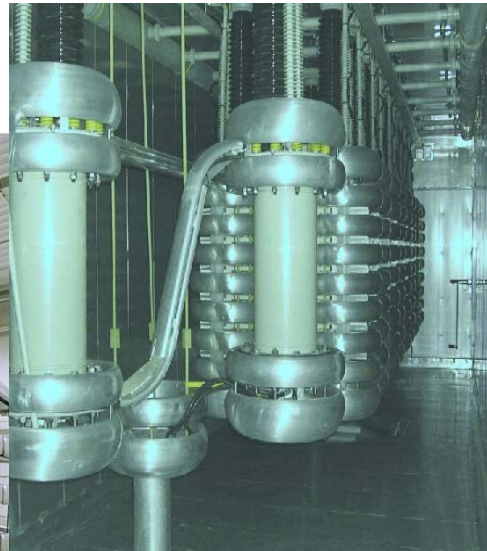
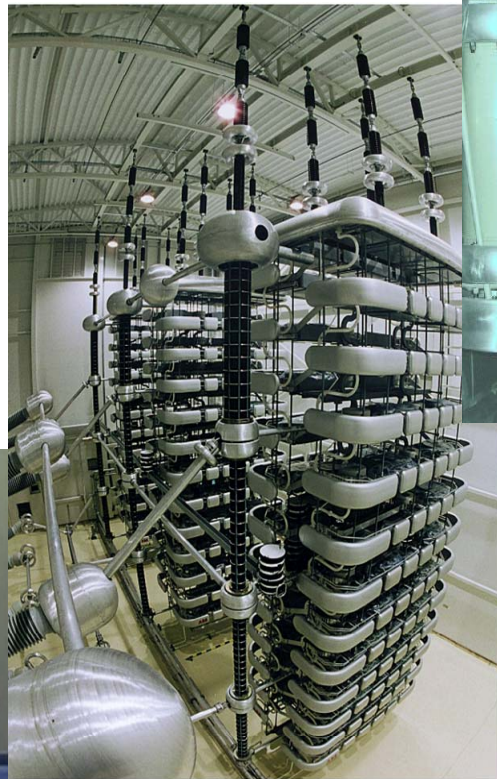


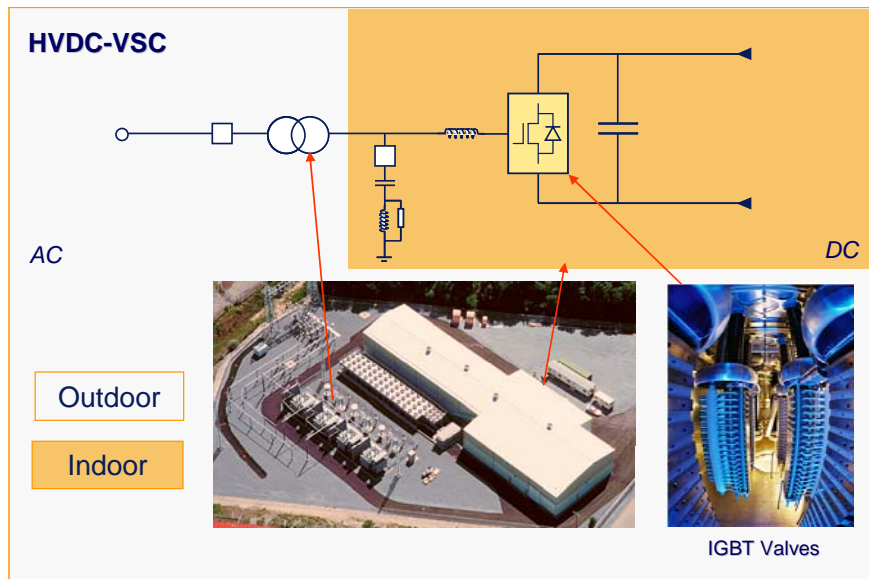
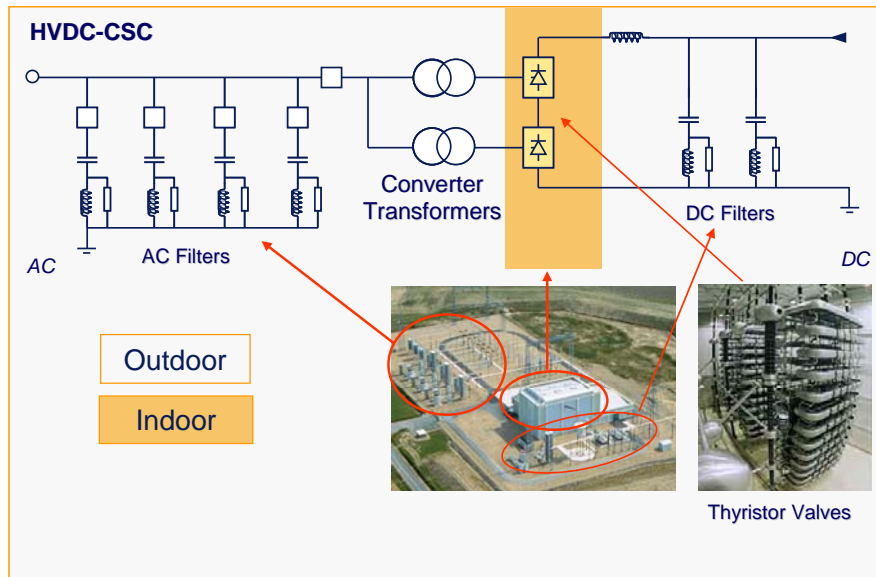
Topics

- HVDC Fundamentals
 - Conventional Converters
 - Capacitor Commutated Converters
 - Voltage Source Converters
 - Reactive Power Requirements
 - System Configurations
 - Tapping
 - Control basics
 - High Power Transmission

Evolution . . .



Core HVDC Technologies



■ HVDC Classic

- Current source converters
- Line-commutated thyristor valves
- Requires 50% reactive compensation (35% HF)
- Converter transformers
- Minimum short circuit capacity > 2x converter rating

■ HVDC Light

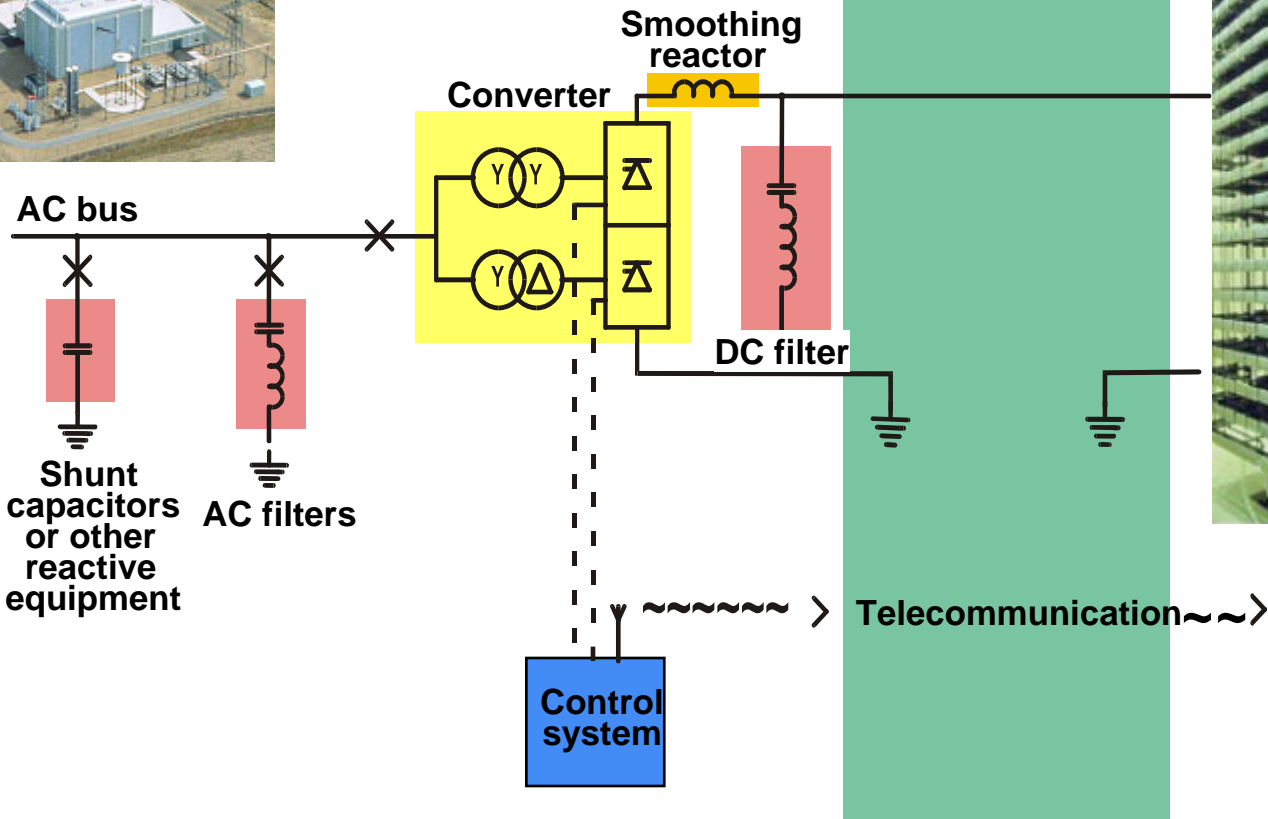
- Voltage source converters
- Self-commutated IGBT valves
- Requires no reactive power compensation (15% HF)
- Standard transformers
- No minimum short circuit capacity, black start

The HVDC Classic Converter Station



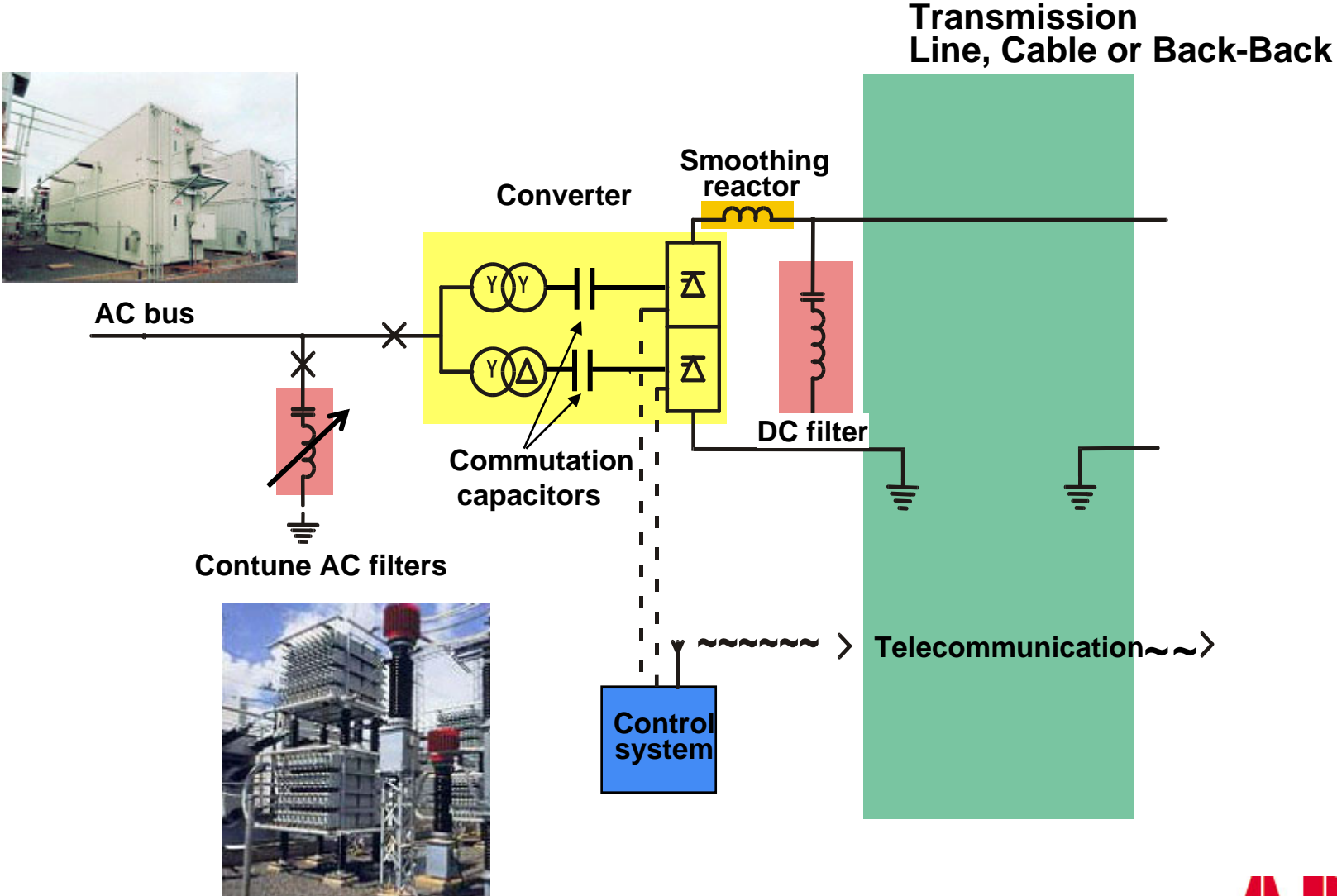
Converter station

Transmission line or cable

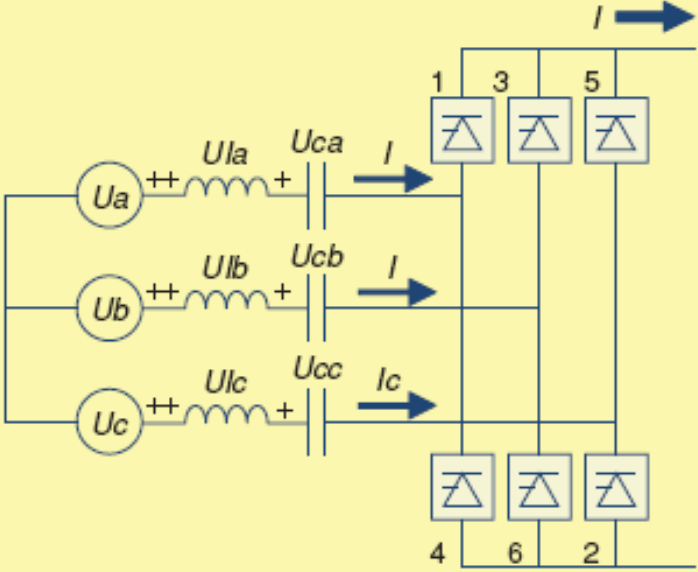
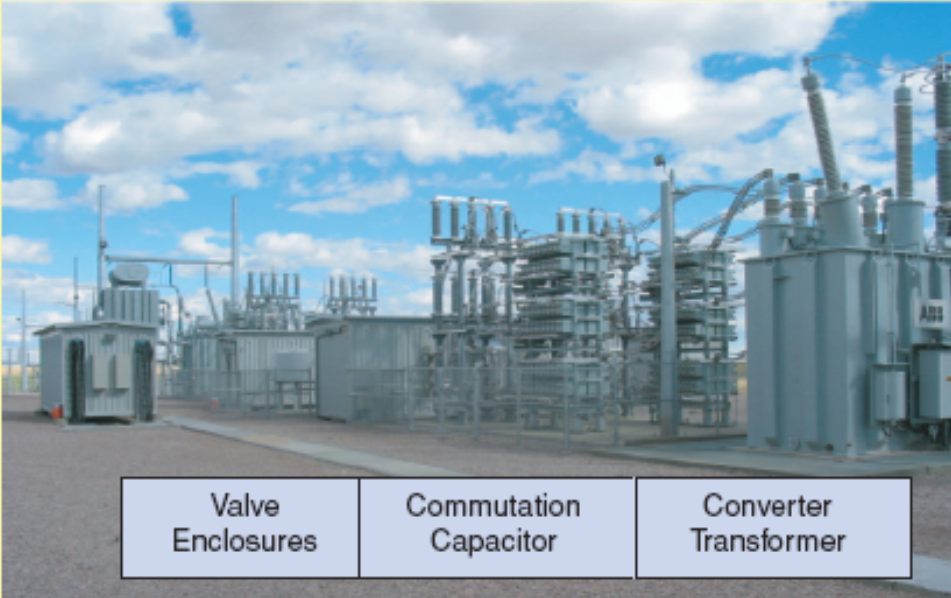


The CCC* Station

*Capacitively-commutated converter

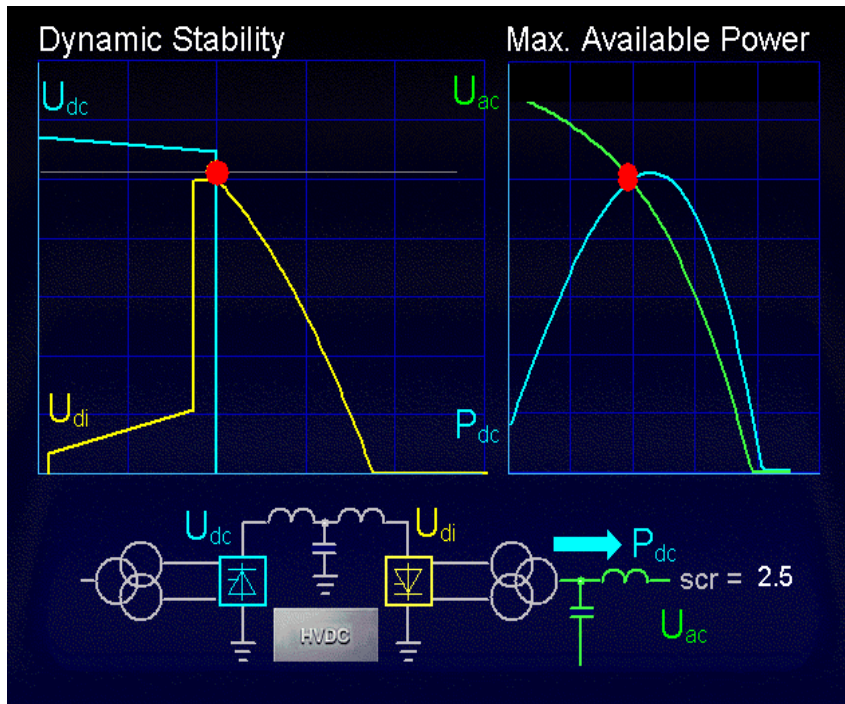


Modular Back-to-Back CCC Asynchronous Tie

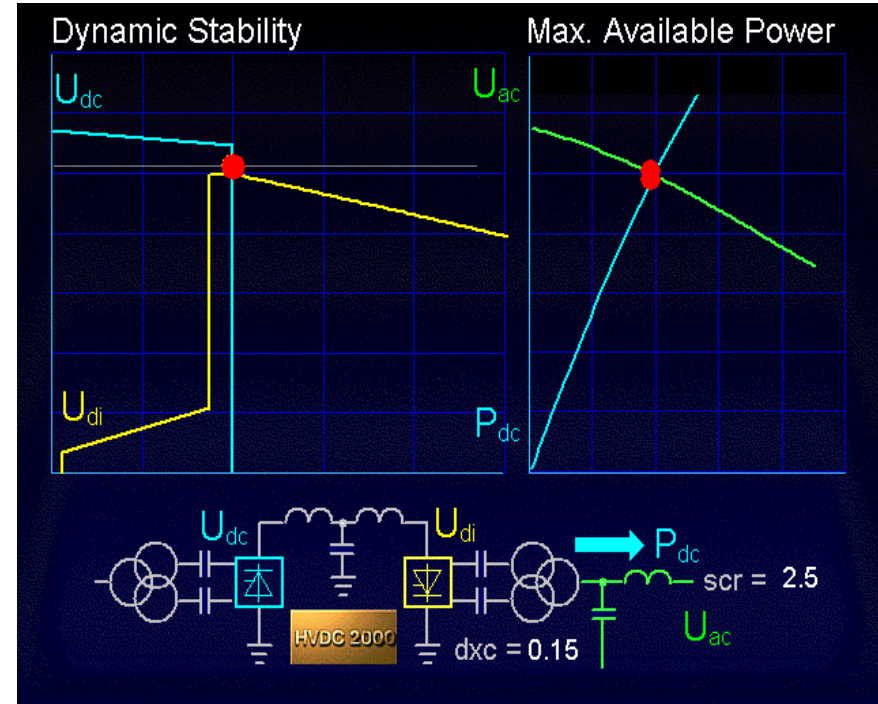


Improved Stability and Higher Power Transfer

HVDC Classic

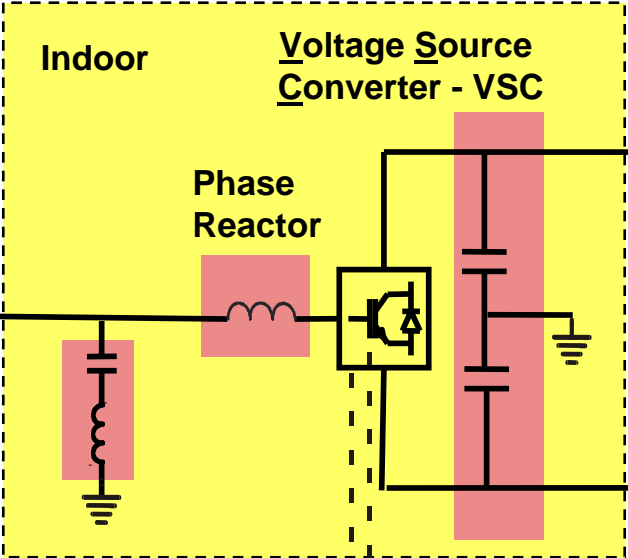


HVDC CCC



The HVDC Light Converter Station

Converter station



Transmission Cable



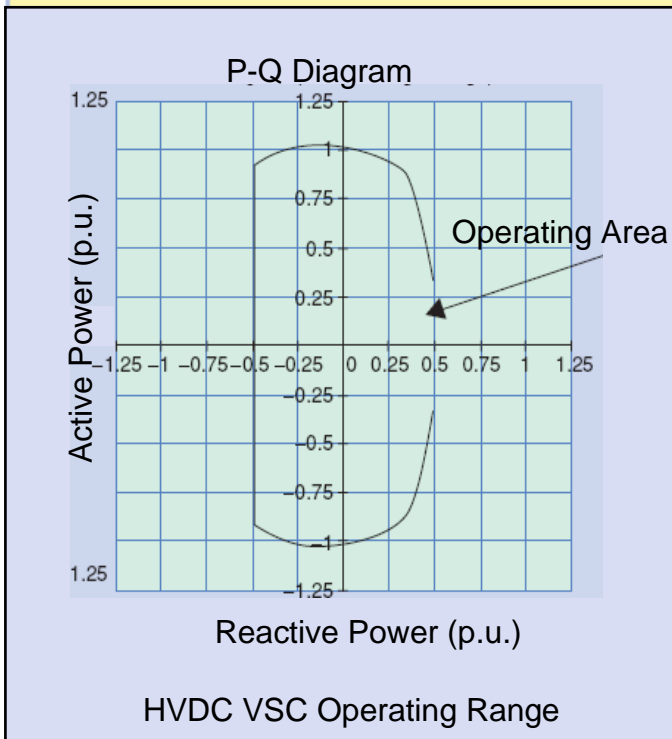
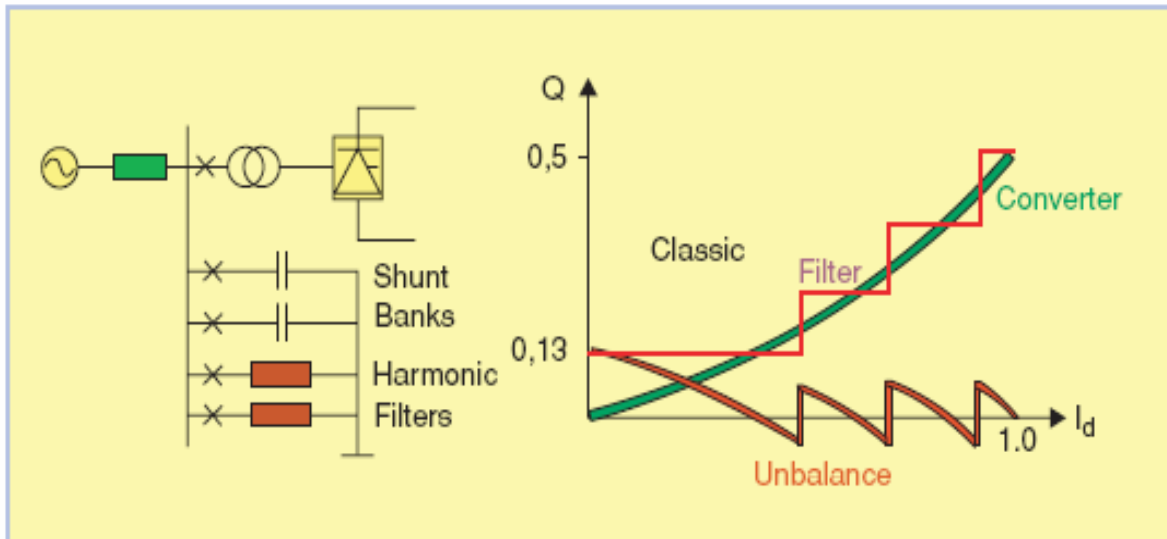
Dry DC Capacitor



IGBT Valves

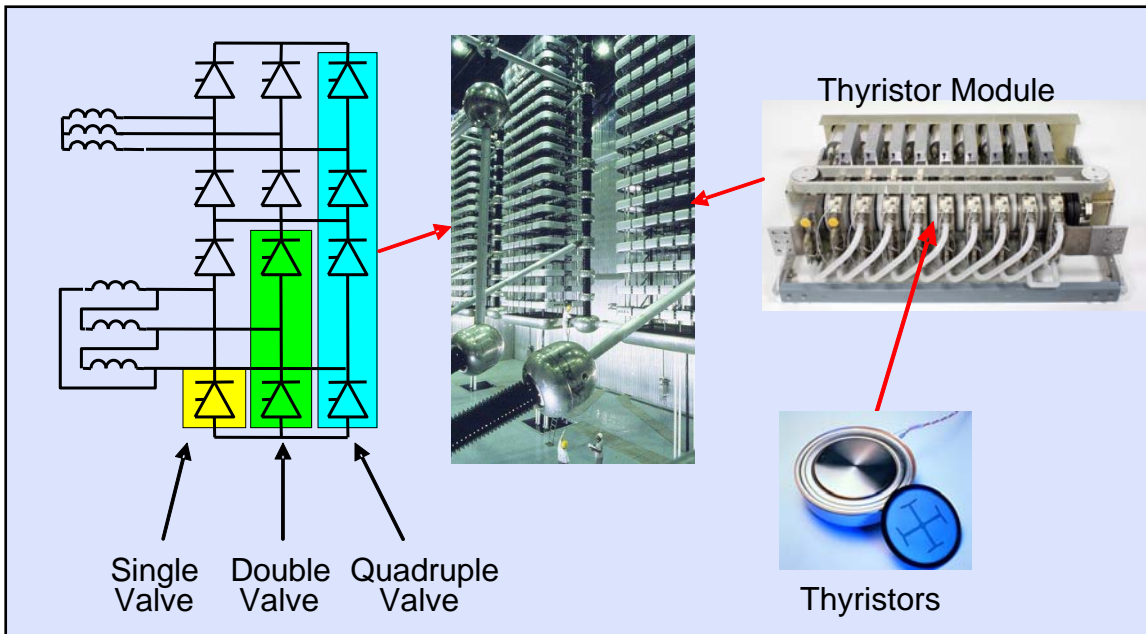


Comparison of Reactive Power Characteristics



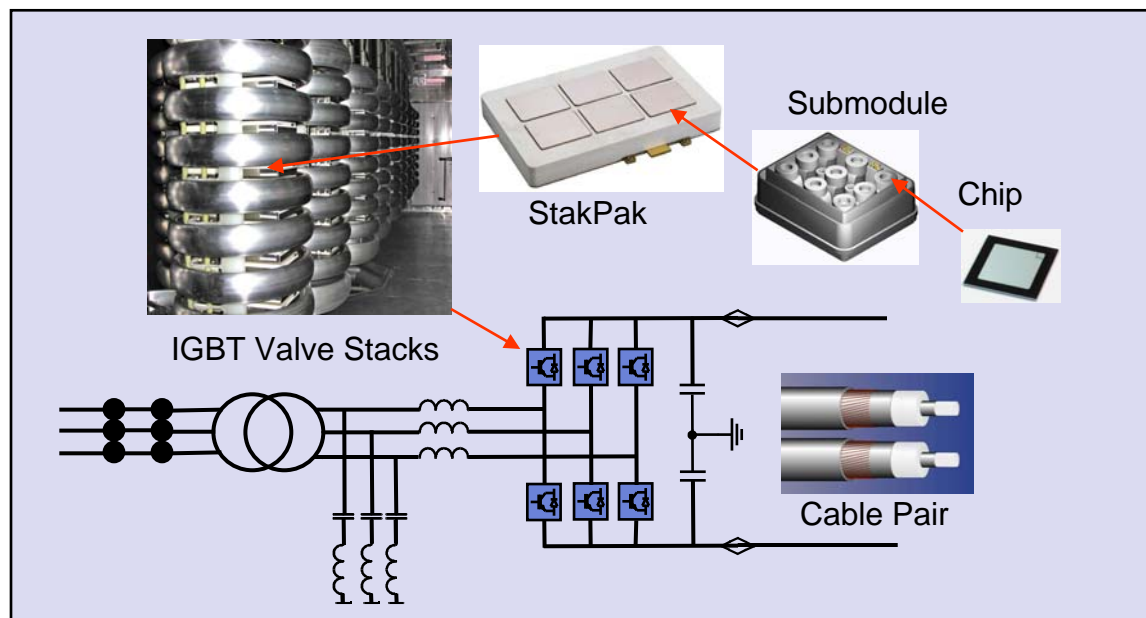
- Conventional HVDC – HVDC Classic
(~ SVC with TCR+FC, $-0.5P_d / +0$ MVar)
- VSC Based HVDC – HVDC Light
(~ STATCOM, $-0.5P_d/+0.5P_d$ MVar)

HVDC Converter Arrangements



HVDC Classic

- Thyristor valves
- Thyristor modules
- Thyristors
- Line commutated

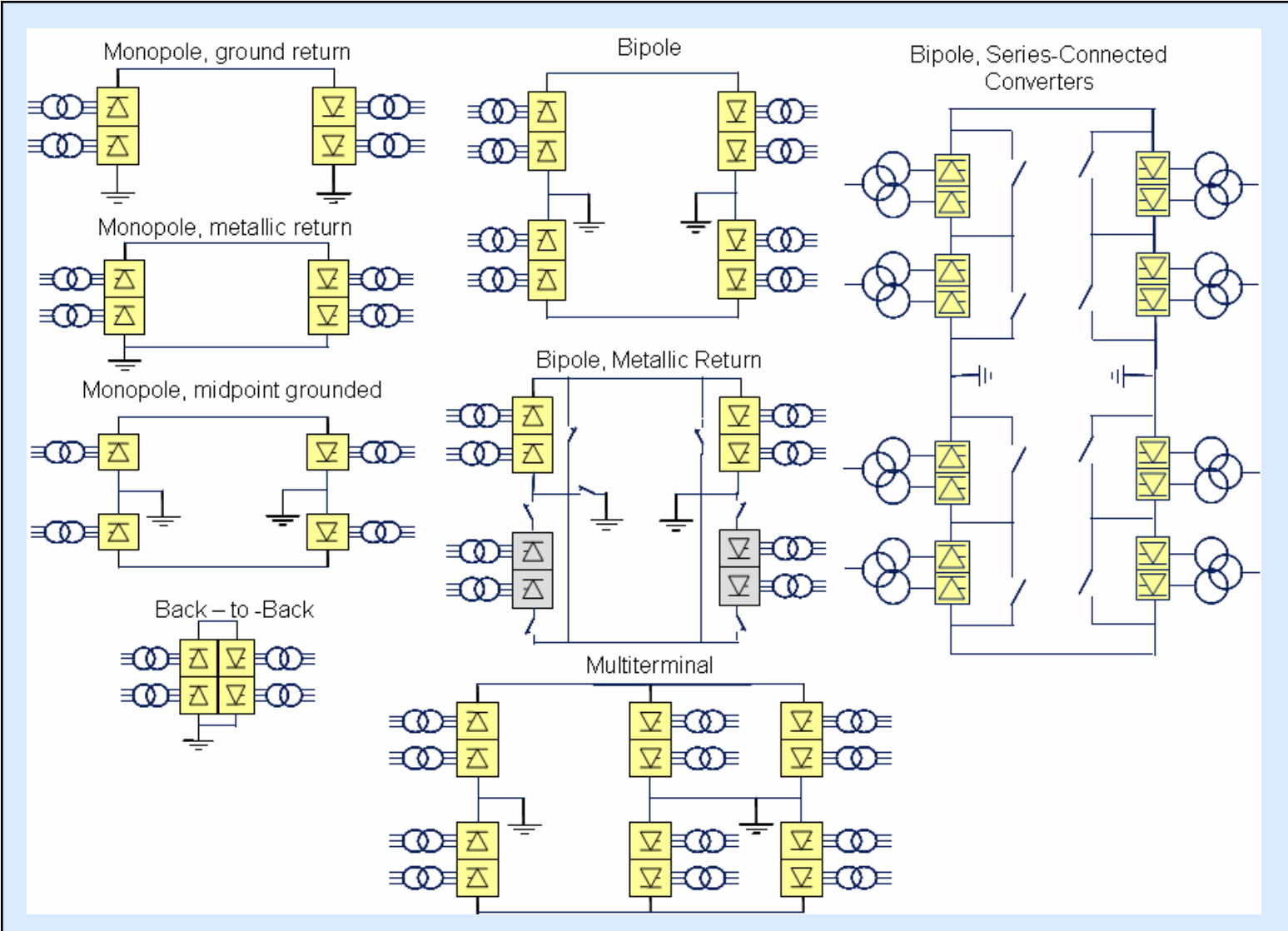


HVDC Light

- IGBT valves
- IGBT valve stacks
- StakPaks
- Submodules
- Self commutated

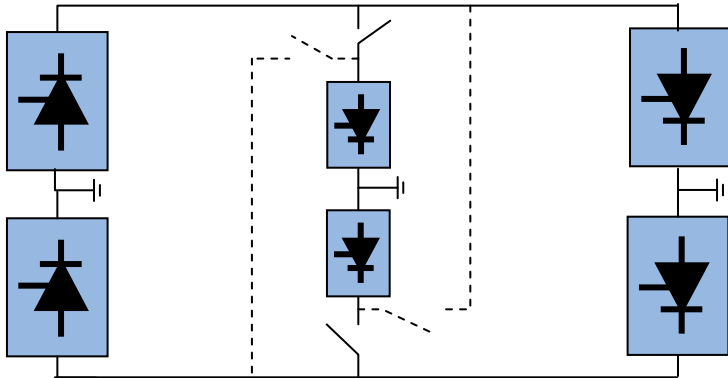


HVDC Operating Configurations and Modes



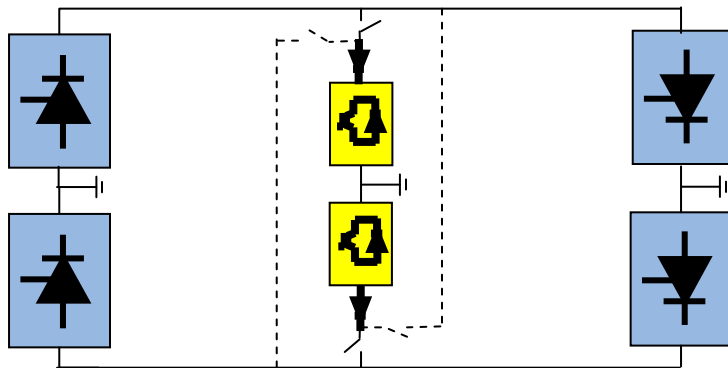
Tapping OVHD HVDC with Large VSC Converters

HVDC Tap



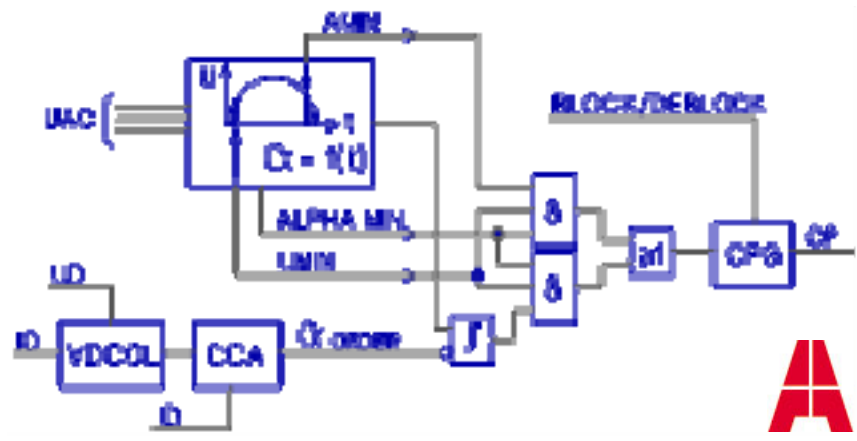
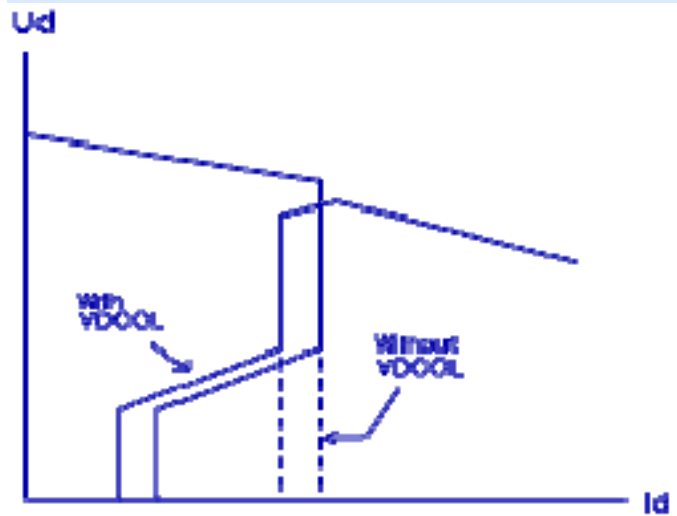
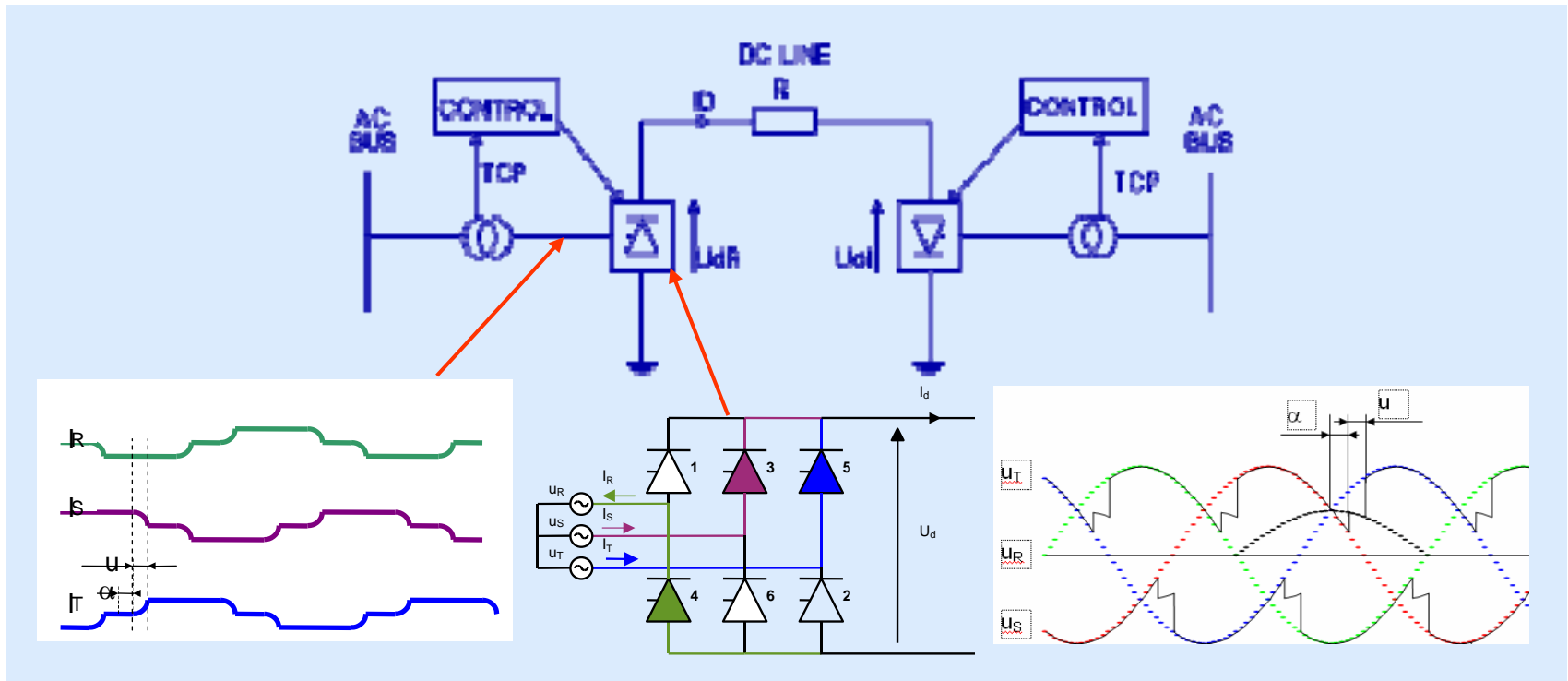
- Reverse power by polarity reversal
- Electronic clearing of dc line faults
- Fast isolation of faulty converters
- Reactive power constraints
- Momentary interruption due to CF at tap
- Limitations on tap rating, location and recovery rate due to stability

HVDC Light Tap

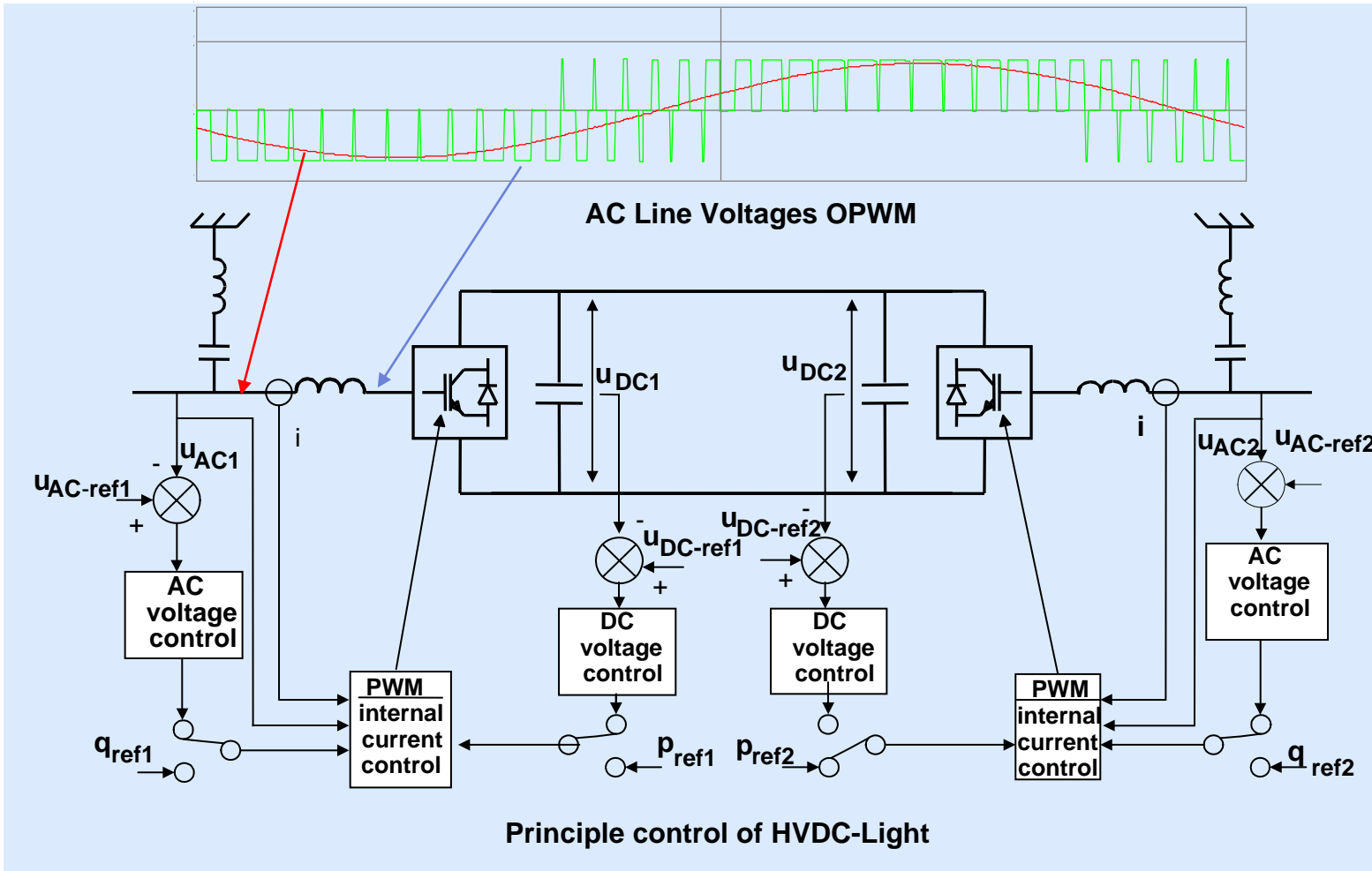


- Polarity reversal if main link is bidirectional
- Cannot extinguish dc line fault current contribution without special provision, e.g., diode coupling for inverter
- No interruption to main power transfer due to CF at tap
- Less limitations on tap rating and location
- Cascade VSC connection for lower tap rating
- No reactive power constraints
- Improved voltage stability

HVDC Classic Control



Control of VSC Based HVDC Transmission



Comparison - AC, HVDC, HVDC CCC and HVDC Light

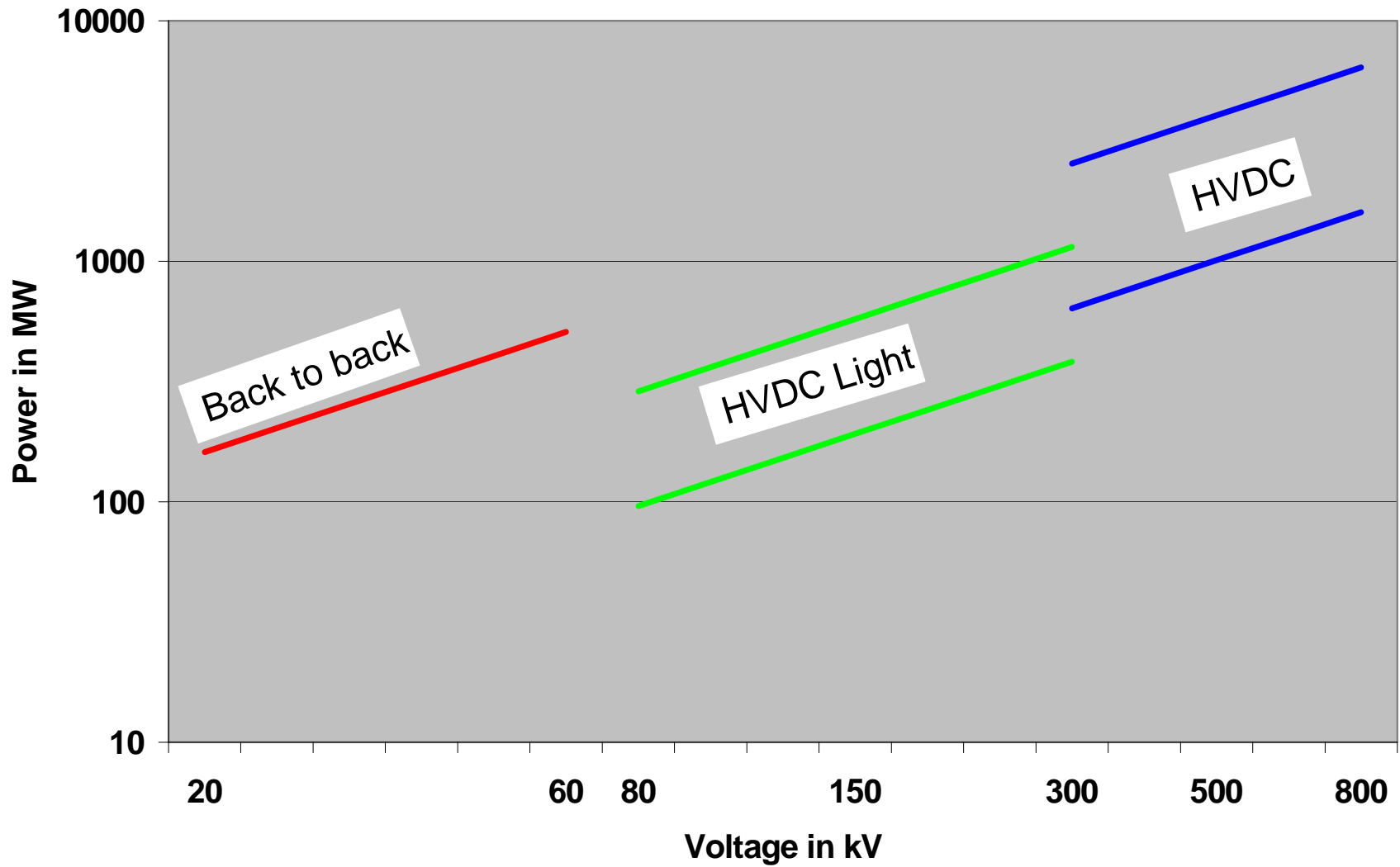
Attributes	AC Cable	HVDC - Conventional	HVDC – Capacitor Commutated	HVDC Light
Power flow control	None unless PST or series reactor	Continuous $\pm 0.1P_r$ to $\pm P_r$	Continuous $\pm 0.1P_r$ to $\pm P_r$	Continuous 0 to $\pm P_r$
Reactive power demand	$3 I^2 X$ - $3 V^2 B$	Reactive power demand = 50% power transfer	Reactive power demand reduced by series cap	No reactive power demand
Reactive power compensation & control	Shunt reactors	Switched shunt banks 35% in filters + 15% in capacitors	Filters + series compensation of $3 I^2 X_{cc}$	STATCOM + 15% in fixed filters
AC voltage control	Static	Slow - switched filters, capacitors & reactors + LTC	Slow - switched filters, capacitors & reactors + LTC	Dynamic – virtual generator
Voltage stability	Dependent on P, Q and Z	Degraded, special control	Improved, CF lower probability	Superior, no CF
AC system limitation	Cable derated with distance by charging current	Min SCC > 2x converter rating	Min SCC > 1.3x converter rating	None – black start, passive load, induction generators OK



Running Underground

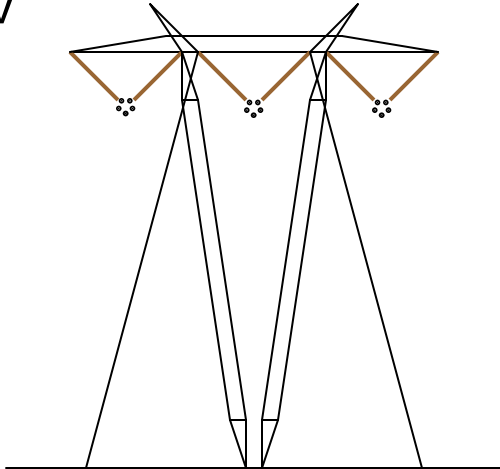


Power Ranges HVDC-Classic and HVDC-Light

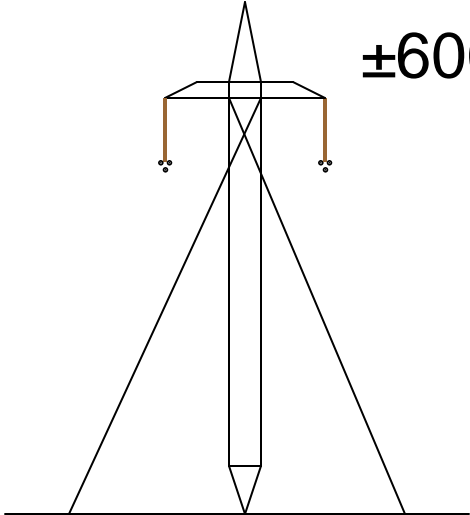


Comparison of overall line design

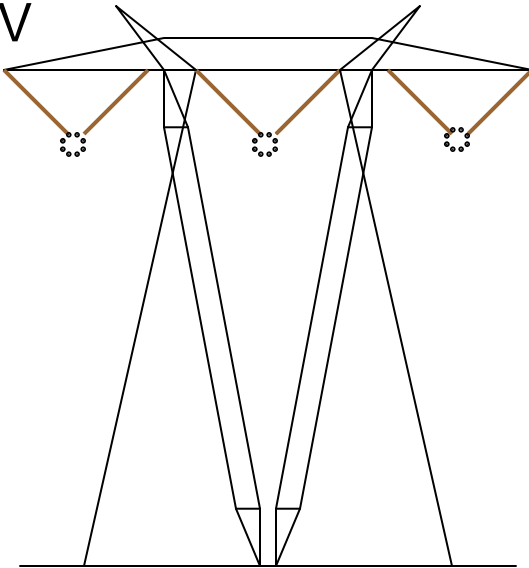
800 kV



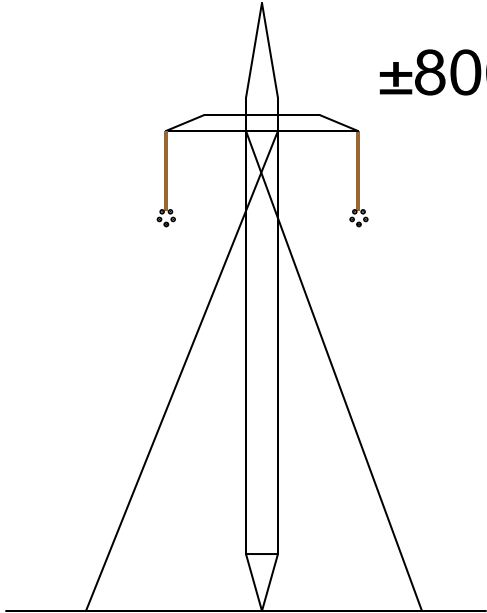
± 600 kV



1000 kV



± 800 kV



Itaipu 765 kV AC Line Performance

	765 kVac Transmission Lines								
	Line 1			Line 2			Line 3		
	Trans	Perm	Length	Trans	Perm	Length	Trans	Perm	Length
1995	0	4	891	1	11	891	-	-	0
1996	1	13	891	0	7	891	-	-	0
1997	0	6	891	2	13	891	-	-	0
1998	0	10	891	2	16	891	-	-	0
1999	1	27	891	1	10	891	-	-	0
2000	3	15	891	3	14	891	2	9	602
2001	2	4	891	4	8	891	2	5	915
2002	4	12	891	1	7	891	4	16	915
8 year	11	91	7128	14	86	7128	8	30	2432

Trans = 0,198 faults / 100km / year

Perm = 1,240 faults / 100km / year

Trans = Successful reclose, one attempt

Perm = Permanent, excluding tower failures

Isokeraunic Level 90 (Foz) to 50 (SP)

Note: “,” = “.”

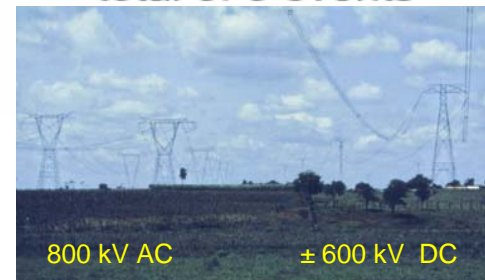
Tower Failures due to wind:

1994 3 both circuits*

1997 2 both circuits*

1998 2 both circuits*

*total of 3 events



Itaipu 600 kV HVDC Line Performance

	Bipole 1						Bipole 2					
	P1 -			P2 +			P3 -			P4 +		
	Trans	Red.V	Perm	Trans	Red.V	Perm	Trans	Red.V	Perm	Trans	Red.V	Perm
1993	0	1	0	8	1	2	2	0	3	2	0	0
1994	3	0	3	3	0	1	1	2	3	3	0	1
1995	4	0	0	3	0	1	0	0	0	3	1	0
1996	3	0	0	5	0	0	0	0	0	5	0	0
1997	5	2	5	0	0	1	0	0	1*	2	0	1*
1998	2	1	0	4	2	2	0	0	1*	1	0	1*
1999	2	0	0	3	0	0	2	0	1	2	0	1
2000	5	0	1	7	0	1	2	0	0	3	0	0
8 year	24	4	9	33	3	8	7	2	7	21	1	2
Ave.	3	0,5	1,13	4,13	0,38	1	0,88	0,25	0,88	2,63	0,13	0,25

Trans = 0,659 pole faults / 100km / year

RedV = 0,078 pole faults / 100km / year

Perm = 0,202 pole faults / 100km / year

*Line Tower Failures
total two events

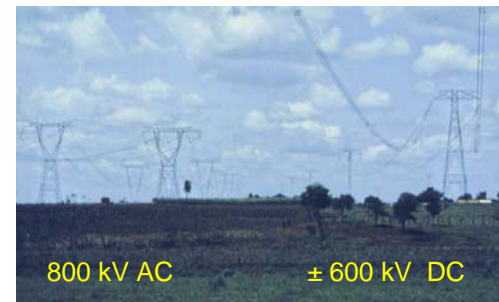
Isokeraunic Level 90 (Foz) to 50 (SP)

Trans = Successful restart at full voltage

RedV = Successful restart at reduced voltage (450 kV)

Perm = Permanent, excluding tower failures

Note: “,” = “.”



800 kV AC

± 600 kV DC

