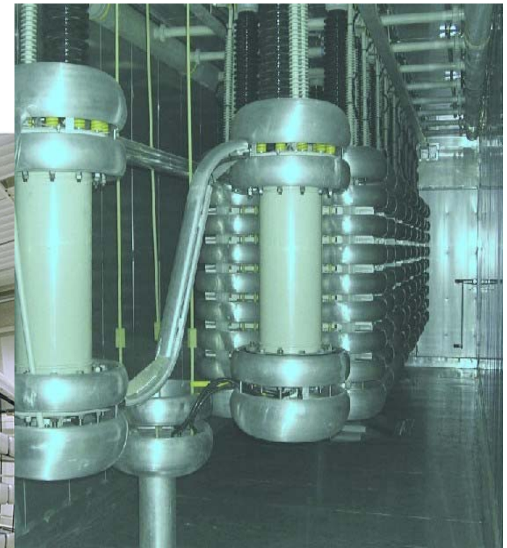
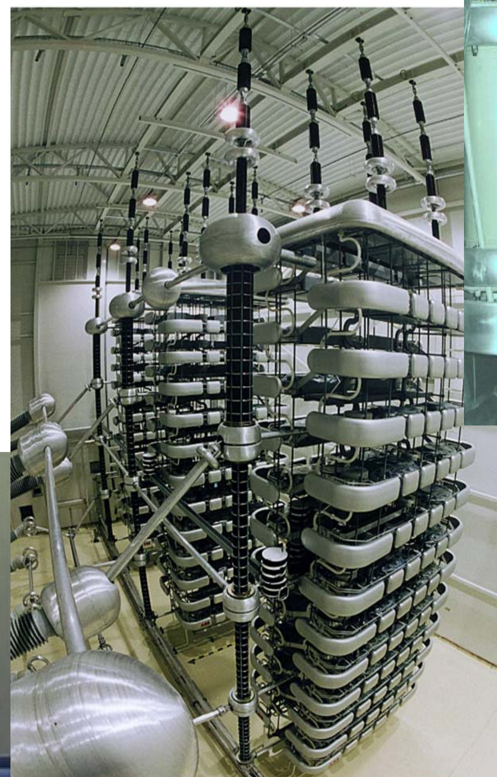
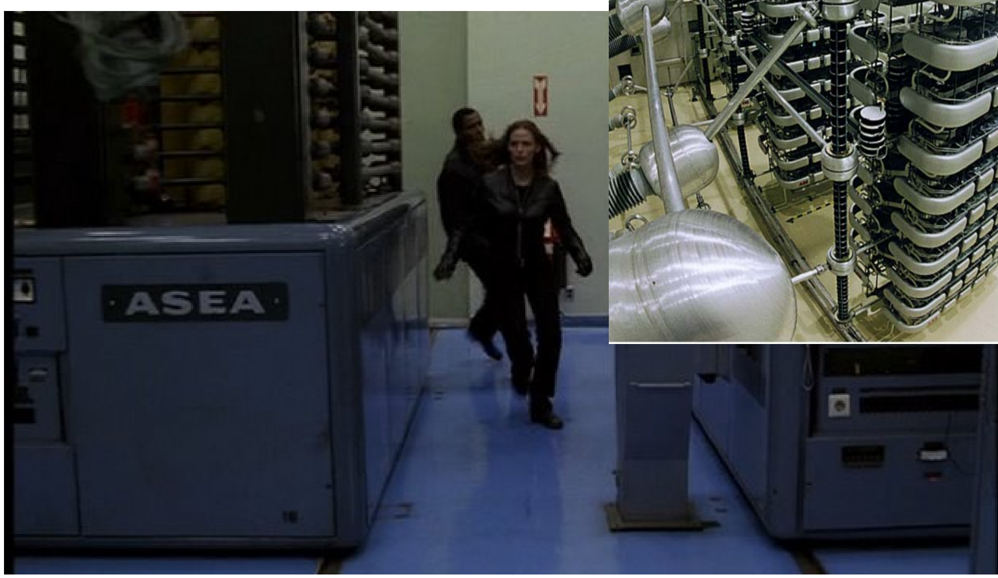
Topics

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

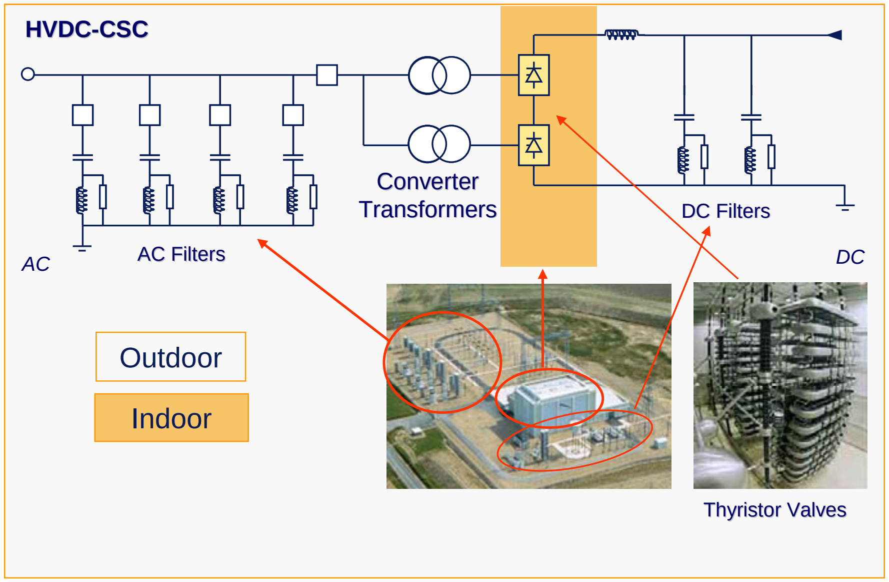
Evolution . . .

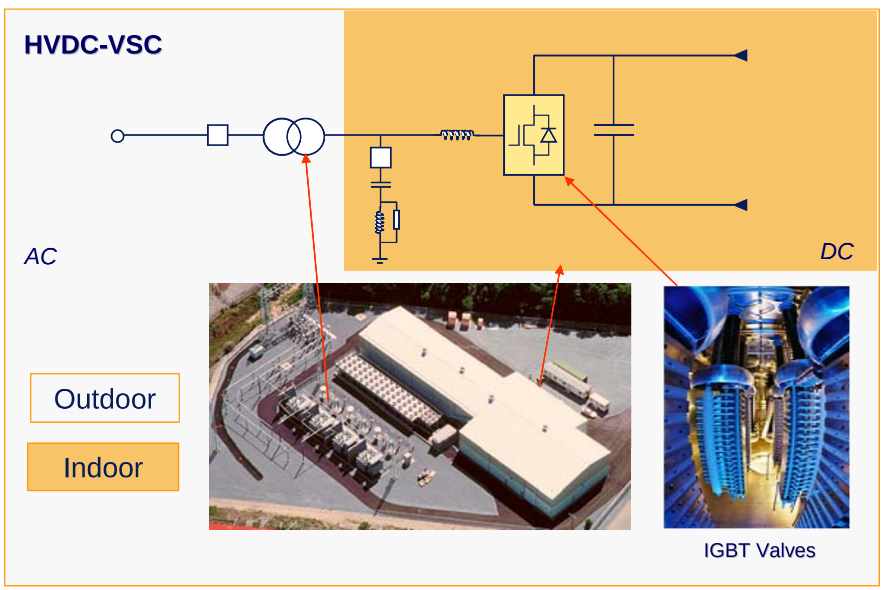






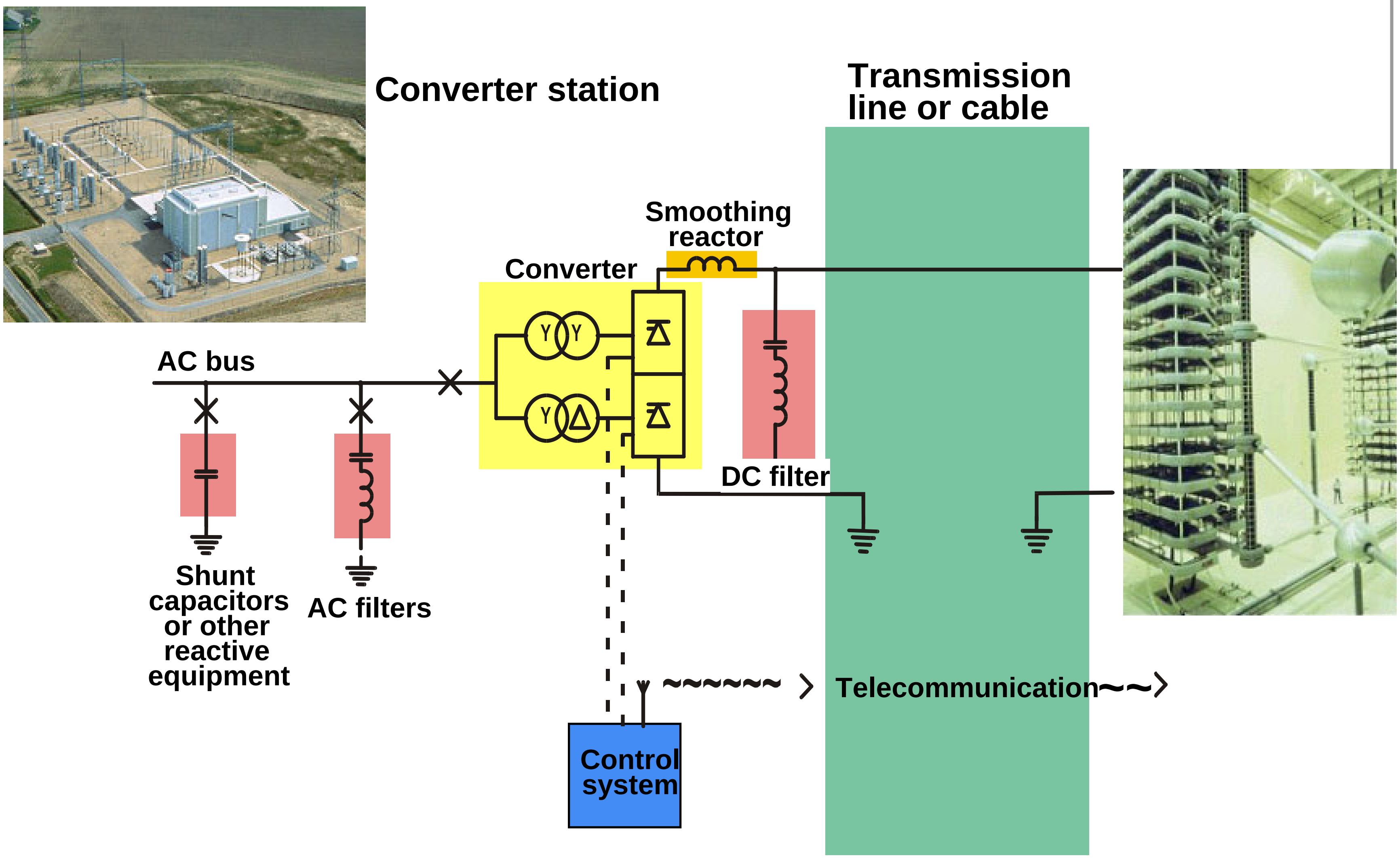
Core HVDC Technologies





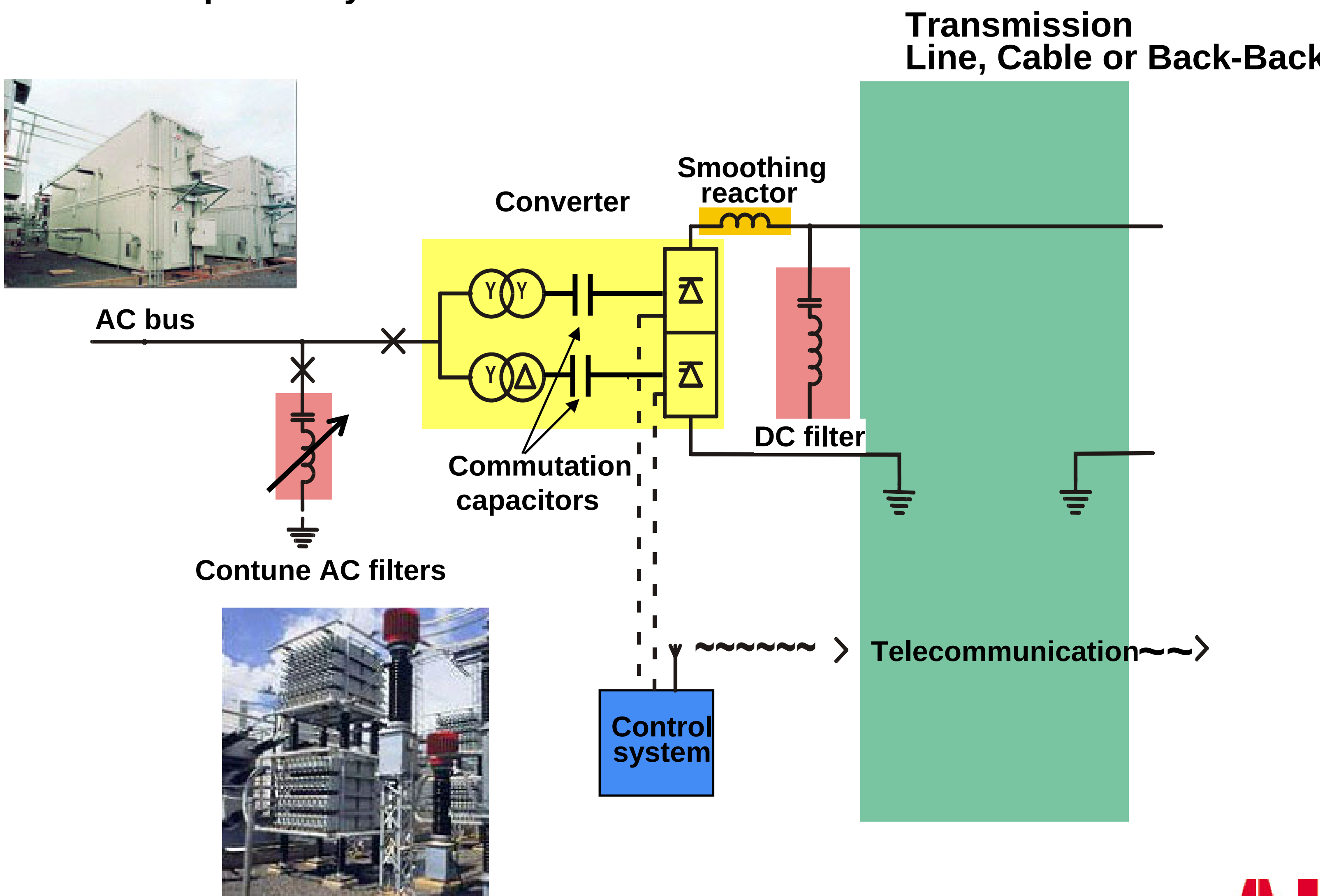
- HVDC Classic
  - Current source converters
  - Line-commutated thyristor valves
  - Requires 50% reactive compensation (35% HF)
  - Converter transformers
  - Minimum short circuit capacity > 2x converter rating
- HVDC Light
  - Voltage source converters
  - Self-commutated IGBT valves
  - Requires no reactive power compensation (15% HF)
  - Standard transformers
  - No minimum short circuit capacity, black start

The HVDC Classic Converter Station

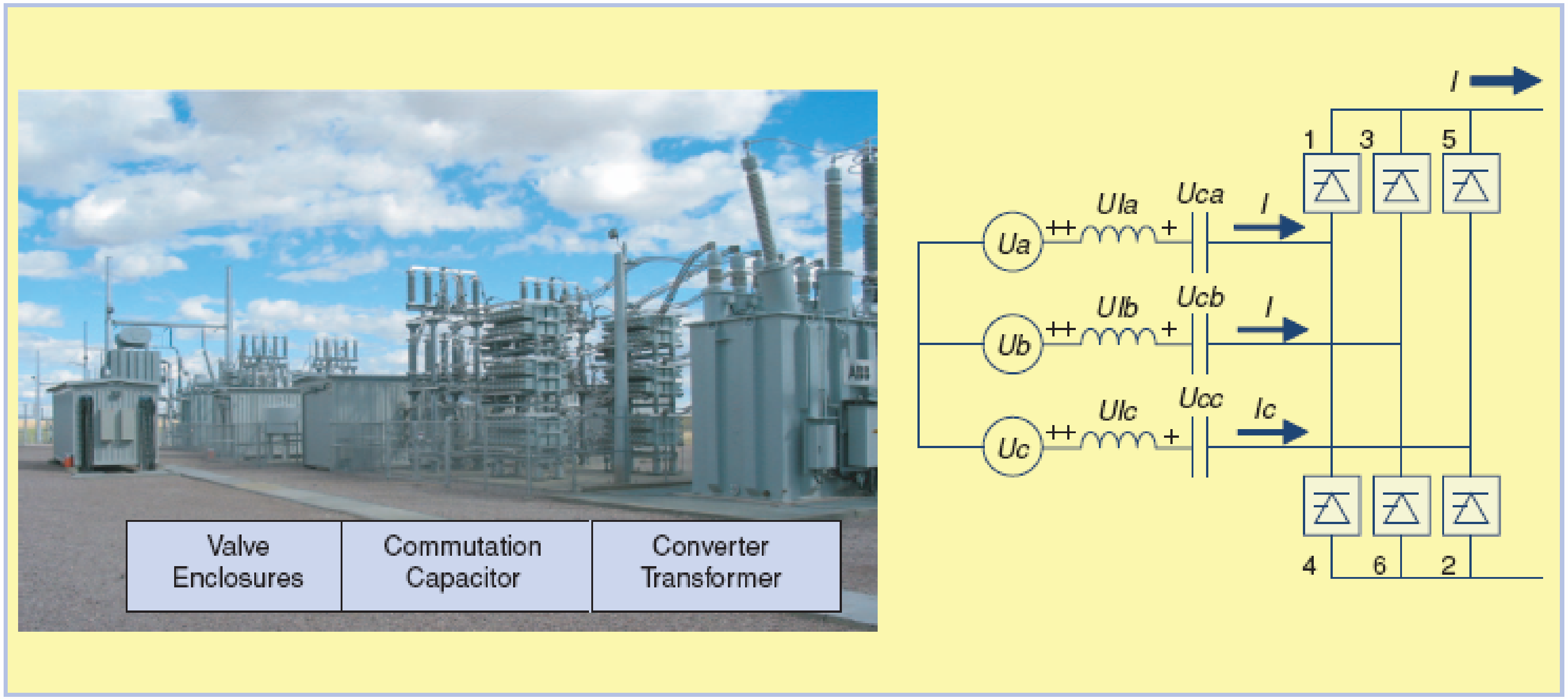


The CCC* Station

*Capacitively-commutated converter

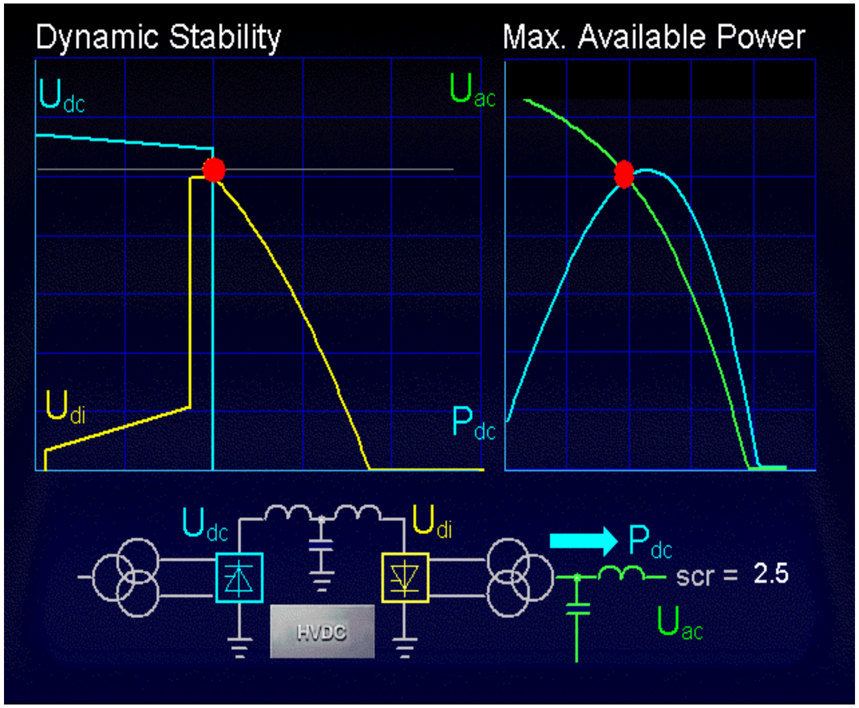


Modular Back-toBack CCC Asynchronous Tie

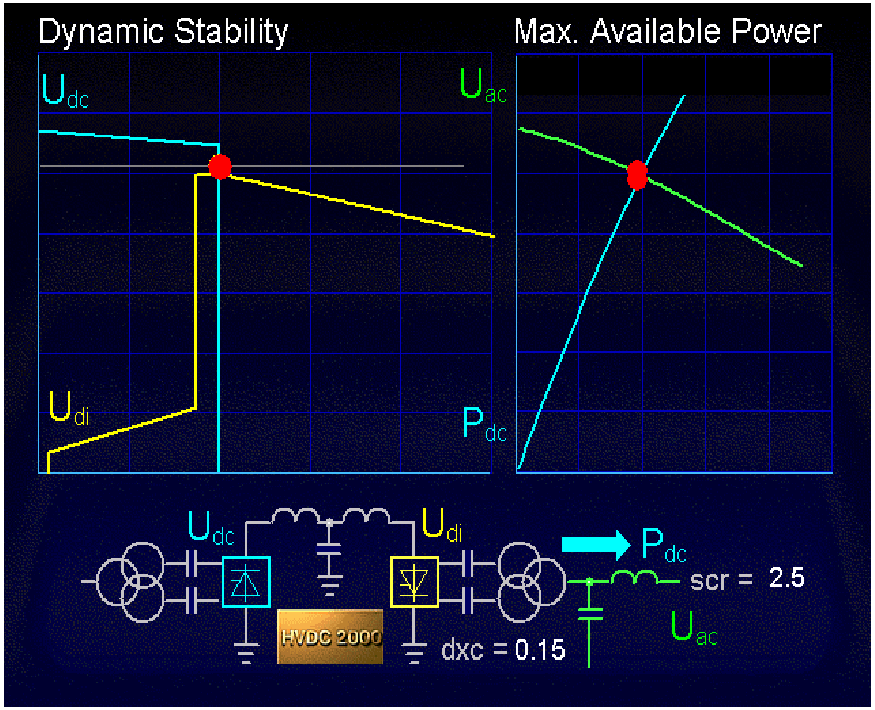


Improved Stability and Higher Power Transfer

HVDC Classic

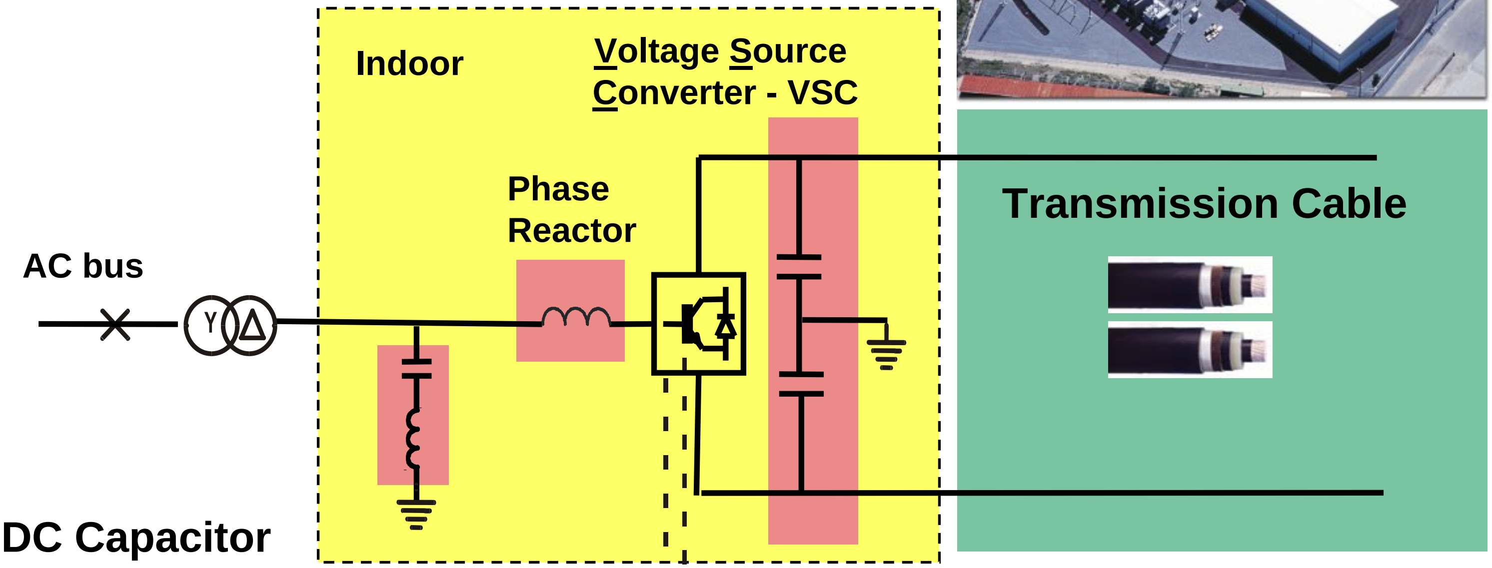


HVDC CCC



The HVDC Light Converter Station

Converter station



AC filters

DC Capacitor

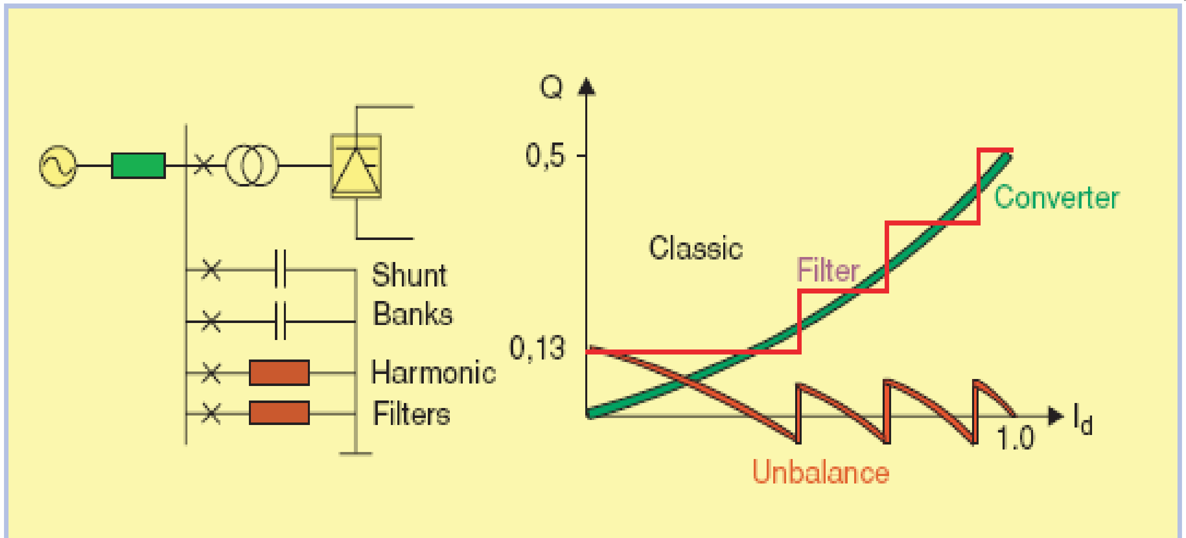
Control system

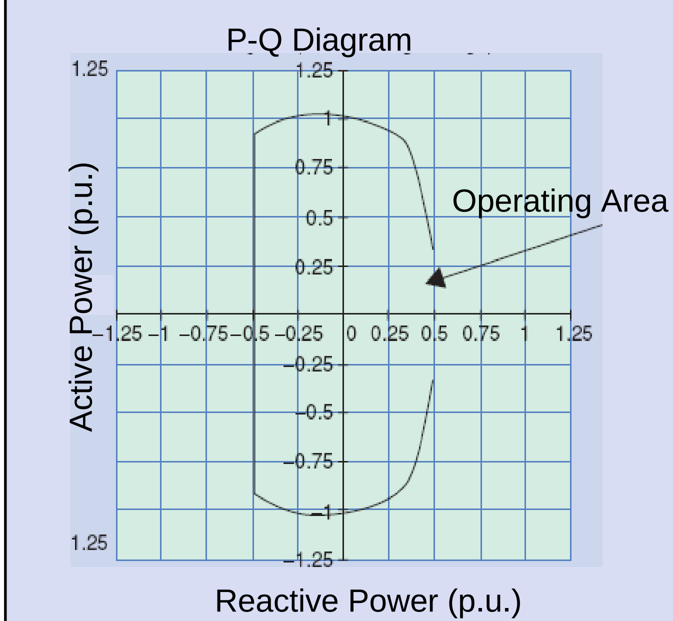
Dry DC Capacitor

IGBT Valves

ABB

Comparison of Reactive Power Characteristics



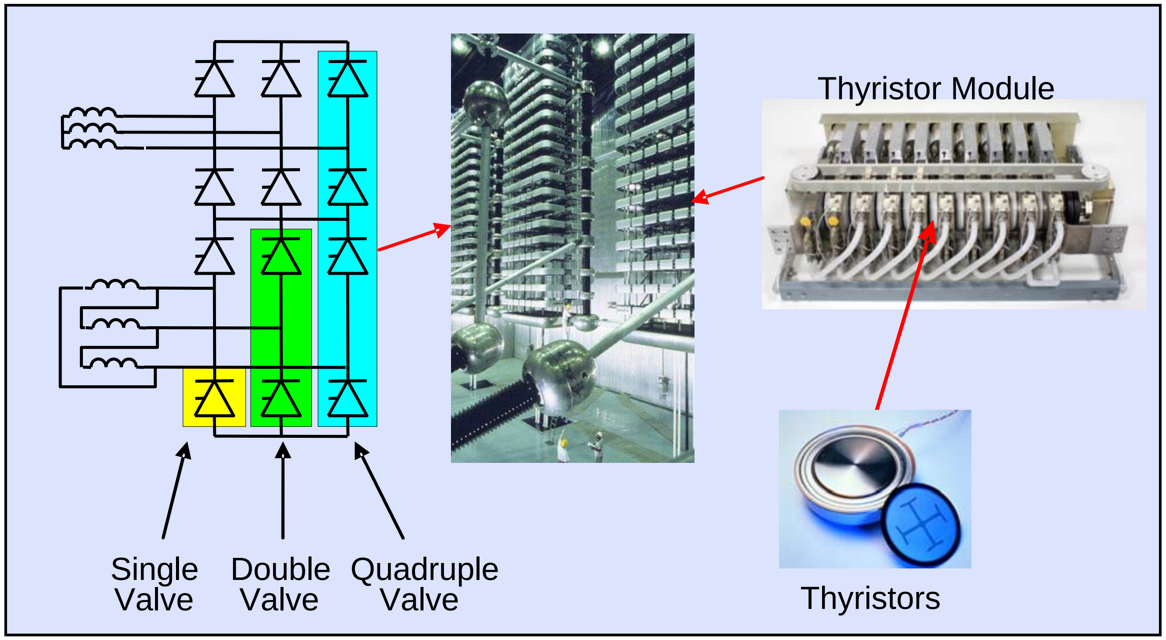


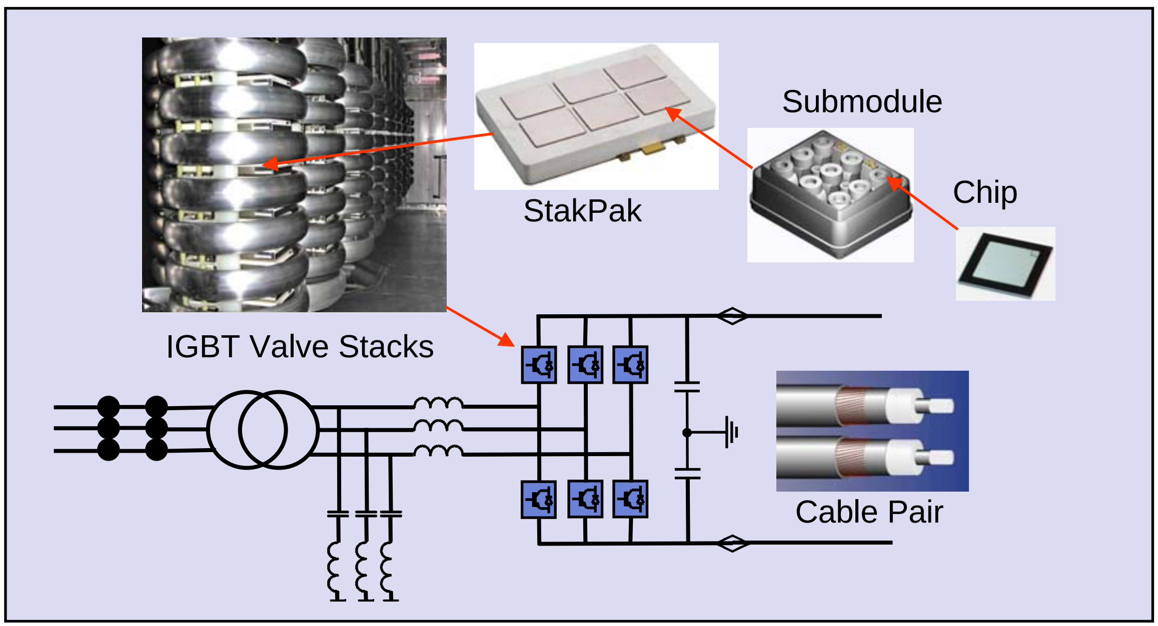
HVDC VSC Operating Range

- Conventional HVDC – HVDC Classic
  (~ SVC with TCR+FC, -0.5Pd / +0 MVAr)

- VSC Based HVDC – HVDC Light
  (~ STATCOM, -0.5Pd/+0.5Pd MVAr)

HVDC Converter Arrangements





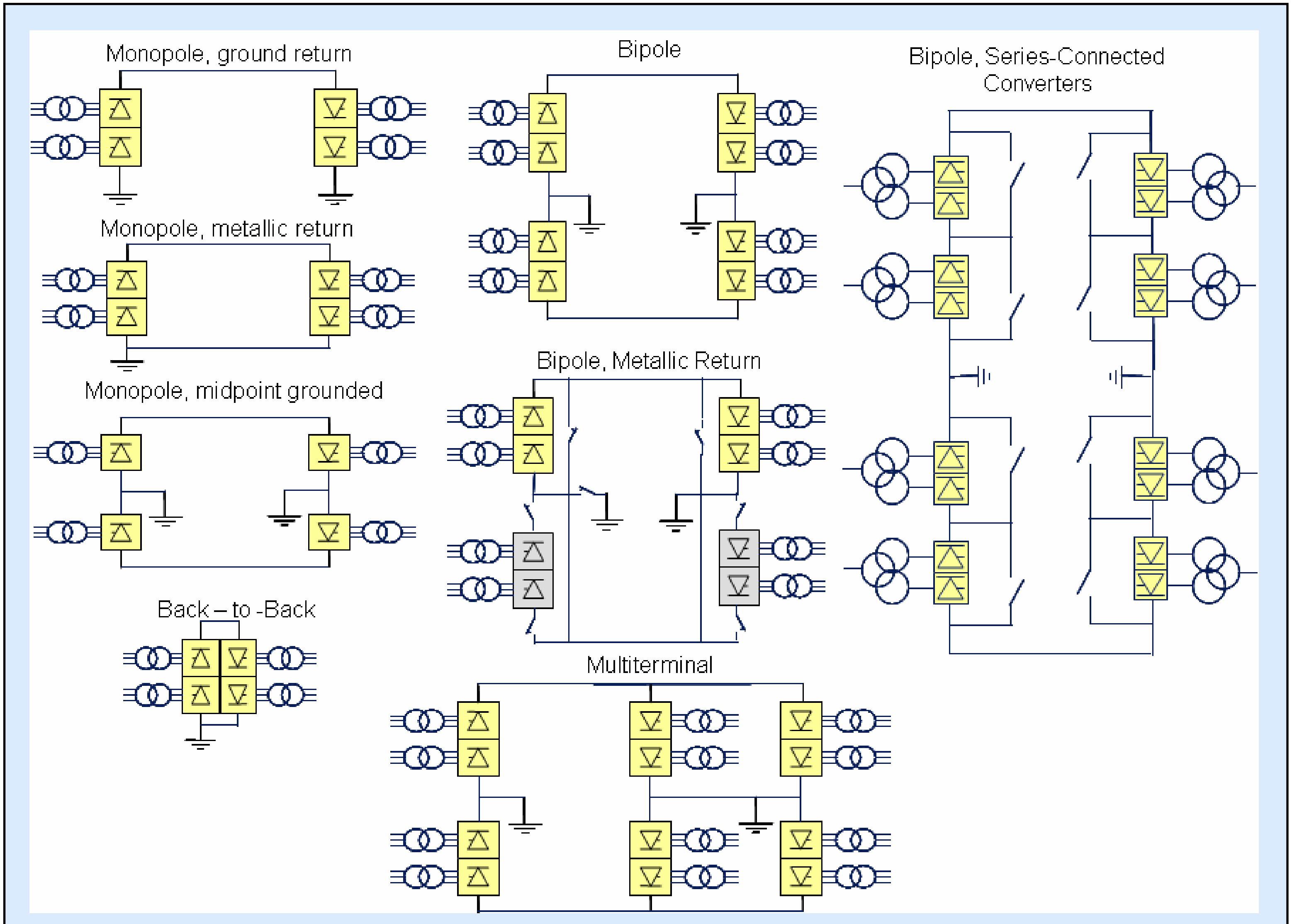
HVDC Classic

- Thyristor valves
- Thyristor modules
- Thyristors
- Line commutated

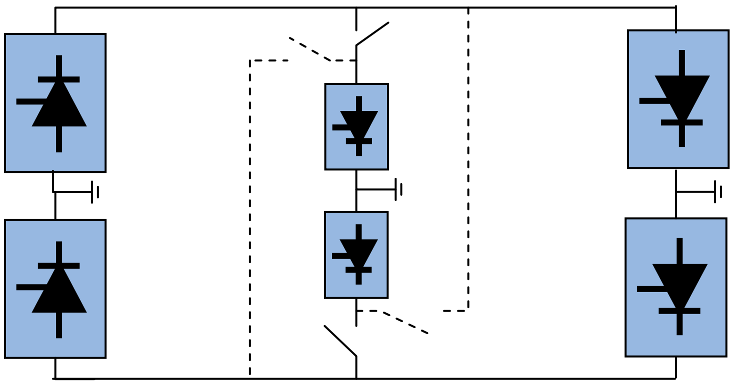
HVDC Light

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

HVDC Operating Configurations and Modes

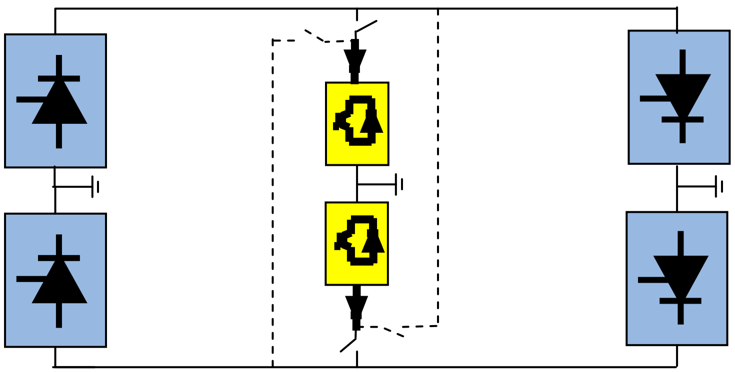


Tapping OVHD HVDC with Large VSC Converters



HVDC Tap

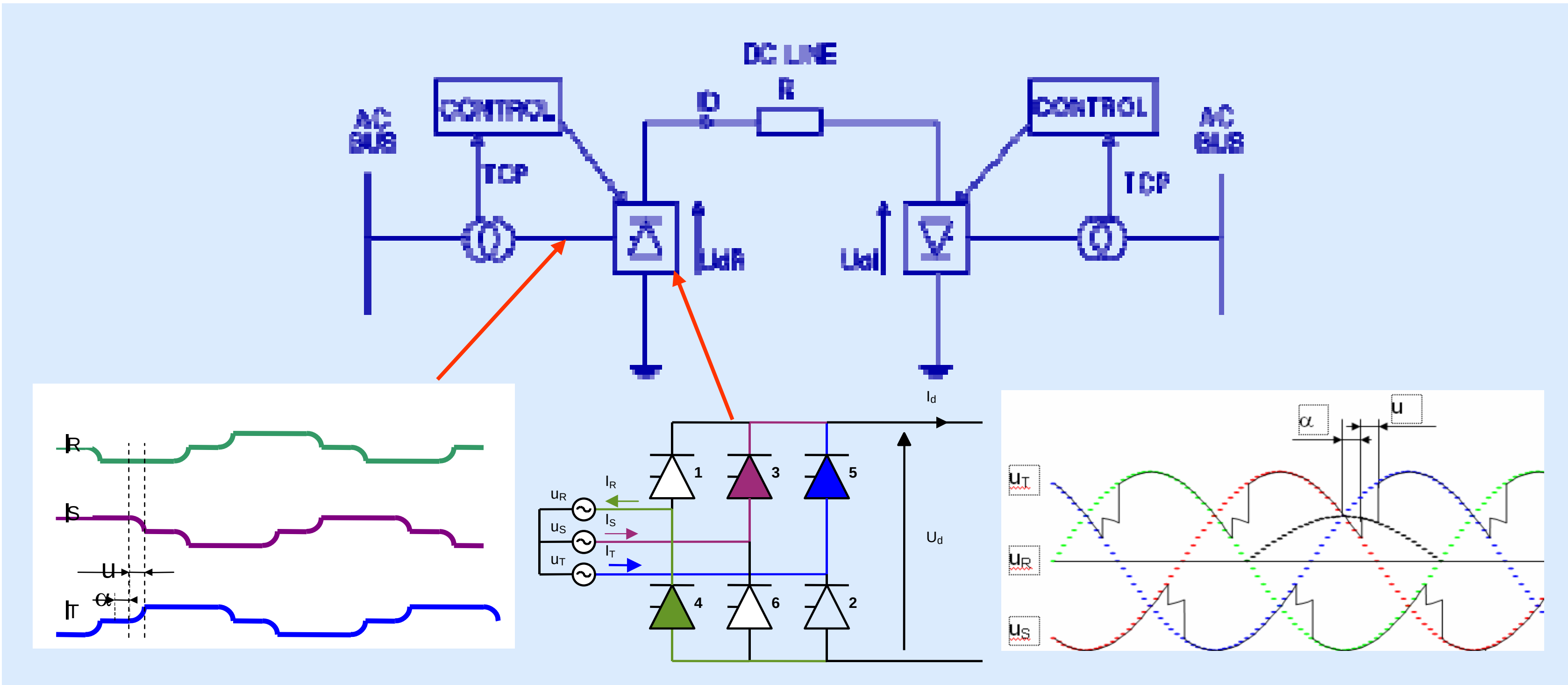
- Reverse power by polarity reversal
- Electronic clearing of dc line faults
- Fast isolation of faulty converters
- Reactive power constraints
- Momentary interruption due to CF at tap
- Limitations on tap rating, location and recovery rate due to stability

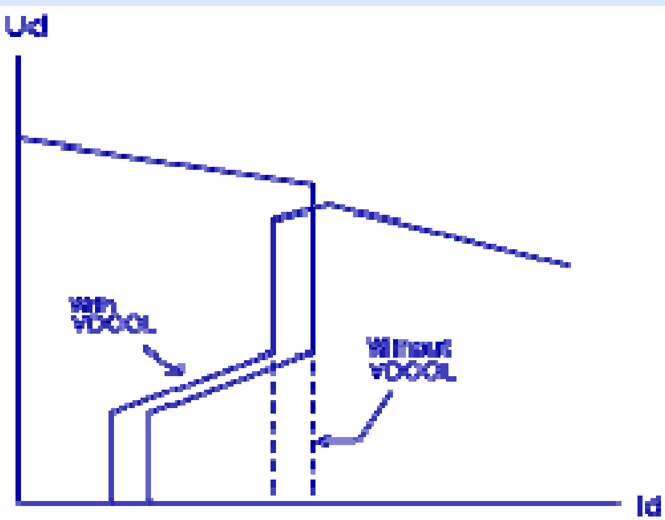


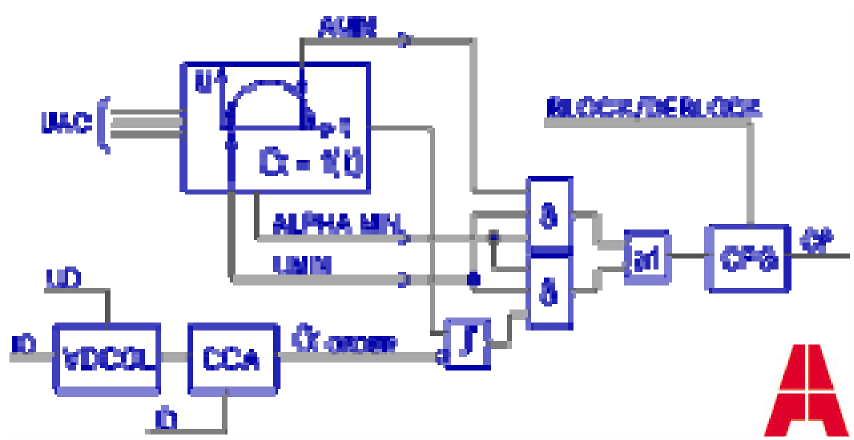
HVDC Light Tap

- 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

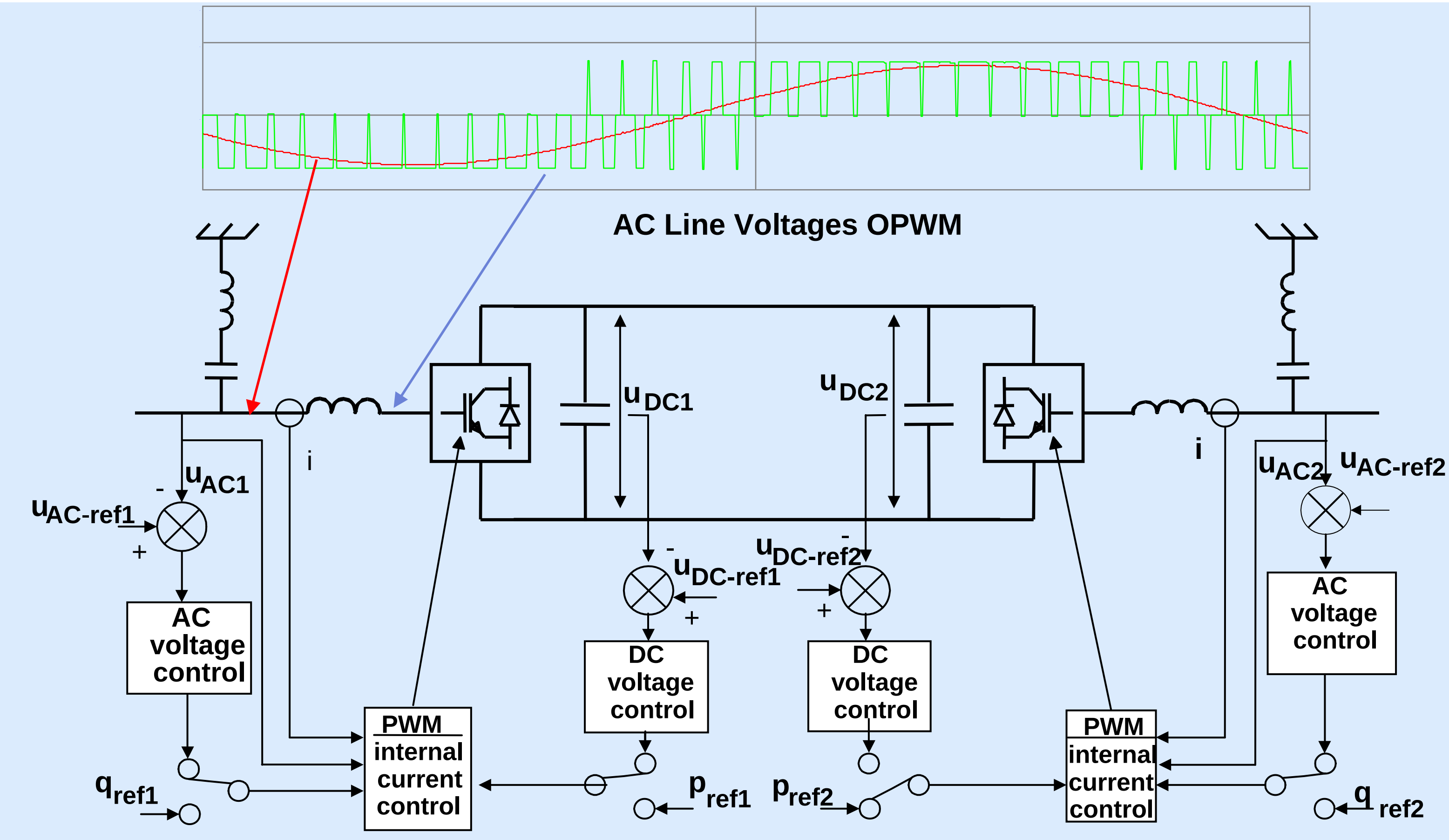
HVDC Classic Control







Control of VSC Based HVDC Transmission



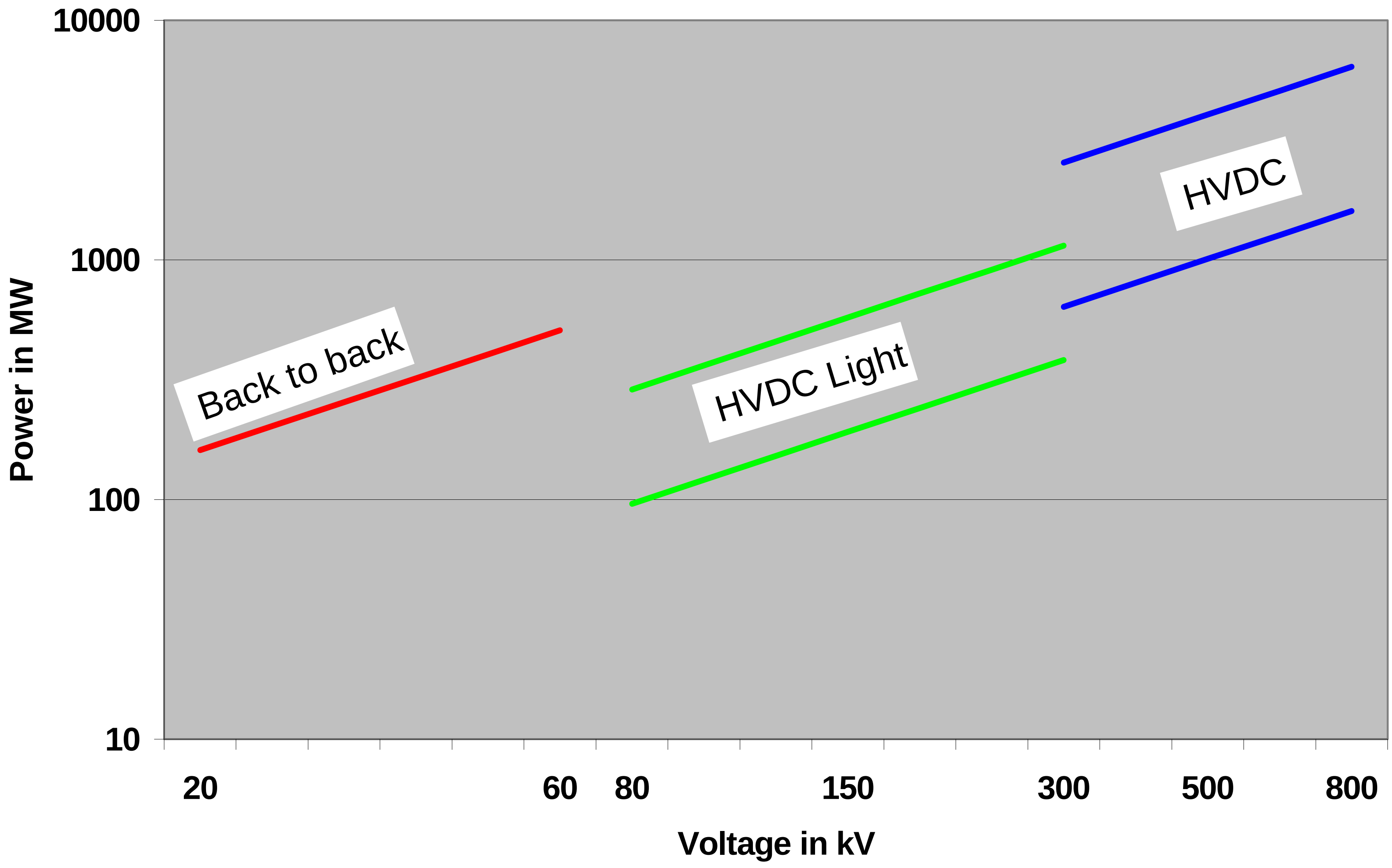
Principle control of HVDC-Light

Comparison - AC, HVDC, HVDC CCC and HVDC Light

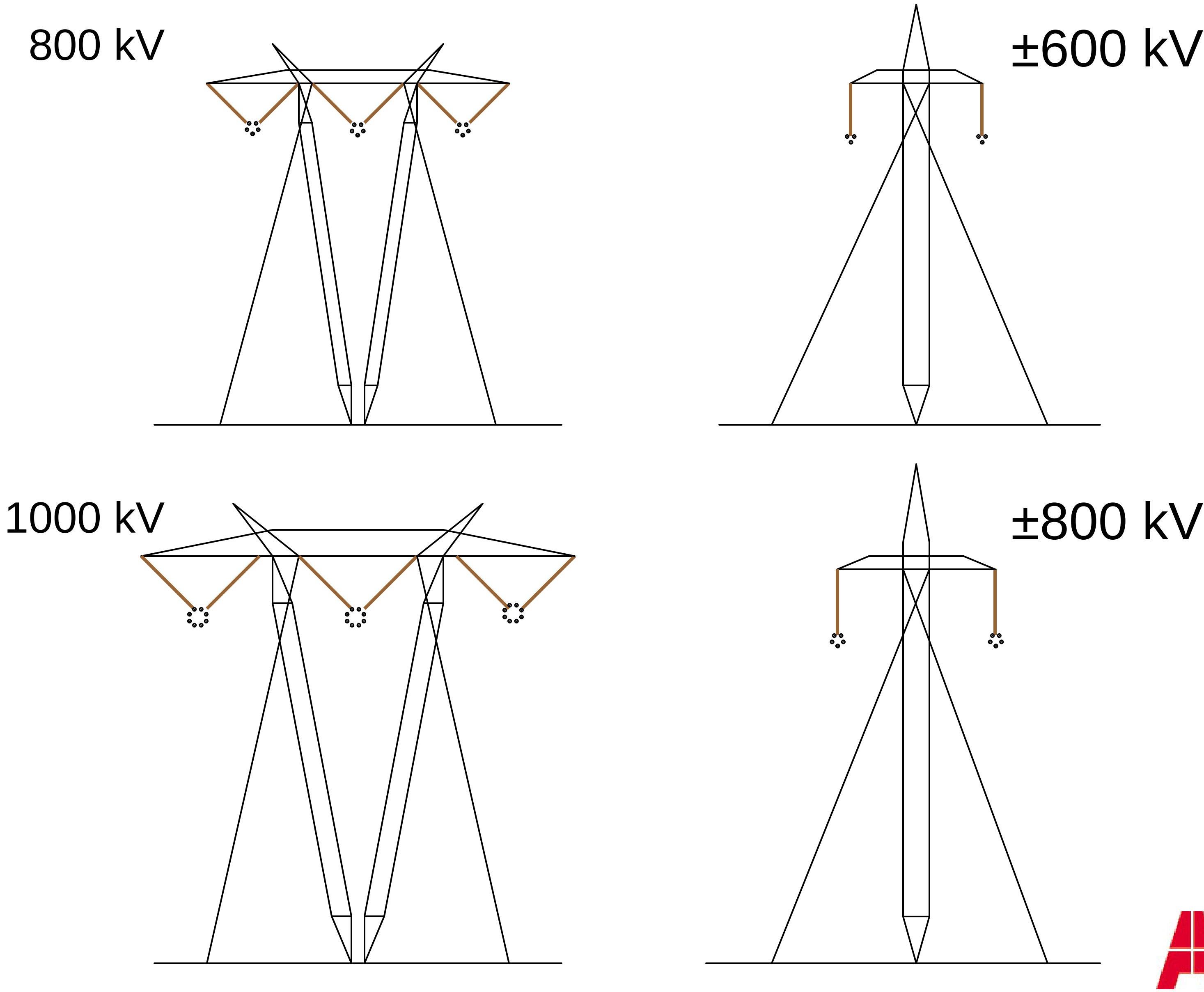
Attributes	AC Cable	HVDC - Conventional	HVDC – Capacitor Commutated	HVDC Light
Power flow control	None unless PST or series reactor	Continuous ±0.1Pr to ±Pr	Continuous ±0.1Pr to ±Pr	Continuous 0 to ±Pr
Reactive power demand	3 I^2 X - 3 V^2 B	Reactive power demand = 50% power transfer	Reactive power demand 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 Xcc	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



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: "," = "."