up to ±300kV, 1100MW

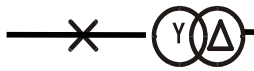
Converter station

Voltage Source(d) Converter - VSC

Phase Reactor

Transmission Cable

AC bus



AC filters

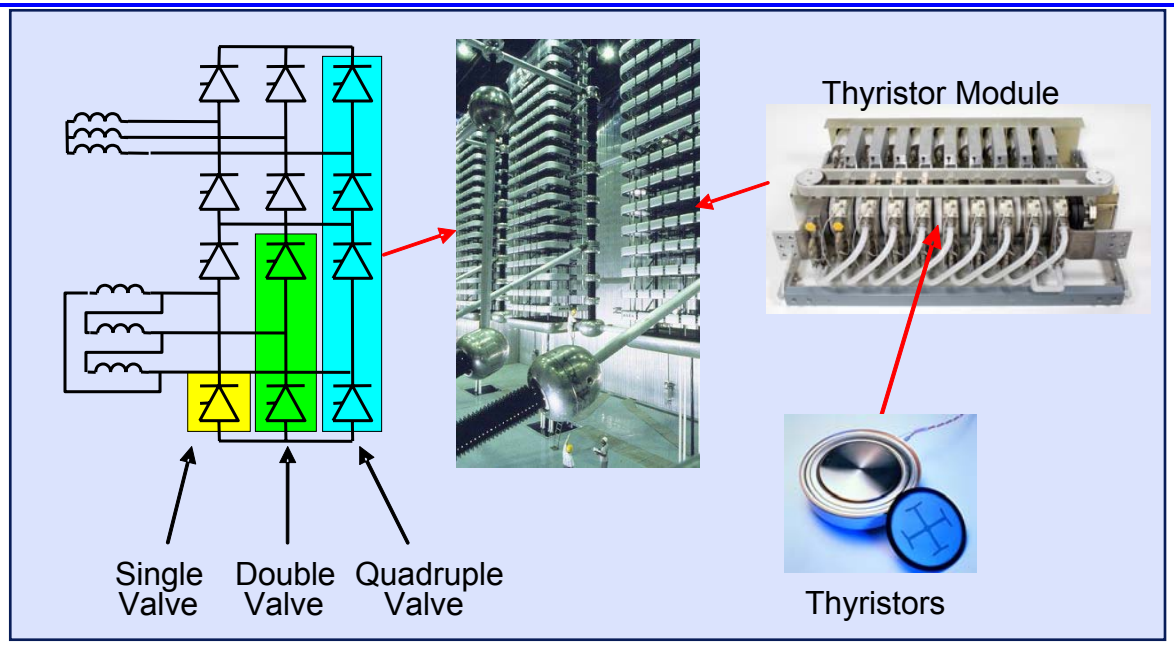
DC Capacitor

Control system

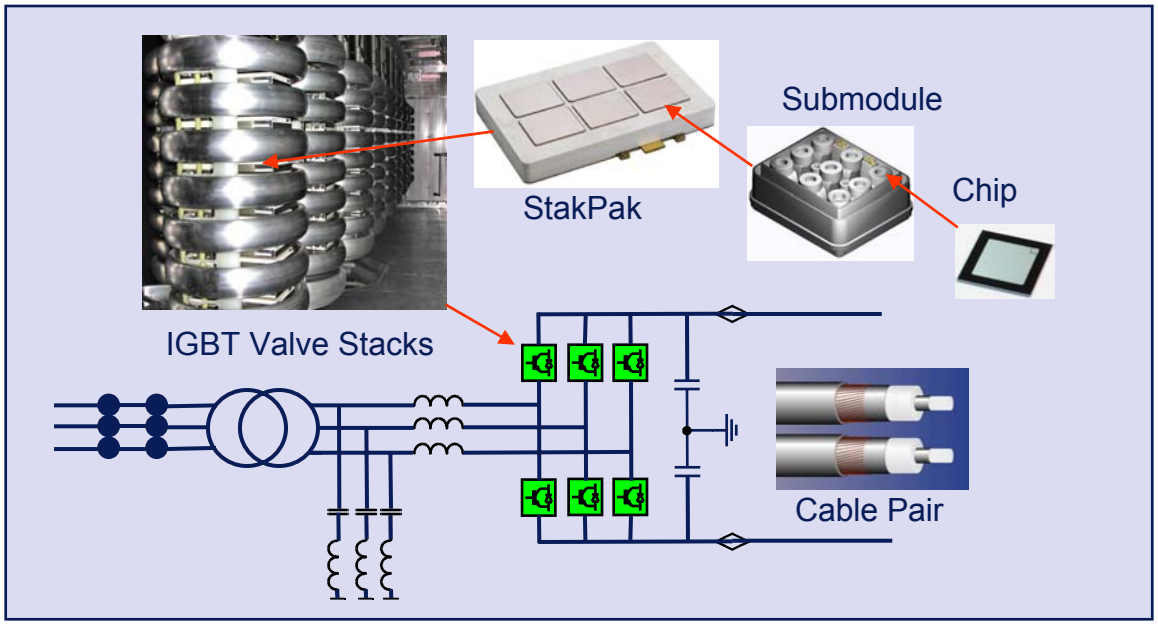
Dry DC Capacitor

IGBT Valves

HVDC Converter Arrangements

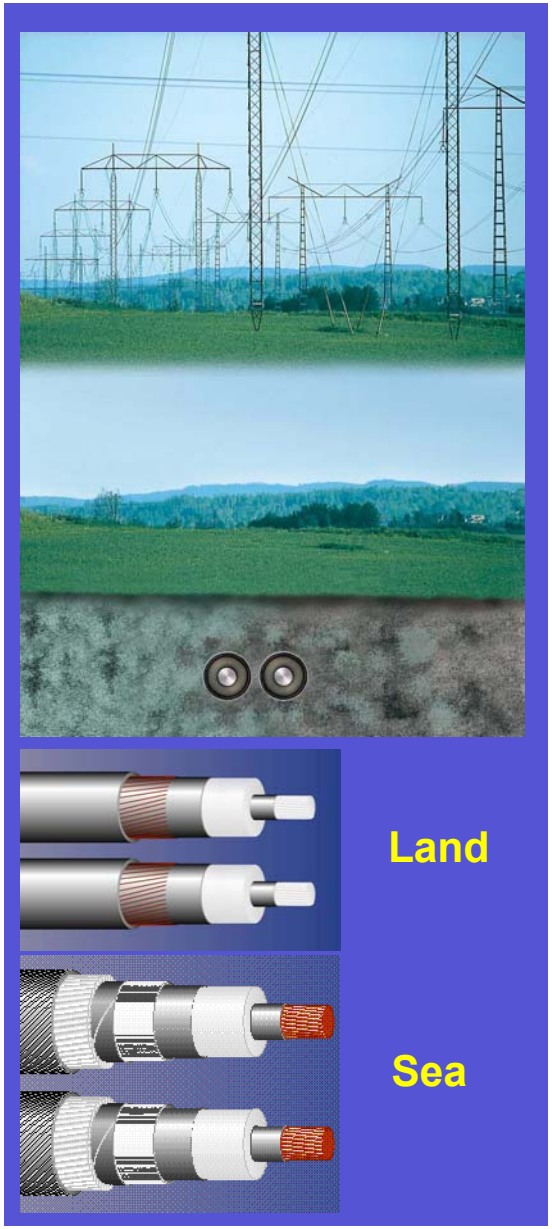


Conventional HVDC



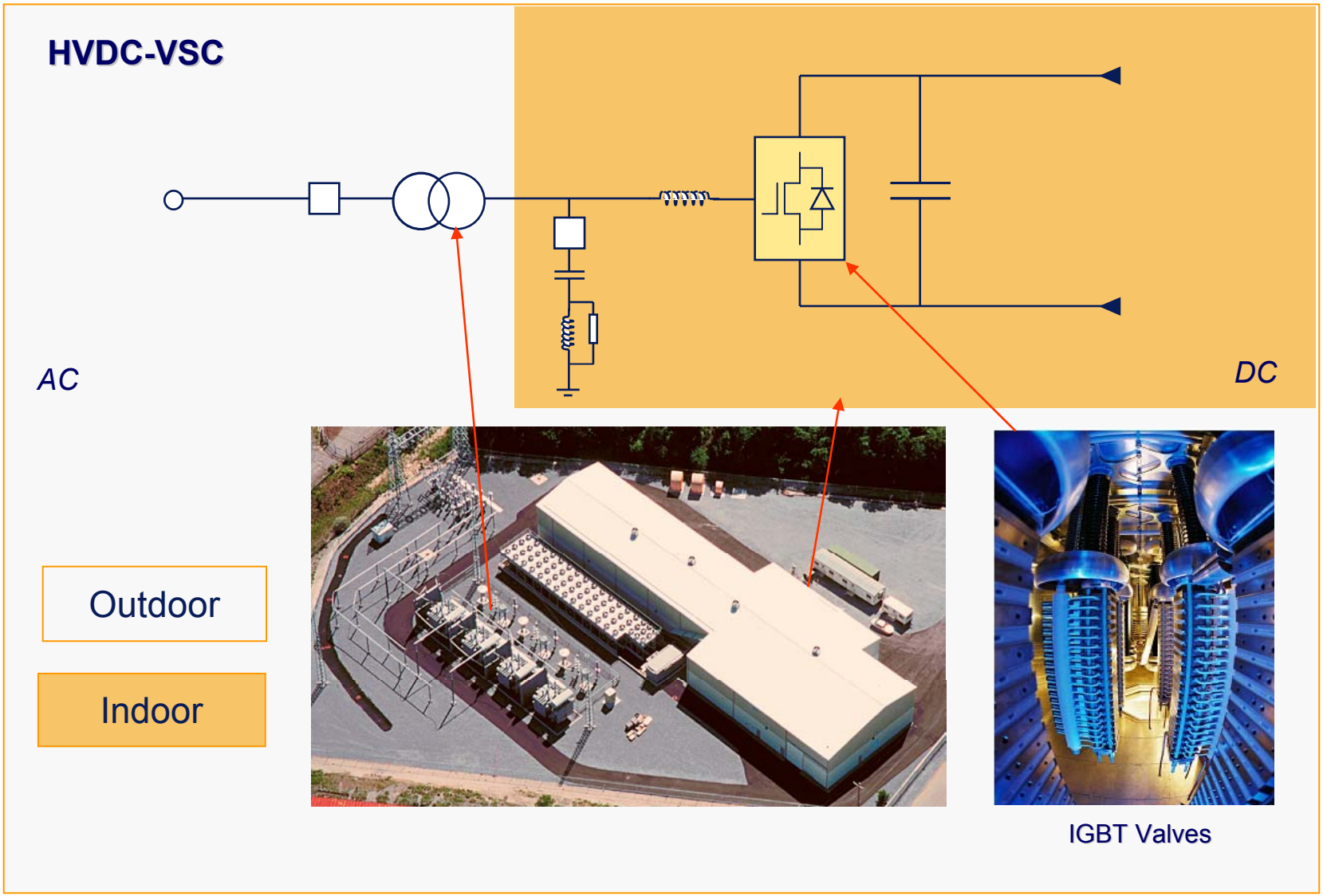
VSC Based HVDC

Underground Cable Systems with HVDC Light

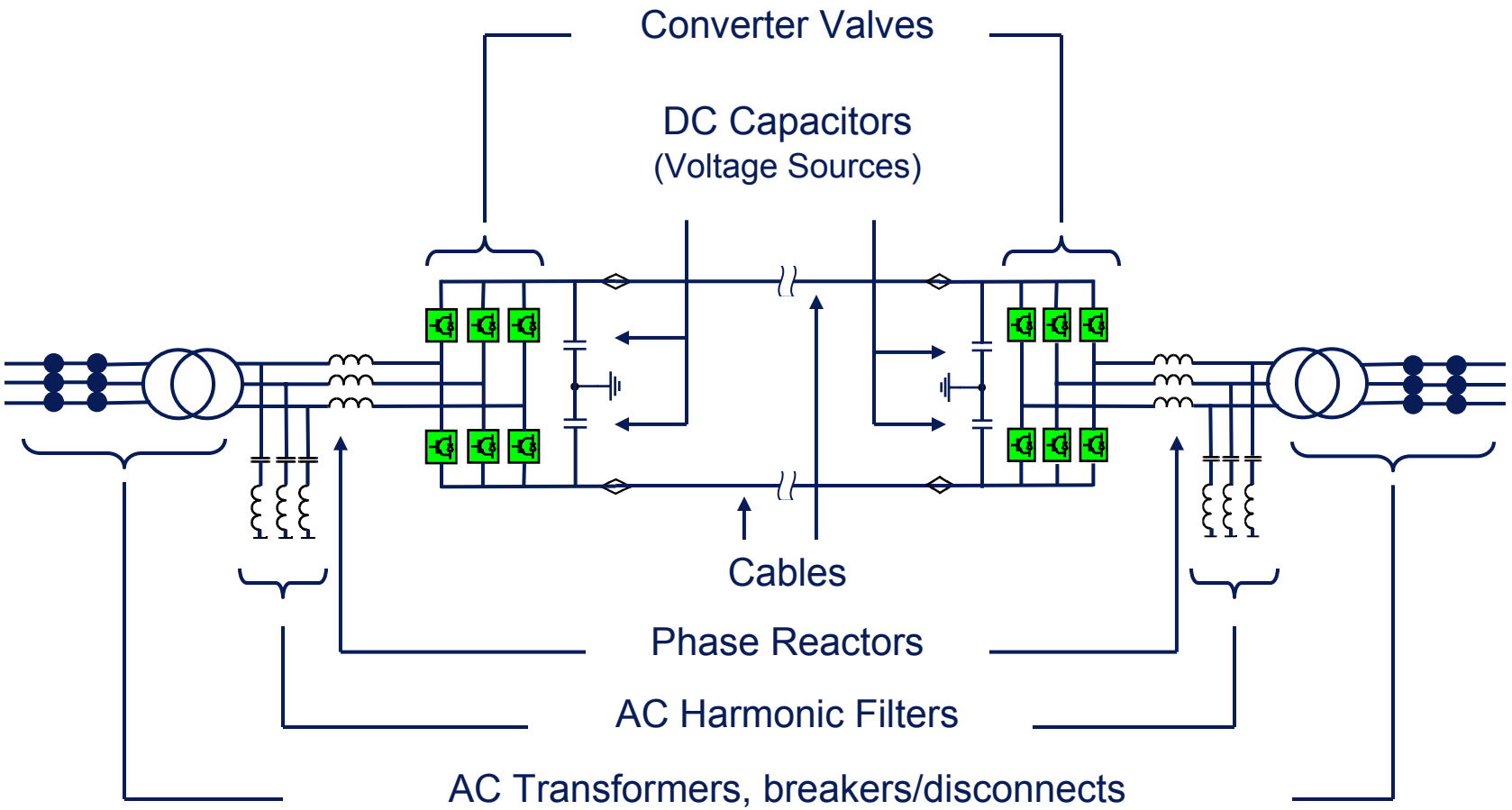


- Economic
  - No distance limitation
  - Full utilization – no reactive power
  - Two cables v three cables for AC
  - Light, flexible and simpler design
  - Timely permitting
  - No induced circulating currents
  - Half the losses
  - Easier transport and installation
- Reliability
  - No cable overloads possible
  - Dynamic reactive power support
  - Congestion relief
  - Isolate disturbances
  - Share ROW without increasing exposure
  - Black-start capability

HVDC Light Converter Station

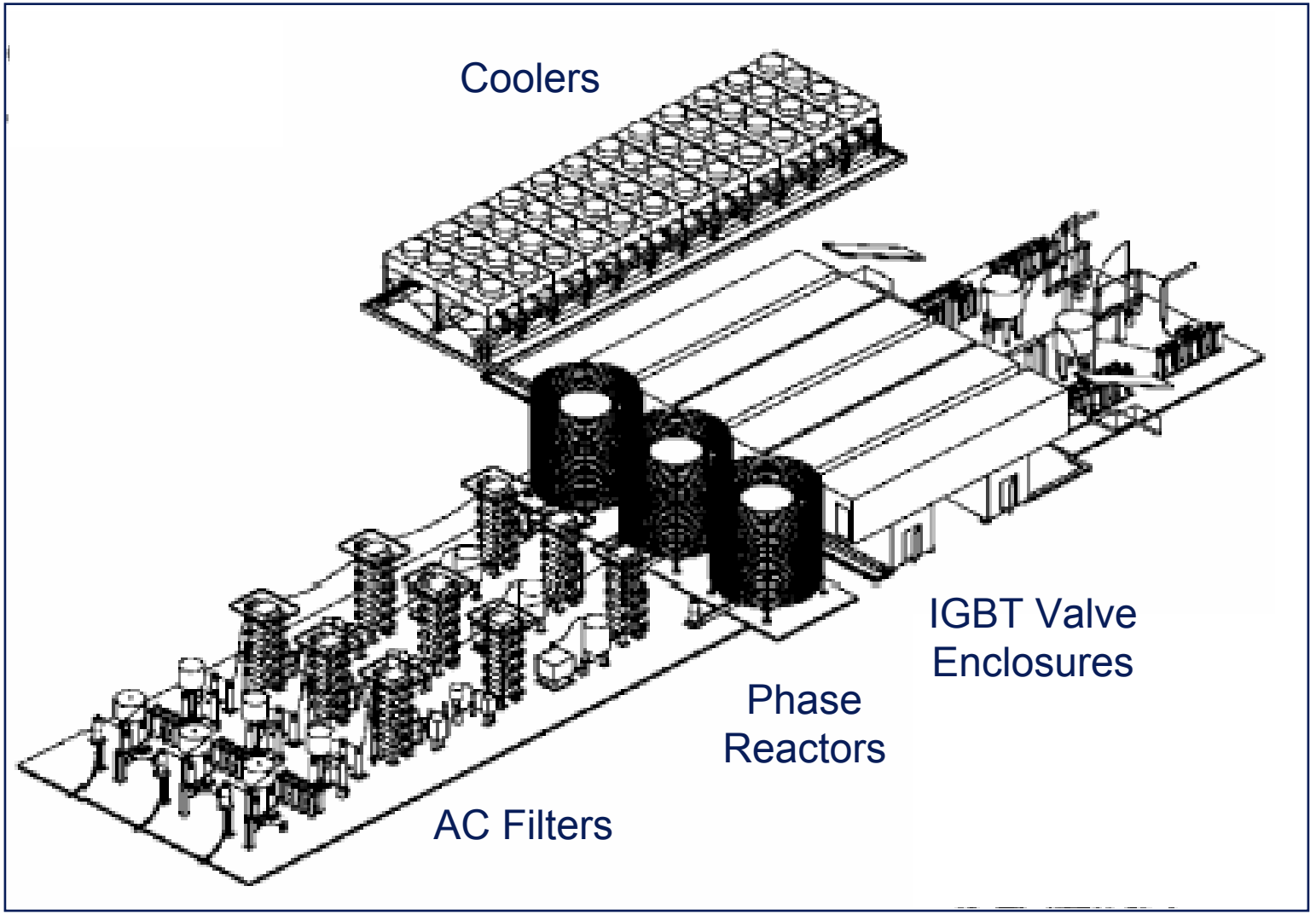


HVDC Transmission with Voltage Source Converters

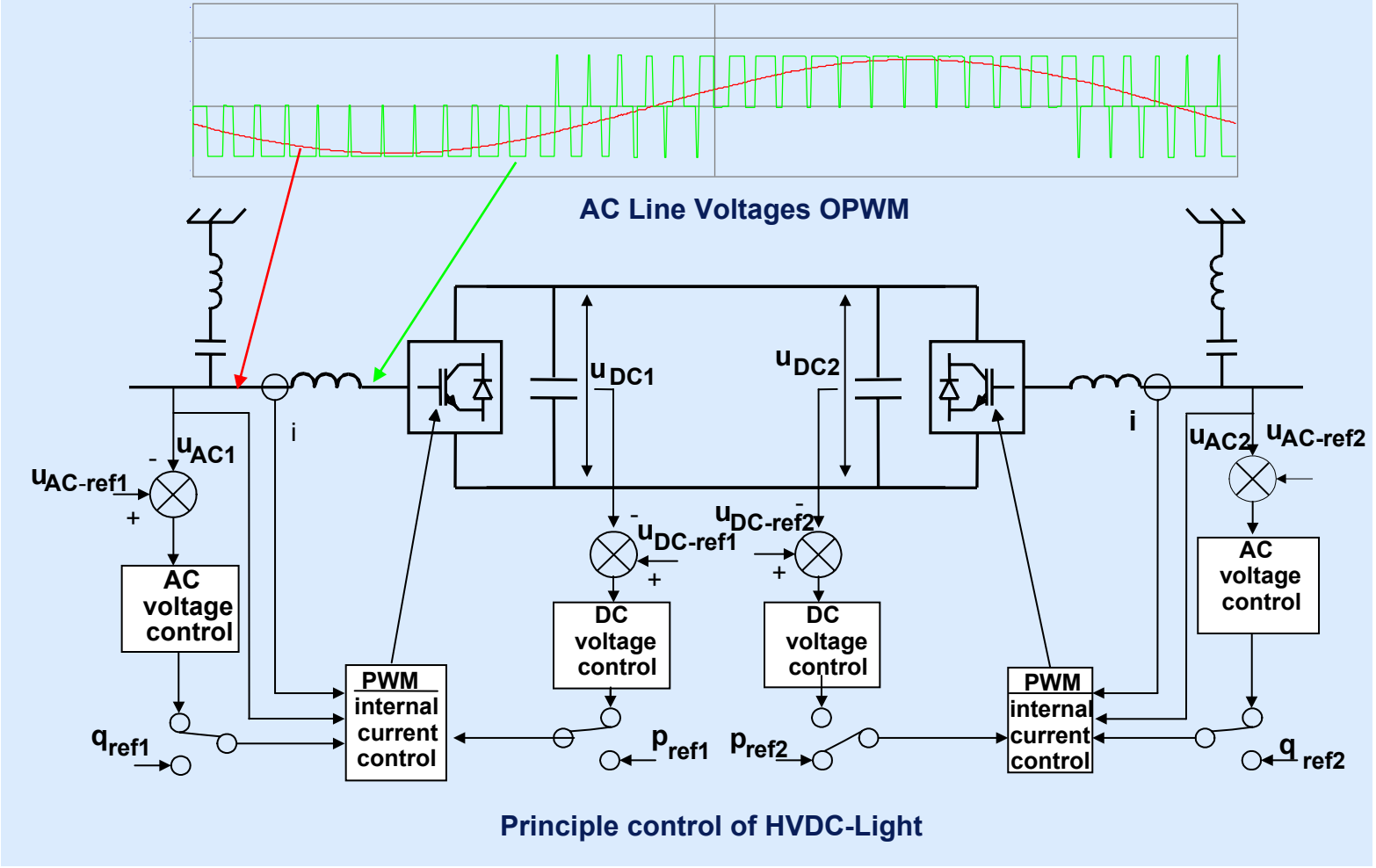


Simplified Single Line Diagram (SLD)

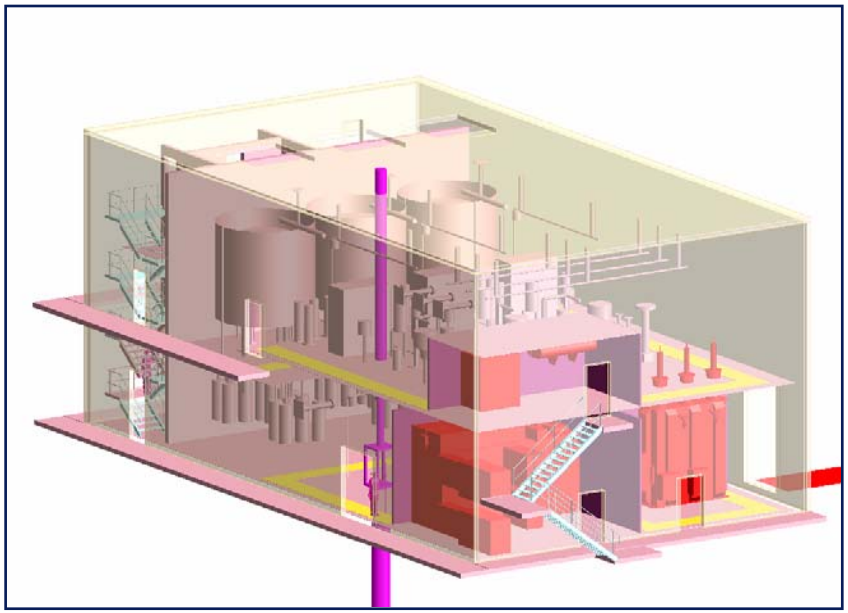
HVDC Light Converter Station



Control of VSC Based HVDC Transmission



Offshore Applications of HVDC Light



Comparison of Reactive Power Characteristics