HVDC Technology

HVDC - High Voltage Direct Current

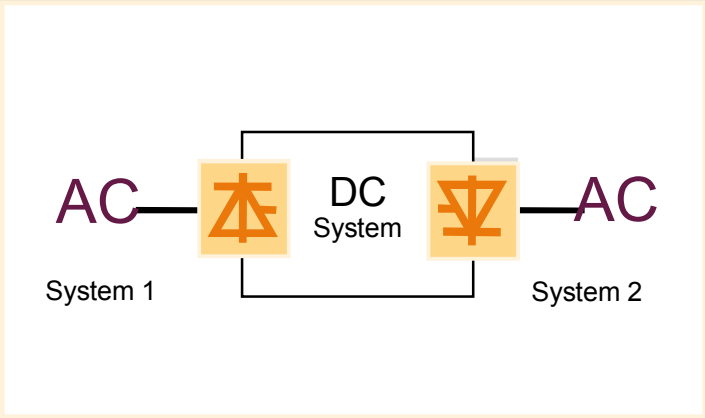
SIEMENS

- Why HVDC?
- Technology – Classic & PLUS

Why HVDC?
HVDC – Many Benefits

SIEMENS

HVDC is a unique Solution for:



- Long Overhead Lines with high Transmission Capacity and limited Right-of-Way
- Long Cable Transmissions
- Asynchronous Interconnections
- New Links in Grids where Short-Circuit Currents are at upper Limits
- Fast Control of Power Flow
  - Sharing of Spinning Reserve
  - Supply of Peak Power

Basics of HVDC
HVDC Applications

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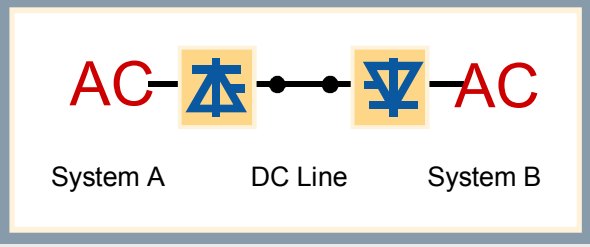
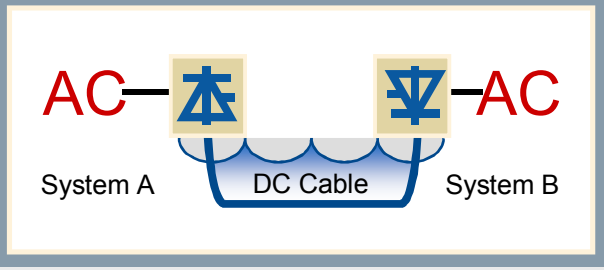
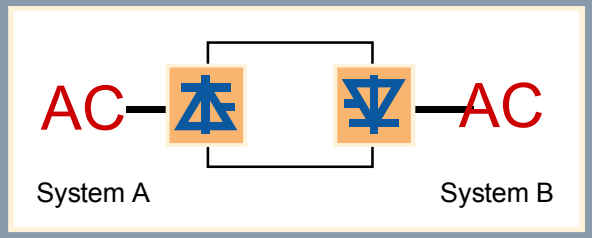
- Long Distance



- DC Cable



- Back-to-Back



Why HVDC?
Technical Advantages of HVDC Controllability

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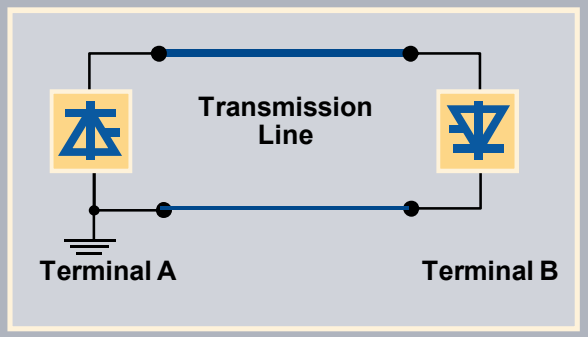
HVDC Controllability is beneficial for

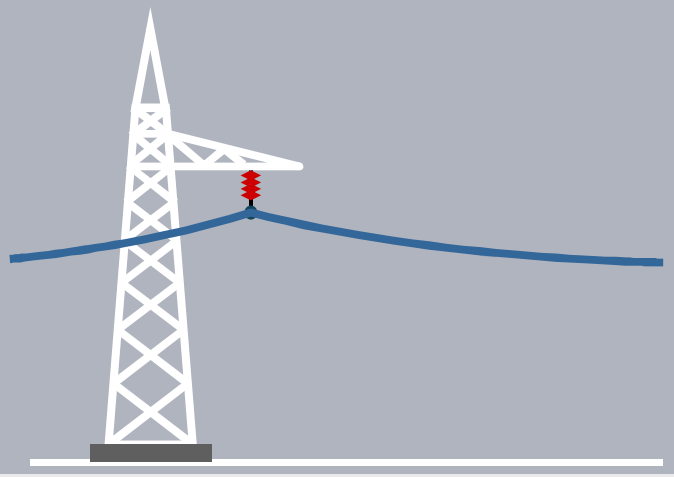
- Exact Control of Power Flow in either Direction
- Enhancement of AC System Stability
- Reactive Power Control / Support of AC Voltage
- Frequency Control
- Overload Capability
- Emergency Power Functions
- Power Oscillation Damping

HVDC is a Firewall against Cascading Disturbances

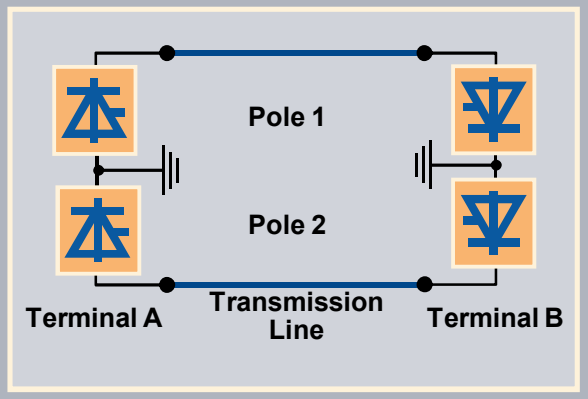
HVDC Long Distance Transmission Systems

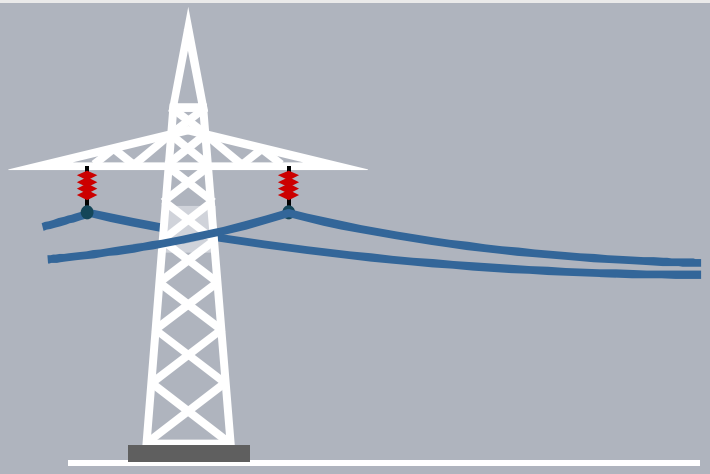
Monopolar





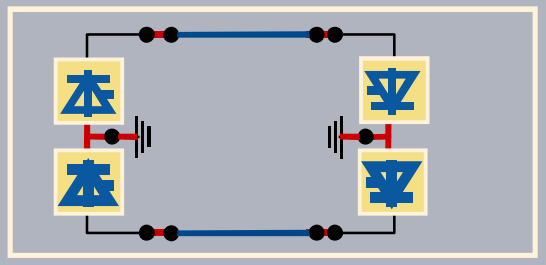
Bipolar



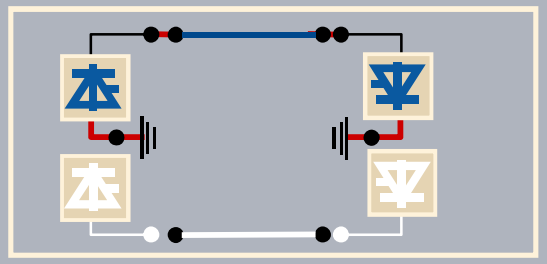


HVDC Long Distance Transmission Systems

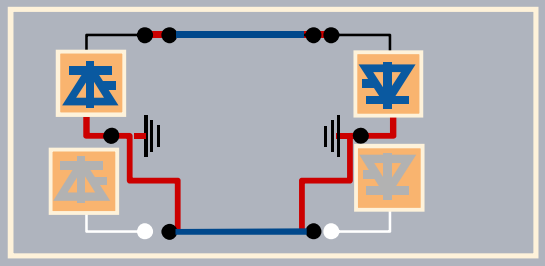
Bipolar System: Operating Modes



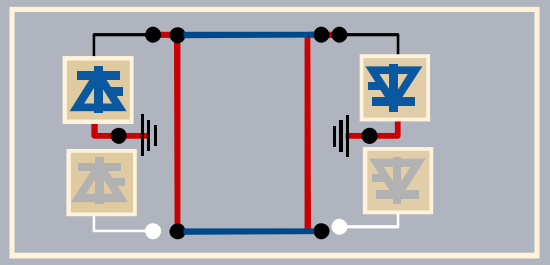
Bipolar



Monopolar, ground return one DC line pole*



Monopolar, metallic return*



Monopolar, ground return two DC line poles*

*depending on Reliability Criteria as well as National Electric Safety Code

HVDC Long Distance Transmission Systems

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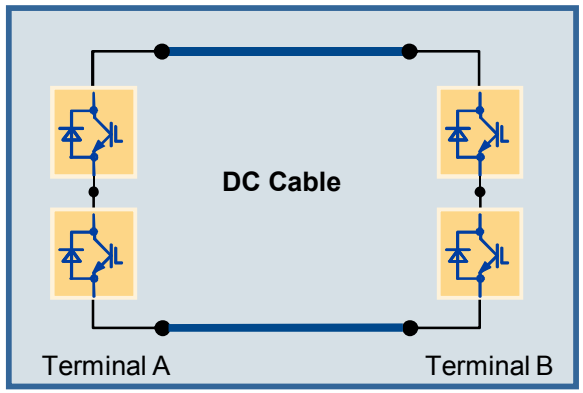
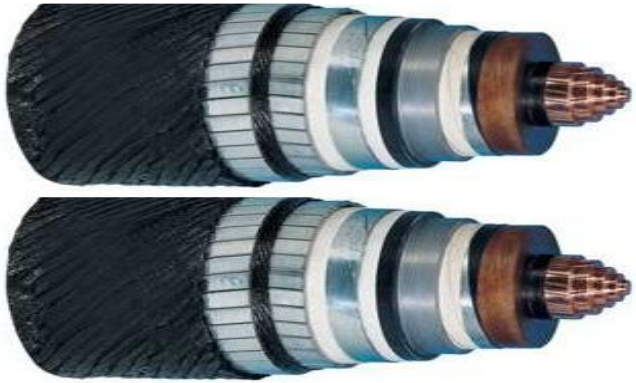
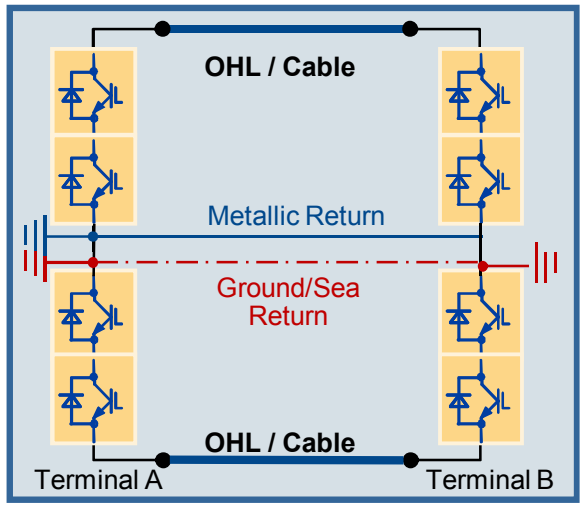
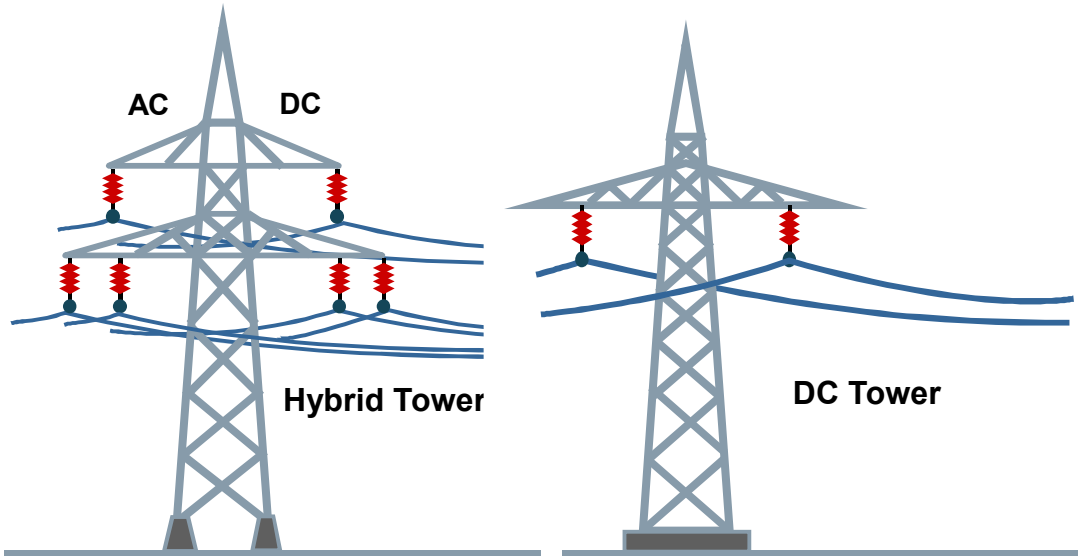
- Symmetrical Monopole





- Bipole





Benefits & Advantages
DC Vs AC Transmission

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Transmission Line Cost Estimate Matrix - New Facility

				Base Cost
	Voltage (kV)	# of Circuits	MW Capability	$M/Mile
New	<230	1	300	$1,100,000
	230	1	600	$1,150,000
	230	1	900	$1,580,000
	230	2	1200	$1,800,000
	345	UG	500	$19,750,000
	345	1	900	$2,100,000
	345	1	1800	$2,500,000
	345	UG	1800	$25,000,000
	345	2	3600	$2,800,000
	345	UG	3600	$28,000,000
	500	1	2600	$3,450,000
	765	1	4000	$5,550,000

Substation Cost Estimate Matrix - Upgrade Facility

		Base Cost	EIPC
	Voltage (kV)	$M/Bay	NEEM Regional Multipliers
Upgrades	<230	$2,000,000	1.0
	230	$2,500,000	1.0
	345	$3,000,000	1.0
	500	$5,000,000	1.0
	765	$11,000,000	1.0

Transmission Line Cost Estimate Matrix - HVDC

				Base Cost
	Voltage (kV)	# of Circuits	MW Capability	$M/Mile
HNDV	500kV	bipole	3500	$1,600,000
	HVDC Terminal (both ends)			$550,000,000

Source: April 2013

EIPC Eastern Interconnection Planning Collaborative

pjm

Entergy

ISO new england

MISO

ISO

SOUTHERN COMPANY

TVA

ATC AMERICAN TRANSMISSION COMPANY

Benefits & Advantages

DC Vs AC Transmission – Break-even

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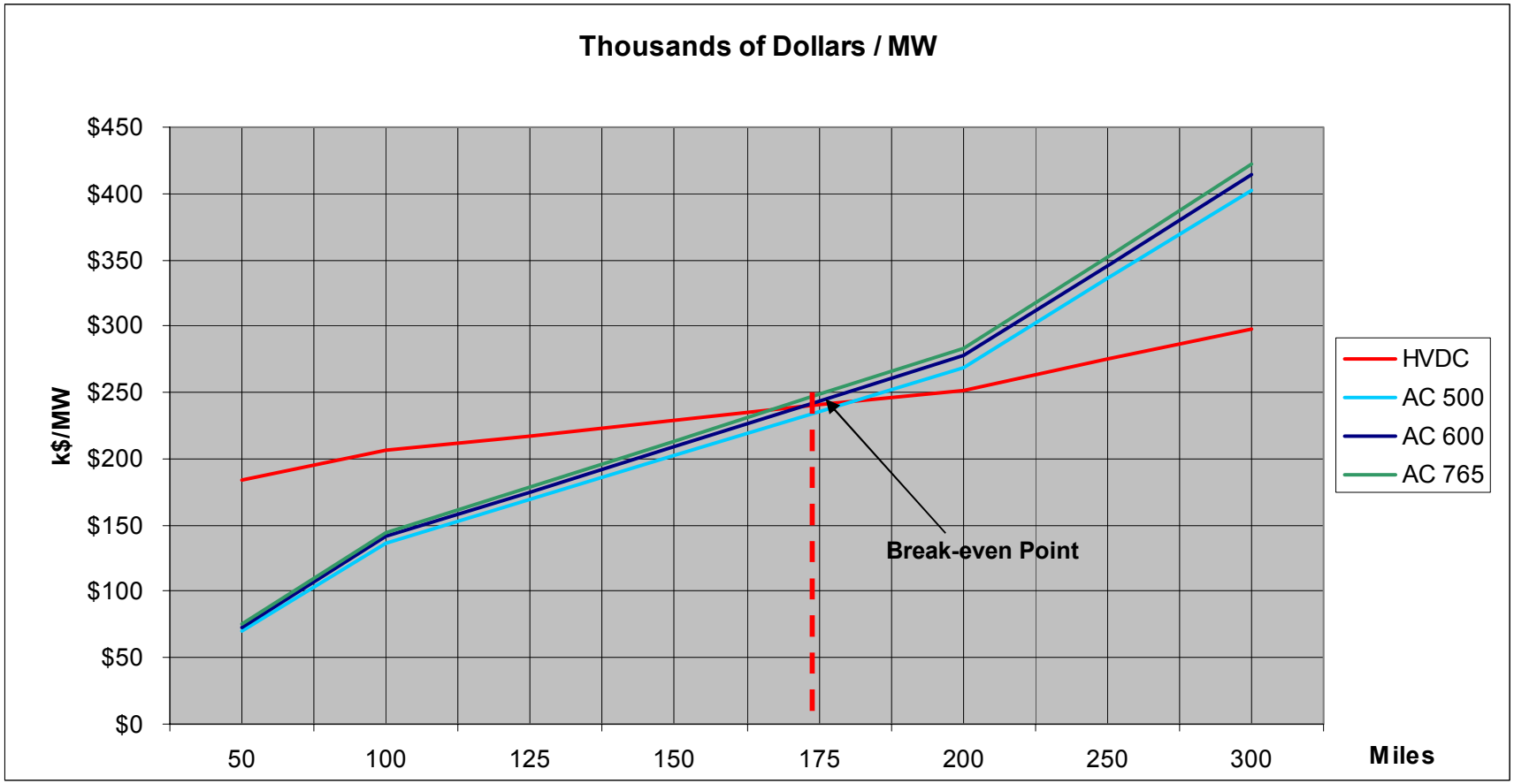
Break-even Distance



Benefits & Advantages
DC Vs AC Transmission – Other advantages

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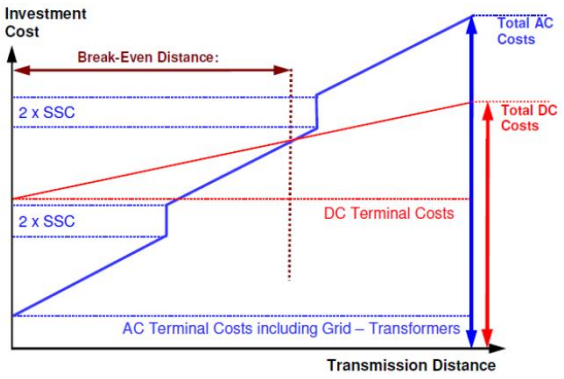
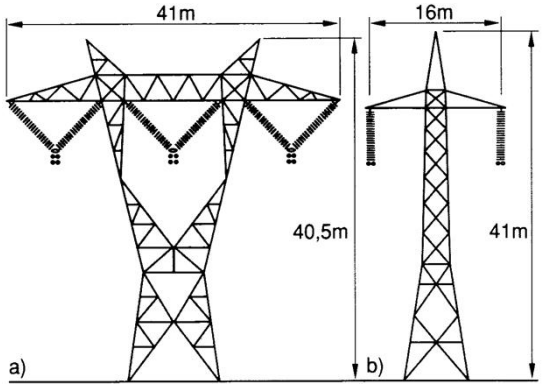
Reactive Power



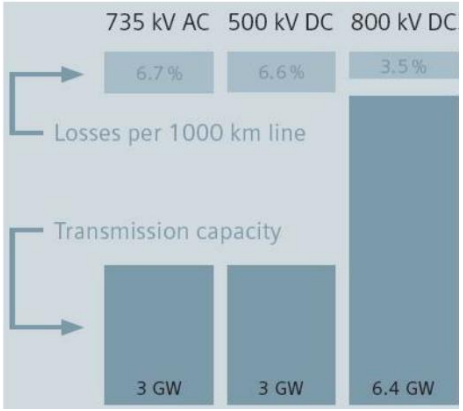
- Increasing AC transmission distances require Series and Shunt reactive power Compensation (SSC)

Right of Way



- Comparison of Towers at the same transmission capacity of 3000 MW for:
  - a) 765kV AC Line
  - b) 500kV DC Line

Transmission Losses



- At similar voltage level, a DC line can transmit more than double the power at around half the losses compared to an AC line.

Source: March 2013 FRIENDS OF THE SUPERGRID

HVDC - High Voltage Direct Current

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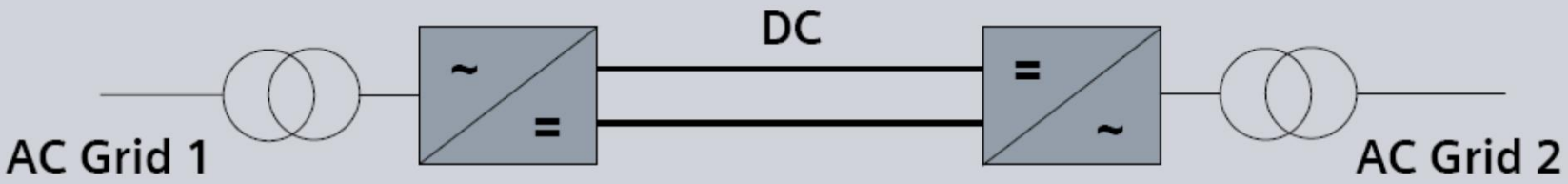
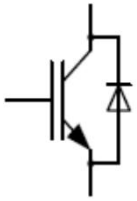
- Why HVDC?
- **Technology – Classic & PLUS**

HVDC Classic – HVDC PLUS



HVDC Classic	HVDC VSC
Line-commutated current-sourced Converter	Self-commutated voltage-sourced Converter
Thyristor with turn-on Capability only	Semiconductor Switches with turn-on and turn-off Capability, e.g. IGBTs



HVDC "Classic"
Principle of HVDC

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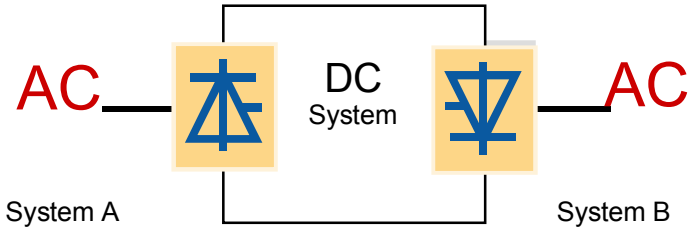
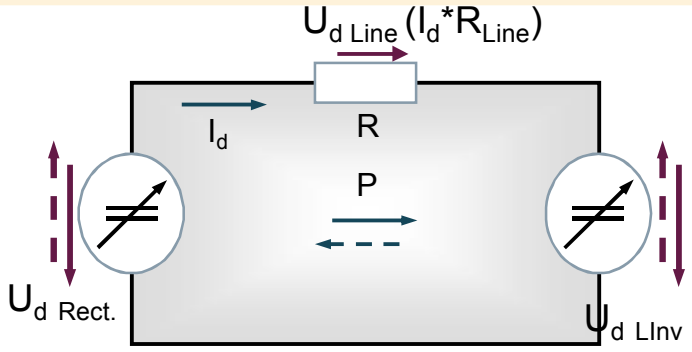
Simplified Block Diagram

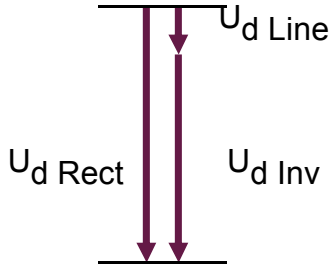


Equivalent Circuit



Characteristics

- I_d in one Direction only
- Magnitude of P / I_d is controlled by the Converter DC Voltages
  ⇨ $I_d = (U_{d\ Rect} - U_{d\ Inv}) / R$
- Direction of P is controlled changing the Polarity of the DC Voltages ($U_{d\ Rect}$, $U_{d\ Inv}$)



HVDC Classic - Principles

HVDC Classic is generally the name used by all manufacturers but the technology may be referred to as LCC or Thyristor

HVDC Classic the AC-DC conversion (and vice versa) is carried out by a thyristor arrangement known as a valve.

The thyristor valve needs a relatively strong system to support its operation however additional equipment such as SVC and Synchronous Condensers can provide local system reinforcement to allow HVDC Classic to operate in “weak” systems.

HVDC Classic can generate significant harmonics on to the connecting system.

Each HVDC Classic installation requires, therefore, multiple filters to mitigate the harmonics which can require significant footprint at the converter station site.

HVDC Classic is available up to +/- 800kV with power transfer of up to 8GW (8,000MW)

HVDC “Classic” Example

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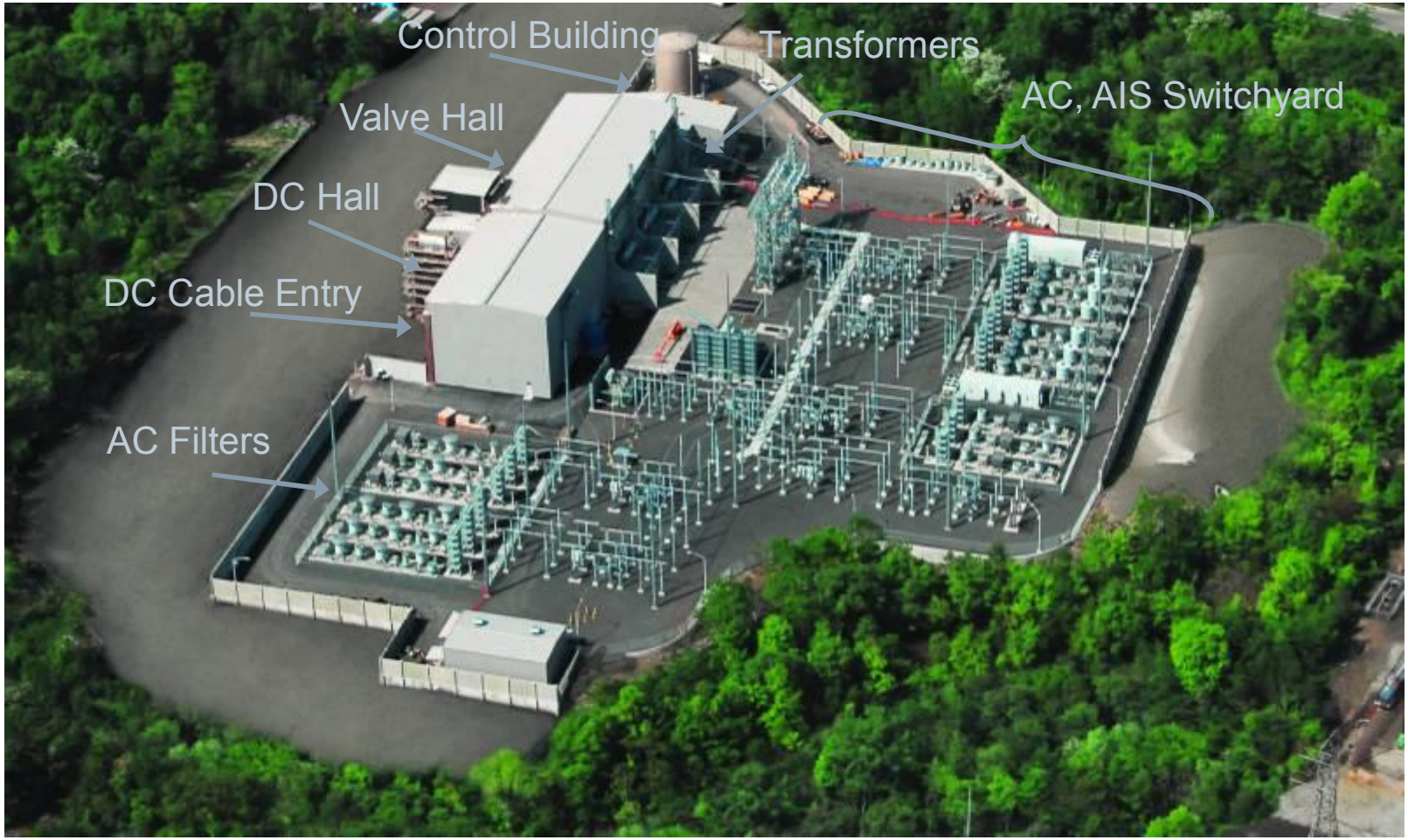
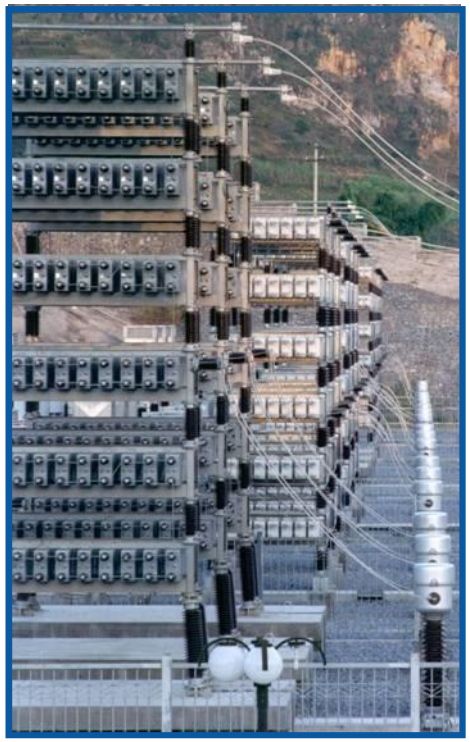
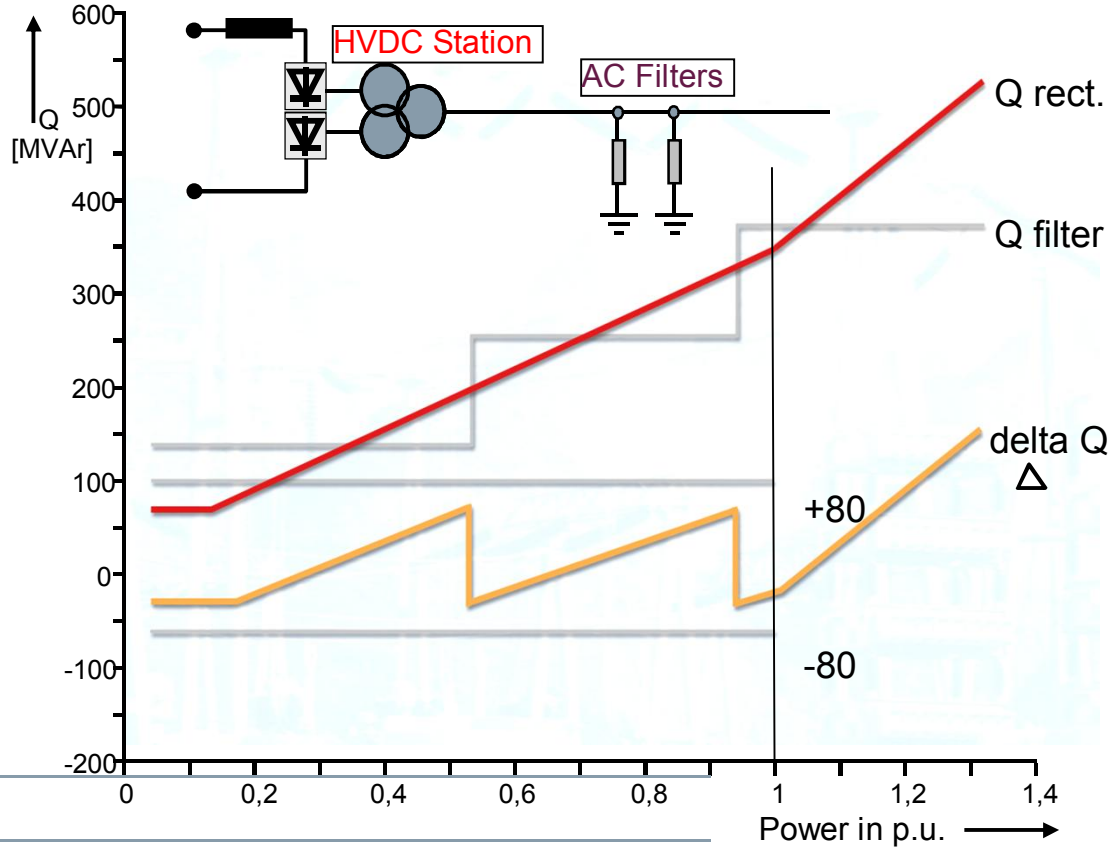
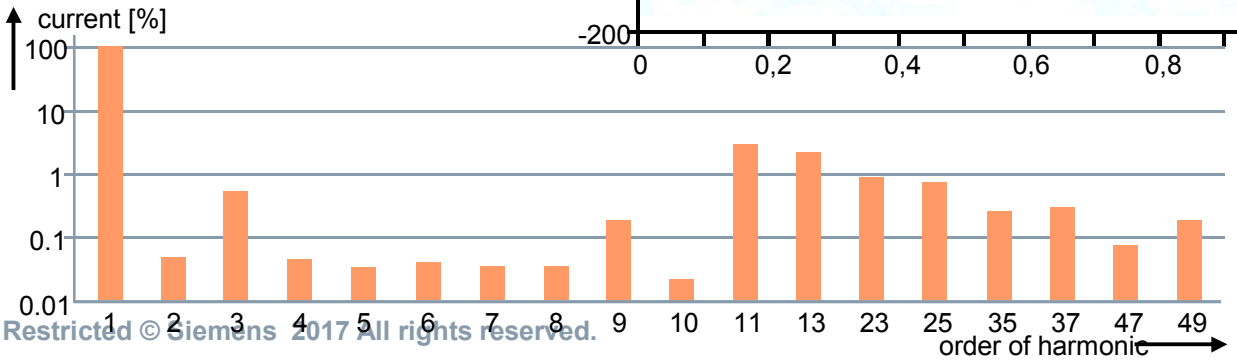


AC Filters, Capacitor Banks
Reactive Power and AC Filtering

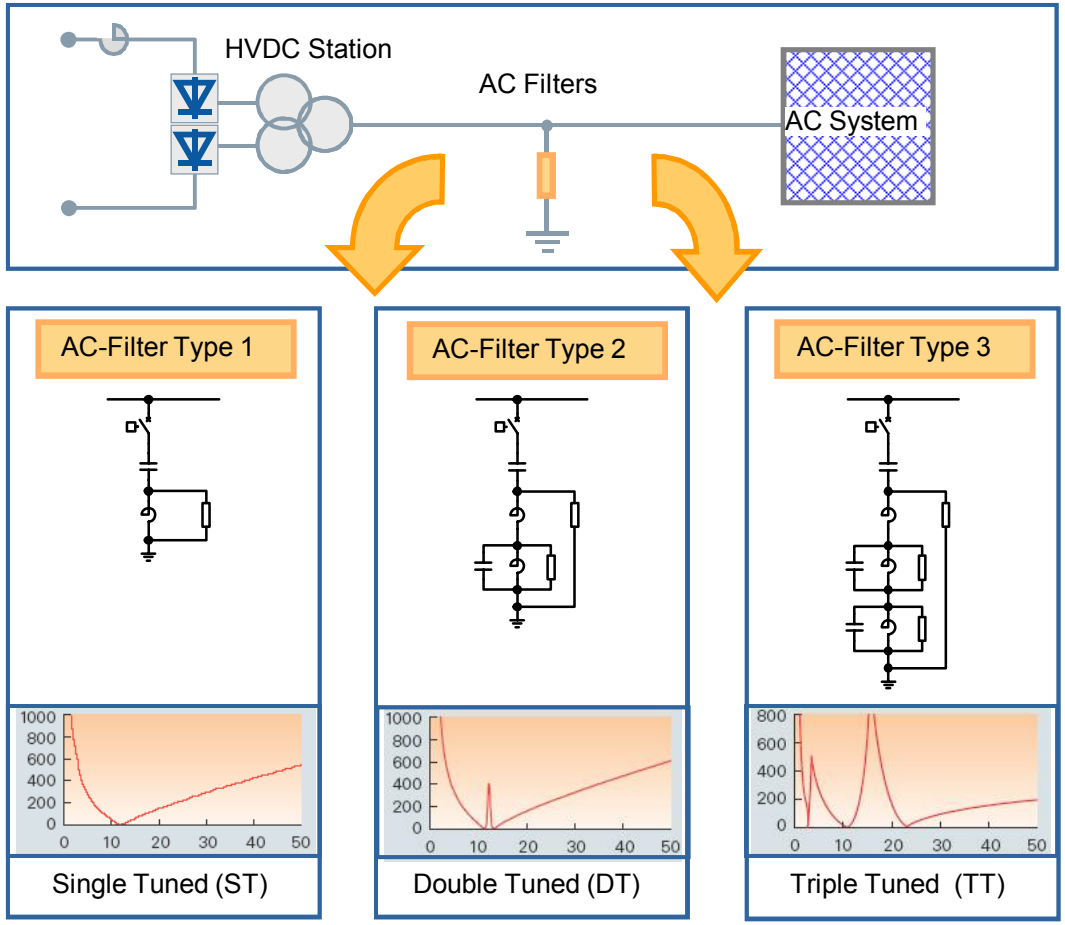
SIEMENS







AC Filters, Capacitor Banks
Harmonic AC Filter



Converter Transformers
Single Phase, 3 Winding

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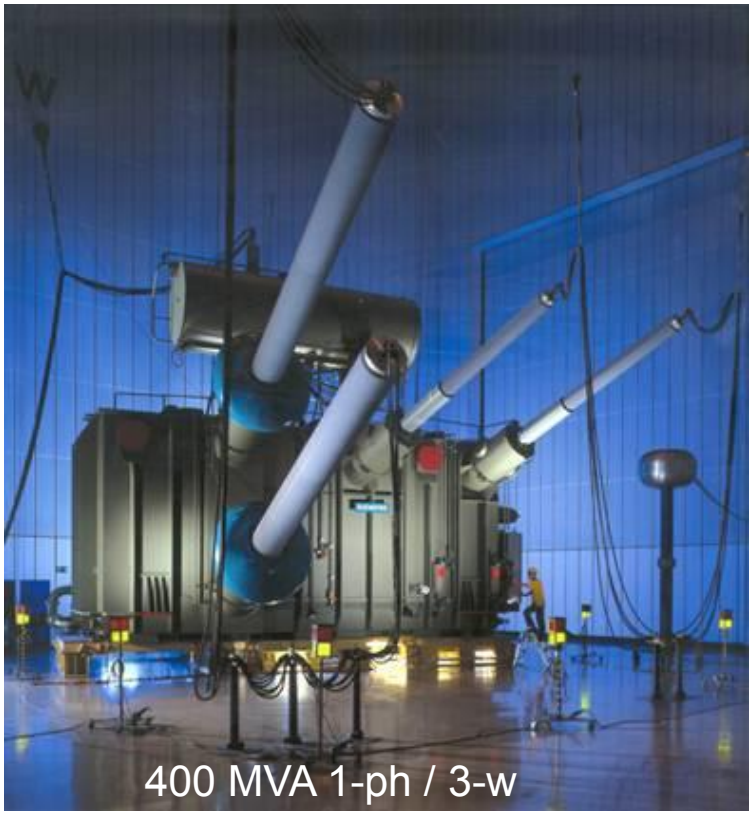
Siemens HVDC Converter Transformers - Outstanding Performance since 1977



Converter Transformer: Obtain the AC voltage needed for the required DC voltage

Obtain 12-pulse operation (star and delta connection)

Allow for series connection of 6-pulse bridges

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Valve Hall

Key Components
Thyristor

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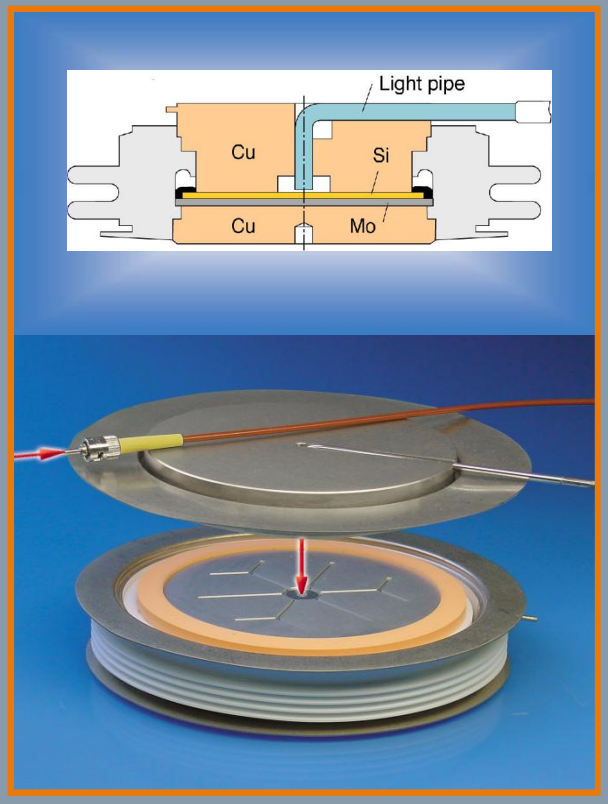
Thyristor Technology – Direct Light Triggered Thyristor LTT

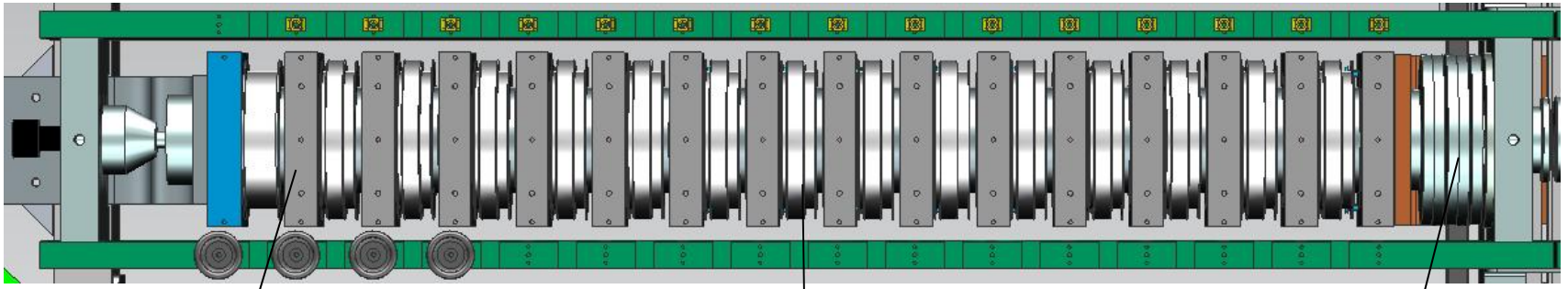


High Reliability:

- 80 % less Electronic Components
- Direct Laser Light-triggered Thyristor
- Wafer-integrated Overvoltage Protection
- Thyristor Blocking Voltage: 8 kV
- Thyristor Wafers:
  - 4" for currents up to 2,200 A
  - 5" for currents up to 4,000 A
  - 6" for currents up to 4,500 A (ETT)

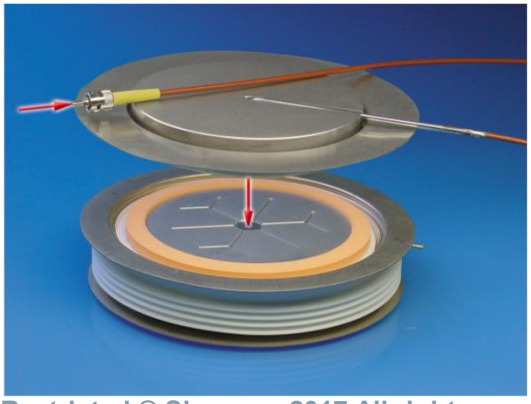
Valve Design

Design of Thyristor Stack



Valve Design: 5 x 16 = 80 Thyristors

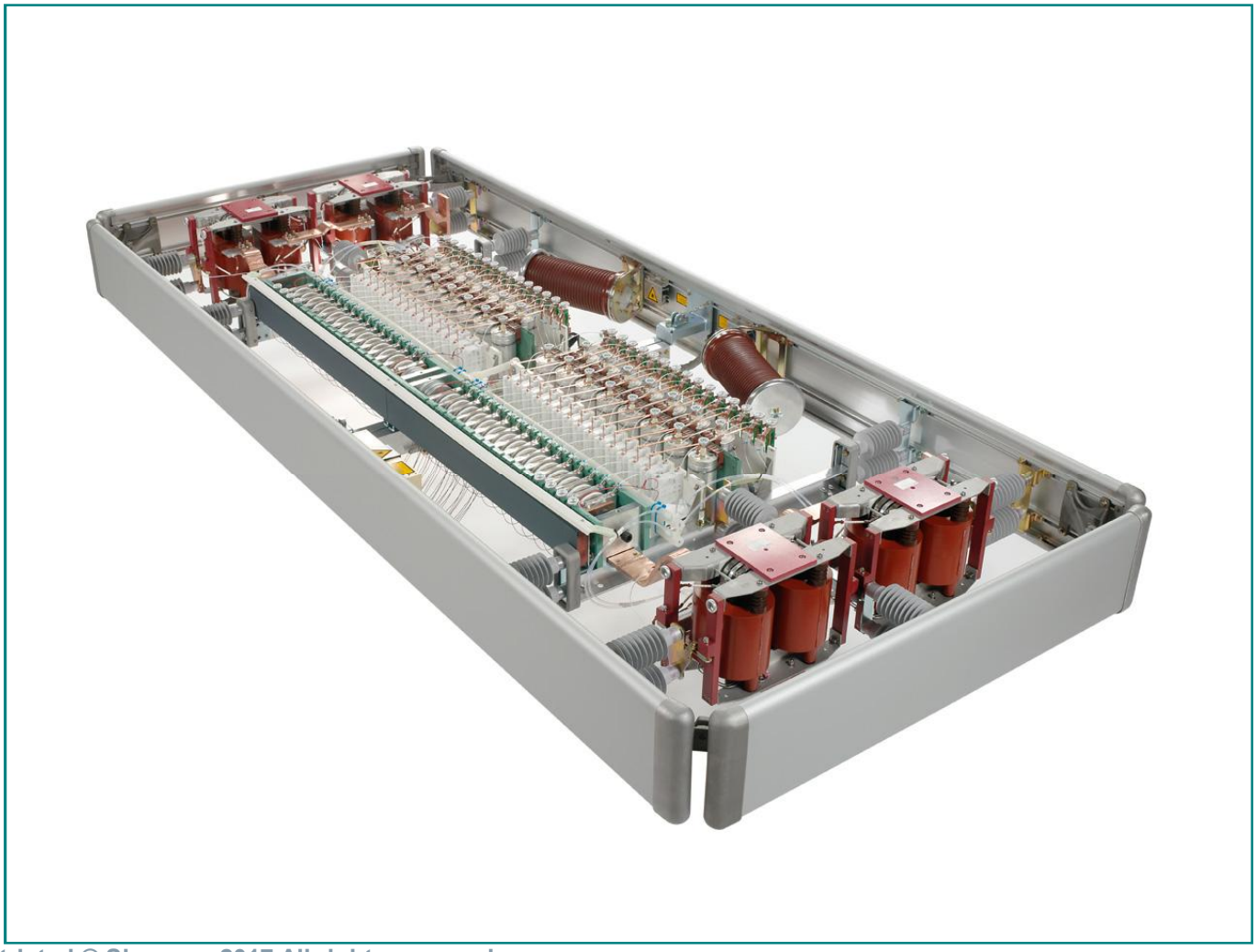
⇒ Optimum usage of thyristor stack size



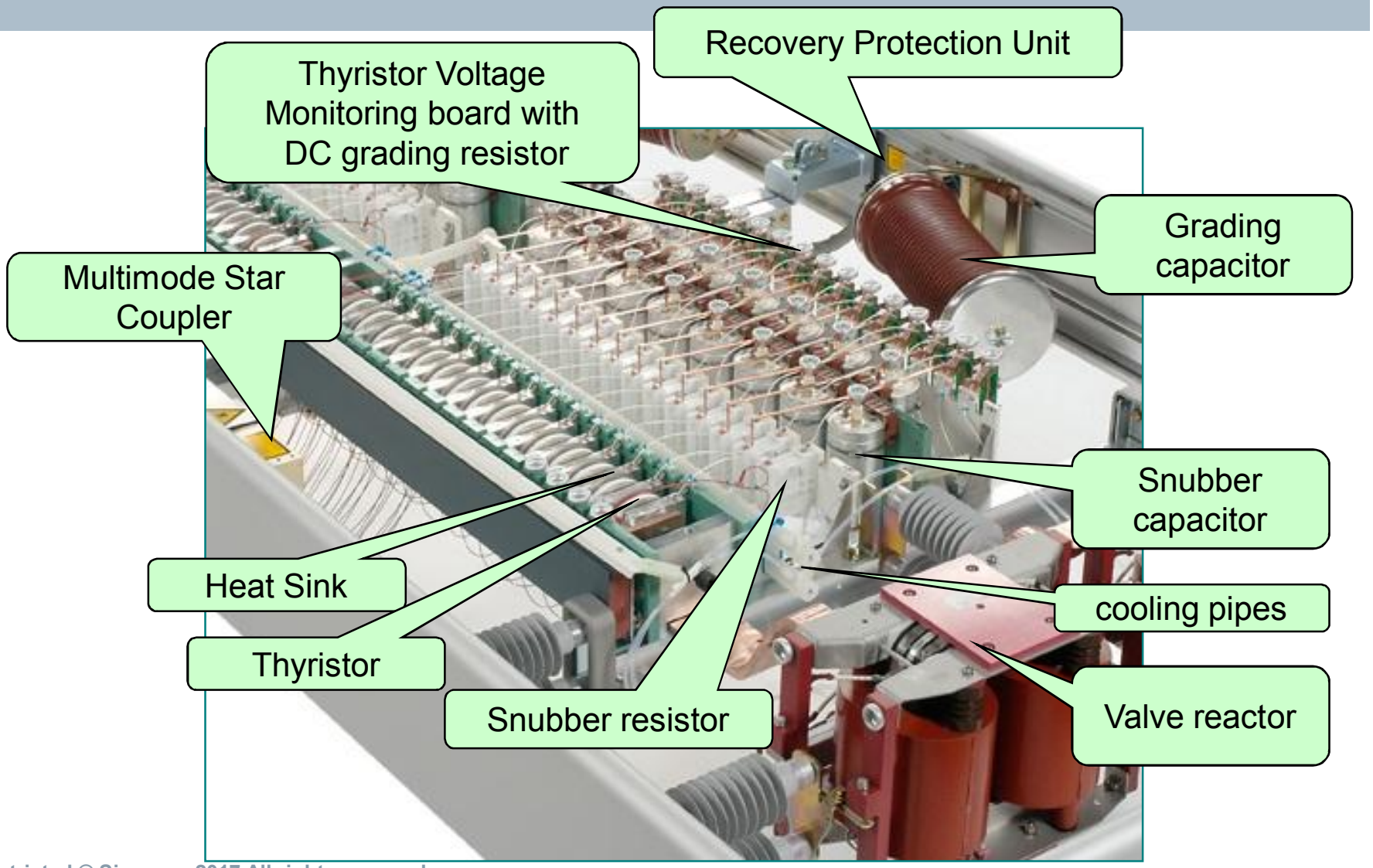
Thyristor Features:

- Blocking Voltage > 8 kV
- Direct Light Triggered (LTT)
- Integrated overvoltage protection (BO)
- 5“-LTT: T 2563 N 80 T S 34

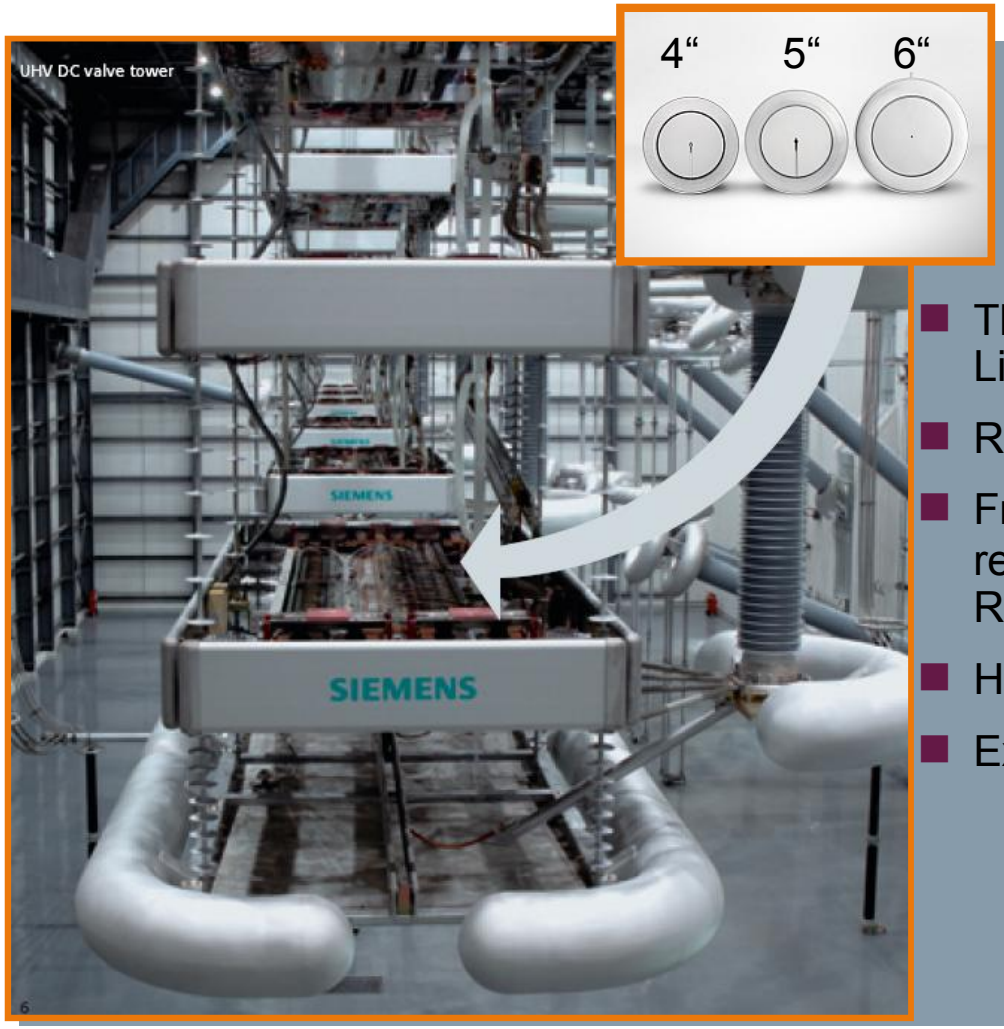
Modular Unit / Valve Sections



Valve Components



Thyristor Valves



- Thyristor Technology with direct Light- Triggered Thyristors
- Rated Voltage up to 800 kV DC
- Free from Oil and exclusive Use of Flame-retardant self-extinguishing Materials ⇨ Reduced Fire-Hazard
- High Efficient Water Cooling
- Excellent Seismic Performance

Smoothing Reactors and DC Filters

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Smoothing Reactor:

- Reduction of Current Ripple (on the DC Cable)
- Limitation of DC Fault Currents
- Protection of Valves against Transient Overcurrents
- Prevention of Resonance in the DC Circuit
- Prevention of intermittent Currents

Oil immersed Design

270 mH

500 kV DC

3,000 A

Air-Core Design

150 mH

500 kV DC

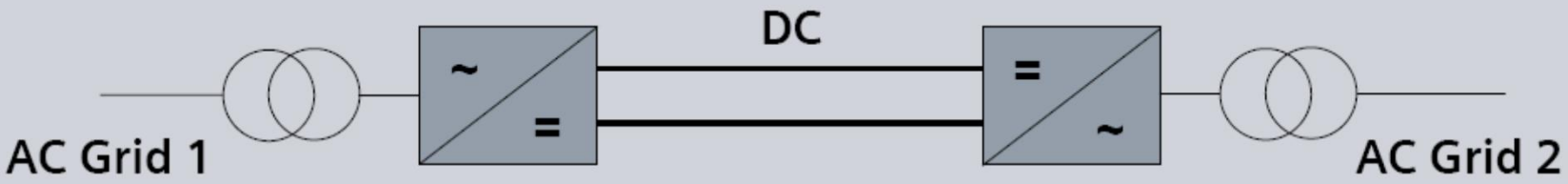
1,800 A

800kV Converter Station

SIEMENS

Shenzhen Converter Station

HVDC Classic – HVDC PLUS



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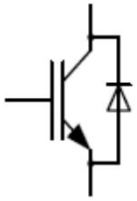

VSC HVDC - Principles

VSC HVDC is a generic name but most manufacturers try to use their brand name: Siemens – HVDC PLUS

In HVDC PLUS the AC-DC conversion (and vice versa) is carried out by an IGBT (Insulated Gate Bipolar Transistor) arrangement known as a power module.

HVDC PLUS works well with weak systems as it does not need any external references to generate voltage or frequency. HVDC PLUS does not generate any harmonics on to the connecting system and so does not need filters.

HVDC PLUS independently controls active and reactive power e.g. at each end there is effectively a Statcom.

HVDC PLUS can support Blackstart (network restoration) and can be used with a range of underground or undersea cable technologies and overhead lines.

HVDC PLUS is currently available up to +/- 525kV with power transfer of up to 2,000MW

HVDC PLUS
The Evolution of HVDC PLUS and VSC Technology

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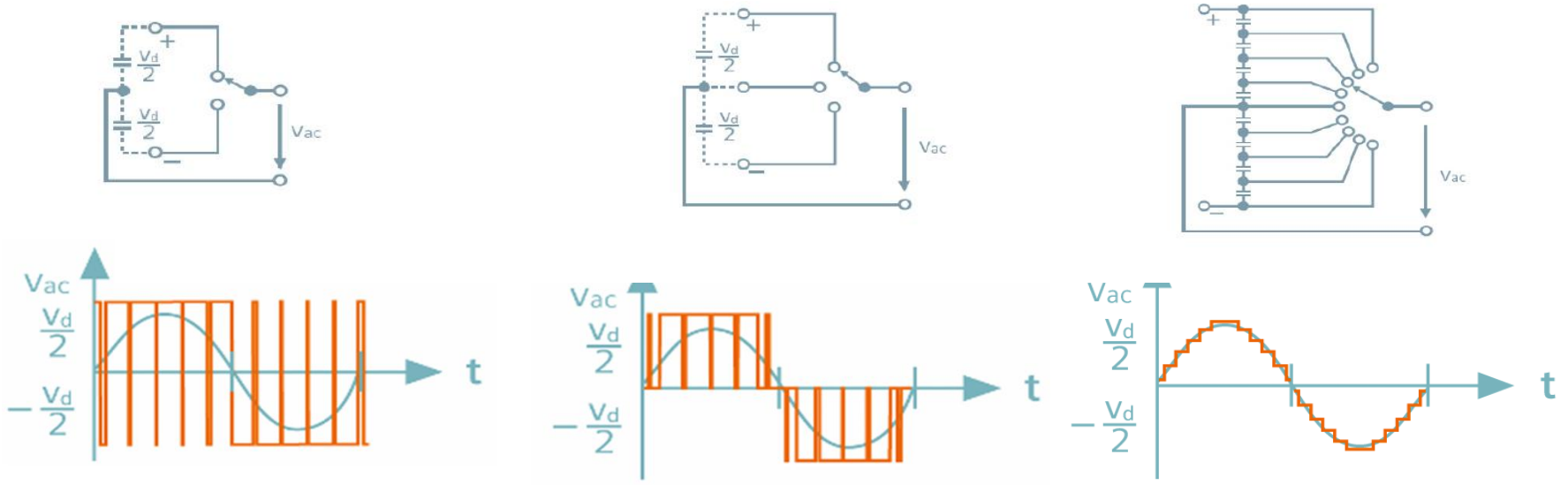
Topology of VSC

Two-Level	Three-Level	Multilevel



Power Electronic Devices

GTO /IGCT	IGBT in PP	IGBT Module

HVDC PLUS Converter
AC Voltage Generation

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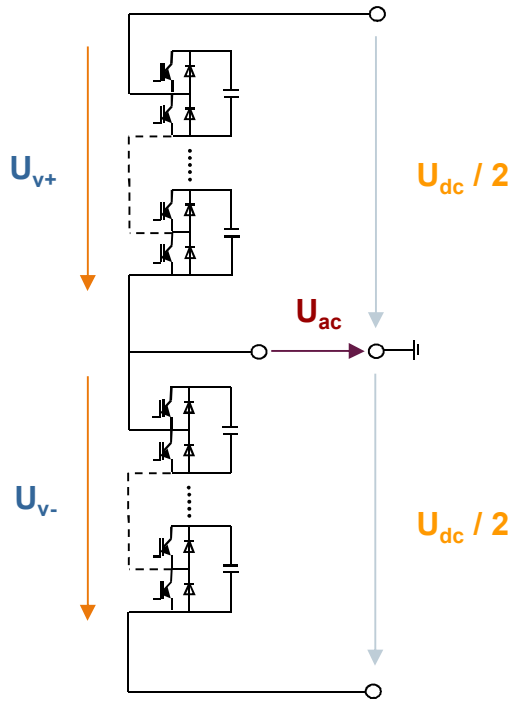
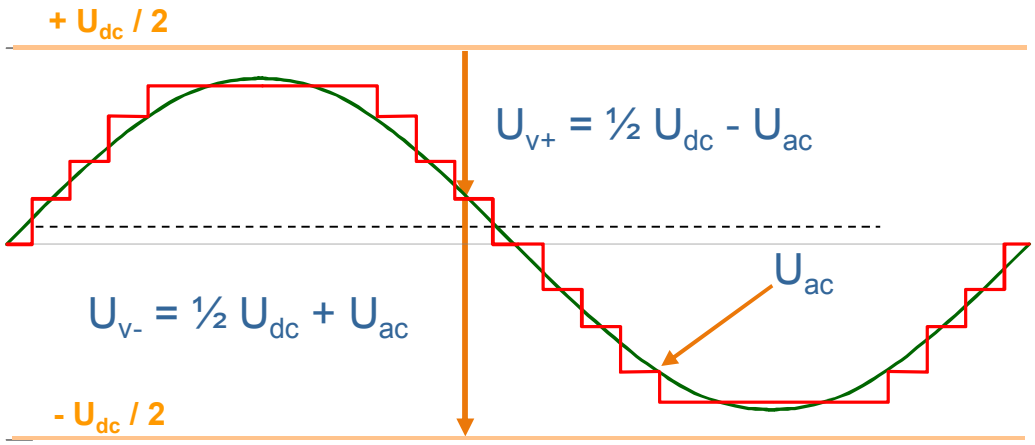
Simplified Block Diagram



Multilevel Technology



Characteristics

- Switching of individual Power Modules:
  1. Tolerance Band of AC Voltage
  2. Voltage Balance of Power Modules
- No fix Pulse Pattern

Power Module (5)
Modular Design

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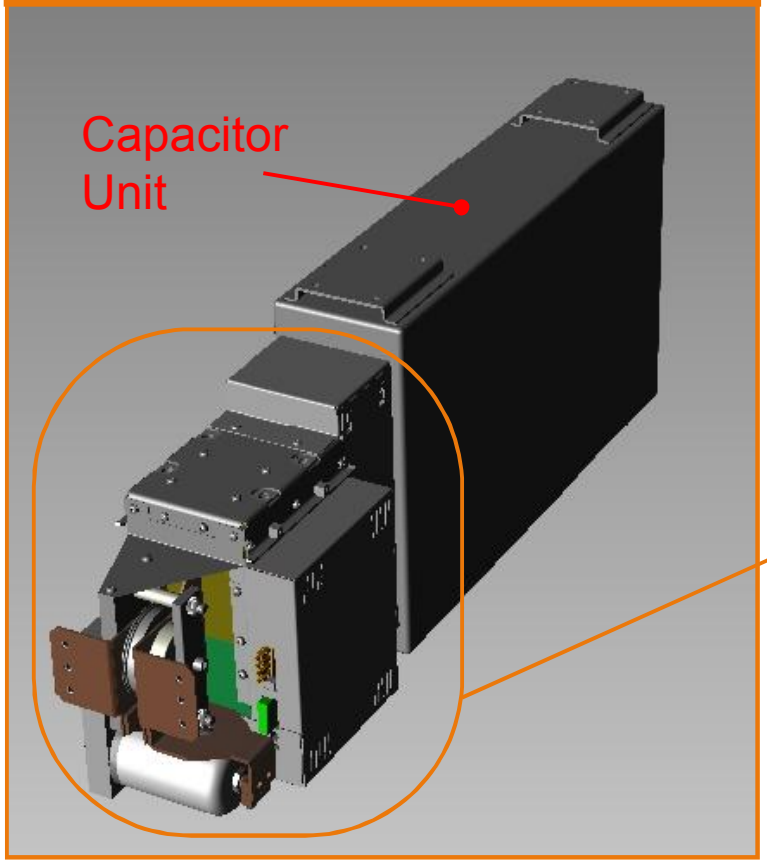
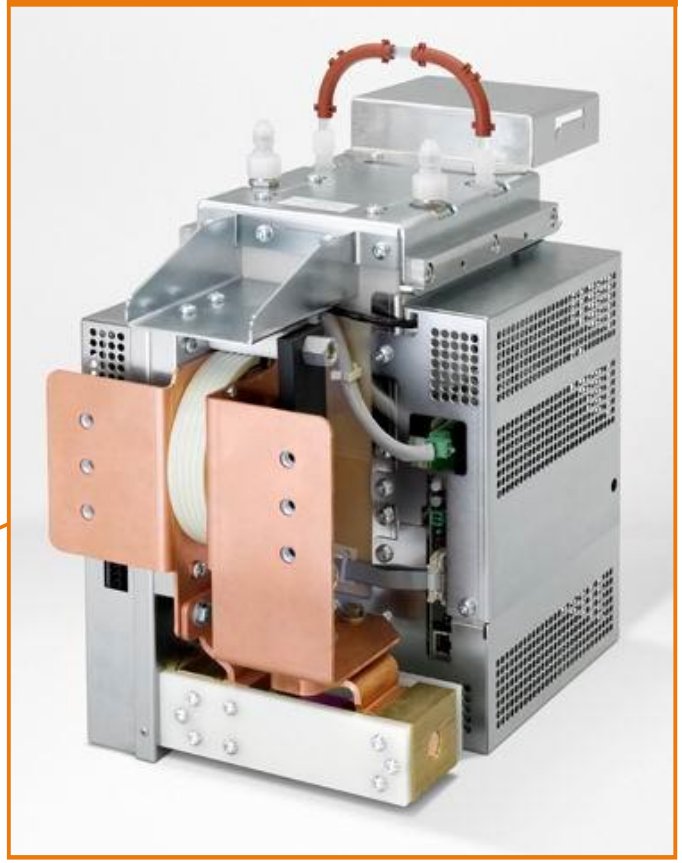
The Power Module
- a two terminal component



The Power Electronics



Power Module (5)
Modular Converter Design

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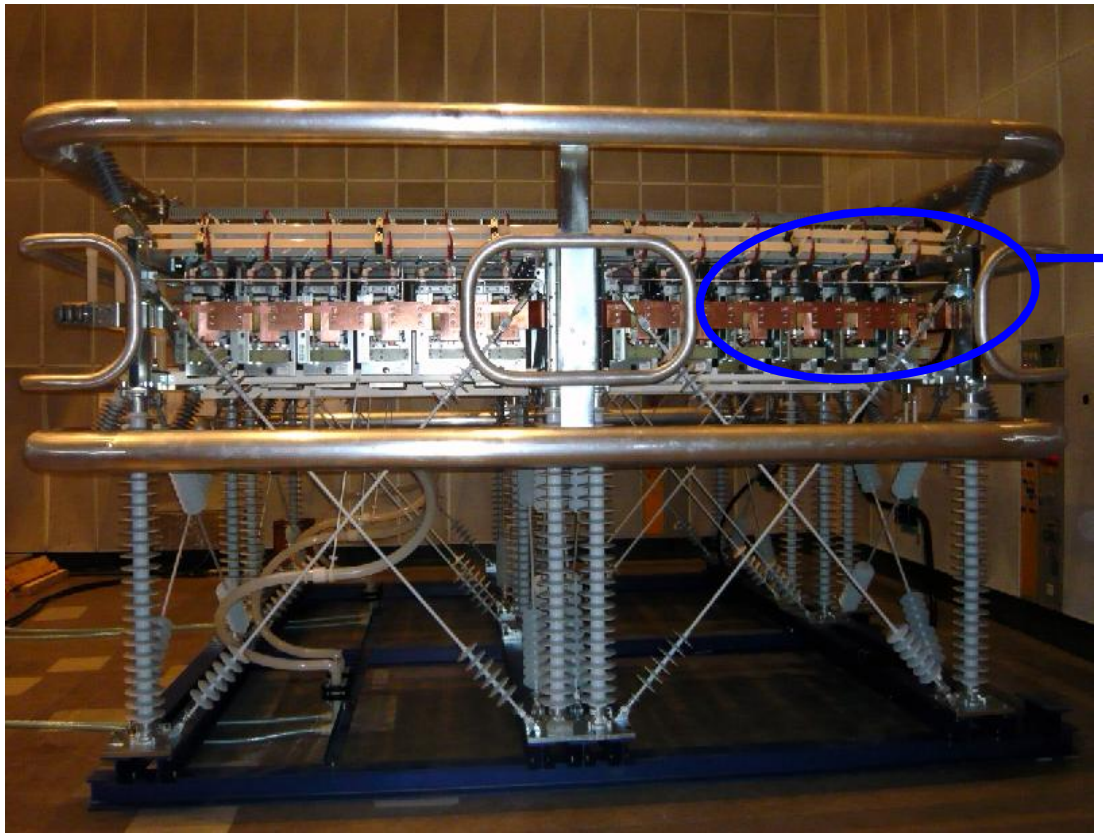

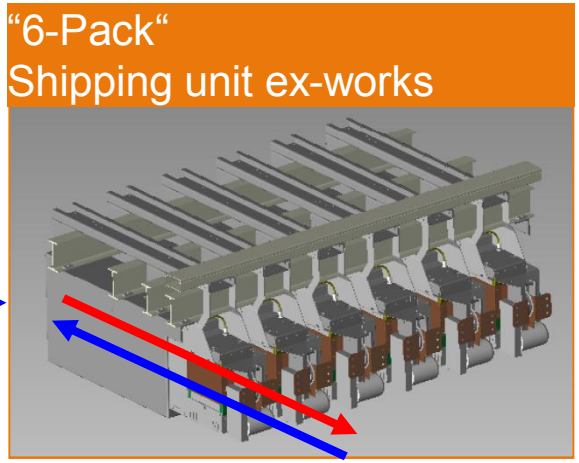

Replacement of
single Power Modules

Double Tower with:

- 3 Floors (72 Power Modules)
- 4 Floors (96 Power Modules)

- Defined internal Voltage Stress
- Compact Installation

Power Module
HVDC PLUS – One Step ahead

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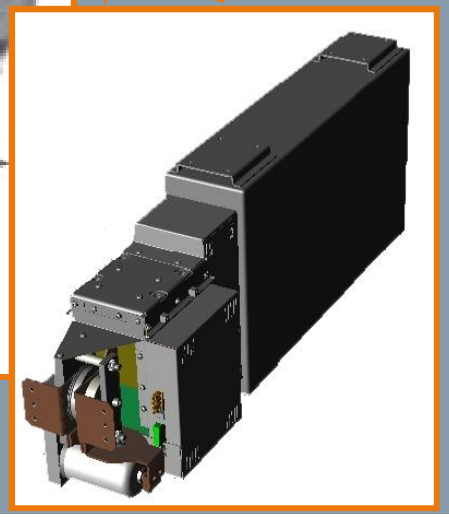
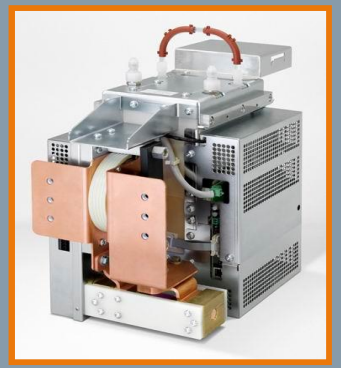
- Compact Design
- Modular Design
- Lower Space Requirements
- Advanced VSC Technology
- Maintenance friendly





HVDC PLUS – Trans Bay Cable Project
World's first MMC-VSC Technology in Commercial Operation

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Trans Bay Cable Project
Valve Hall

SIEMENS

INELFE Project
Valve Hall

SIEMENS

New Applications
Comparison of Half and Full Bridge Power Modules

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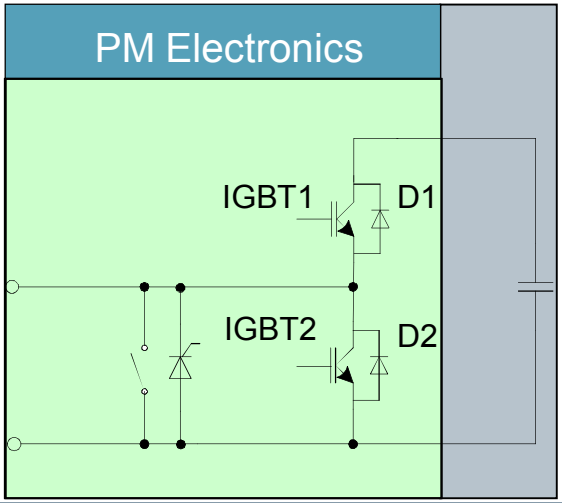
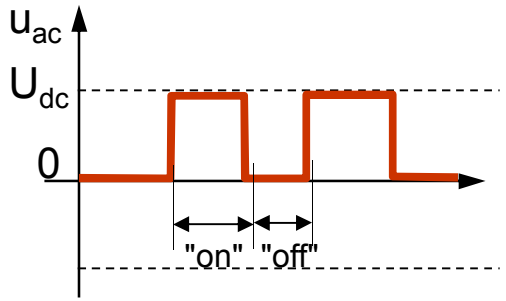
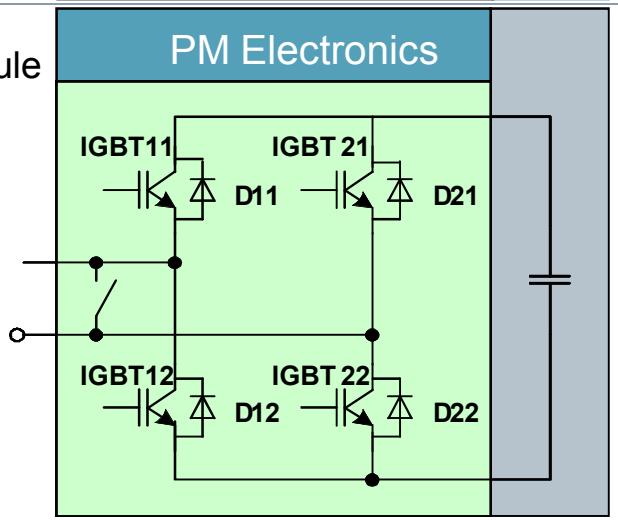
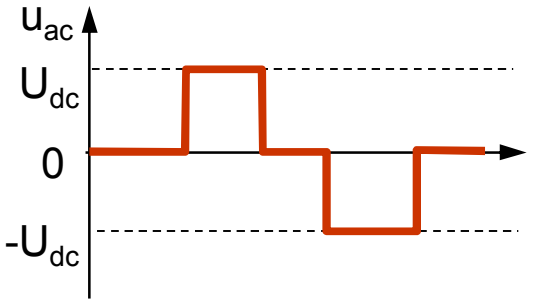
- Half Bridge Power Module
  The Solution for Cable
  Transmission w/o OHL





- Full Bridge Power Module
  For Transmission with
  OHL with or w/o Cable





New Applications
MMC Half Bridge

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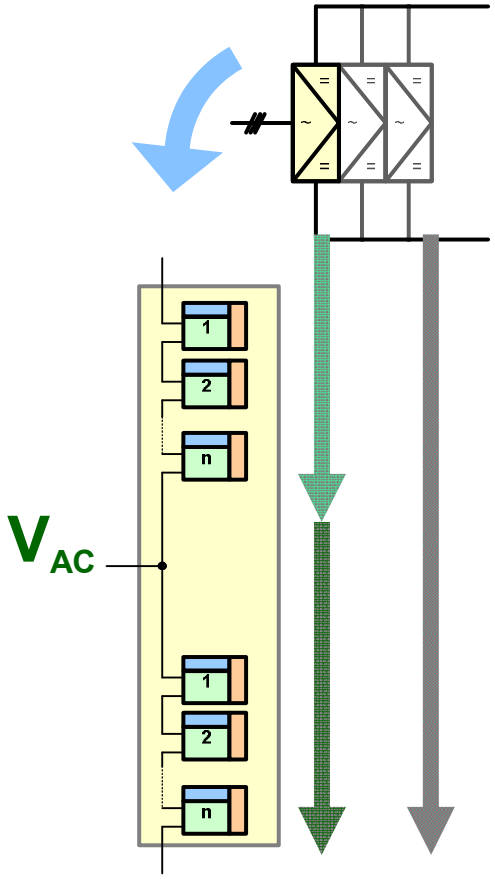
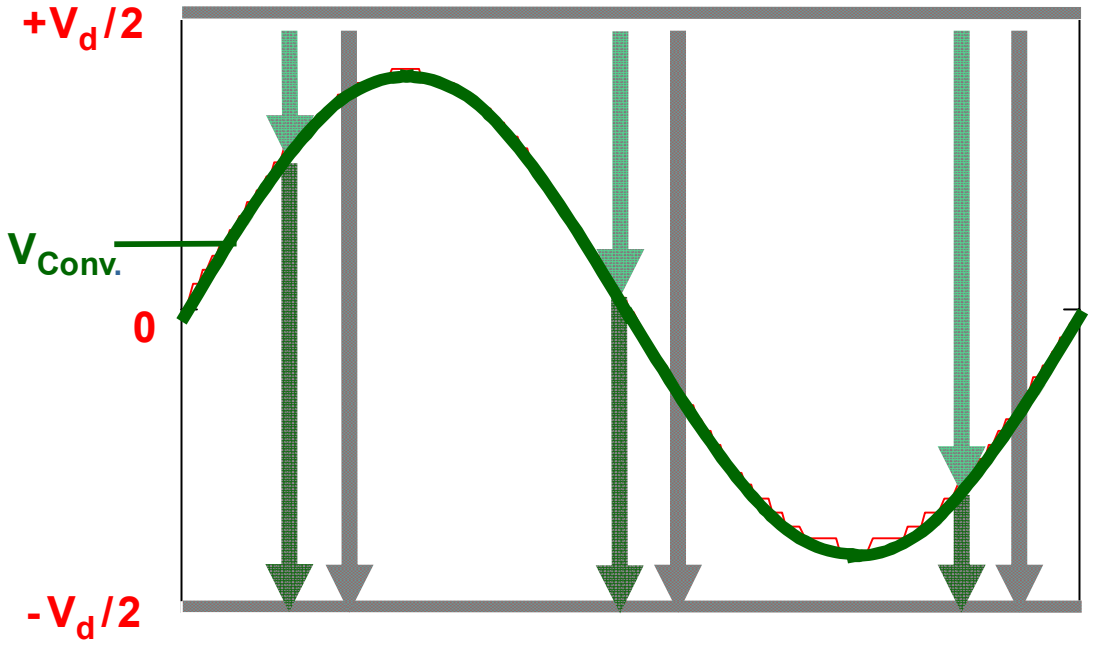
The DC voltage is always higher than the AC voltage



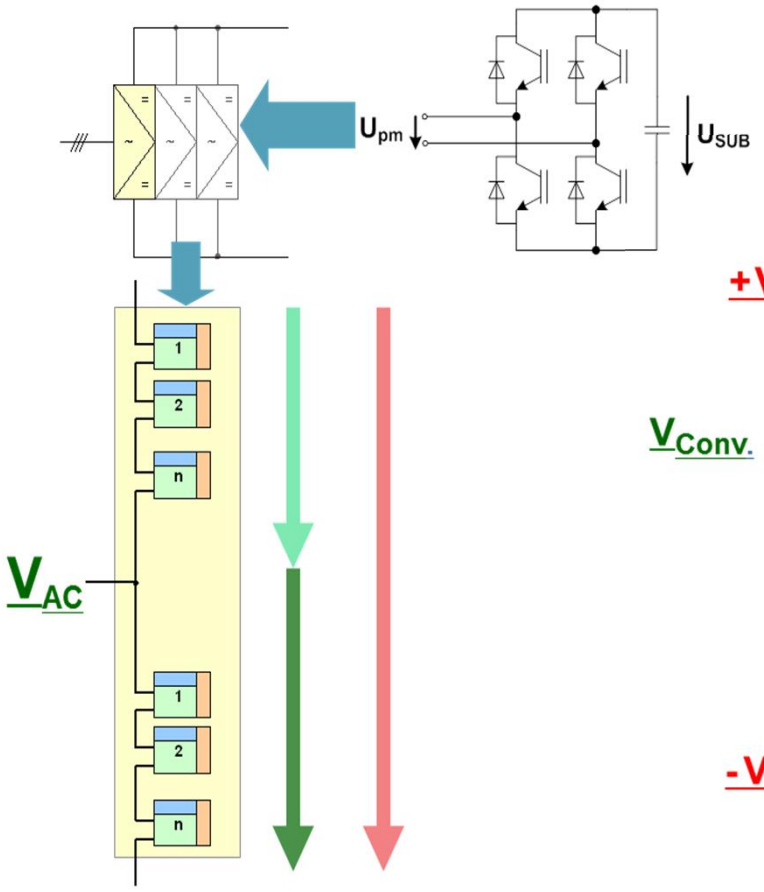
AC and **DC** Voltages controlled by Converter Module Voltages:



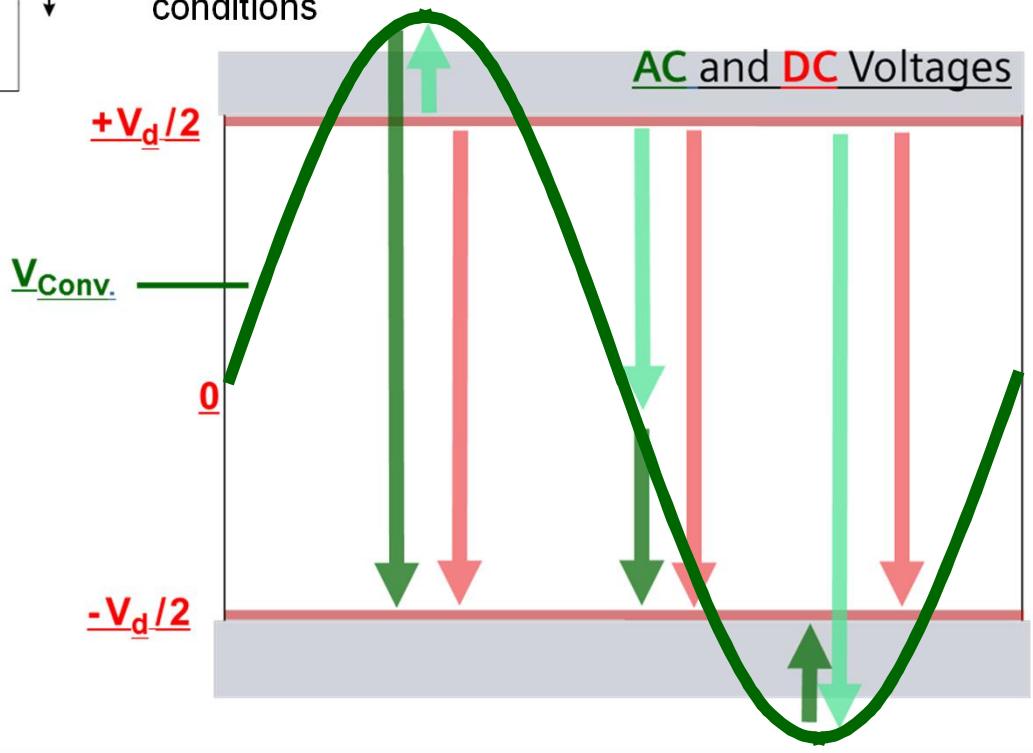
New Applications
MMC Full Bridge

SIEMENS

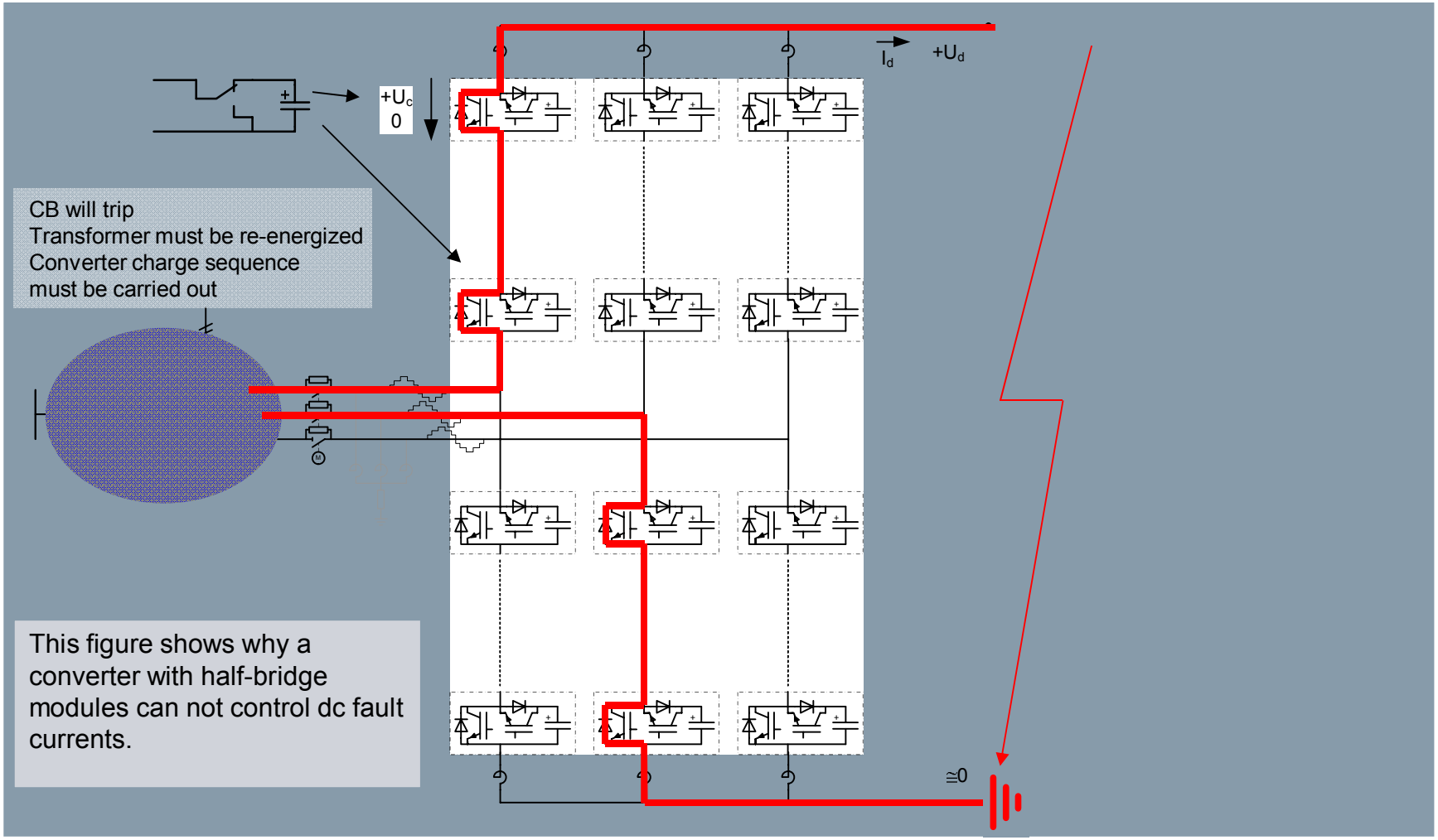
The DC voltage is independent from the AC voltage



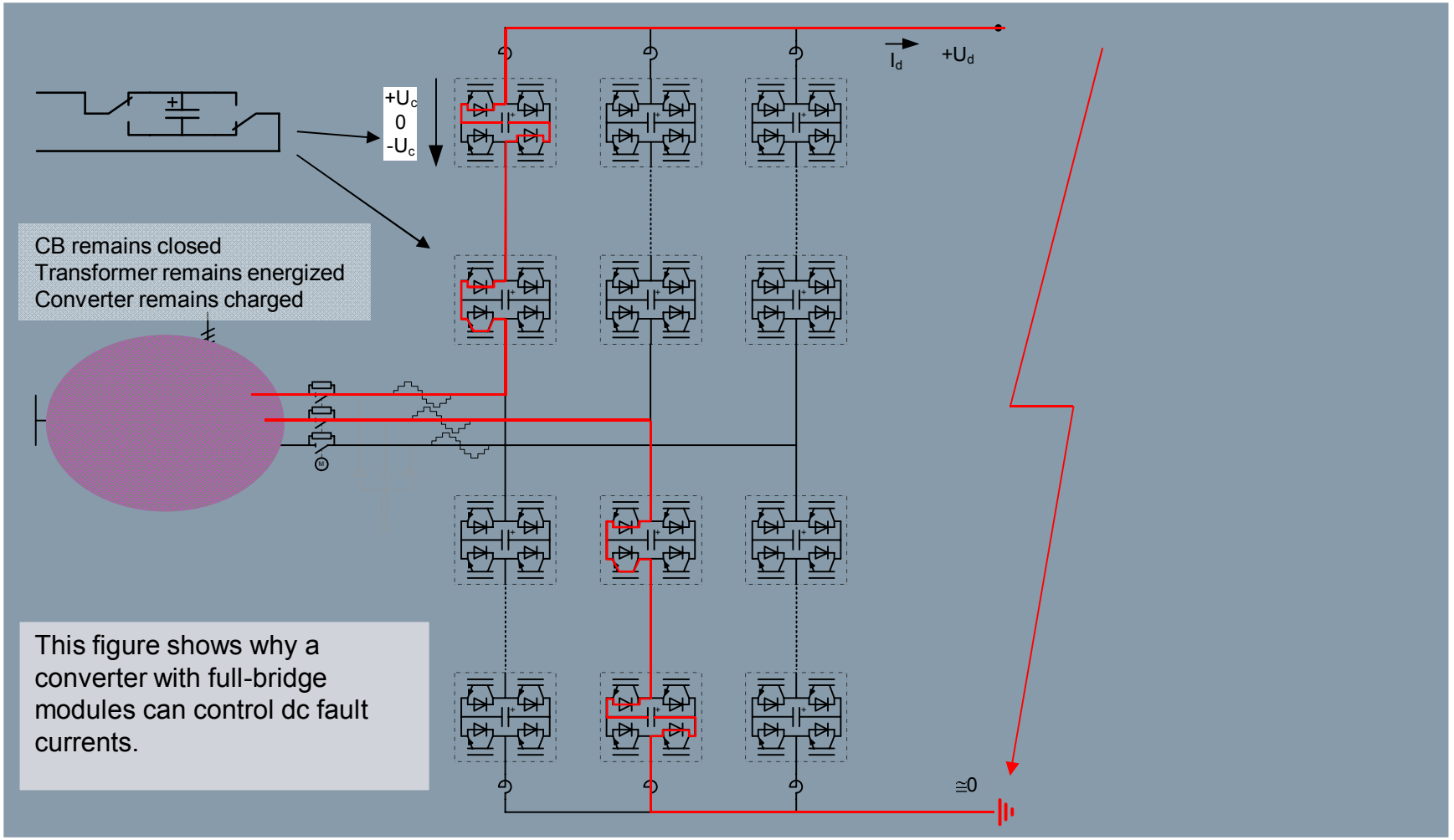
The DC voltage can be controlled to Zero or even be entirely reversed maintaining current control on the AC and DC sides including under short circuit conditions



New Applications
DC Line Fault with Grounded MMC Half-bridge



New Applications
DC Line Fault with Grounded MMC Full-bridge



New Applications
Fast DC Line Fault Clearing – the key for System Stability

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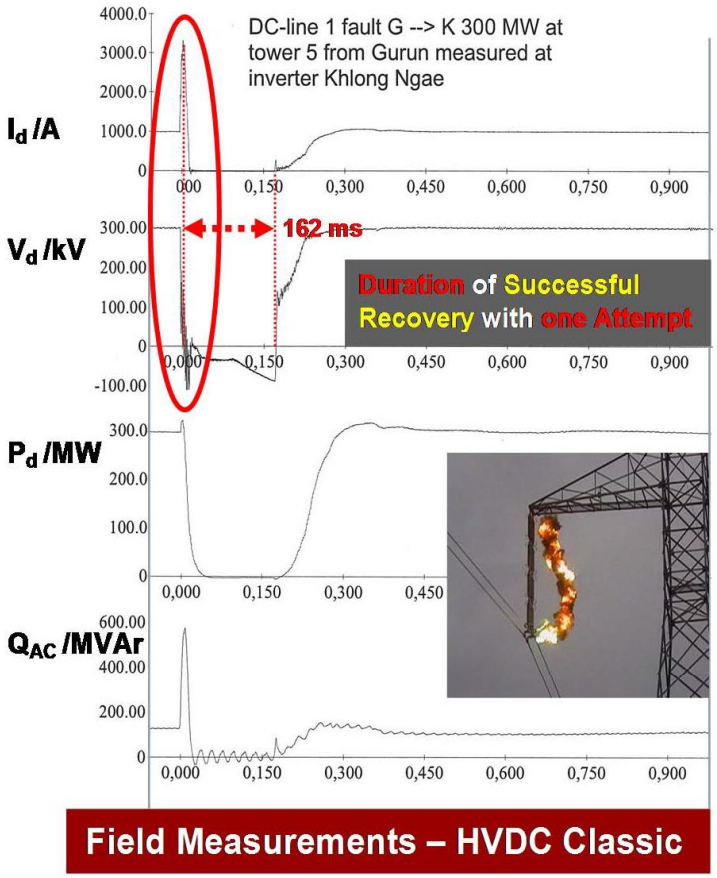

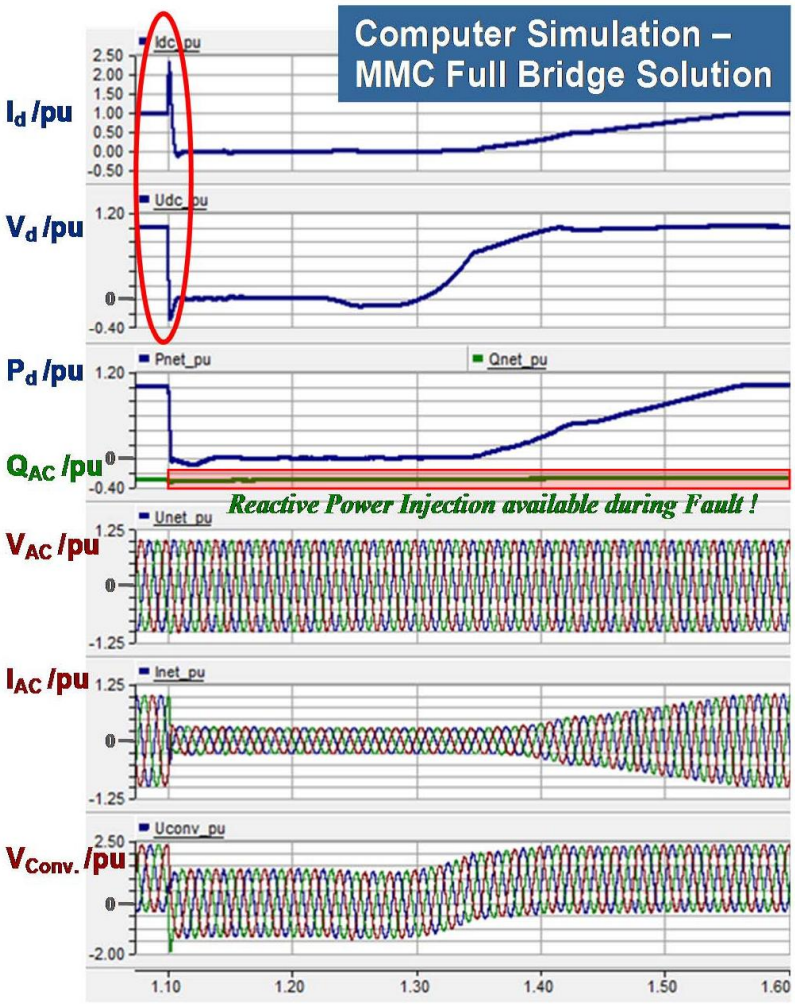

Advantages and Benefits of Classic (LCC) HVDC and Siemens HVDC PLUS (VSC) Technology

SIEMENS

Characteristics	SIEMENS HVDC LCC Technology ("**Classic**")	SIEMENS HVDC VSC Technolgy (**HVDC PLUS**)
Rating	"Classic" ≤ 4 GW "Bulk" ≤ 10 GW	"Smart" ≤ 1,100 MVA (Cable) Full Bridge ≤ 2200 MVA (Overhead)
Overload Capacity	Thyristor - very high	IGBT strictly limited
Total Converter & Station Losses	≤ 1.5 %	close to 2 %
Voltage, POD & Frequency Control	Available	Available
Dynamic Performance	High	Very High
Filter Requirements	Typically. 50 % (in MVAR) of reated power transmission capability	None
Independent Control of Reactive Power	Stepwise linear	Fully linear
Space Requirements	High	Less
Grid Access for weak AC Networks	Restricted (with additional measures like installation of Synchronous Condensers (SCO))	Quite easy
Supply of passive Networks and Black-Start Capability	No	Yes
Reversion of Current Polarity for Multiterminal Schemes	complexe DC-SWY in LCC-Multiterminal Stations required	inherent converter function
**Value for transmission - Highlighted boxes: yellow and grey*	****Very High***	****High***

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Common HVDC Misconceptions/Comments

- HVDC Classic cannot be used in a weak system
- Only VSC can support system voltage
- VSC contributes to the short circuit current
- VSC is only good for about 1000MW
- HVDC causes big problems to generators
- HVDC is only for bulk long distance Transmission
- HVDC is inflexible

Real Time Power Control
Trans Bay Cable Data

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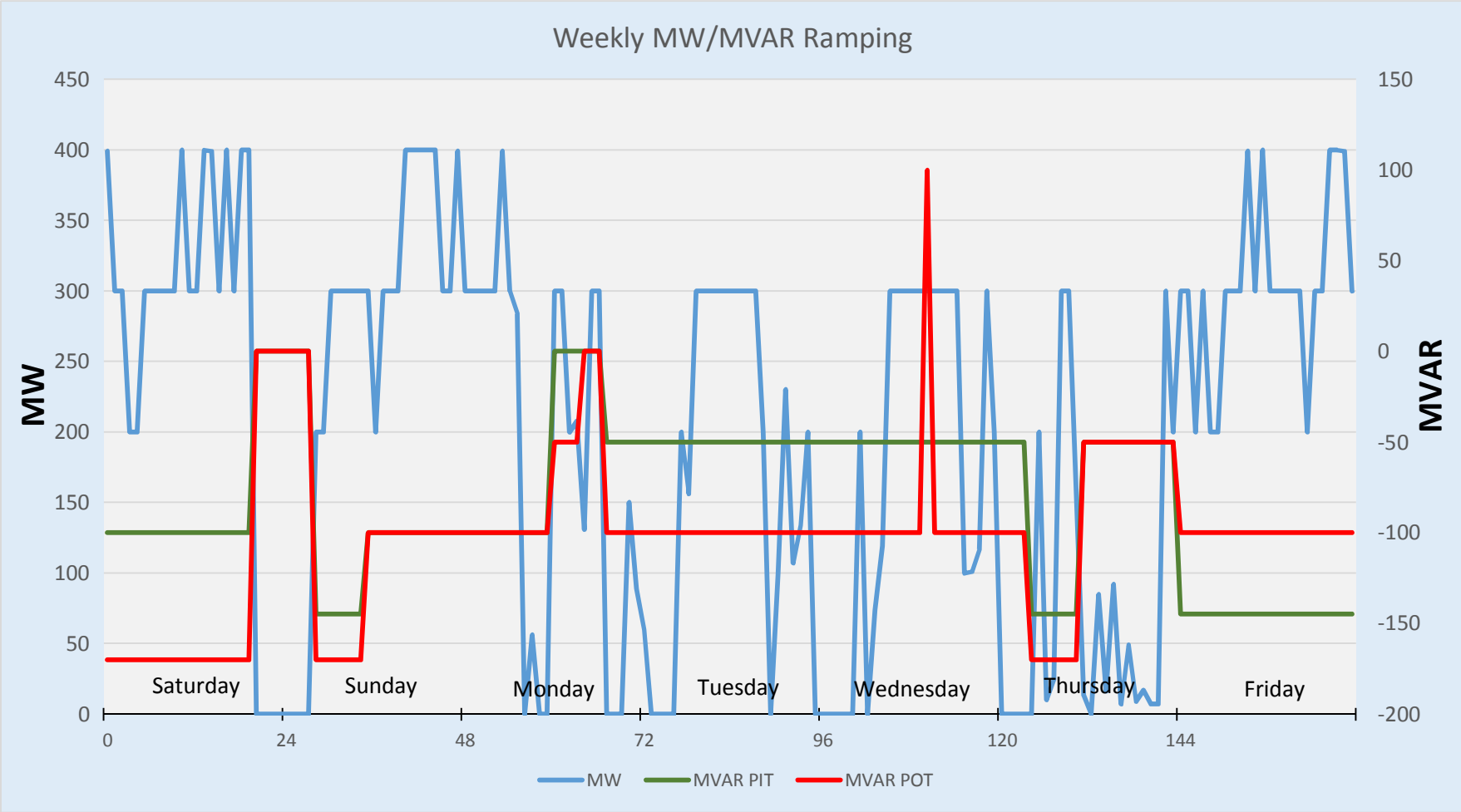

Common HVDC Misconceptions/Comments

- HVDC Classic cannot be used in a weak system
- Only VSC can support system voltage
- VSC contributes to the short circuit current
- VSC is only good for about 1000MW
- HVDC causes big problems to generators
- HVDC is only for bulk long distance Transmission
- HVDC is inflexible
- HVDC is expensive
- Why can’t HVDC be more like AC?

HVDC Products and Solutions - Overview

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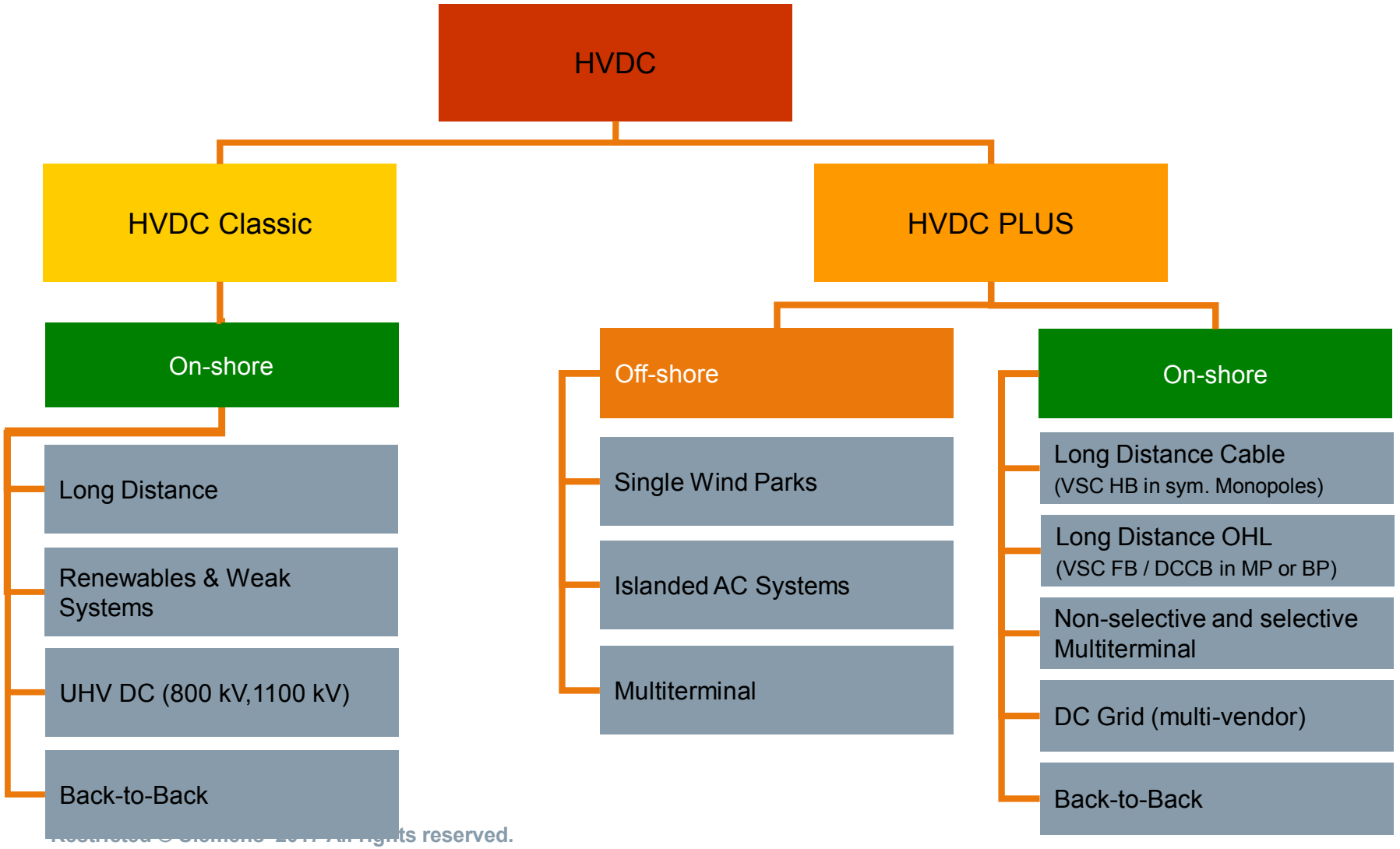

Thank You

Peter Kohnstam
HVDC Business Development Manager

4601 Six Forks Rd
Raleigh, NC 27609

Mobile: +1 (919) 917 8096

E-mail:
peter.kohnstam@siemens.com

siemens.com/answers