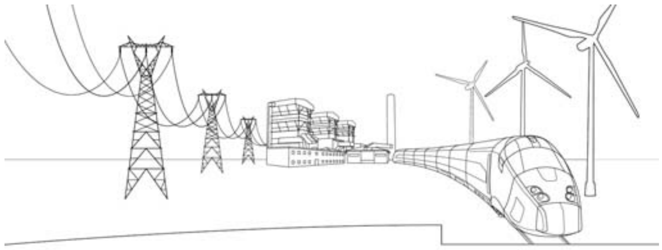
Annex II



Comparing Technology

R.Bonchang, S. Chakravorty

Delhi

Feb 2015

ALSTOM
Shaping the future

- **Types of Converters**
- Main Equipment & Performance Comparisons
- Impact on Cable Schemes
- Impact on Over Head Line Schemes
- Summary

ALSTOM

Line-Commutated versus Self-Commutated converters

•Line-Commutated Converters	•Self-Commutated Converters
•Use semiconductors which can turn on by control action	•Use semiconductors which can turn on or off by control action
•Turn-off and "commutation" rely on the external circuit	•Turn-off can be whenever you want
•Require an AC system with rotating machines at all times	•Can feed into any type of AC system or load
•Cannot feed into a "dead load" (eg a resistor)	

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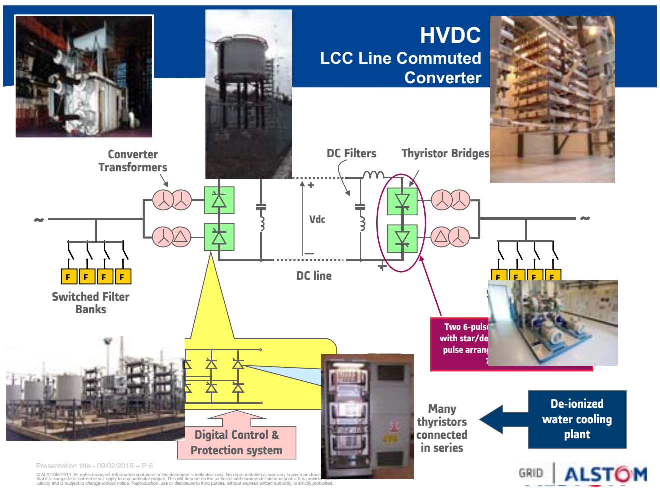
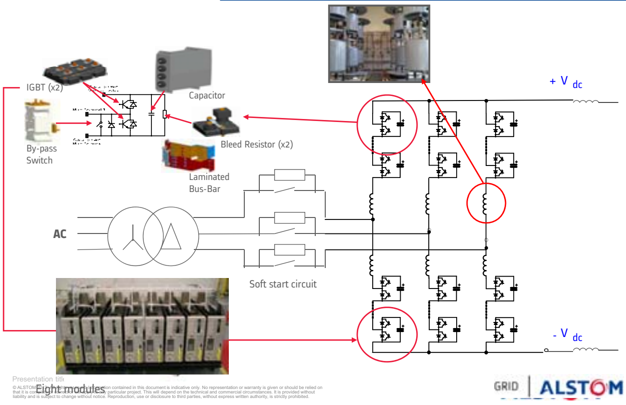


GRID | ALSTOM

HVDC
VSC Voltage Source Converter



Why VSC HVDC?
Key Benefits Compared to LCC HVDC - 1

- Can use ordinary transformers
  - Any ALSTOM T&D power transformer factory could build
- Both active and reactive power control in one equipment
  - Eliminates need for separate compensation equipment
- No reactive power switching
  - Significantly reduces application engineering
- Operation down to very low short-circuit ratios
  - Connect into any network without complex studies and system reinforcement
- Multi-terminal configuration are simpler to engineer
  - Ideal for offshore wind farm grids

Why VSC HVDC?
Key Benefits Compared to LCC HVDC - 2

- Inherent Black Start capability
  - Always a requirement for offshore wind and island feeding applications
- Compact dimensions and lower weight
  - Ideal for inner cities, reduced visual impact
- Power reversal by adjusting the DC voltage at both converter stations
  - Enables the use of low cost polymeric cables

Rapidly growing interest in VSC HVDC + underground cables as an alternative to overhead AC lines, particularly for inner city feeding

Significantly easier route permitting procedures

Easier building planning applications

Much simpler system studies to create the RFQ

Disadvantages of VSC HVDC

Higher capital equipment cost
- 15-20%, but falling

Higher converter station power losses
- For LCC around 0.7 – 0.8 % per station
- VSC 1.0 – 1.1 % per station

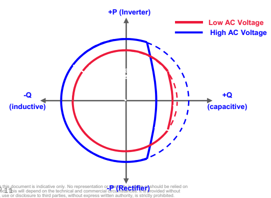
EMC issues much more important

Limited voltage/power ranges
- Unlikely to ever replace LCC HVDC at very high powers (3000MW+)

Lack of understanding of the technology in the marketplace
- **But this is rapidly changing!**

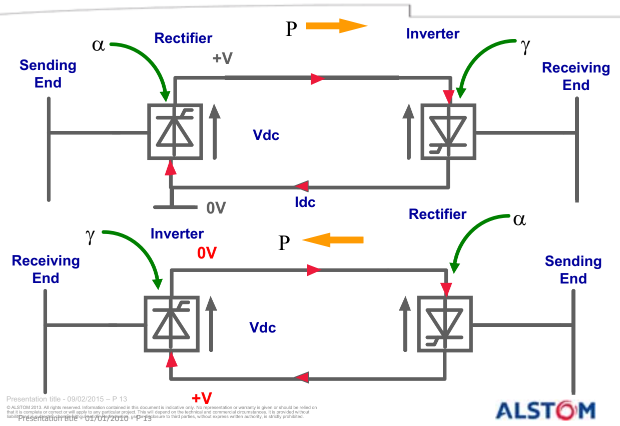
Real vs Reactive Power

- With Line-Commutated Converters, there is a clear-cut division between HVDC (real power) and FACTS (reactive power)
- With Self-commutated, Voltage Sourced-Converters the distinction is less clear-cut
- A VSC has a defined operating characteristic in the P-Q plane and can operate anywhere within this envelope:



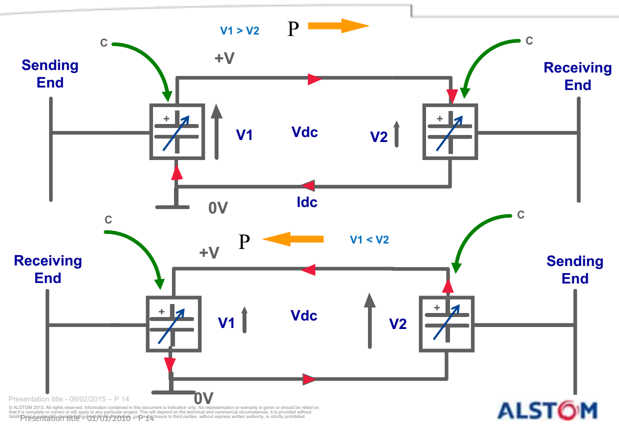
- Types of Converters
- Main Equipment & Performance Comparisons
- **Impact on Cable Schemes**
- Impact on Over Head Line Schemes
- Summary

LCC HVDC Transmission : Bi directional



ALSTOM

VSC HVDC Transmission : Bi directional



ALSTOM

Mass Impregnated Non-Draining (MIND) cables

- ***Uses oil impregnated paper insulation***
- ***Rated up to 600 kV DC***
- ***Low operating temperature tolerance reduces power capacity***
- ***Expensive and heavy compared to polymeric extruded cables***
- ***New developments include Paper Polypropylene Laminate (PPL)***

ALSTOM

Cross Linked Polymeric Cables - XLPE

- Widespread use in AC transmission up to 500-kV
- Free from oil or grease
  - more environment-friendly
- Lighter in weight compared to MIND cables
  - Reduces the number of cable joins
- Version developed for VSC HVDC
  - In service voltage today limited to 320kV
    - 500kV being tested

ALSTOM

Cables for VSC HVDC

- As DC voltage never reverses, it is possible to use extruded polymeric insulated cables such as XLPE
  - Cross linked polyethylene
  - No danger of trapped charges in the x-linked voids
- Compared to MIND cables, XLPE and similar cables have the following characteristics:
  - Lighter weight & more flexible, smaller cable drums
  - Smaller bending radius, Lower manufacturing cost
- Faster and lower cost installations
  - Both bipolar cables buried close to each other in one trench
  - No oil present, lower operation temperature
  - BUT similar to MIND for subsea applications due to extra lead and armouring required to prevent compression of the x-linked voids at high pressure
- These characteristics, for a cable scheme, can make VSC HVDC competitive with classical HVDC

ALSTOM

Submarine & Underground power cable types

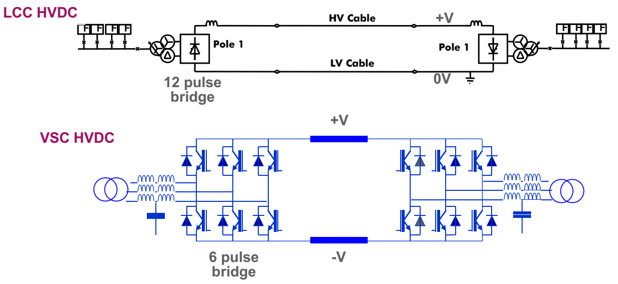
	Mass Impregnated	XLPE
Voltage (kV)	500 (DC)	320 (DC) *
Installed Power Rating(MW)/cable	660	200
Planned Power Rating(MW)/cable	800	500
Diameter (mm)	110 to 140	90 to 120
Weight (kg/m)	30 to 60	20 to 35
Convertor	LCC/VSC	VSC/LCC in near future
Application	Pref. Long Dist (>100km)	Pref. Short Dist (<100km)

* Viscas (Japan) currently doing Cigré validation testing of 500kV XPLE cable

ALSTOM

Monopole

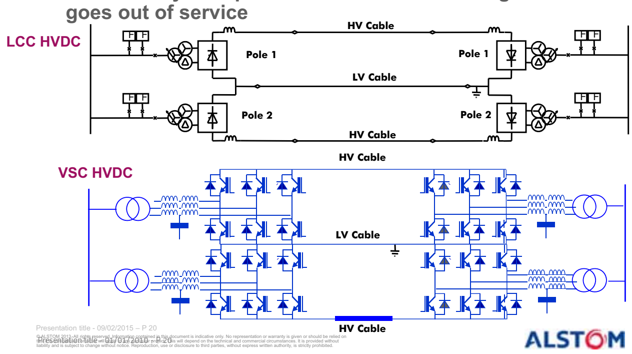
- Monopole
  - Loss of link if one cable or one leg of converter goes out of service



+V and –V equates to "bipolar" operation to create sinewave at the AC side
It is not a BIPOLE

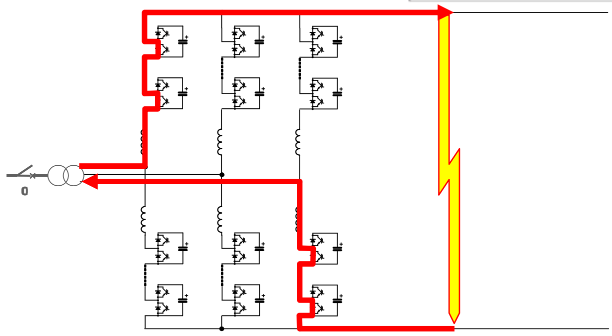
Bipole and "Bipolar"

- Bipole
  - Loss of only 50% power if one cable or one leg of converter goes out of service



- Types of Converters
- Main Equipment & Performance Comparisons
- Impact on Cable Schemes
- **Impact on Over Head Line Schemes**
- Summary

Half-bridge MMC: Response to faults on DC side



- **Cannot** electronically suppress faults on the DC side (unlike LCC-HVDC)
- Must open AC circuit breaker to clear fault
- Two-level VSC circuit is the same

LCC : Gnd Fault on a BP OHL

- Fault is Detected in P1
- Rectifier changes to Inverter mode (Force Retard), removing energy & discharging the Line quicker
- Rectifier AC Busbar experiences a temporary over frequency & transient voltage disturbance
- P2 if possible operated in Overload mode to compensate.

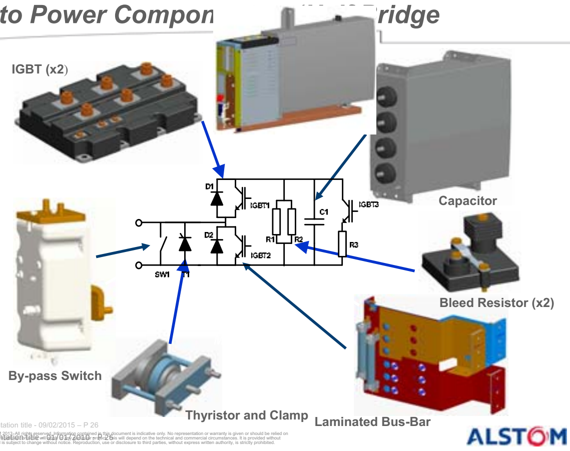
VSC HB : Gnd Fault on a BP OHL

- Fault detected in P1
- Rectifier AC Bus effectively sees a 3 phase S/C which is also seen by Healthy P2 until Breakers Open (80 ms) leading to Load rejection of 1 pu
- Trip AC Breakers both end
- DC Line takes longer to Discharge (seconds ?: dependant on time constant of DC Circuit)
- P2 Blocks when fault detected for at least 60 ms until fault cleared
- Now P2 can increase Power & go to O/L if available

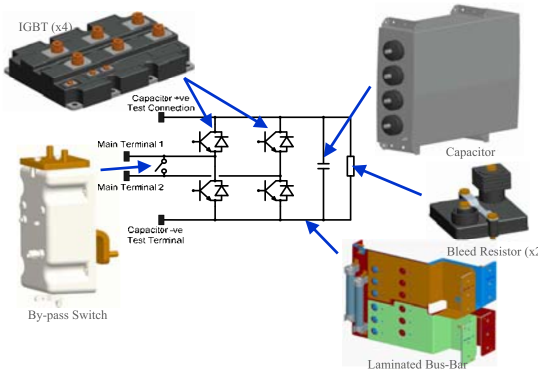
VSC FB : Gnd Fault on a BP OHL

- Fault detected in P1
- Converters change operation mode to starve the fault of energy.
- When Voltage near zero then P1 Block
- Rectifier AC Bus at worse same as in LCC eg temp over frequency & Overvoltage Transient.
- P2 can increase Power & go to O/L if available

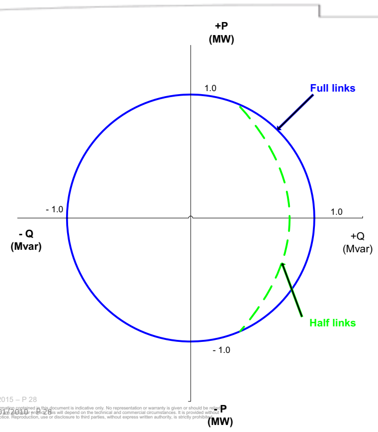
Relating Power Module Circuit Diagram to Power Compon ... ridge



Relating Power Module Circuit Diagram to Power Components – 'Full Bridge'



P/Q Diagram

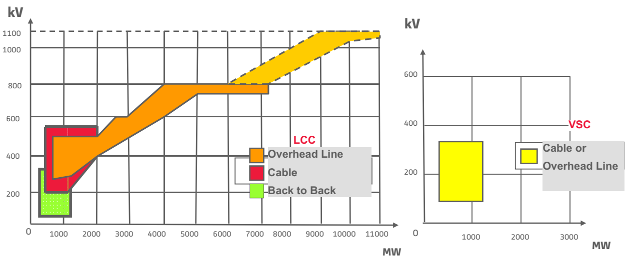


Comparison of Bridge Types

Half-bridge circuit	Full-bridge circuit
Low component count 2 IGBTs + protective thyristor	Higher component count 4 IGBTS, but no thyristor required
Low losses from 2 switching devices	Higher losses from 4 switching devices
Sub-modules dimensions 1500mm x 650mm x 300mm	Sub-module dimensions 1500mm x 650mm x 300mm
DC fault cleared by AC breakers	DC fault suppressed by converter
Not suitable for operation with LCC converters	Suitable for operation with LCC converters, as polarity reverses
Not ideal for multi-terminal operation	Suitable for use on multi-terminal schemes
Ideal for point – point cable schemes	Ideal for OHL or mixed OHL/cable schemes

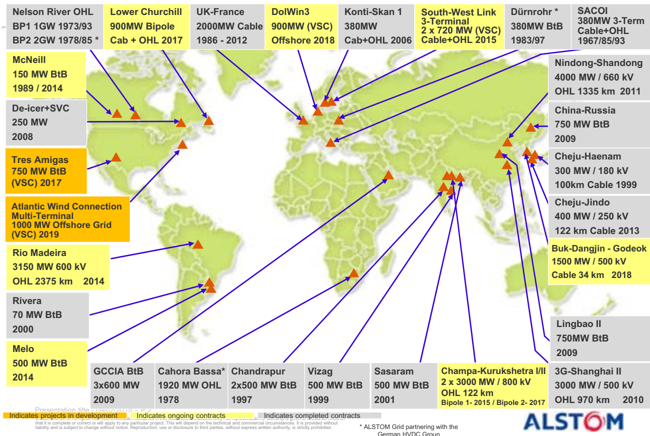
- Types of Converters
- Main Equipment & Performance Comparisons
- Impact on Cable Schemes
- Impact on Over Head Line Schemes
- **Summary**

Which Technology : LCC or VSC



Classical Thyristor LCC HVDC **IGBT VSC HVDC**

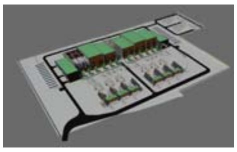
Installed and Ongoing ALSTOM HVDC Projects



* ALSTOM Grid partnering with the German HVDC Group

Sweden/ South West Link – HVDC MaxSine

★ Site Location



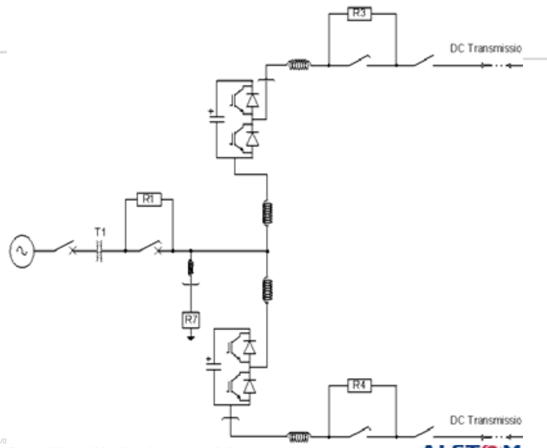
Phase 1: South West Link

- -4 x VSC Converter Stations
- -2 x 720 MV links, +/- 300 kV DC, OHL & Cables (by others)

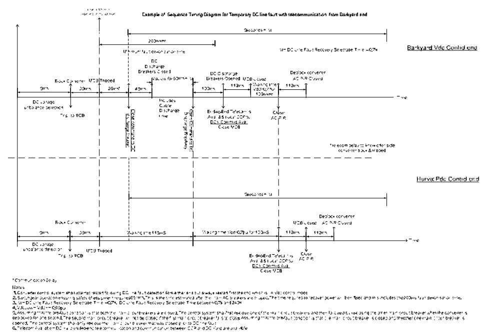
Phase 2:

- -2 x VSC Converter Station towards other Swedish cities

SLD



1. DC Line Fault Sequence when End-to-End Telecom is available (Temporary DC Line Fault) Vdc / Pdc



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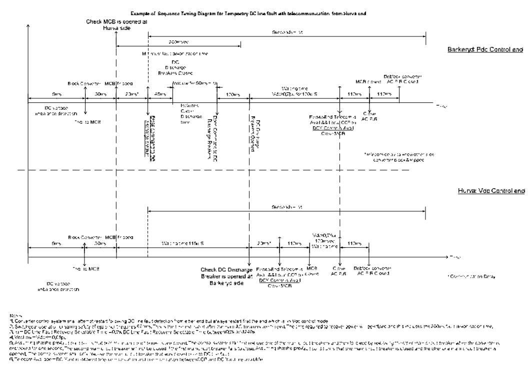

TSO Recent (last 5 yrs) VSC Projects involving Cable Interconnectors

Project	Location	Technology	Cable & Station Lots
ALEGRO – Bid in preparation	Germany Netherlands 4 yr delivery	VSC 1000 MW Monopole	Gnd Cable separate Lots
Nordlink – Bid in evaluation	Germany Norway, 5 yr delivery	VSC Bipole 1400 MW	Submarine & Gnd Cable Separate Lots
NSN – Bid in evaluation	UK Norway, 5 yr delivery	VSC Bipole 1400 MW	Submarine & Gnd Cable Separate Lots
France Italy – Bid in evaluation	5 yr delivery	2 x 600 MW Monopoles	Gnd Cable separate Lots
Nemo – Bid in evaluation	UK Belgium, 52 mths delivery	VSC 1000 MW	Submarine & Gnd Cable Separate Lots
NordBalt - In construction	Sweden Lithuania, 5 yr delivery	VSC 700 MW	Submarine & Gnd Cable Separate Lots.
South West - In construction	Sweden, 4 yr delivery	2 x 720 MW Monopoles	Gnd Cable separate Lots
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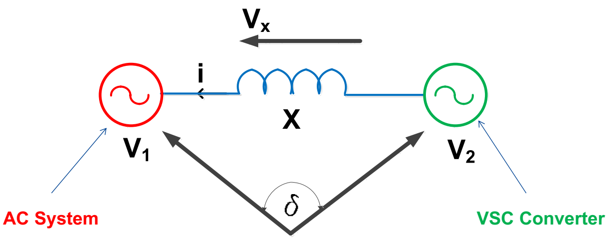
Basic HVDC Building Blocks



VSC Converter can control: V2 and δ

How to assess the power flow in this circuit?

ALSTOM

Real vs Reactive Power

- **With Line-Commutated Converters, there is a clear-cut division between HVDC (real power) and FACTS (reactive power)**
- **With Self-commutated, Voltage Sourced-Converters the distinction is less clear-cut**
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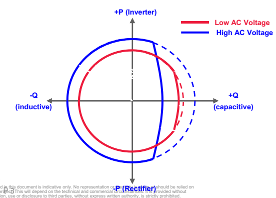

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Customer Name: Standard
Project Name: Standard
Project No: Standard
Document No: STAND/6016/PUBL
Revision: E

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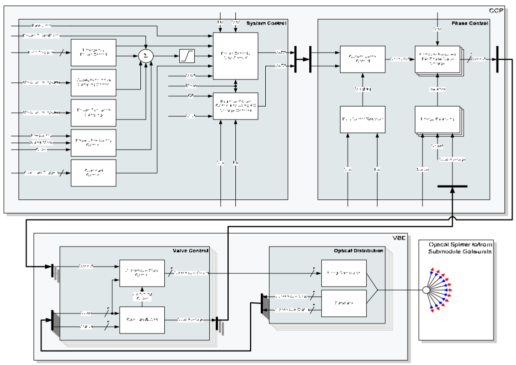
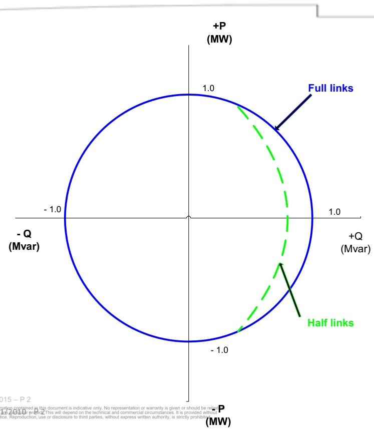


Figure 2 – Converter Control System Block Diagram

P/Q Diagram



ALSTOM

Submarine power cable types

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Installed Power Rating(MW)/cable	660	200
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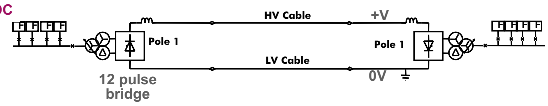
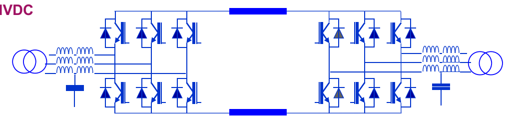
Monopole

- Monopole
  - Loss of link if one cable or one leg of converter goes out of service

LCC HVDC



VSC HVDC



+V and –V equates to "bipolar" operation to create sinewave at the AC side
It is not a BIPOLE

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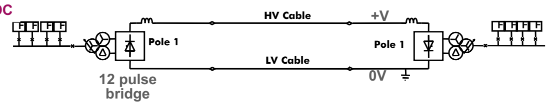
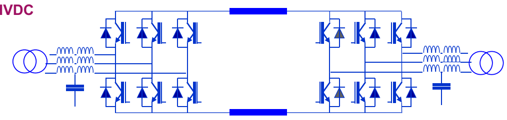
LCC HVDC



VSC HVDC



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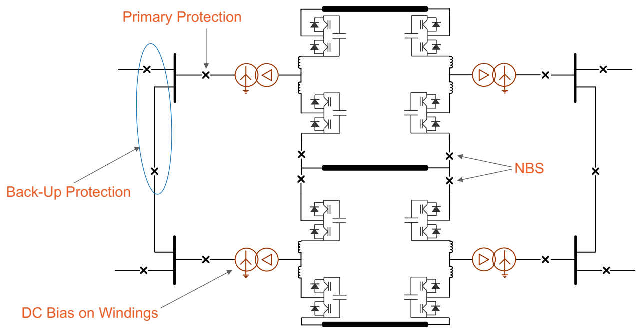
It is not a BIPOLE

Half-Bridge Bipole



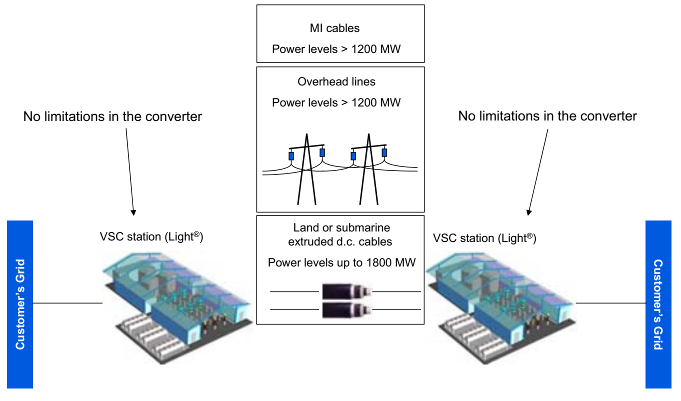
Peter Lundberg, Global Product Manager HVDC Light, 2015-02-12

HVDC Light Technology; PGCIL, Delhi
Basic Principles, System Aspects, Equipment & References

Agenda

- Basic principles
- System aspects
- SLD, Layout, Equipment
- Project references

Overview of VSC offerings
Transmission capacities**



**= for one system

VSC compared to CSC
Light compared to Classic

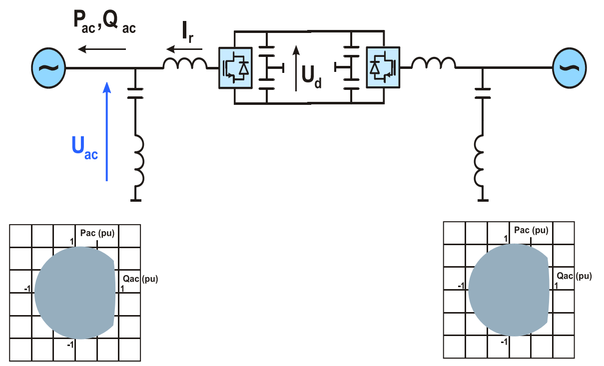
HVDC Classic - Current Source Converters (CSC)

- Line-commutated thyristor valves
- Requires 50% reactive compensation (35% HF)
- Converter transformers exposed to DC
- Minimum short circuit capacity ~2x converter rating
- Telecommunication between stations for best performance
- Significant inherent short term overload capability
- Reversal of power requires polarity reversal of the DC voltage (takes time)

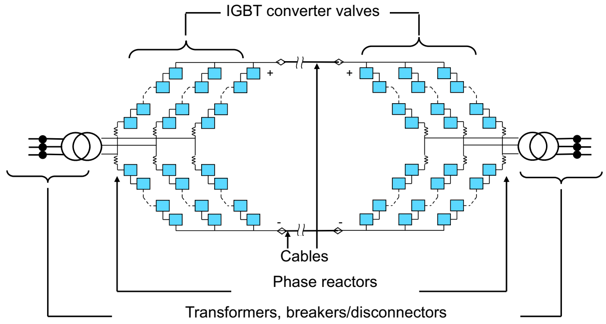
HVDC Light - Voltage Source Converters (VSC)

- Self-commutated IGBT valves allows for independent control of P and Q
- Compact design due to a minimum of filters and reactive compensation
- Standard transformers
- No limitation in short circuit capacity (black start possibility)
- No telecommunication required for normal operation
- No inherent overload capability
- Reversal of power can be made instantaneous by current reversal

Control of active and reactive power

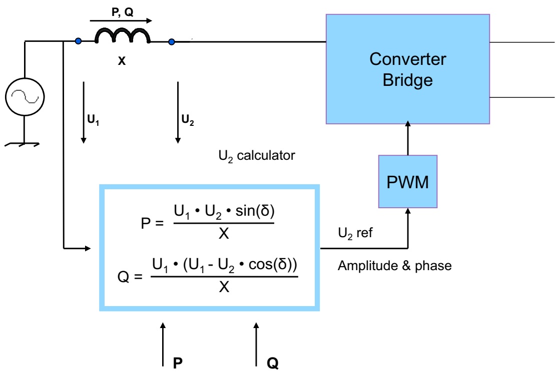


HVDC Light – Building blocks



Main-circuit diagram

Active and reactive power control



Control functions

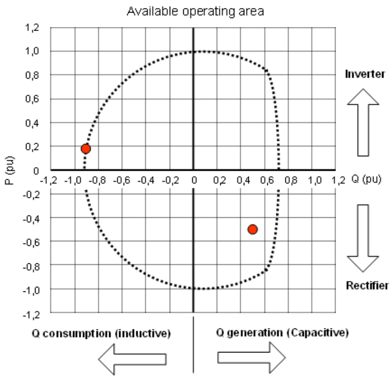
Basic controls

- Active power control
- DC voltage control
- Reactive power control
- AC voltage control

High level controls

- Frequency control
- Damping control
- Emergency power control

PQ-diagram



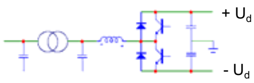
PQ limiting conditions

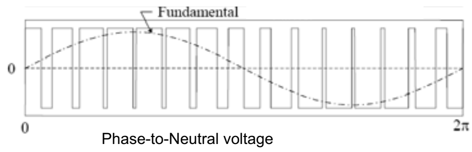
- Valve current
- Modulation index
- AC and DC voltage
- DC cable rating
- Cell voltage

Converter bridge technology - Historical review
1997 - 2001

Two-level converter

- Converter losses 3 %
- High switching frequency
- Filters required



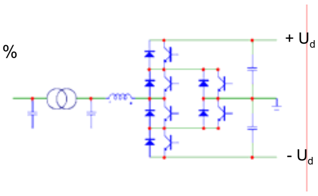


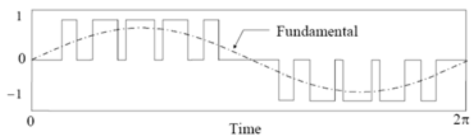
Phase-to-Neutral voltage

Converter bridge technology - Historical review
2002 - 2004

Three-level converter

- Converter losses 1.7 %
- Reduced switching frequency
- Less harmonics



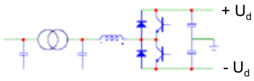


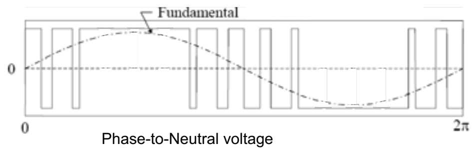
Phase-to-Neutral voltage

Converter bridge technology - Historical review
2005 - 2009

Two-level converter

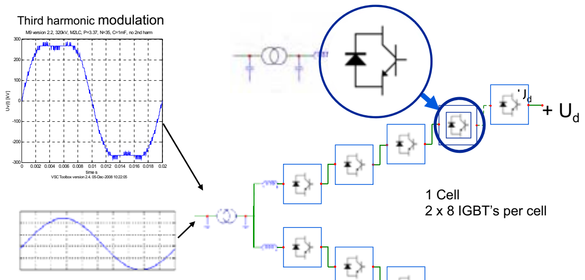
- Converter losses 1.7 %
- Optimized switching pattern
- Maintained harmonic generation





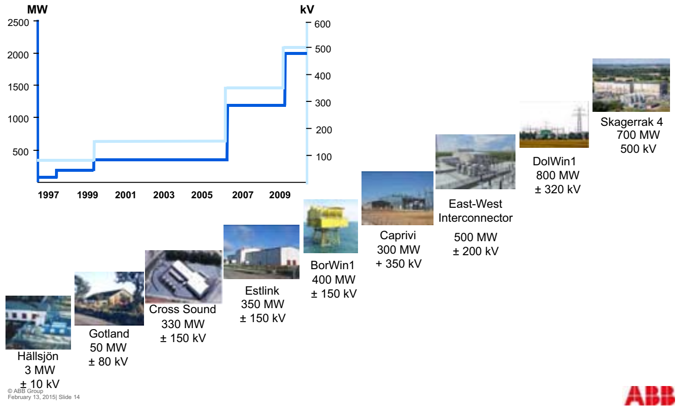
Phase-to-Neutral voltage

Converter bridge technology - Historical review
Cascaded Two-Level Converters, 2009 -

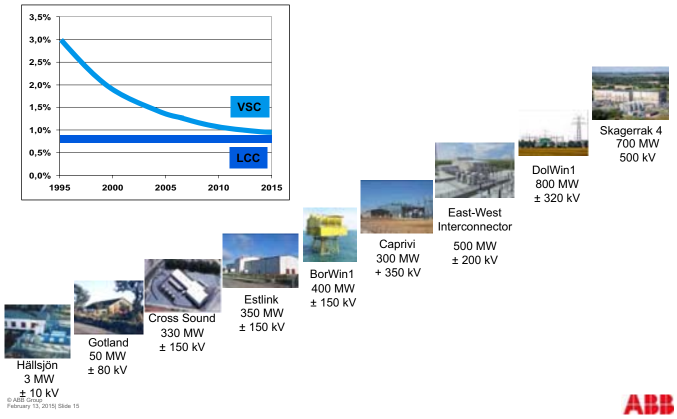


- Significantly reduced switching losses
- Excellent output voltage quality
- Scalable to high voltages

HVDC Light
Technical development

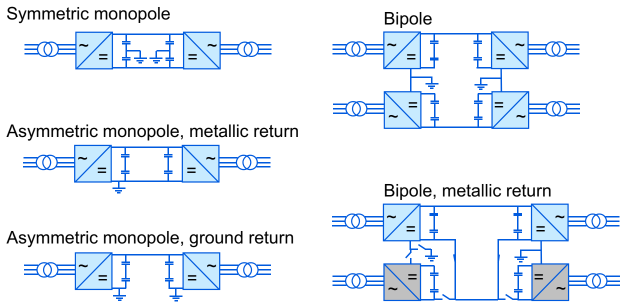


HVDC Light
Technical development



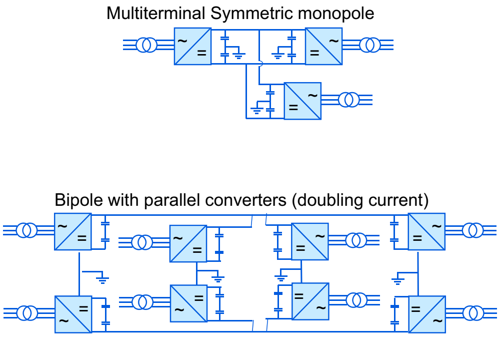
ABB

HVDC system configuration
System layout



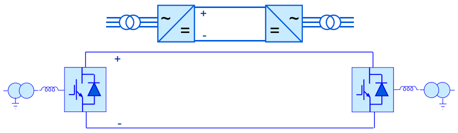
ABB

HVDC system configuration
System layout



ABB

Two-terminal configurations
Symmetric monopole



	580 A_{AC}	1140 A_{AC}	1740 A_{AC}
+/- 80 kV_{DC}	100 MVA	200 MVA	300 MVA
+/- 150 kV_{DC}	190 MVA	370 MVA	540 MVA
+/- 320 kV_{DC}	400 MVA	790 MVA	1210 MVA
+/- 500 kV_{DC}	625 MVA	1220 MVA	1850 MVA

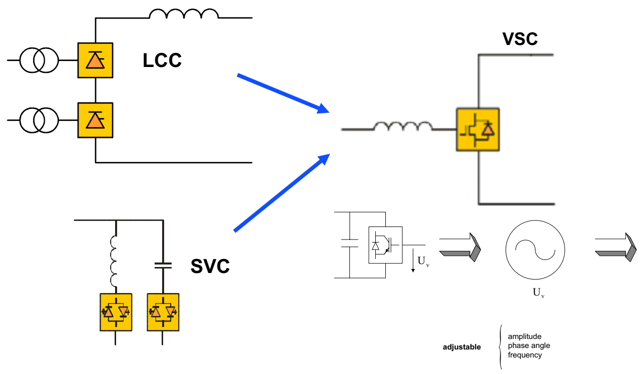
ABB

Agenda

- Basic principles
- System aspects
- SLD, Layout, Equipment
- Project references

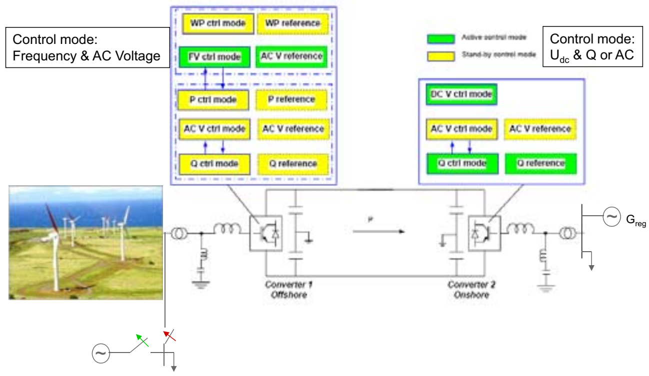
ABB

Merge of two technologies
LCC + SVC = VSC

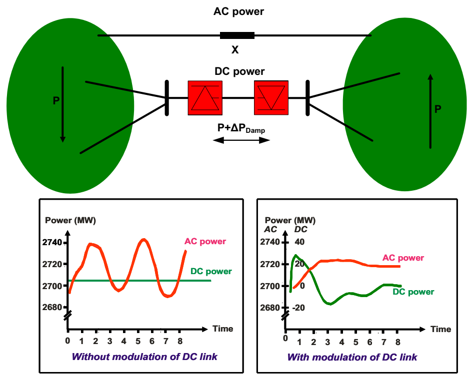


ABB

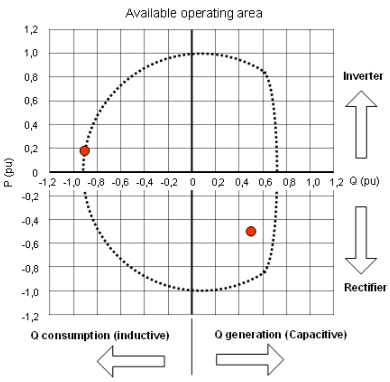
VSC control for isolated wind plant
Wind connected converter acts like an infinite source



Performance and stability aspects
Damping control

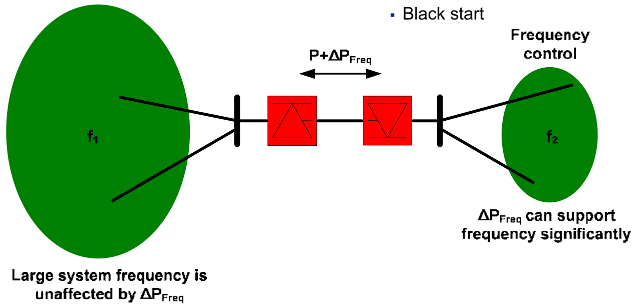


PQ-diagram

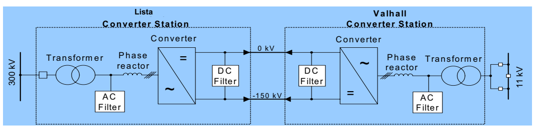


Performance and stability aspects
Frequency control

- Freqency control
- AC voltage control
  - Black start



Valhall



Description

- One HVDC Light station offshore and one station onshore
- 292 km HVDC cable

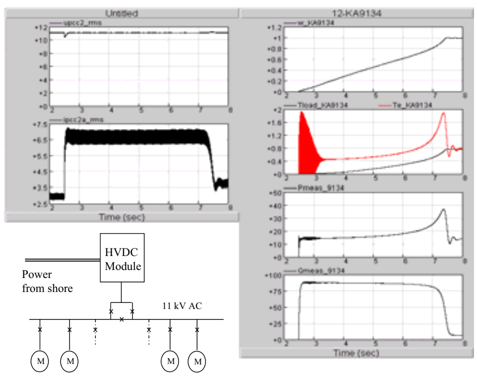
Main data

- P = 78 MW
- U_{DC} = 150 kV

Status

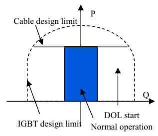
- Onshore station in operation as SVC to support AC grid with reactive power
- Offshore module built in UK
- Commercial operation 2010

Valhall Re-Development Project - Power from shore
Direct-on-line start of motor, 15 MW

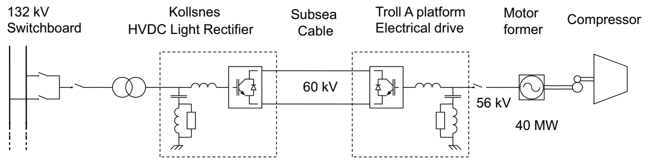


HVDC Light enables

- Control of Valhall AC voltage & frequency
- Direct On Line start of large asynchronous machines
- Ride Through mainland AC system disturbances
- Onshore AC voltage support

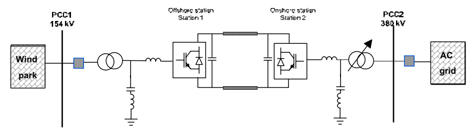


Troll A EDS, System overview

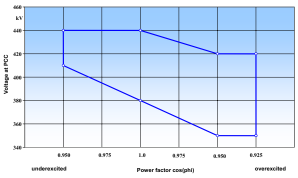


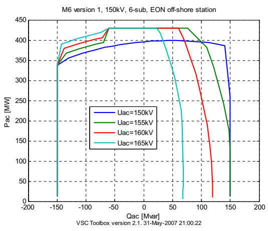
Grid code compliance

Windfarm	HVDC	Windfarm	HVDC
P/Q capability AC voltage support Droop characteristic Fault ride through Fault current contribution Harmonics / Flicker	P/Q capability Frequency control AC voltage control Fault ride through Fault current contribution Harmonics / Flicker	P capability P control Active power support – Emergency power – Runback – Power modulation	Q capability AC voltage support – Droop characteristic – Fault ride through – DC chopper action Fault current contribution Harmonics / Flicker Active power support – Frequency variation

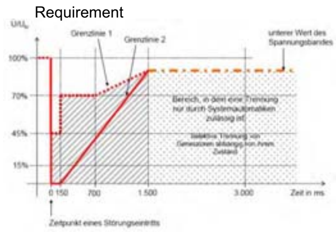


Main Circuit – PQ capability charts
Requirement





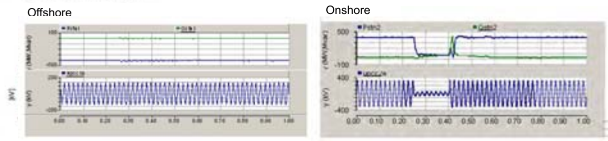
Dynamic behavior



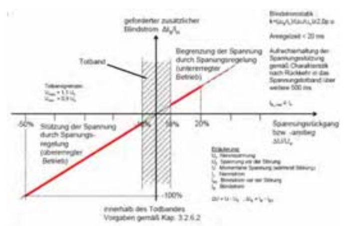
- Symmetrical and unsymmetrical faults at PCC
- Remaining voltage (highest phase) / Fault Duration

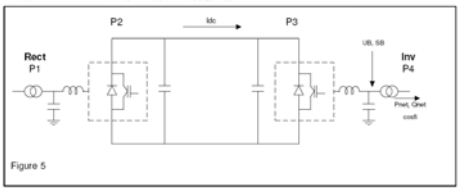
Remaining voltage (highest phase)	Fault Duration
~ 15%	150 ms
~ 50%	150 ms
~ 50%	350 ms
~ 75%	150 ms
~ 80%	700 ms
~ 85%	5 s

- Power ramp: 10% / 20% of nominal power

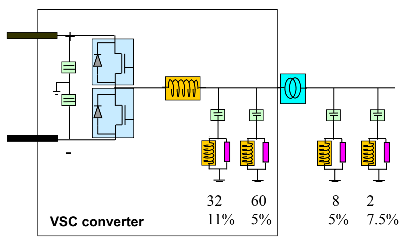


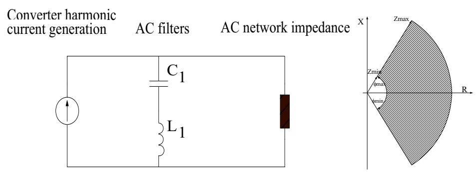
Reactive current / AC voltage support
Requirement





Background harmonic filters





Agenda

- Basic principles
- System aspects
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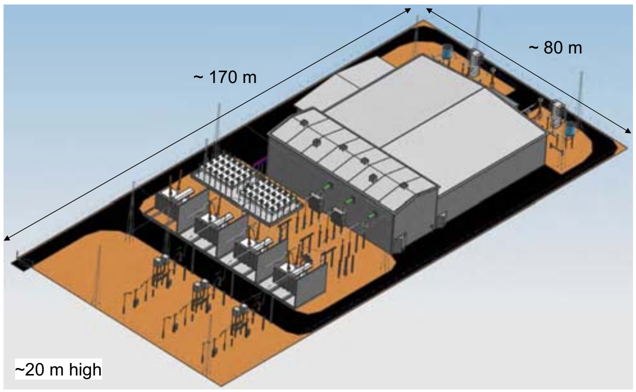
Typical converter layout
1000 MW

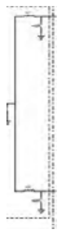


Power transformer

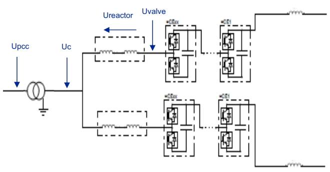
- Conventional single or three phase transformer
- Tap changer location: optimized according to the project
- Y/y/d winding configuration
- Tertiary D for black-start
- No DC component
- Practically no harmonic currents
- Arrester on neutral valve side for voltage limitation at converter bus fault
- Some low order zero sequence harmonic voltage (3rd harmonic) in the arrester (less than 0.2 p.u.)

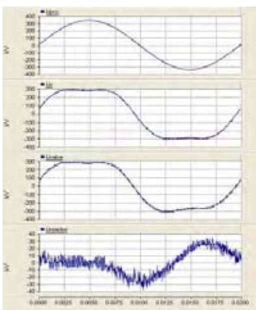
Converter reactor

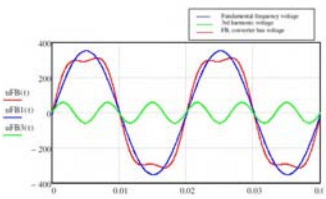
- Conventional air-insulated AC reactors in each valve arm
- Inductance 10-90mH
- Low losses



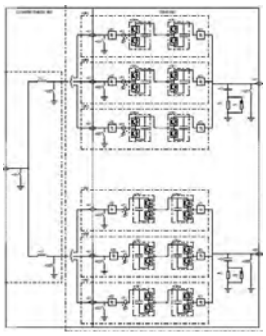
Voltages from AC side to converter reactor







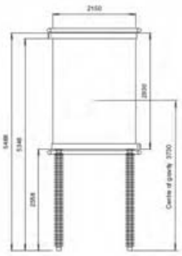
Wall bushings

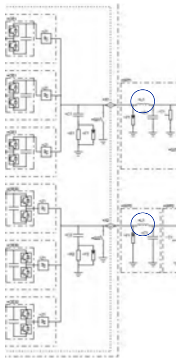


- Gas insulated bushings
- AC yard - converter reactor hall
- Converter reactor hall - valve hall

Smoothing reactor
DC side

- Typical inductance 10mH
- Requirements on losses
- Harmonics present

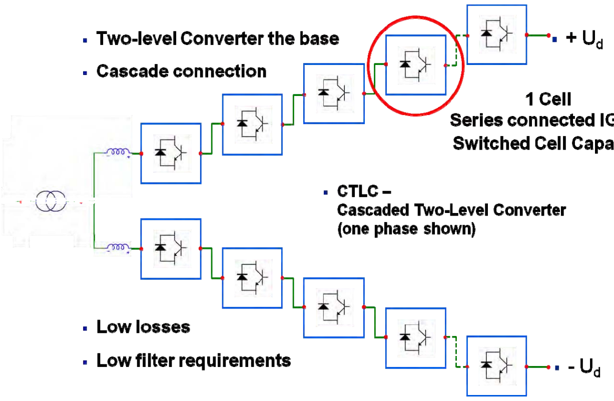




ABB

Valves for Light

- Two-level Converter the base
- Cascade connection

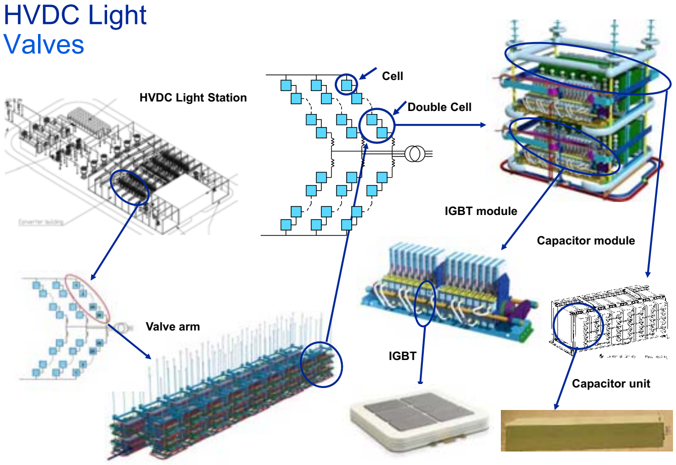


- CTLC –
  Cascaded Two-Level Converter
  (one phase shown)

- Low losses
- Low filter requirements

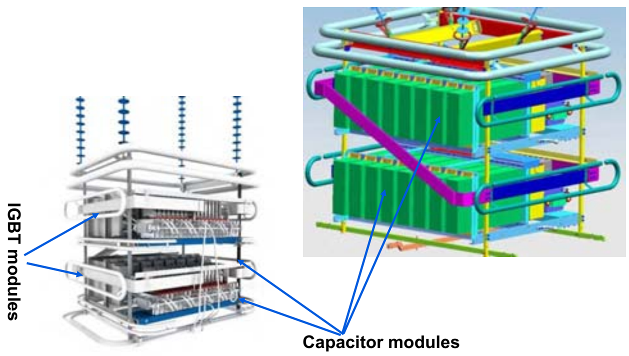
ABB

HVDC Light
Valves



ABB

Valves for Light
Double cell



ABB

Cell capacitor
Capacitor module

- Dry capacitor
- Metallized polypropylene
- Self healing
- Mechanical size optimized to the IGBT module
- Minimize of weight
- Design, rated and tested in accordance with IEC 61071
- Several possible suppliers

ABB

Agenda

- Basic principles
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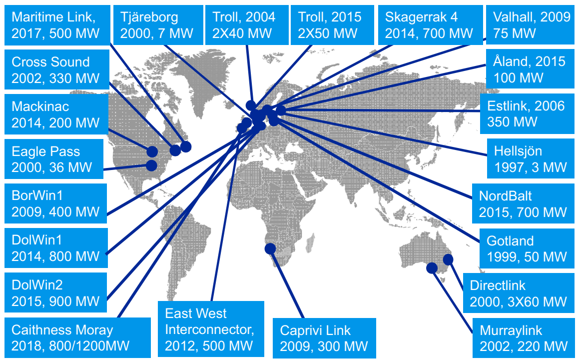
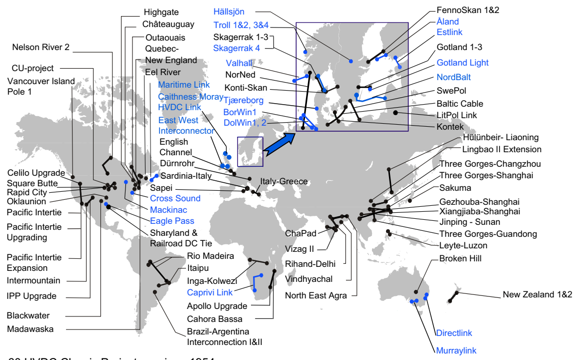
ABB

Project references
HVDC Light technology



ABB

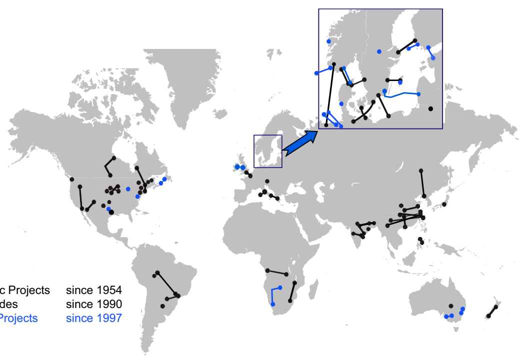
ABB has supplied to more than half of the 190 HVDC projects
The track record of a global leader



60 HVDC Classic Projects	since 1954
24 HVDC Upgrades	since 1990
21 HVDC Light Projects	since 1997

ABB

HVDC by ABB
Let our experience work for you



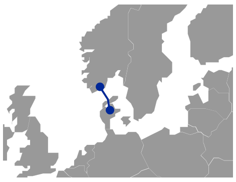
60 HVDC Classic Projects	since 1954
24 HVDC Upgrades	since 1990
21 HVDC Light Projects	since 1997

ABB

Skagerrak 4
Norway - Denmark

Customer:
Energinet.dk & Statnett

Year of commissioning:
2014



Customer's need

- Boost transmission capacity with 700 MW
- Use electricity more efficiently
- Enable networks to add more renewable energy

ABB's response

- Two 700 MW HVDC Light stations
- 500 kV – new voltage record for the HVDC Light technology

Customer's benefits

- Network stability
- Low losses and high reliability
- Quick grid restoration with black-start capability

ABB

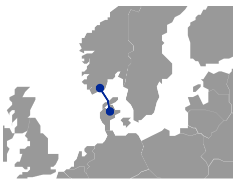
Skagerrak 4 - An excellent example
Benefits that can be achieved through interconnections

ABB

Skagerrak 4
Norway - Denmark

Customer:
Energinet.dk & Statnett

Year of commissioning:
2014



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Boost transmission capacity with 700 MW

Use electricity more efficiently

Enable networks to add more renewable energy

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Two 700 MW HVDC Light converter stations

500 kV – new voltage record for the HVDC Light technology

Customer's benefits

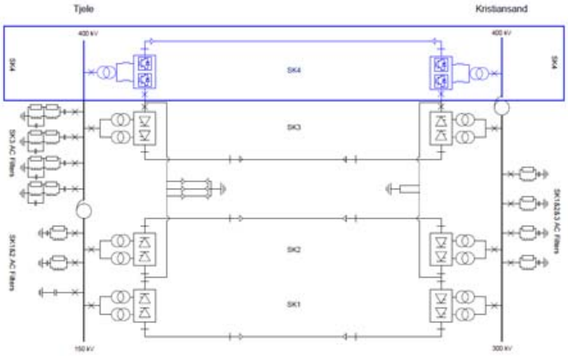
Network stability

Low losses and high reliability

Quick grid restoration with black-start capability

ABB

Skagerrak 1, 2, 3 & 4



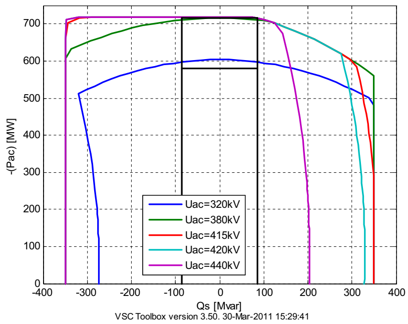
ABB

Skegerrak 4 – Technical Parameters

- Solution: Monopole, HVDC Light G 4
- Rated Power: 715 MW
- Rated voltage: 500 kV
- AC voltage: 420 kV, both sides
- Bipolar operation with Skagerrak 3
- Black start capability
- SVC operation
- Power reversal – 1000 times/year

ABB

Skagerrak 4 – PQ curve



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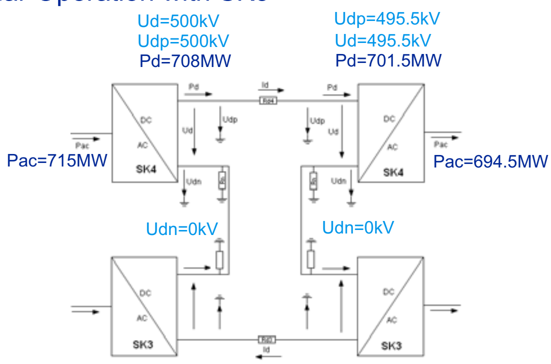
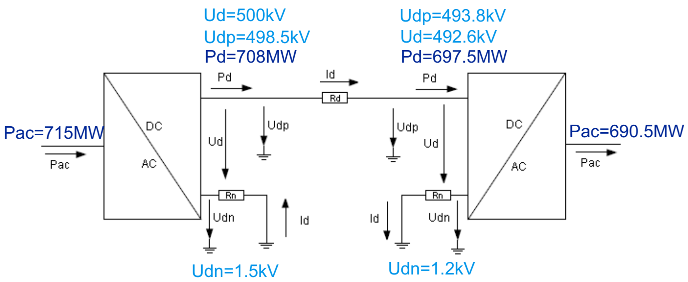
Bipolar Operation with SK3



Regulated Udn=0kV in both stations:
Highest inverter power
No neutral losses, only SK4 cable losses

ABB

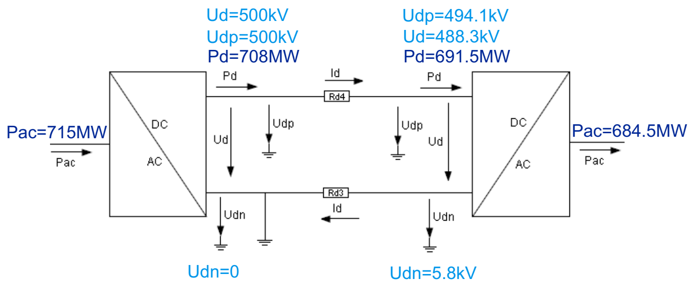
Ground Return



2nd highest inverter power
Low neutral losses

ABB

Metallic Return with SK3 cable



Lowest inverter power due to highest cable losses
High neutral voltage drop in ungrounded station

ABB

Technical solution
IGBT Valves

- Quadruple cell structure
- 6-sub IGBT, 4.5 kV

Skagerrak 4 - Transformer solution

- Design: Single phase, Y/Δ, solidly earthed neutral
- Rated Power 243 MVA
- Tap changer on the primary side

Skagerrak 4 – Converter Building

- Tjele Station

Skagerrak 4 – Transmission test

- Energization converter and cables
- Transmission test – both power directions
  - Active Power Control
  - Reactive Power Control
- Heat Run test
- Black Start
- Joint Reactive Power Control
- Joint Active Power Reversal Sequence
- Frequency Control Test

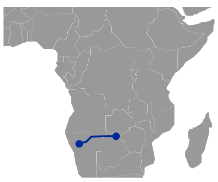
Skagerrak 4
Achievements

- Worlds first 500 kV HVDC Light in operation
- Worlds first combined HVDC Light and HVDC Classic

Caprivi Link Interconnector
Namibia

Customer: NamPower

Year of commissioning: 2010



Customer's need

- Connect the grid in the north west with the grid in the central parts of the country

ABB's response

- Turnkey 350 kV 300 MW HVDC Light®
- Option for another 300 MW
- First HVDC Light® with overhead lines

Customer's benefits

- Stability in two very weak AC networks

Maritime Link
Canada

Customer:
NSP Maritime Link
(Emera)

Commissioning year:
2017

Customer's need
- Integrate renewable generation into the the North American grid

ABB's response
- Bipole HVDC Light solution
- Two 500 MW HVDC Light stations
- Two AC substations at 230 kV
- One AC substation at 345 kV

Customer's benefits
- Improved grid stability
- Power sharing enabled

ABB

Caithness Moray HVDC link
Scotland

Customer:
Scottish Hydro Electric
Transmission Ltd (SHET

Commissioning year:
2018

Customer's need
- Strengthening power network

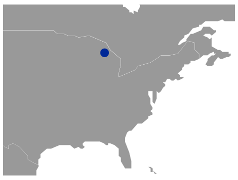
ABB's response
- Two HVDC Light converter stations, 1,200 MW and 800 MW
- Submarine and underground cable transmission of nearly 160 kilometers

Customer's benefits
- Enable integration of renewable energy

ABB

Mackinac
USA

Customer: ATC
Year of commissioning: 2014



Mackinac back-to-back station

Customer's need
- Power flow control and allow for integration of additional renewable energy in the State of Michigan

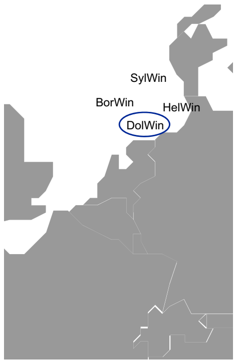
ABB's response
- Turnkey 200 MW HVDC Light® back-to-back station

Customer's benefits
- Enhanced network stability
- Islanded operation possible
- Black-start – restarting the grid after a black-out
- Automatic power reduction at disturbances

ABB

DolWin2
Germany

Customer: TenneT
Year of commissioning:
2015



Customer's need
- 135 km long subsea and underground power connection
- Robust grid connection

ABB's response
- Turnkey 900 MW HVDC Light system
- ± 320 kV extruded cable delivery

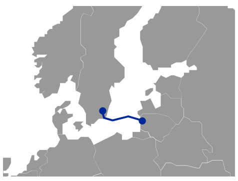
Customer's benefits
- Environmentally sound power transport
- Low losses and high reliability
- Reduce CO_2-emissions by 3 million tons per year by replacing fossil-fuel generation
- Grid connection 90 km inland

ABB

NordBalt
Lithuania - Sweden

Customers:
Svenska Kraftnät and LITGRID turtas

Year of commissioning:
2015



Customer's need
- Strengthen security of supply in Baltic region and southern Sweden
- Integrate electricity markets of the Baltic and Nordic countries

ABB's response
- Turnkey 700 MW HVDC Light system
- Designed for integration into a future pan-European DC grid

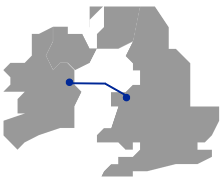
Customer's benefits
- Low losses and high reliability
- Network stability through active AC voltage support
- Quick grid restoration with black-start capability

ABB

East West Interconnector
Ireland – Wales, UK

Customer: EirGrid

Year of commissioning:
2012



Customer's need
- Connect the grids of Ireland and Wales to enable power trade

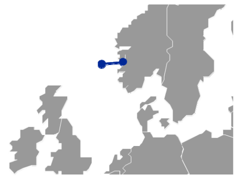
ABB's response
- Turnkey 500 MW HVDC Light®
- 186 km sea cable + 70 km land cable
- First HVDC Light® with ±200 kV cables

Customer's benefits
- Security of supply
- "Black start"
- Active AC voltage support

ABB

Troll A 3&4
Norway

Customer: Statoil
Year of commissioning: 2015



Customer's need
- Enable power supply from mainland to platform to minimize emission of large amounts of CO2 and unnecessarily high fuel consumption

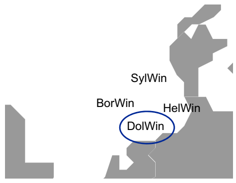
ABB's response
- Turnkey 2x50 MW ±66 kV HVDC Light® offshore transmission system
- DC sea cables
- VHF (Very high frequency) motors

Customer's benefits
- Lower CO2 emissions
- Better and safer work environment on platform

ABB

DolWin1
Germany

Customer: TenneT
Year of commissioning: 2013



Customer's need
- 165 km long subsea and underground power connection
- Robust grid connection

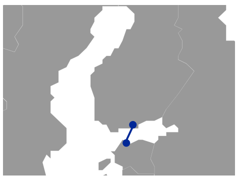
ABB's response
- Turnkey 800 MW HVDC Light system
- First ± 320 kV extruded cable delivery

Customer's benefits
- Environmentally sound power transport
- Low losses and high reliability
- Reduce CO_2 emissions by 3 million tons per year by replacing fossil-fuel generation
- Supports wind power development in Germany

ABB

Estlink HVDC Light®
Finland - Estonia

Customer: Nordic Energy Link AS
Year of commissioning: 2006



Customer's need
- Create a common open electricity market in the enlarged European Union

ABB's response
- Turnkey 350 MW HVDC Light® transmission system

Customer's benefits
- Environmentally adapted to sensitive coastal region by compact converters and totally under sea/ground system
- Increased security of supply and loss reduction in existing network through voltage and VAR control
- Delivery time: 19 months!

ABB

SIEMENS

Transmission Solutions

HVDC – Technology, Benefits, Applications
Workshop Powergrid of India, January 23, 2015

siemens.com/energy/power-transmission-solutions

SIEMENS

Agenda

- Design aspects and system configuration HVDC Classic 800 kV, 6000 MW
- VSC HVDC concept and principles
- VSC Configurations Options for VSC HVDC configurations for 2x1000MW, 200KM (overhead line and cable)
- Selection of voltage for 2x1000 MW VSC, 200 KM HVDC link.
- VSC HVDC layout
- Type of cables for the proposed VSC
- Type of transformer and reactor for VSC HVDC
- Past experience on VSC HVDC project

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Project Requirements: Raigarh-Pugalur

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- Nominal Voltage: ±800 kV
- Nominal Power Rating 6000MW
- Overload Requirement: 33% at 50° C ambient temperature
-

Decision Criteria for Converter Arrangements

SIEMENS

- Transport restrictions of large equipment: Profile, weight (e.g. transformers)
  -> possible mitigation measures available
- Available electrical equipment, e.g. power ratings
  -> cost aspect, need of additional R&D
- Demand of footprint
- RAM: Reliability, Availability and Maintainability
- Installation & commissioning time
- Costs (invest + operation)

Principle of HVDC

Bipolar Converter Arrangements

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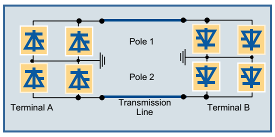
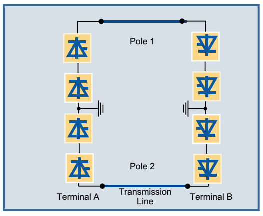
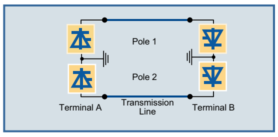
- Parallel 12-Pulse Bridges



- Series Connected 12-Pulse Bridges



- Single 12-Pulse Bridge



UHV DC Topologies

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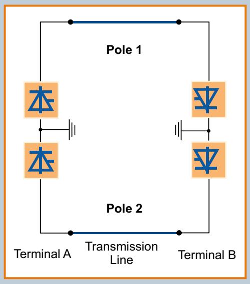
One 12-Pulse Groups per pole

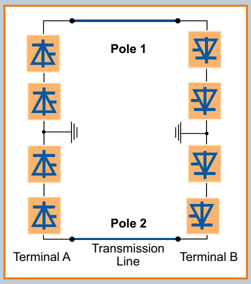


- Suitable for bulk power transmission, up to around 6 000 MW at ± 800 kV (limited by transformer transportation weight). Preferred solution for all lower transmission voltage levels
- Lowest cost, lowest complexity and lowest space requirements, fastest installation&commissioning
- Proven design from most Long-Distance HVDC Systems

UHV DC Topologies

SIEMENS

Two 12-Pulse Groups per pole

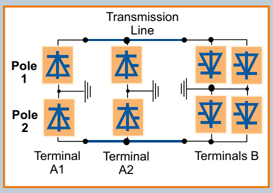


- Suitable for bulk power transmission in case of transport limitations
- Transport limitations may make it necessary to divide the total transformer rating on four six-pulse groups per pole
- Bypass switchgear allows flexible configuration and increases power availability
- Additional valve group level controls

UHV DC Topologies

SIEMENS

Parallel 12-Pulse Groups per pole



- Multi-terminal configuration
- Bulk power transmission suitable for geographically distributed generation / load centers
- Paralleling switches allow to connect&disconnect poles
- Additional control & protection requirements for multi-terminal operation

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Comparison of Alternatives

	2 x 12p series	2 x 12p parallel	single 12p
Possible transport limitations	0	0	-
Availability	(+)	(+)	0
Reliability	0	0	+
Footprint Demand	-	--	+
Line Losses	(0)	+	+
Operation Complexity	-	-	+
Maintenance Flexibility	+	+	0
Costs	-	--	+
Installation&commissioning	-	-	+

- disadvantage
0 neutral
+ advantage

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Parallel Converters increase scope & complexity

Impacts:

- Valves: doubled number (depending on available thyristor power ratings)
- Transformers: same installed power but higher number of tanks
- Buildings : double number of valve halls, larger control building, DC yard (if applicable)
- C&P: double number of dc control cubicles plus modified master control (station)
- Auxilliary equipment: double number

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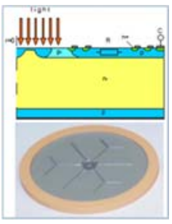
6“ Direct Light-Triggered Thyristor



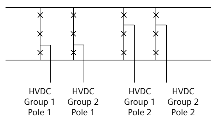
Combines high power rating of 6" ETT with advantages of LTT technology:
Blocking Voltage 8.5 kV
Improved current ratings up to 6.25 kA possible
Current of 5 kA at 50 ° C ambient temperature feasible

SIEMENS

6000MW Bipole: Single Bipole Design

Draft Design 800kV, 6000 MW:

- Transformer ratings: 1ph 2winding, approx. 598 MVA (nominal)
  dimensions: approx. 13 m x 5 m x 5 m
- DC Current 3.75 kA (5 kA overload)
  -> DC equipment available as thyristor valves, disconectors, MRTB, DC bushings
- AC Busbar arrangement for 1 ½ breaker scheme allows equipment with 4kA rating



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Questions on Raigarh-Pugalur

- Location of sites? Altitude?
- Transport limitations?

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Agenda

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Basics of HVDC PLUS
Comparison HVDC Classic – HVDC PLUS

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

HVDC Classic:
- Direct-light-triggered Thyristor (LTT)
- Up to 10000 MW
- MI Cable up to 600 kV
- OHL up to 800 kV

Western Link	2,200 MW
China projects	8,000 MW

HVDC PLUS:
- XPLE Cable up to 320 kV DC
- Half bridge up to 1,56 kA
- Full bridge up to 2 kA

Trans Bay Cable	400 MW
5 x TenneT Offshore	576 – 900 MW
INELFE	2 x 1,000 MW

Basics of HVDC PLUS
Siemens, a Leader in VSC Technology since its early Beginning

SIEMENS

History - FACTS & Voltage-Sourced Converters

1974	1st SVCs, Nebraska, USA, GE & 1975, Minnesota, Westinghouse 1)
1985	1st EHV FACTS (500 kV NGH, SSR-Damping), California, Siemens
1992	1st TCSC (for Load-Flow Control), Kayenta, Siemens
1995	1st STATCOM, Sullivan, USA, Westinghouse 1)
1998	1st UPFC, Inez, USA, Westinghouse 1)
2001	Worlds largest SFC (Static Frequency Converter), Richmond, USA, Siemens
2001/03	1st CSC (Convertible Static Compensator), Marcy, USA, Siemens

SVC PLUS & HVDC PLUS – Modular Multilevel Converters (MMC)

2009	SVC PLUS @ Thanet, UK, Siemens
2010	HVDC PLUS @ Trans Bay Cable, San Francisco, USA, Siemens

1) Now Siemens

Basics of HVDC PLUS
The Evolution of HVDC PLUS and VSC Technology

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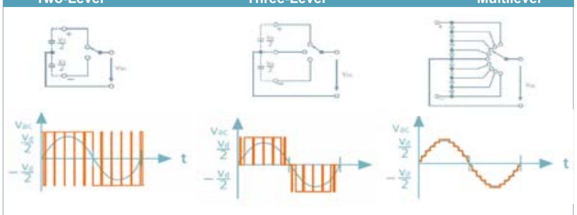
Topology of VSC

Two-Level | Three-Level | Multilevel



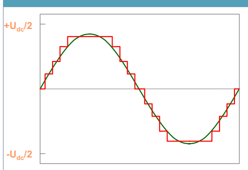
Power Electronic Devices

GTO /IGCT | IGBT in PP | IGBT Module

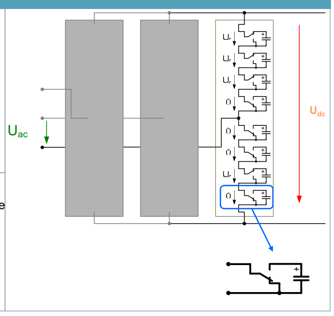
Basics of HVDC PLUS
Modular Multilevel Converter - MMC

SIEMENS

Examples Half Bridge



- Low level of harmonics and HF noise
- Low switching losses
- Modular arrangement with identical two-terminal power modules



Basics of HVDC PLUS
General Features of VSC Technology

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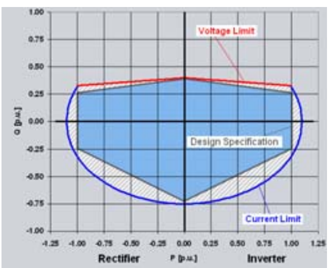
Features and Benefits

- Grid Access of weak AC Networks
- Independent Control of Active and Reactive power
- Supply of passive Networks and Black Start Capability
- High dynamic Performance
- Low Space Requirements



Basics of HVDC PLUS
Features and Benefits of MMC Topology

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Features	Benefits
High Modularity in Hardware and Software	High Flexibility, economical from low to high Power Ratings
Low Generation of Harmonics	Only small or even no Filters required
Low Switching Frequency of Semiconductors	Low Converter Losses
Use of well-proven Standard Components	High Availability of State-of-the-Art Components
Sinus shaped AC Voltage Waveforms	Use of standard AC Transformers
Easy Scalability	Low Engineering Efforts, Power Range up to 1000 MW
Reduced Number of Primary Components	High Reliability, low Maintenance Requirements
Low Rate of Rise of Currents even during Faults	Robust System

Comparison of Features of HVDC Technologies

SIEMENS

Characteristics	HVDC Classic (LCC Technology)	HVDC PLUS (VSC Technolgy)
Rating	up to 10 GW per bipole at ±800kV	up to 2 GW per bipole at ±500kV
Overload Capacity	Thyristor - very high	IGBT strictly limited
Total Converter & Station Losses	≤ 1.5 %	close to 2 % (half-bridge)
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 and flexible
Grid Access for weak AC Networks	Limited – Improvement possible with additional installation of STATCOMs or Synchronous Condensers (SCO)	Yes
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

Basics of HVDC PLUS
Station Design

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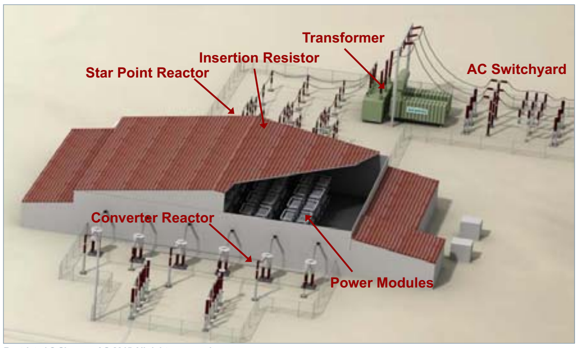

Basics of HVDC PLUS
Key Components

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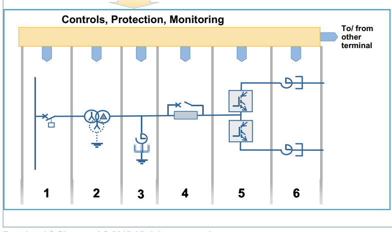
Example: Symmetrical Monopole



1. AC Switchyard
2. Transformers
3. Star Point Reactor
4. Insertion Resistor
5. Power Modules
6. Converter Reactor

Basics of HVDC PLUS
Key Components of a Bipolar HVDC Converter Station

SIEMENS

Tasks of Equipment

- **AC Switchyard (1)**
  - Connect the terminal to the AC system
- **Transformers (2)**
  - Obtain the AC voltage needed for the required DC voltage
  - Optional 3rd winding for auxiliary system In feed
- **Star Point Reactor (3)**
  - Ensuring symmetrical voltages during steady static conditions
- **Insertion Resistor (4)**
  - Charging of DC circuit decoupled from converter deblocking
- **Power Modules (5)**
  - Modular Multilevel Conversion

Basics of HVDC PLUS
Key Components of a Bipolar HVDC Converter Station

SIEMENS

Tasks of Equipment

- **Converter Reactor (6)**
  - Damp balancing currents between different phases
  - Limit current gradients during severe faults
- **Control and Protection System (7)**
  - Controlling the system and ensuring stable operation
  - Protecting main equipment
- **Auxiliary Systems (8)**
  - Valve Cooling
  - HVAC Systems
  - Station Service Supply
- **HVDC Transmission Line (9)**
  - DC Overhead Transmission Line
  - DC Cable System

Basics of HVDC PLUS
AC Switchyard (1)

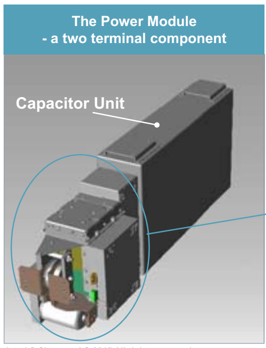
SIEMENS

Basics of HVDC PLUS
Transformers (2) - Conventional Transformers

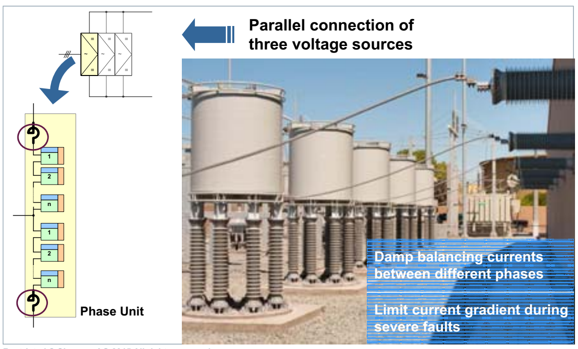
Basics of HVDC PLUS
Star Point Reactor (3)

Basics of HVDC PLUS
Insertion Resistor (4)

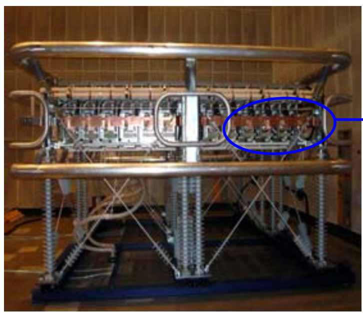
Basics of HVDC PLUS
Power Module (5) - Modular Design

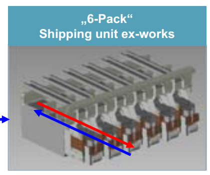


Basics of HVDC PLUS
Converter Reactors (6)



Basics of HVDC PLUS
Power Module (5) - Modular Converter Design





Replacement of single Power Modules

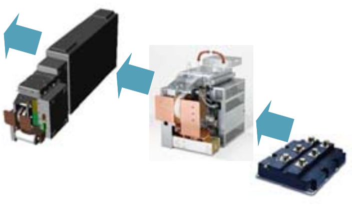
Double Tower with:

- 3 Floors (72 Power Modules)
- 4 Floors (96 Power Modules)
- Defined internal Voltage Stress
- Compact Installation

Basics of HVDC PLUS
Power Module (5)

SIEMENS

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



Basics of HVDC PLUS
Options for Converter Modules and Building Arrangements

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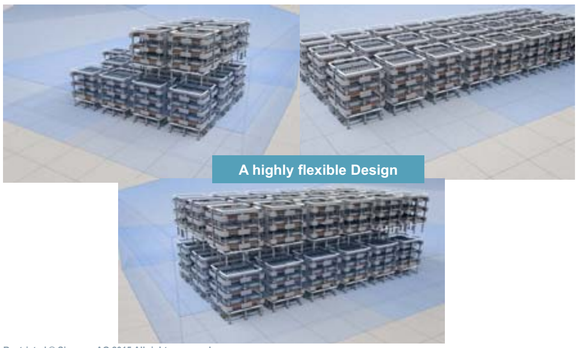

Basics of HVDC PLUS
Power Module (5) - Converter Hall: Example

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Basics of HVDC PLUS
Control and Protection (7)

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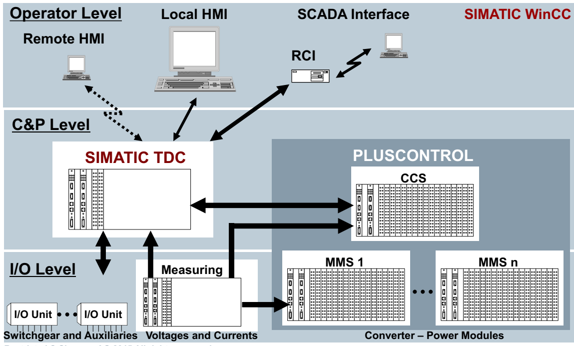

Basics of HVDC PLUS
Auxiliary System (8)

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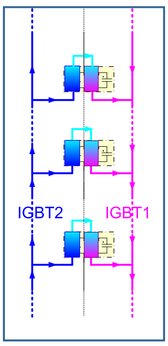

Cooling Concept:

Parallel Cooling of ALL Power modules:

- Identical operating Conditions for all Power modules (Aging of IGBTs)
- Long term proven concept of HVDC classic
  Stricter requirements of IGBTs compared to Thyristors (Heat Capacitance Chips, Wire Bonds)

Within each Power Module:

- Best cooling of IGBT2 with ~25K higher thermal stress
  Cooling plates designed for single IGBT (water flow)

Cooling at IGBT with pure deionized water:

- High heat capacitance, thus lower flow (typ. 20% reduction by Glykol)

VSC Converter Operation

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- Converter Operation Principles
-

Advantages and Benefits of Siemens HVDC PLUS Technology

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States of Submodules

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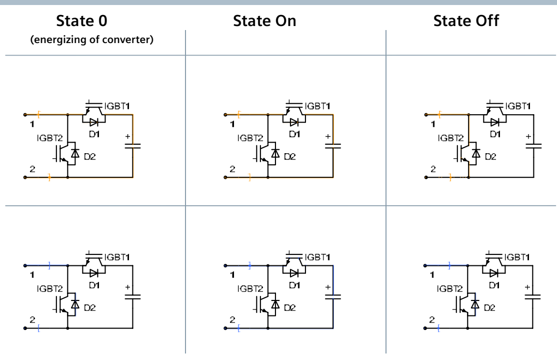

MMC – perfect Voltage Generation

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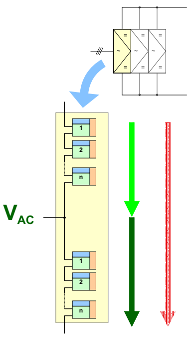
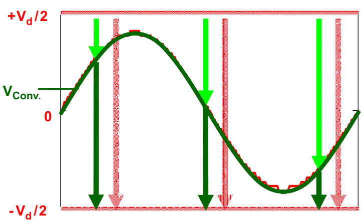
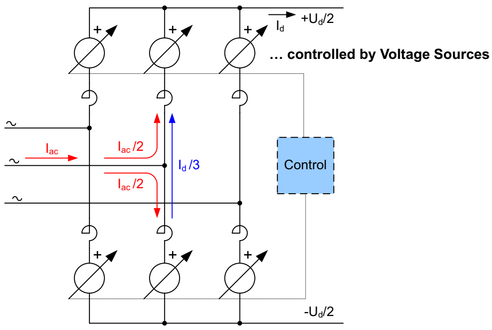


AC and **DC** Voltages controlled by Converter Module Voltages:



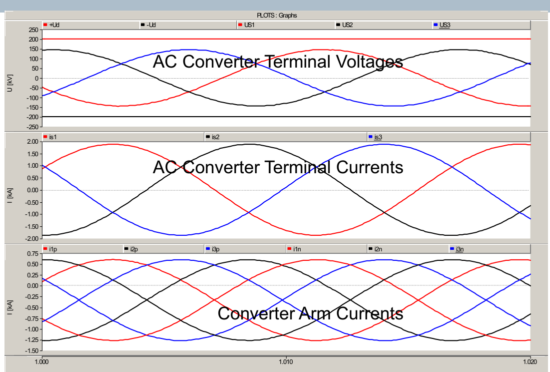
MMC – AC & DC Converter Currents ...

SIEMENS



Simulation Results: 400 MW with about 200 Submodules per Converter Leg

SIEMENS



Complete Converter

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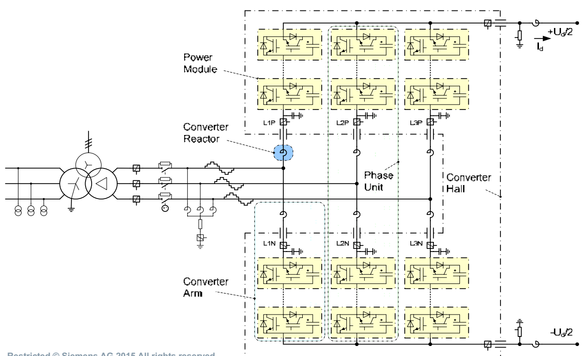

Power Electronics Module - Redundancy

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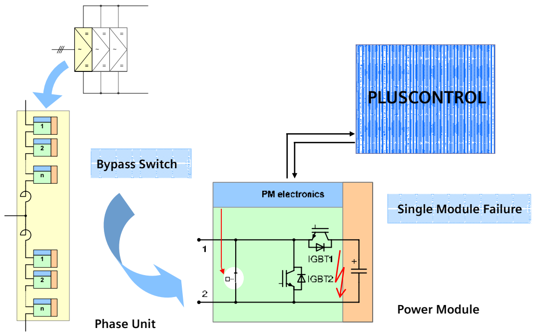

Line-to-Line DC Fault

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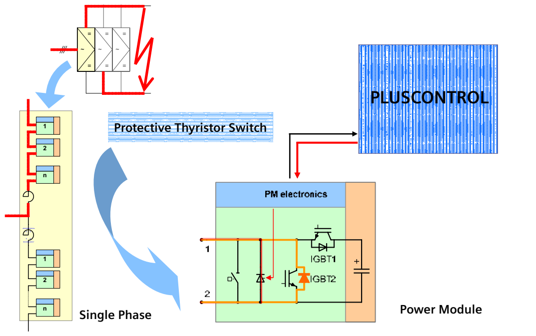
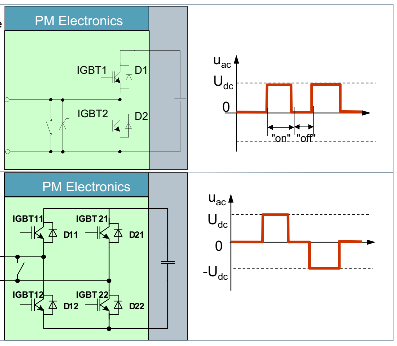


New Applications
Comparison of Hall and Full Bridge Power Modules

SIEMENS

- 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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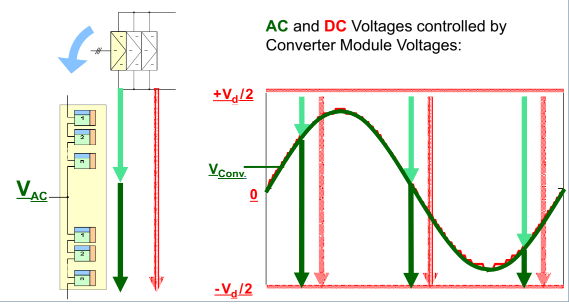
The DC voltage is always higher than the AC voltage

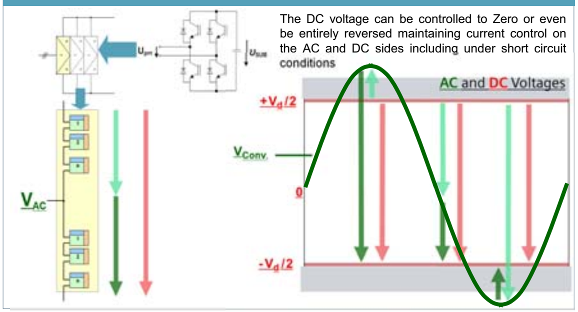


New Applications
MMC Full Bridge

SIEMENS

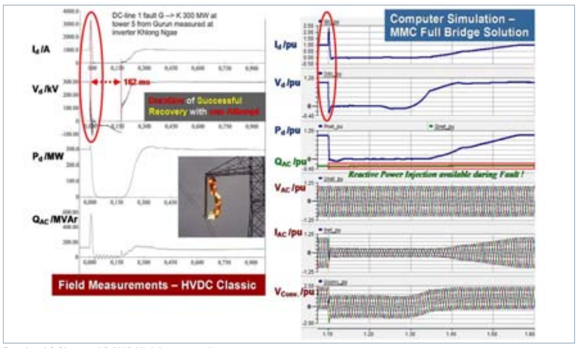
The DC voltage is independent from the AC voltage

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
Fast DC Line Fault Clearing – the key for System Stability

SIEMENS



New Applications
Full Bridge

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Full Bridge Converters - Most Powerful and Flexible Solutions for Transmission

Main Features

Inherent DC turn-off capability

Independent DC Voltage control for

- Load flow control in extended DC Grids
- DC fault current control
- Unlimited number of fast and smooth DC Voltage recoveries after faults

Broad experience in
85 Industrial and Energy applications in operation or in project execution (April 2013)

(static frequency conversion for traction power supply and reactive power compensation)

Full Bridge MMC as used for power frequency conversion and reactive power compensation in Industry and Energy applications

HVDC PLUS – Converter Topology
DC Line Fault with Grounded Half-bridge

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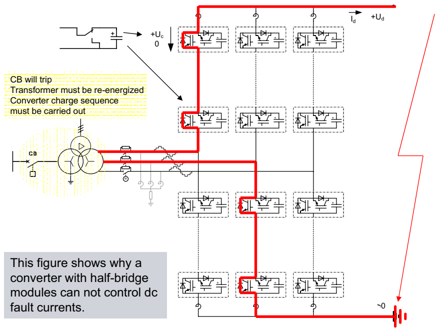
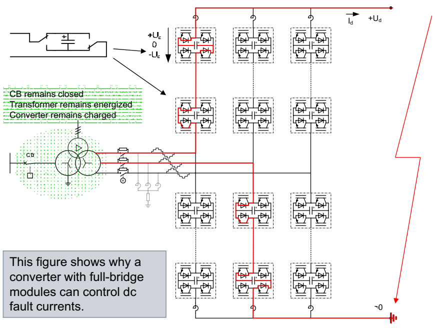


This figure shows why a converter with half-bridge modules can not control dc fault currents.

HVDC PLUS – Converter Topology
DC Line Fault with Grounded Full-bridge

SIEMENS



This figure shows why a converter with full-bridge modules can control dc fault currents.

HVDC PLUS – Converter Topology
AC Converter Terminal Fault with Grounded Half-bridge

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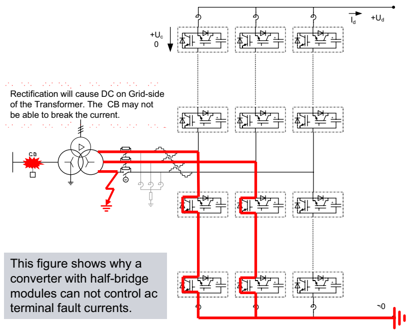

This figure shows why a converter with half-bridge modules can not control ac terminal fault currents.

HVDC PLUS – Converter Topology
AC Converter Terminal Fault with Grounded Full-bridge

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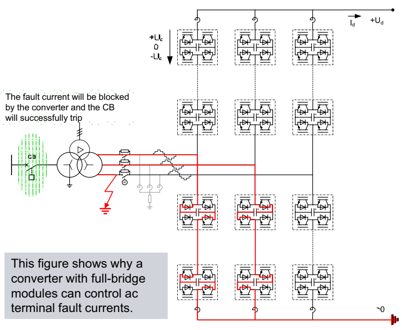

This figure shows why a converter with full-bridge modules can control ac terminal fault currents.

MMC – Full-Bridge Equivalent Circuit

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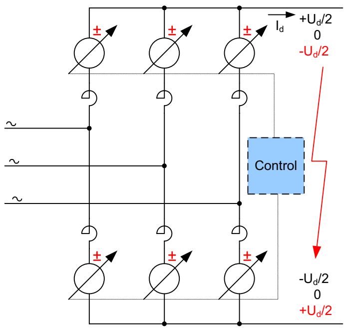

Existing Application with Full-Bridge SVC PLUS

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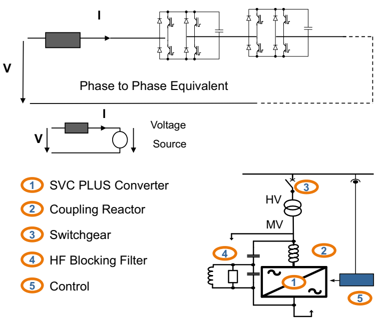

1. SVC PLUS Converter
2. Coupling Reactor
3. Switchgear
4. HF Blocking Filter
5. Control

SVC PLUS in Detail
Insight view

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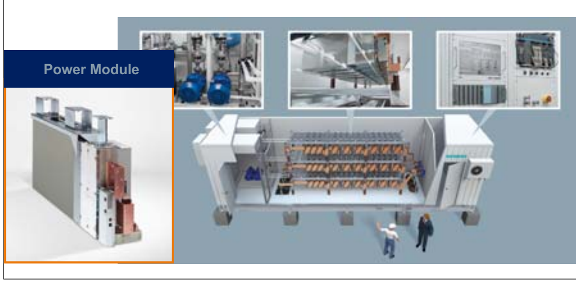
Container solution



Existing Application with Full-Bridge Sitras® SFC plus Static Frequency Converter

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Real Multilevel:

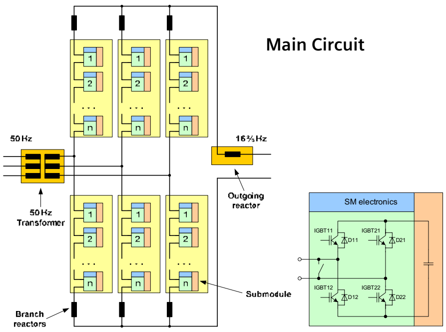
Modular system
Power 12 … 120 MW

Versatile Application:

HVDC (HGÜ)
Reactive power compensation
SFC Static Frequency Converter

Main Components:

Standard transformers
Modular power circuit
Air core reactors



Existing Application of Full-Bridge - Sitras® SFC plus

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E.ON – Converter @ Power Station Franken, Nuremberg

Technical Data:

- 2 Systems with 37.5 MVA, each
- AC Voltages @ 50 Hz 110 - 123 kV
  AC Voltages @ 16.7 Hz 110 - 123 kV
- Noise Level < 90 dB (A)
- Ground Area 27 x 34 m

Agenda

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Basics of HVDC PLUS
Topologies

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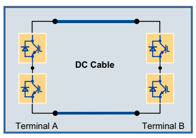
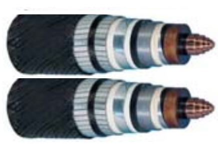
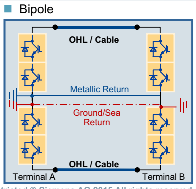
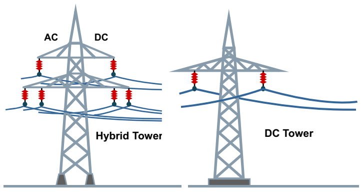
- Symmetrical Monopole





- Bipole





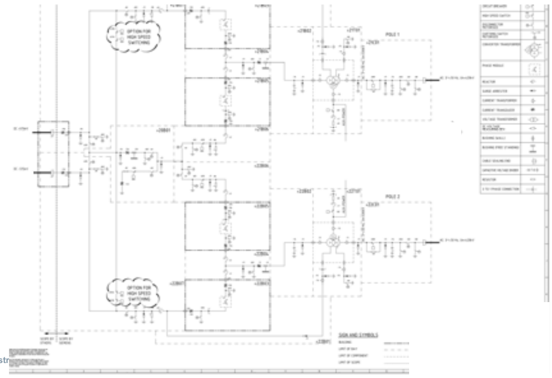
Converter Arrangements

i. Symmetrical Monopole
- Only for pure cable projects due to voltage balancing
- Half Bridge Design

ii. Full Bipole
- Maximum flexible operation, 2 x 50% power, highly independent
- Half Bridge: if dc fault current clearing is not required (5 sec. fault clearance time)
- Full Bridge: if significant overhead line sections are included or if reduced dc voltage is required

iii. Rigid Bipole
- Cost optimized option with some operation restriction (re-configuration time)
- Half Bridge: same as for full bipole
- Full Bridge: same as for full bipole

Rigid Bipole: Typical Single Line Diagram



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Cable Design Criteria

i. Project Requirements
- Land cable / sea cable
- Installation condition: Number of trenches (1 or 2?); diameter, spacing of cables
- Ground condition (normal soil, soft or hard rock, etc.), temperature, humidity of ground

ii. Costs
- Installation / no. of joints
- Material costs (copper ...)

DC Voltage Selection Criteria I

<u>Symmetrical Monopole</u>
- Restricted to short sections with overhead lines
- fully independent on dc side

Alternatives for 2000 MW (extruded cables):
- 2 x 1000 MW, ±320 kV, 1.56 kA -> 4 HV cables total, approx. 2500 mm²
- 2 x 1000 MW, ±400 kV, 1.25 kA -> 4 HV cables total, approx. 1600-1700 mm²
  reduces also required trench diameter
  but increased converter size / submodule levels

DC Voltage Selection Criteria II

<u>Bipole</u>
- Allows operation with overhead lines
- optional w/o DMR (Dedicated Metallic Return conductor): Rigid configuration

Alternatives for 2000 MW:
- ±320 kV, 3.125 kA
  -> 4 HV cables total, approx. 2500 mm² + 2 MV cables, approx 2500 mm²
- ±500 kV, 2.0 kA
  -> 2 HV cables total, approx. 3250 mm² + 1 MV cable, approx 3250 mm²
- ±600 kV, 1.67 kA
  -> 2 HV cables total, approx. 2200 mm² + 1 MV cable, approx 2200 mm²

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Station Layout: Example Transbay Cable Project

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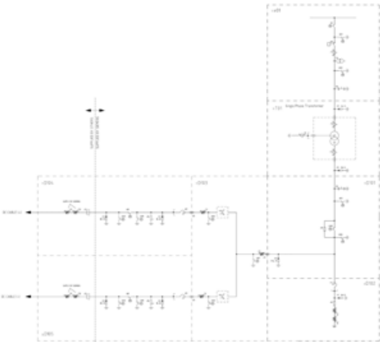
Symmetrical Monopole: Single Line Diagram



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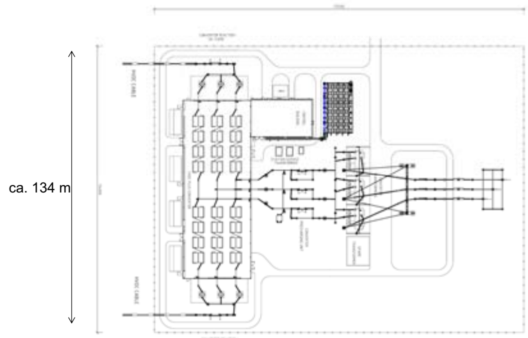
Symmetrical Monopole: Typical Layout



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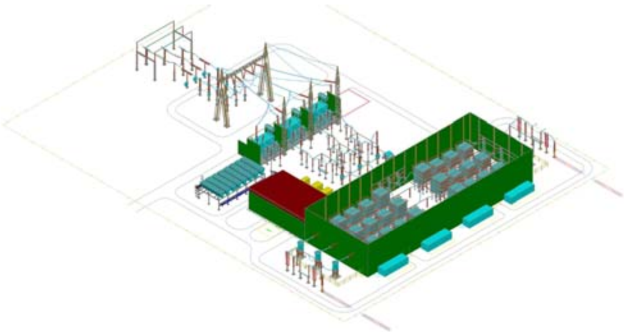
Symmetrical Monopole: Typical Layout



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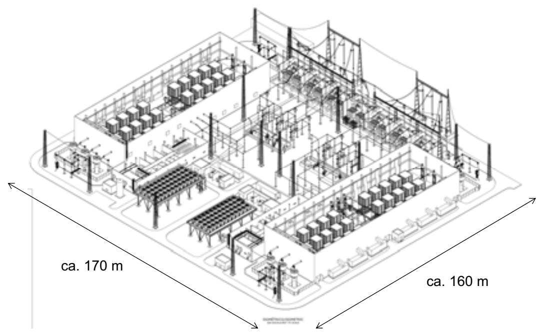
Duo Monopole: Example for Layout



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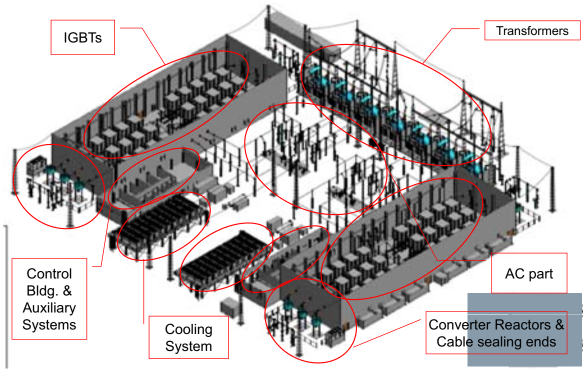
HVDC PLUS – Duo Monopole
Typical Converter Station Layout



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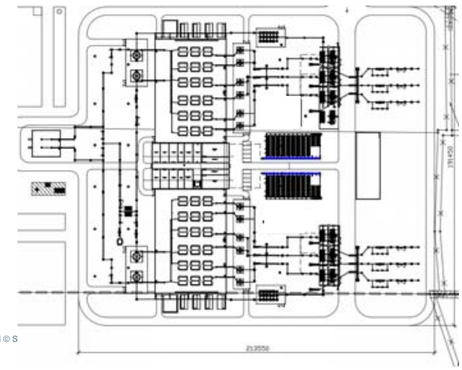
Rigid Bipole 500 kV: Typical Layout



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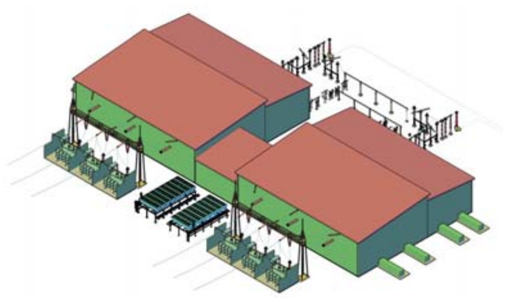
Conceptual Design: HVDC PLUS Bipole



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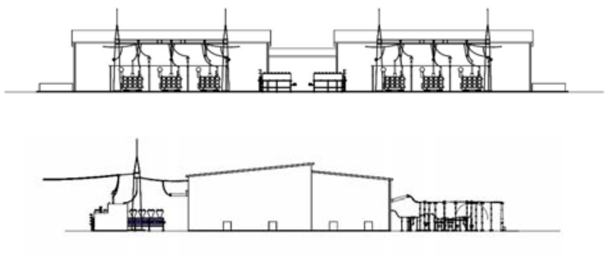
Conceptual Design: HVDC PLUS Bipole



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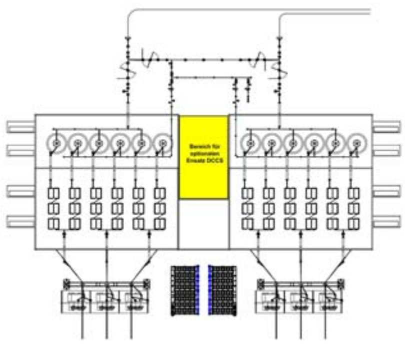
Optional:
DC Compact Switchgear for Reduced Footprint



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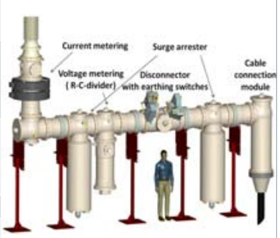
New Applications
320 kV DC Compact Switchgear (DC CS)

Technical Data	
U_{dc} nominal voltage	±320 kV
U_{mcov} maximum continuous operation voltage	±336 kV
Rated lightning impulse withstand voltage (1,2 / 50 µs) - to earth - across the insulating distance at the power frequency voltage	 1175 kV 1175+336 kV
Rated switching impulse withstand voltage (250 / 2500 µs) - to earth - across the insulating distance at the power frequency voltage	 950 kV 950+336 kV
Rated nominal current	4000 A
Rated short-time withstand current	50 kA (1 s)
Ambient temperature range	-30 to +50 °C



New Applications
320 kV DC Compact Switchgear (DC CS)

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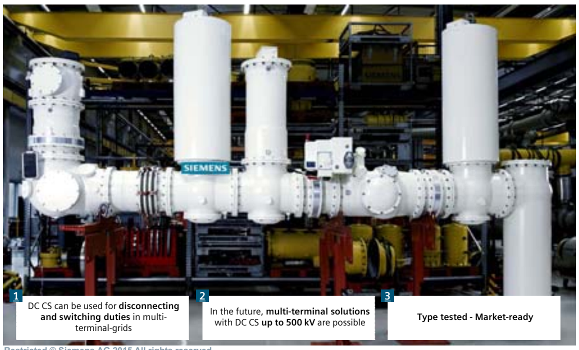

New Applications
DC Compact Switchgear (DC CS)

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DC CS - A new dimension in compactness

- space-saving design
- reduction of DC switchyard in converter stations up to 95 %
- suitable for onshore and offshore application
- safe encapsulation
- reliable operation even under extreme environmental conditions
- high degree of gas-tightness
- high availability and reliability
- low life cycle and maintenance costs

Agenda

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Cables for HVDC Transmission

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- MI/PPL: Insulated with special paper, impregnated with high viscosity compound
- SCFF: Insulated with special paper, impregnated with low viscosity oil
- Extruded: Insulated with extruded polyethylene-based compound

Mass Impregnated / PPL	Self-Contained Fluid Filled	Extruded

Pictures and information provided and copyright by Prysmian

DC Cable Technology:
Cross-linked Polyethylene (XLPE)

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Example: Prysmian (Inelfe Project)

Udc = +-320 kV dc
Idc approx. 1600 Amps
2500 mm^2
4 cables, 64.5 km total
section length: approx. 2 km
totally 144 junctions

DC Cable Technology:
Paper Polypropylene Laminate (PPL)

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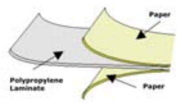
Example: Prysmian (Western Link Project)

Udc = 600 kV dc
Idc = 2200 Amps
2500 mm^2
Features: operation at higher temperatures possible (e.g. 85° C)



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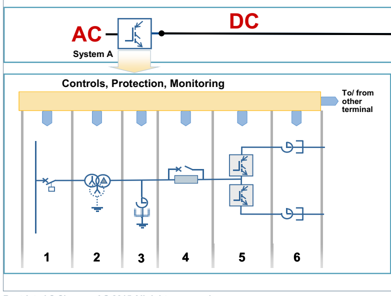
Basics of HVDC PLUS
Key Components

Example: Symmetrical Monopole



1. AC Switchyard
2. Transformers
3. Star Point Reactor
4. Insertion Resistor
5. Power Modules
6. Converter Reactor

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Symmetrical Monopole Scheme
Conventional Transformers

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Transformers/Phase Reactors in VSC Systems

<u>Tasks</u>

- Providing reactance between ac system and VSC unit (interface impedance)
  -> enables control of the ac output voltage
- Adapt ac system voltage level to output level of converter and optimize utilisation of VSC unit
- Prevent zero-sequence currents flowing between ac system and VSC unit
- Size of required reactance influences dynamic behaviour and transients

<u>Design Criteria</u>

- Current stresses (fundamental and harmonics – if applicable)
- Dielectric stresses (dc components for unsymmetrical systems, e.g. bipolar)
- Saturation characteristics (dc flux components)
- Installation of tap changer depending on project specific conditions (e.g. reduction of power losses, ac system voltage range, required operating conditions (low ac voltage))

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Reactors in VSC Systems

<u>Valve Reactor (Converter Reactor)</u>

- Limit circulating currents between phase units
- Limitation of transient currents during faults
- Contribution to interface reactance between ac system and converter

<u>DC Reactor</u>

- Applied in long distance transmission schemes, in series to line
- Limitation of transient currents during faults
- (Limits harmonic content on the line)

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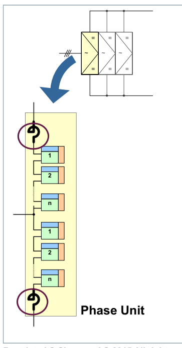
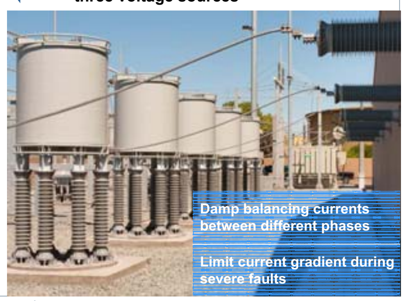
HVDC PLUS
Converter Reactors



Parallel connection of three voltage sources



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HVDC PLUS – Made by Siemens

The Siemens Experience / Our References

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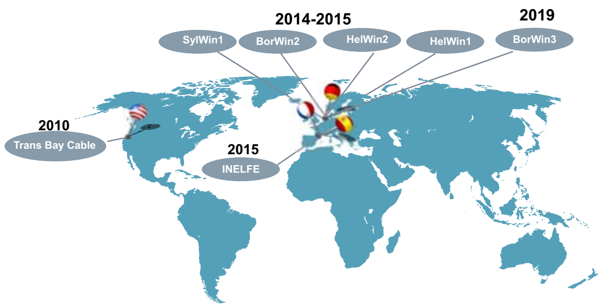

Trans Bay Cable Project, USA

World's first MMC-VSC Technology in Commercial Operation

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Trans Bay Cable Project, USA

Overview

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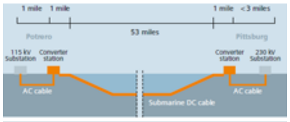
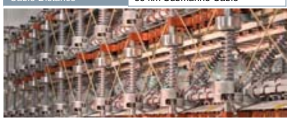


Customer	Tans Bay Cable LLC
Project Name	Trans Bay Cable Project
Location	Pittsburg, CA/San Francisco, CA
Power Rating	400 MW
Type of Plant	HV DC PLUS
Voltage Levels	± 200 kV DC 230 kV / 138 kV AC, 60 Hz
Semiconductors	IGBT
Cable Supplier	Prysmian
Cable Voltage	± 200 kV
Cable Type	XLPE
Max. Depth	50 m
Cable Distance	85 km Submarine Cable



BorWin2, Germany

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Customer	Tennet
Project Name	BorWin2
Location	Diele, Germany
Power Rating	800MW
Type of Plant	200km HVDC PLUS On-/Offshore Cable
Voltage Levels	± 300 kV DC AC 400 kV/155 kV, 50 Hz
Semiconductors	IGBT

BorWin3, Germany

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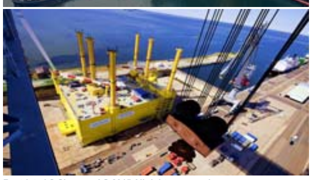
Customer	Tennet
Project Name	BorWin3
Location	Diele, Germany
Power Rating	900 MW
Type of Plant	160 km HVDC PLUS On-/Offshore Cable
Voltage Levels	± 320 kV DC AC 400 kV/150 kV, 50 Hz
Semiconductors	IGBT



SylWin1, Germany

SIEMENS

Customer	Tennet
Project Name	SylWin1
Location	Büttel, Germany
Power Rating	864 MW
Type of Plant	205 km HVDC PLUS On-/Offshore Cable
Voltage Levels	± 320 kV DC 155 kV / 300 kV / 380 kV AC, 50 Hz
Semiconductors	IGBT

HelWin2, Germany

SIEMENS

Customer	Tennet
Project Name	HelWin2
Location	Büttel, Germany
Power Rating	690 MW
Type of Plant	130 km HVDC PLUS On-/Offshore Cable
Voltage Levels	± 320 kV DC AC 155 kV/300kV/380kV, 50 Hz
Semiconductors	IGBT

HelWin1, Germany

SIEMENS

Customer	Tennet
Project Name	HelWin1
Location	Büttel, Germany
Power Rating	576 MW
Type of Plant	130 km HVDC PLUS On-/Offshore Cable
Voltage Levels	± 250 kV DC AC 400 kV / 155 kV, 50 Hz
Semiconductors	IGBT

INELFE, France-Spain
Worldwide biggest VSC HVDC System with 2000 MW capacity

SIEMENS

INELFE, France-Spain
Overview

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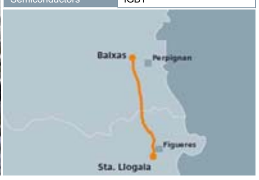
Customer	INELFE (RTE and REE)
Project Name	INELFE
Location	Balxas, France – Santa Llogala, Spain
Power Rating	2 x 1000 MW
Type of Plant	HVDC PLUS
Voltage Levels	± 320 kV DC AC 400 kV, 50 Hz
Distance	65 km underground cable
Semiconductors	IGBT



International Standards on VSC HVDC

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- IEC/TR 62543-2013: HVDC Power Transmission using VSC
- IEC/IS 62747-2014: Terminology for VSC for HVDC Systems
- IEC/IS 62751-1-2014: Power losses in VSC valves for HVDC Systems, Part 1: General Requirements
- IEC/IS 62751-2-2014: Power losses in VSC valves for HVDC Systems, Part 2: Modular Multilevel Converters


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Thank you for your attention!