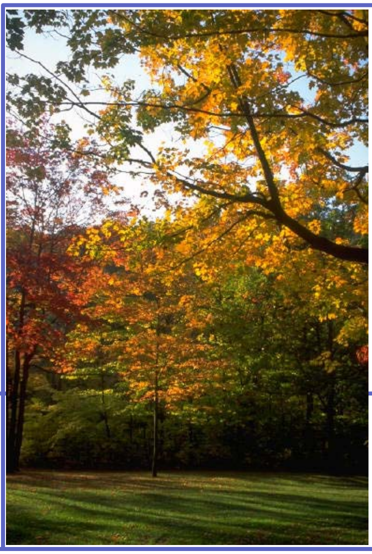


HVDC Light®
Presentation
Anno 1990 –tal



Presentation för VBIK 2022–11-16

Lars Weimers

ABB

Platsen där allt började

The Hellsjön R&D team 1995 ??

Bo Bijlenga   Peter Normand   Rolf Pålsson   Krister Nyberg   Tomy Holmgren

Kjell Svensson   Rolf Jonsson   Tommy Hjort   Bo Danielsson

Market introduction seminar Cassels 1997

Lars Bergström

Kjell Eriksson

Erik Koldby

Carl Axel Rosén

Anders Nilarp

Gunnar Asplund

Bror Axelsson

Lars Weimers

Kjell Svensson

Tommy Hjort

Göran Strömberg

Martin Byggeth

Bo Bijlenga

Mohammed Rashwan

Roberto Rudervall

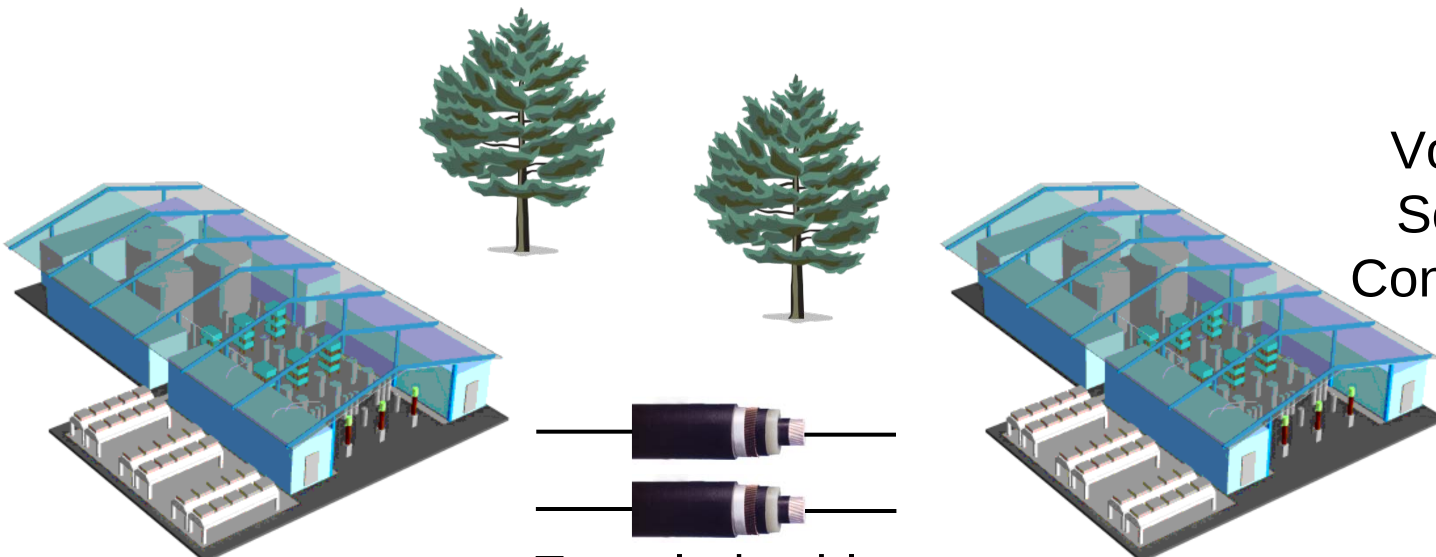
John Bowles

Matt Matele

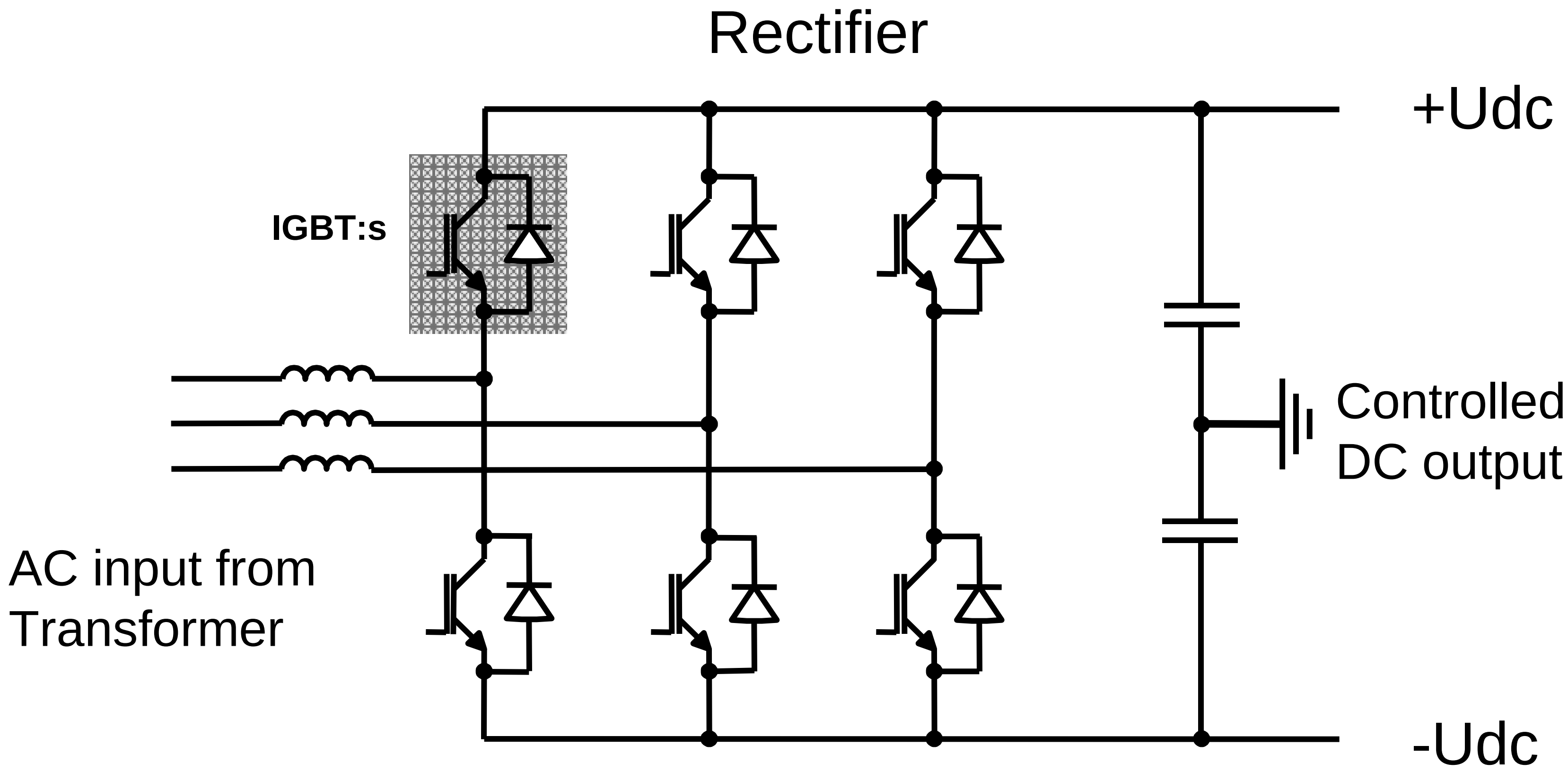
Julfest 1995 1996 ??

What is HVDC Light® ?

- Highly controllable DC transmission
- Voltage Source Converters
- Underground/Submarine cable
- Active and reactive power control
- Power Quality
- Modularized and standardized solutions

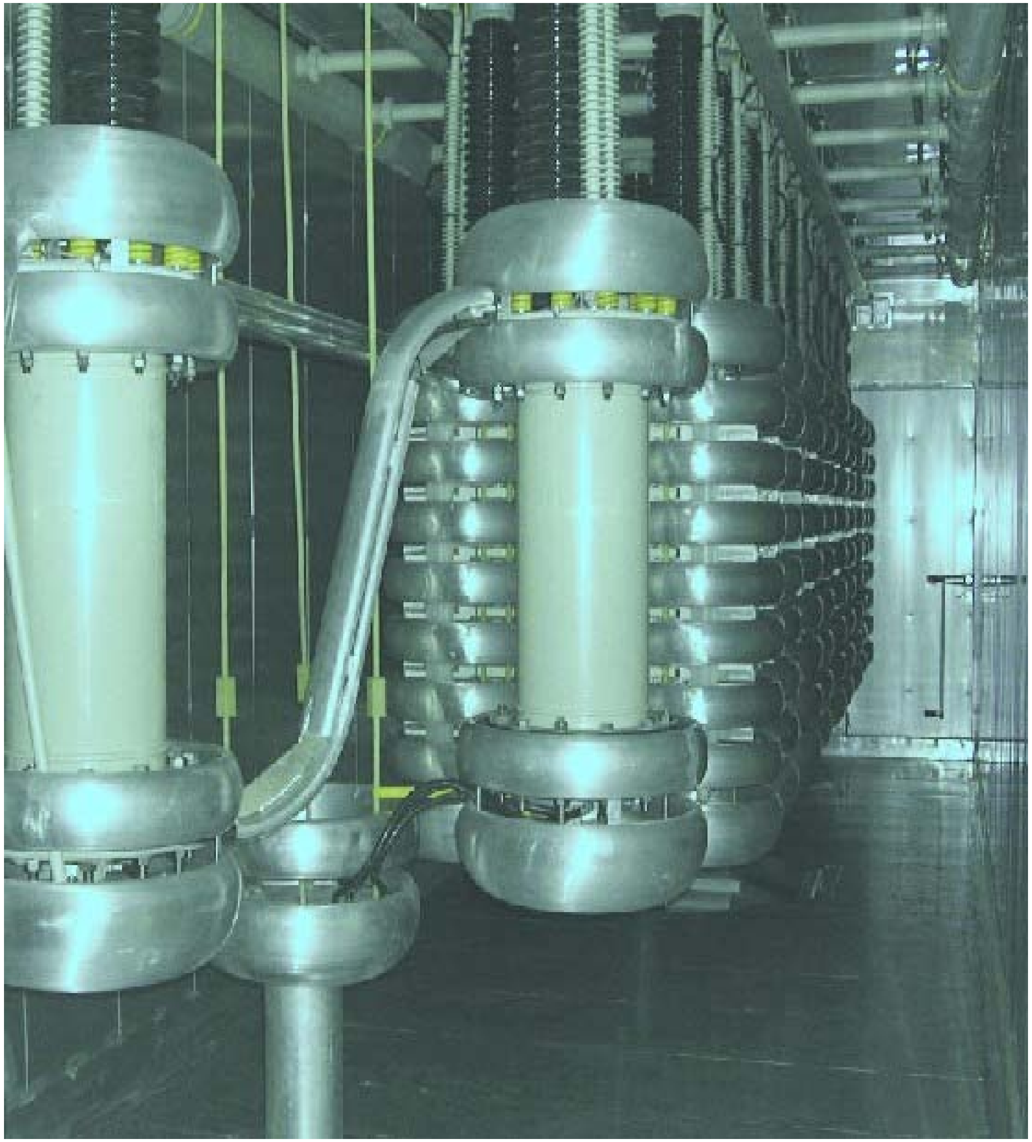


What is HVDC Light® – Voltage Source Converter with IGBT:s



Insulated **G**ate **B**ipolar **T**ransistor (IGBT)

What is HVDC Light® – VSC valves inside the valve compartment



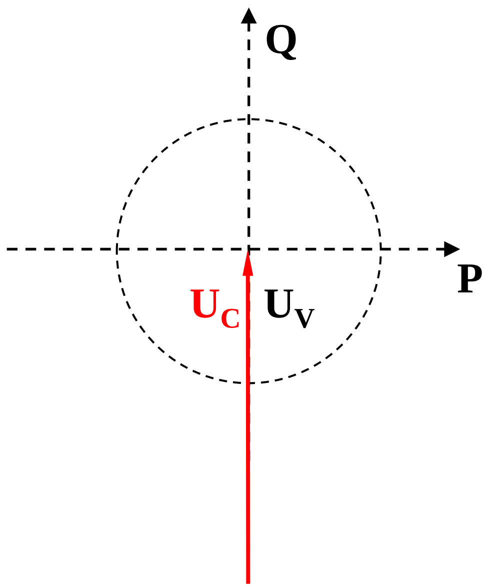
All equipment assembled and tested before shipping

Gotland

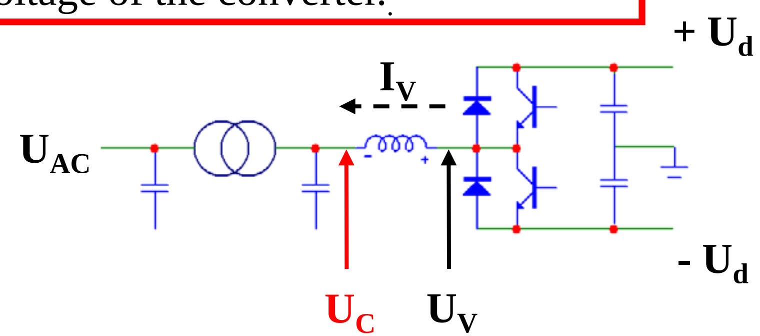
50 MW, 80 kV

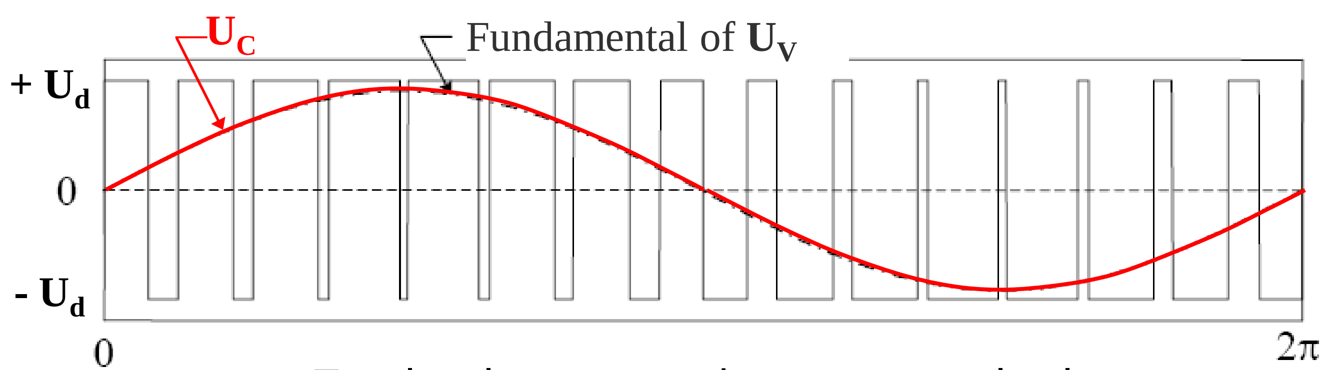
HVDC Light

Summary on VSC Technology



VSC Technology deals with the relationship between the ac-network voltage and the output voltage of the converter.

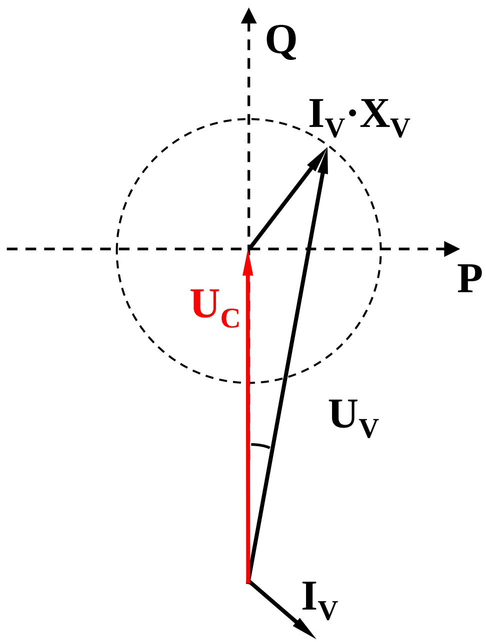




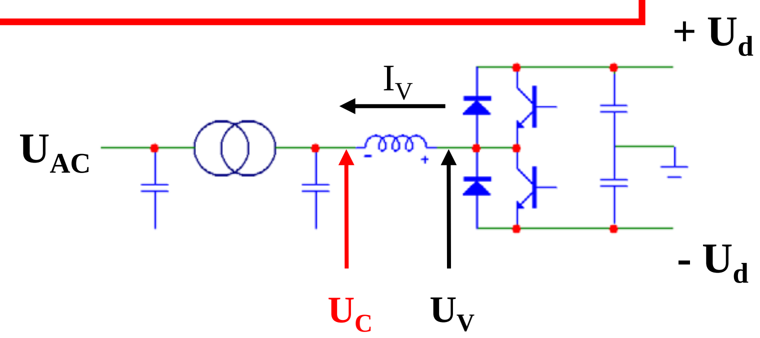
Two-level converter phase-to-neutral voltage

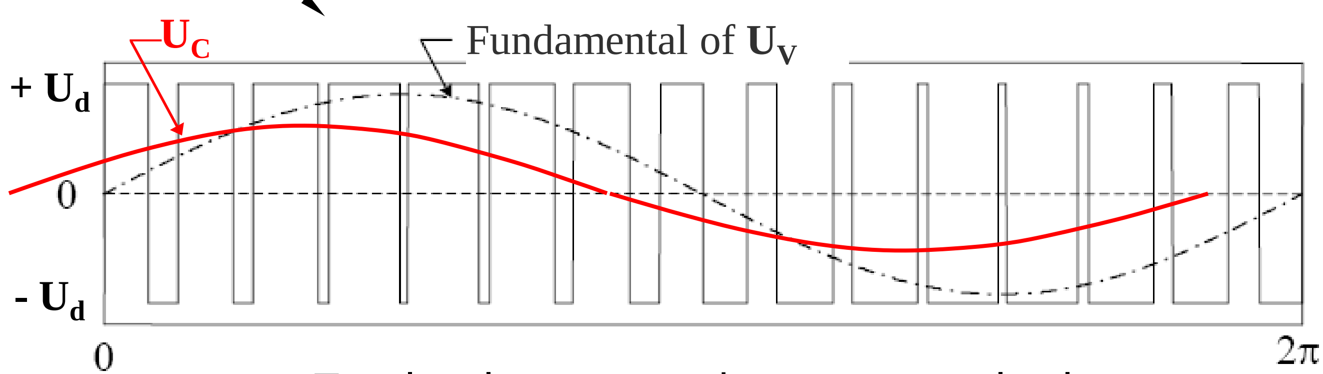
HVDC Light

Summary on VSC Technology



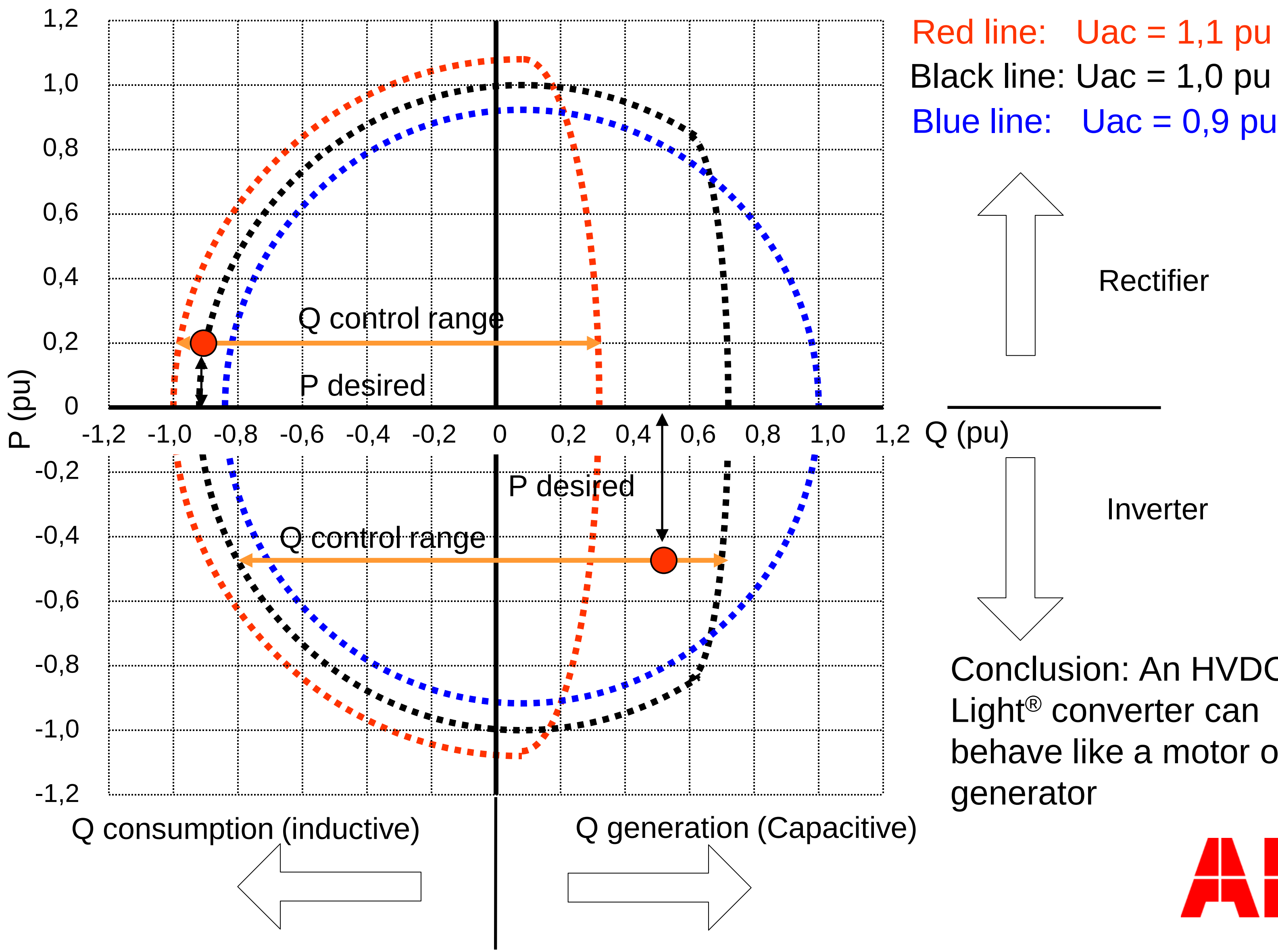
Active and Reactive power flow controlled by controlling the amplitude and phase angle of $\mathbf{U_v}$.





Two-level converter phase-to-neutral voltage

PQ-diagram



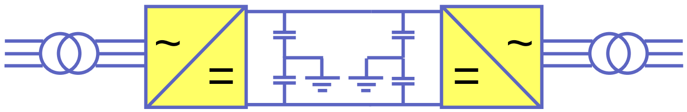
Conclusion: An HVDC Light® converter can behave like a motor or a generator

Control functions

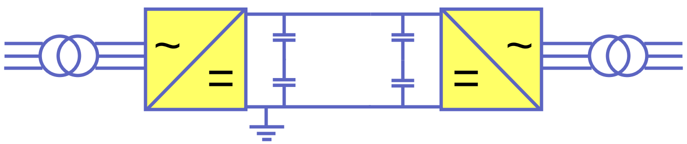
- Active power control
- Reactive power control
- AC voltage control
- DC voltage control
- Frequency control
- Flicker control

Configurations and operation modes

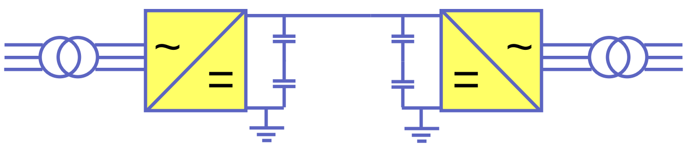
Symmetric monopole



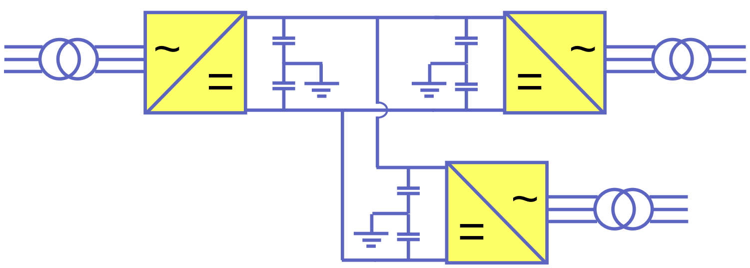
Asymmetric monopole, metallic return



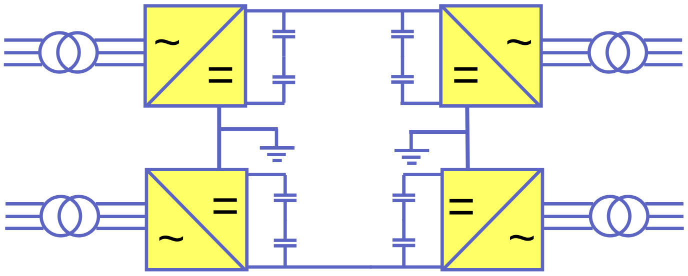
Asymmetric monopole, ground return



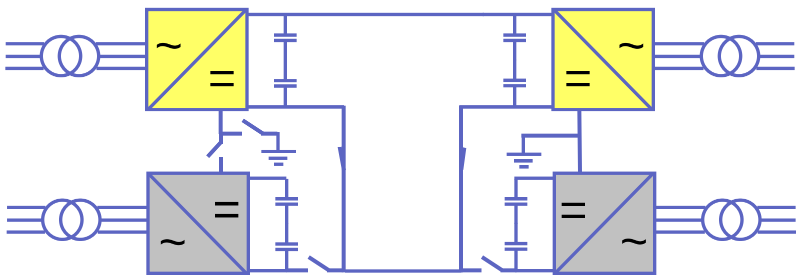
Multiterminal Symmetric monopole



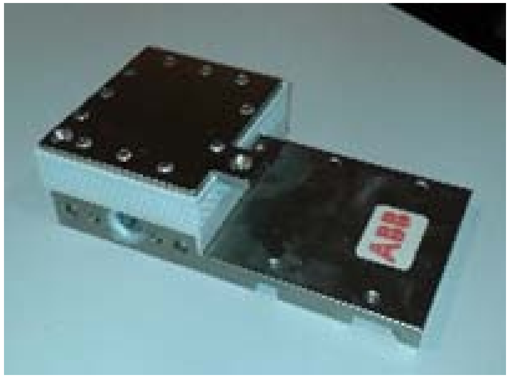
Bipole



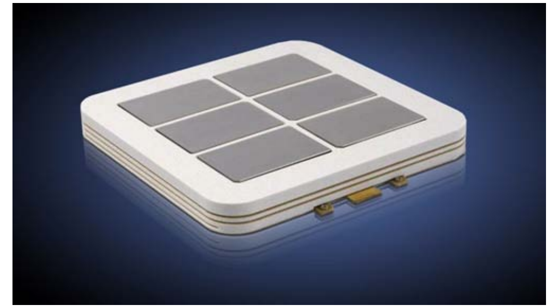
Bipole, metallic return



IGBT Gen 1 – Gen 5



PG3 /Gen 1



StakPak
2000A/4500V
Gen 4

Hällsjön,
prototype

StakPak
1300/2500V
Gen 2

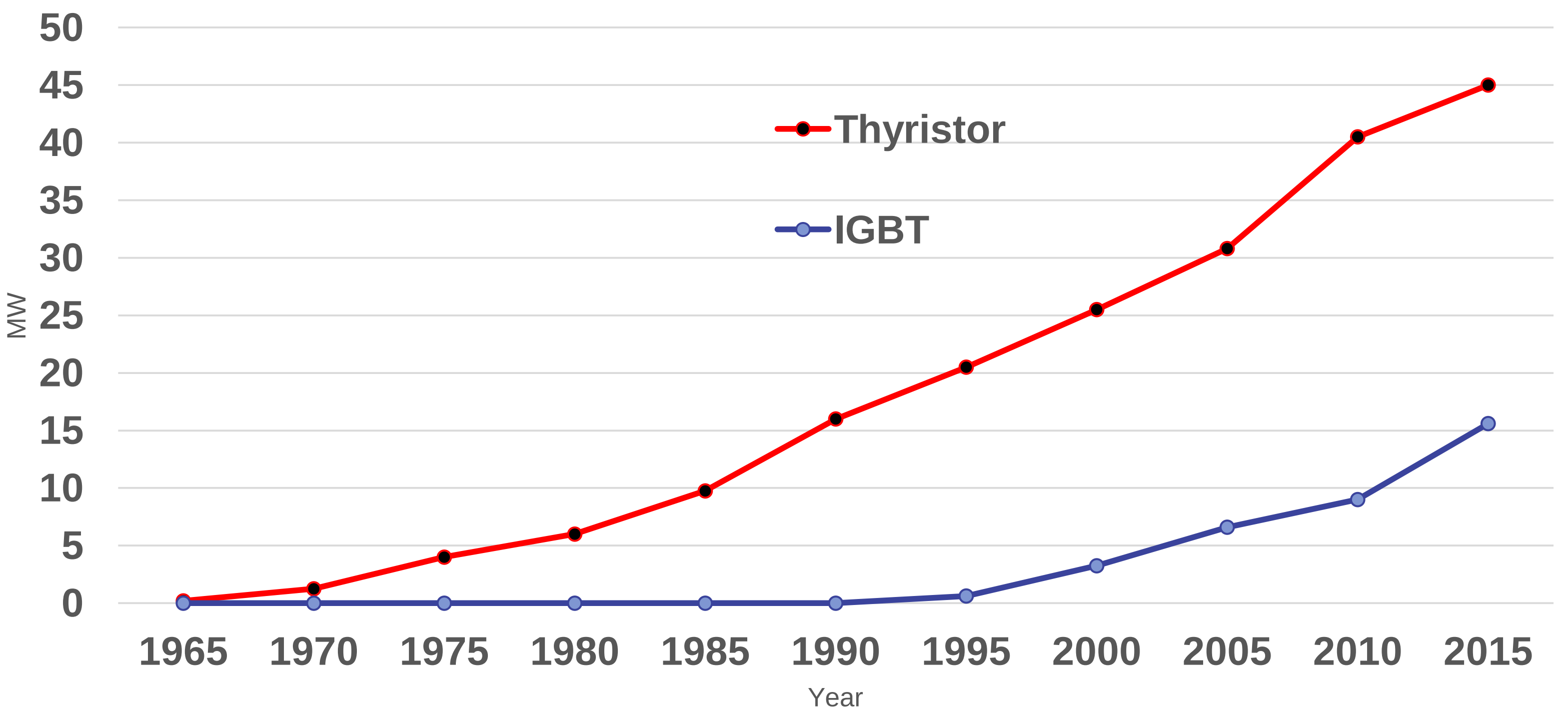
Stakpak 2000A/2500V

Gen 3

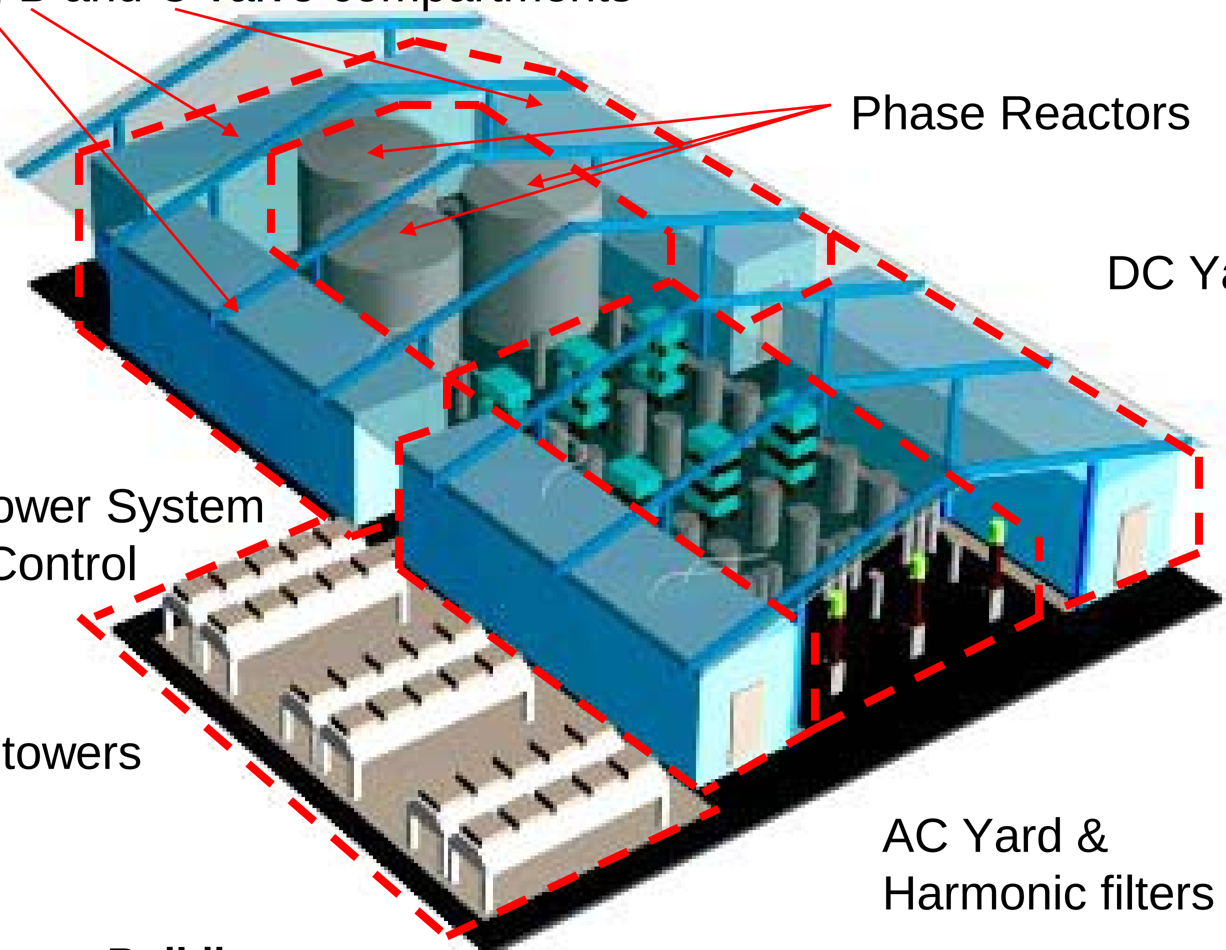
BIGT

2000A/5200V Gen 5

Power capacity Thyristor vs IGBT



Physical Layout, 65 MVA HVDC Light® Converter Station



Building
45 x 18 m

ABB

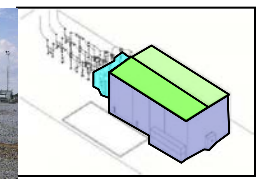
Technical development

1997	1999	2002	2006	2009(15)	2010	2013	2015
3 MW	50 MW	330 MW	350 MW	400 MW	300 MW	500 MW	800 MW
± 10 kV	± 80 kV	± 150 kV	± 150 kV	± 150 kV	+ 350 kV	± 200 kV	± 320 kV
Hällsjön	Gotland	Cross Sound	Estlink	BorWin 1	Caprivi	EWIP	Dolwin 1
G1	G1	G2	G3	G3	G3	G3	G4

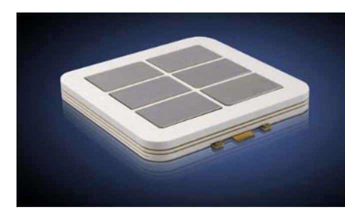










Extruded HVDC Light® Cable, Land

- Smaller & Lighter cables
- Robust
- Low Environmental Impact
- Weight: 1 – 6,5 kg per m
- Power: 60 – 350 MW per pair

Two cables for bipolar operation

HVDC Light® submarine cable for normal static use

- Conductor of copper
- HVDC polymer insulation
- Lead alloy sheath
- Steel wire armor (double layers for deep sea)
- Complete cable

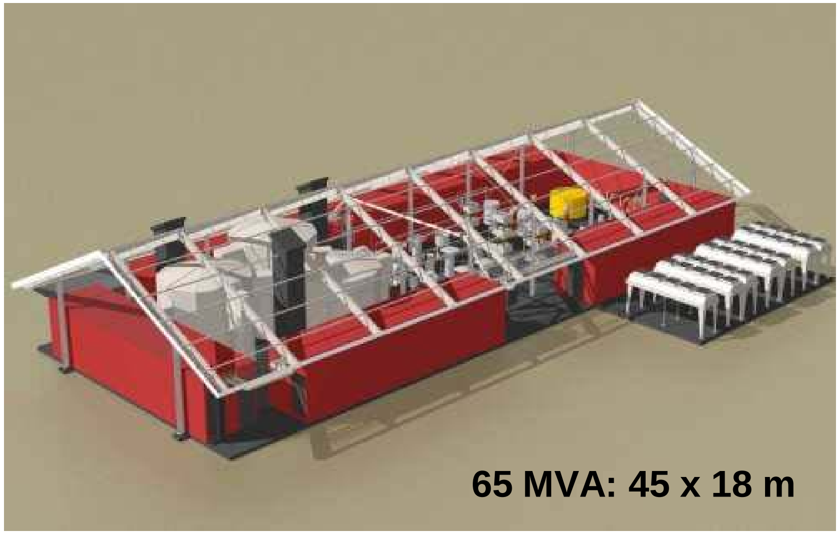
  - diameter 50 - 125 mm
  - weight 8 - 50 ton/km
- 6 - 550 MW per bipole
- Standard voltages: 84 and 150 kV

Two cables for bipolar operation

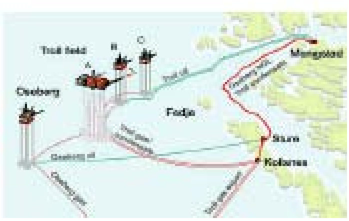
ABB

Benefits - Economical

- Power supply to remote locations becomes cost-efficient
- Power supply from renewable energy source becomes economical
- Step-wise expansion
- Short delivery times
- Easy permitting
- Leasable/Relocatable
- High availability



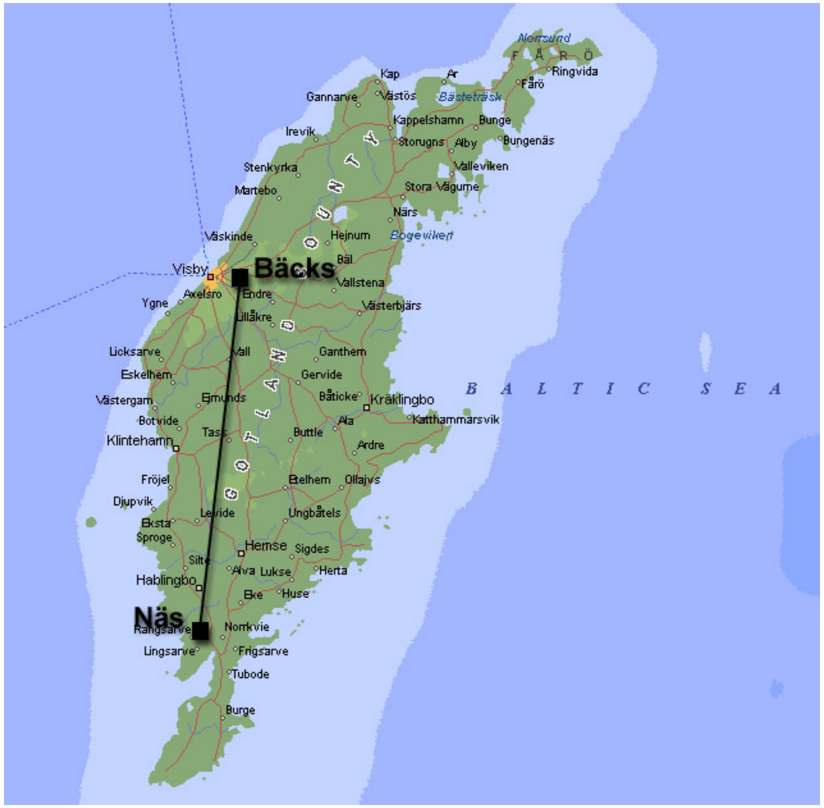
HVDC Light™ Projects



Project	Rating (MW)	Distance (km)	Application	Ordered
Hellsjön	3	10	Interconnection, converting AC line to DC	Apr 1994
Gotland	50	70	Wind power, underground cable	Dec 1997
Tjæreborg	7	4	Wind power, underground cable	Jun 1998
Directlink	180	65	Interconnection, underground cable	Dec 1998
Eagle Pass	36	N/A	BtB Asynchronous Tie and SVC, Dual purpose application	Jul 1999
CSC	330	40	Interconnection , submarine cable	Aug 2000
Murraylink	200	180	Interconnection, underground cable	Dec 2000
Troll	2x40	67	Offshore platform feeding, motor drive	Jun 2002

Hellsjön , the first VSC converter for HVDC 3MW 10 kV

Gotland - the first commercial HVDC Light® project



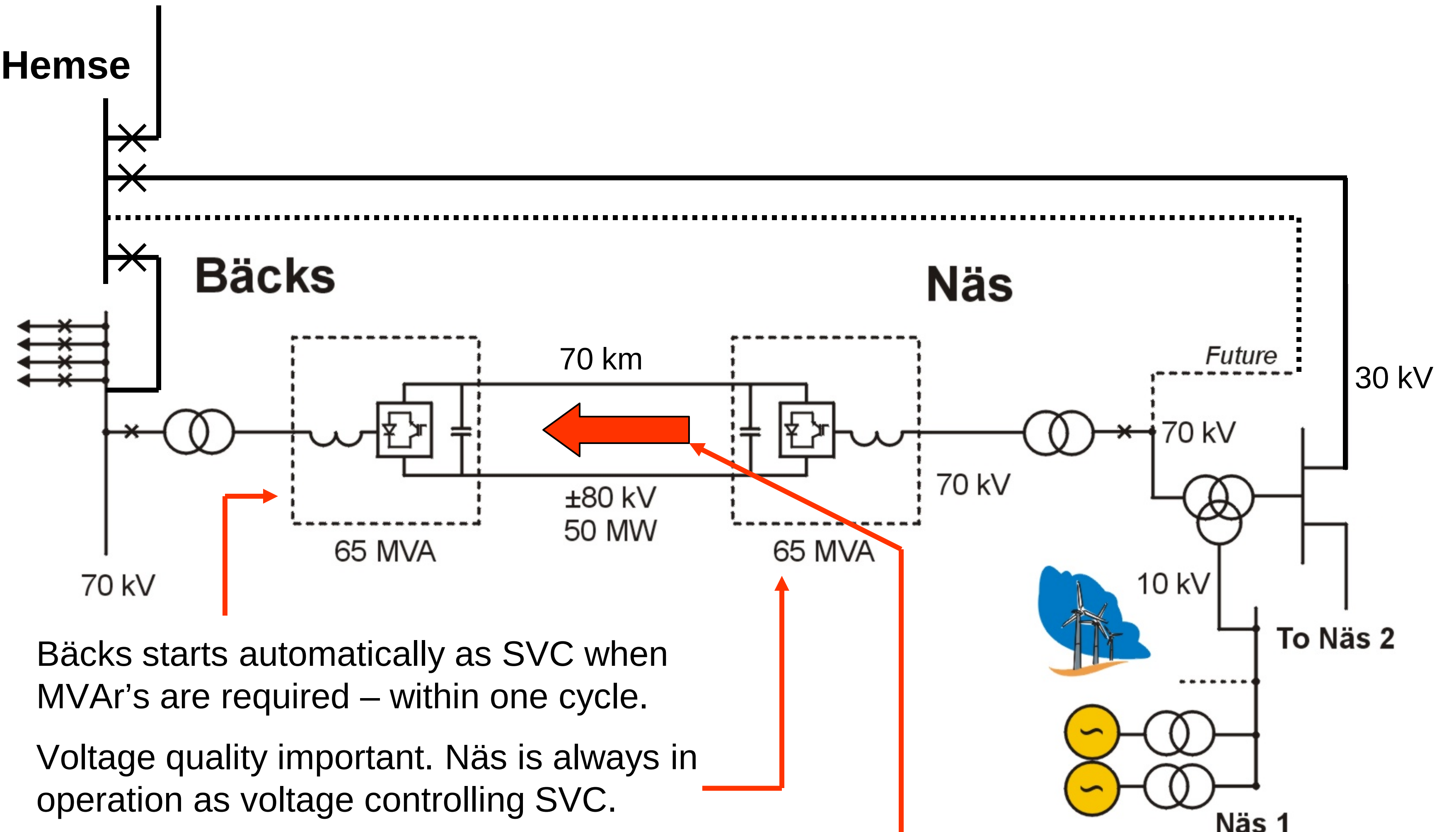
Technical Data

Commissioning year:	**1999**
Power rating:	**50 MW**
AC Voltage:	**70 kV both sides**
DC Voltage:	**± 80 kV**
DC current	**350 A**
Length of DC cable:	**2 x 70 km**

Main reasons for choosing HVDC system: Wind power (voltage support), Easy to get permission for underground cables.

ABB

Gotland HVDC Light®- simplified Single Line Diagram

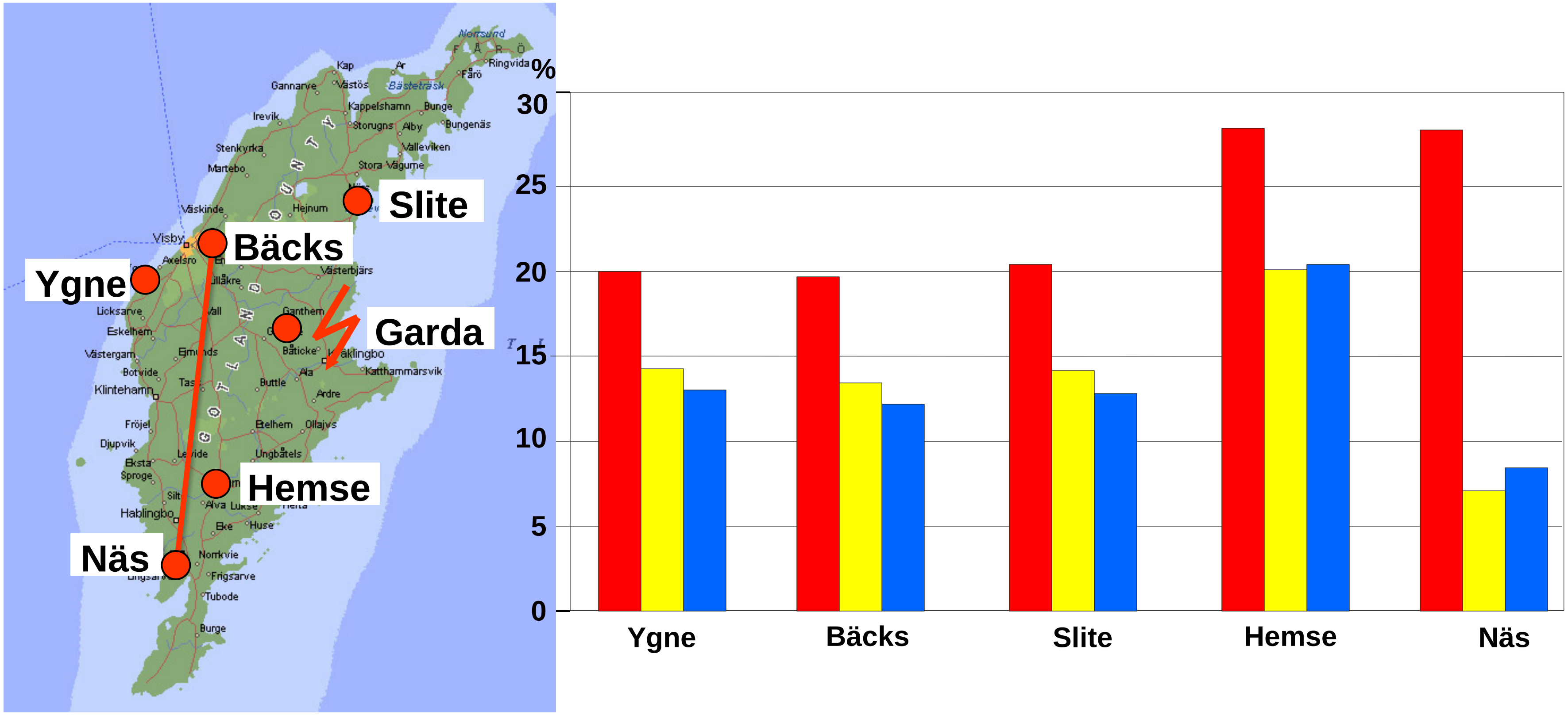


Bäcks starts automatically as SVC when MVAr's are required – within one cycle.

Voltage quality important. Näs is always in operation as voltage controlling SVC.

DC power transmission is started by remote control if wind power generation exceeds 15 MW.

Gotland HVDC Light® - The Garda Fault - Voltage dips

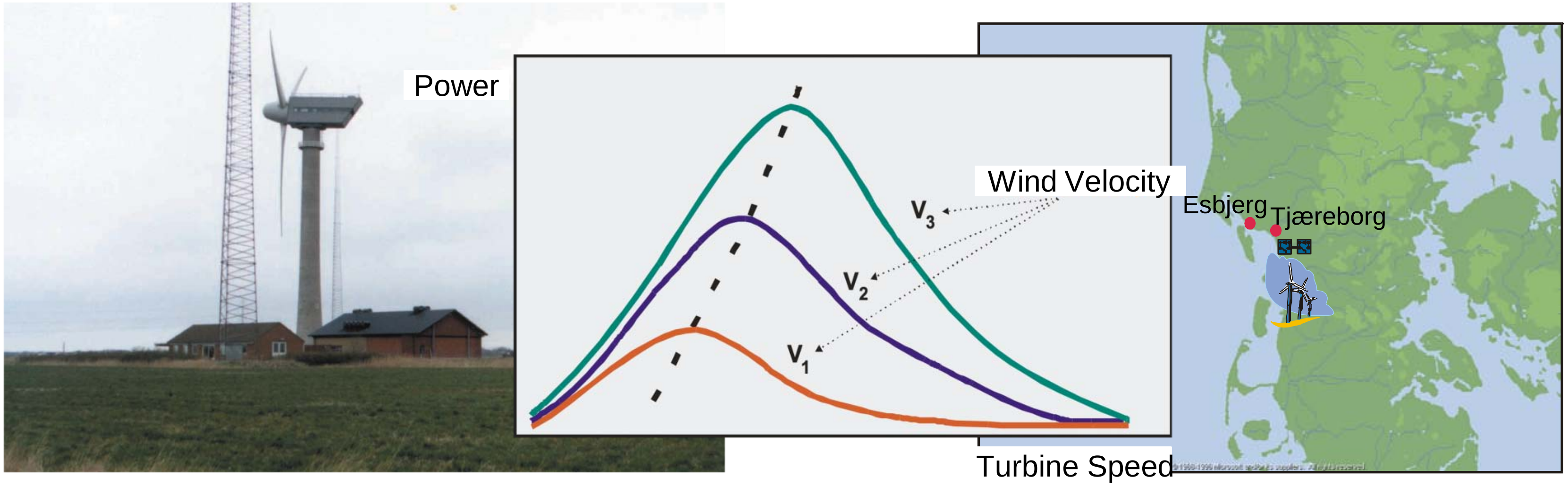


Ground fault in the 10 kV grid

- **Simulations without HVDC Light®**
- **Simulations with HVDC Light®**
- **Measurements**

Gotland HVDC Light®

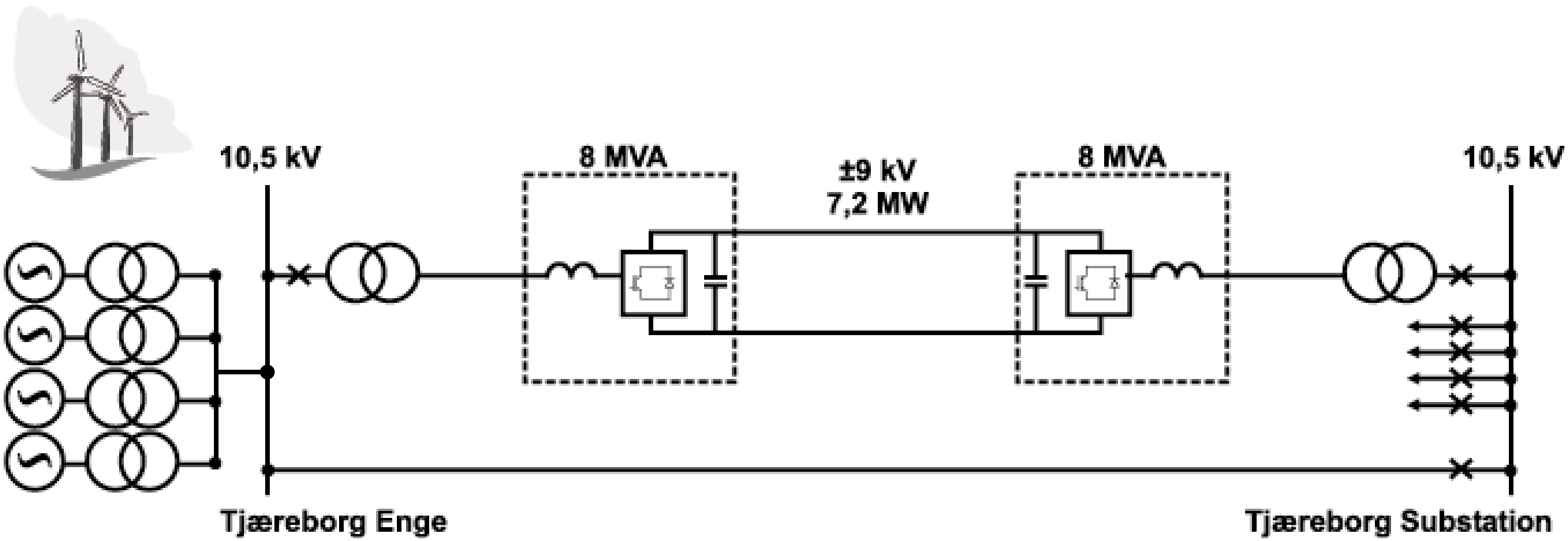
Tjæreborg HVDC Light® - Denmark



- Transmitted power: 7,2 MW
- DC voltage: ± 9 kV
- Verification of wind mill parks
- In service December, 2000
- Length of DC cable: 2 x 4,3 km

”Frequency Control maximizes the utilization of the wind energy”

Tjæreborg HVDC Light® - simplified Single Line Diagram



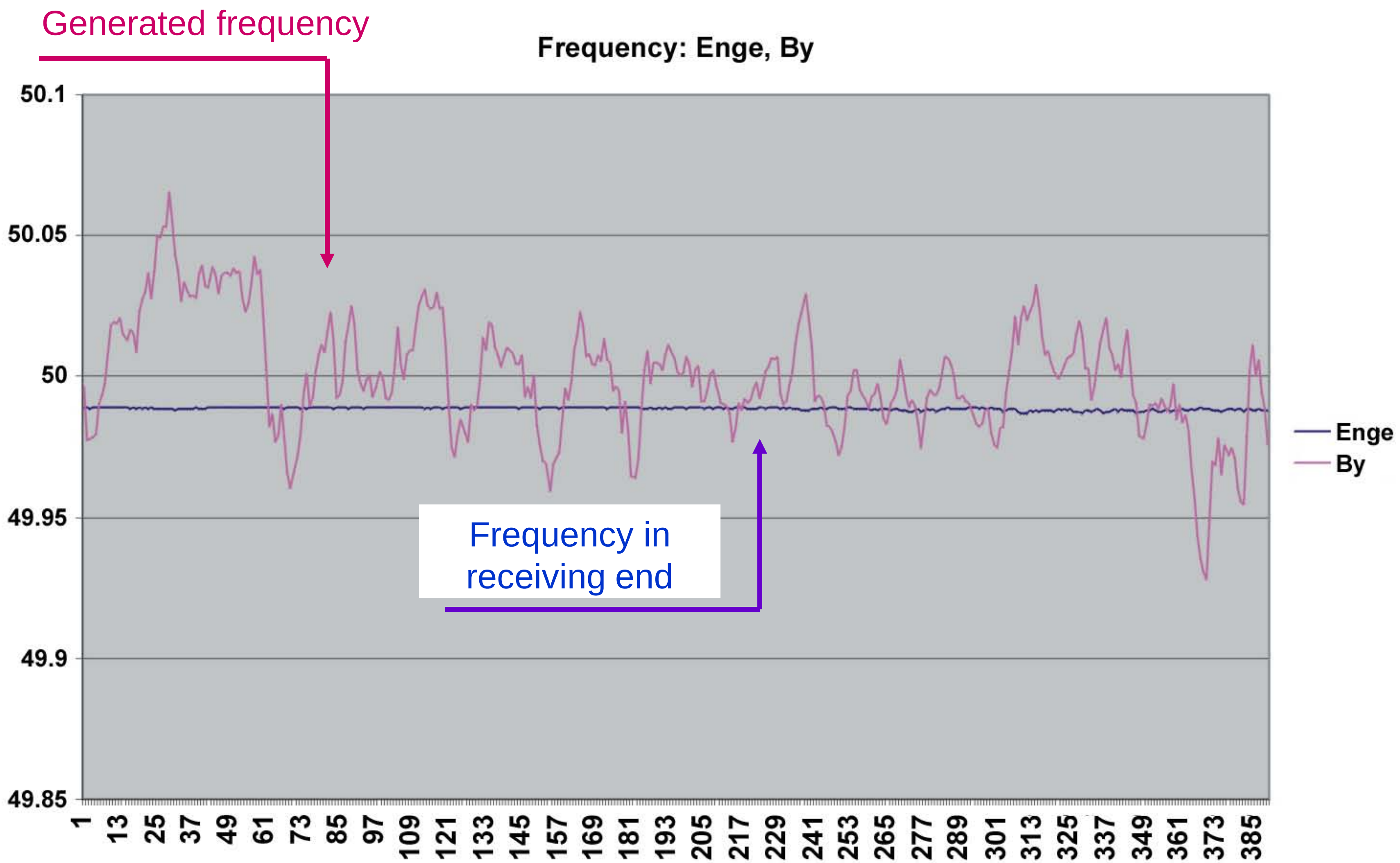
6 MW wind power farm, normally connected to AC and HVDC

HVDC starts automatically at wind power >1 MW on AC cable
AC cable is then opened, wind farm in islanded operation
Frequency of island is controlled by HVDC control
Set point anywhere between 30-65 Hz, but normally 50 Hz

At wind power <0.5 MW, HVDC is synched to AC net, and AC cable is connected

HVDC shuts down

Tjæreborg – Frequency control at isolated operation



Tjæreborg HVDC Light®

Directlink HVDC Light project, Australia

The business case

- Take advantage of price differentials between different power networks and provide transmission capacity as merchant transmitter

The business environment

- Australia has an open market

The solution

- HVDC Light 180 MW ± 80 kV
  Cables 65 km, landcable

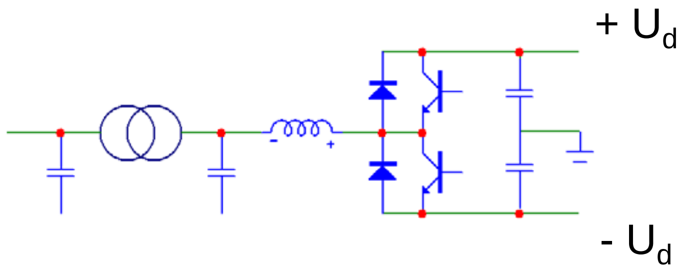
"Enhanced reliability and competitive prices for consumers"

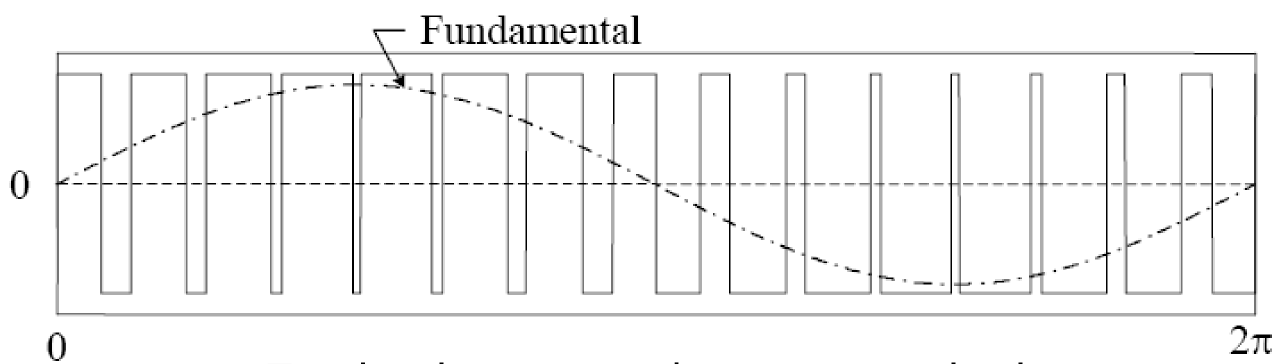
TransÉnergie U.S. Ltd.

Direct Link 3 x 60 MVA HVDC Light

Historical review, 1997-2000 (2015)

- **Two-level Converter, Generation 1**
- Converter losses 3 %
- High switching frequency
- Filters required
- SPWM /3PWM

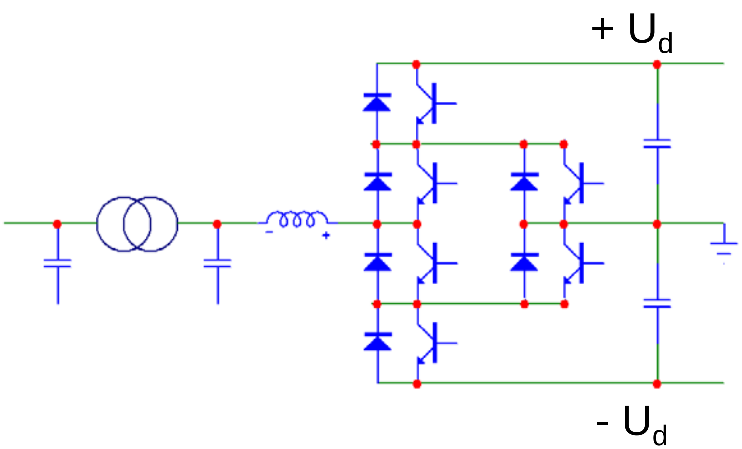


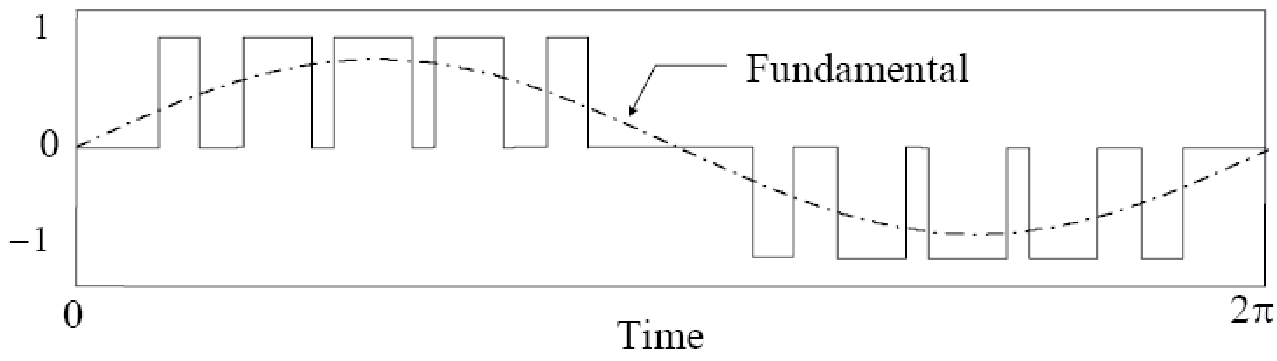


Two-level converter phase-to-neutral voltage

Historical review, 2000-2002

- **Three-level Converter, Generation 2**
- Converter losses 1.7 %
- Switching frequency reduced
- Harmonic generation improved
- SPWM/3PWM

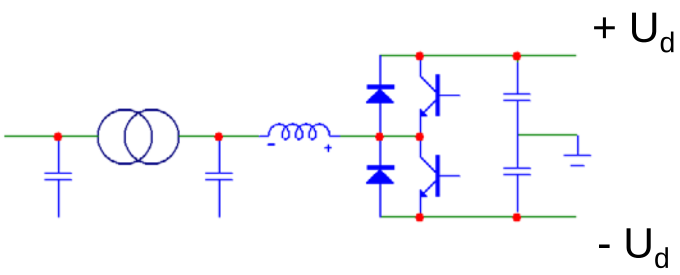


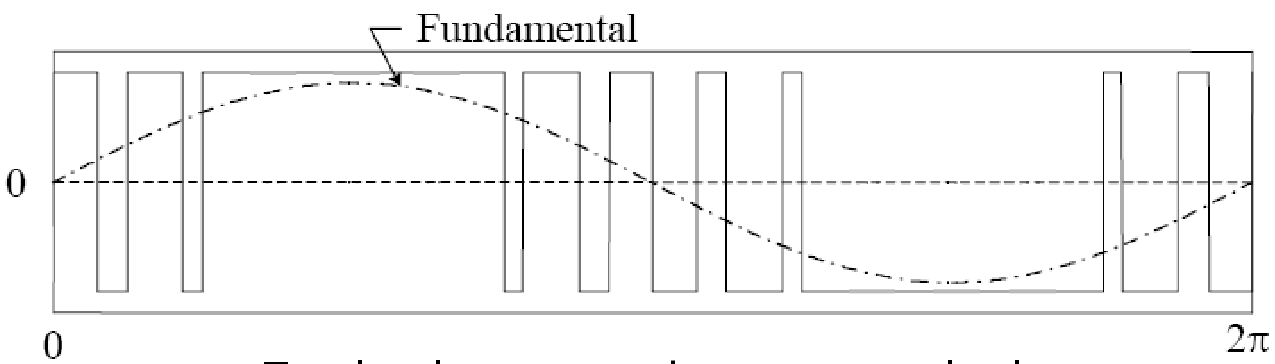


Three-level converter phase-to-neutral voltage

Historical review, 2005-2009 (2015)

- **Two-level Converter, Generation 3**
- Converter losses 1.7 %
  By optimized IGBT and drive
- Lower switching frequency
- Harmonic generation
  maintained
- OPWM

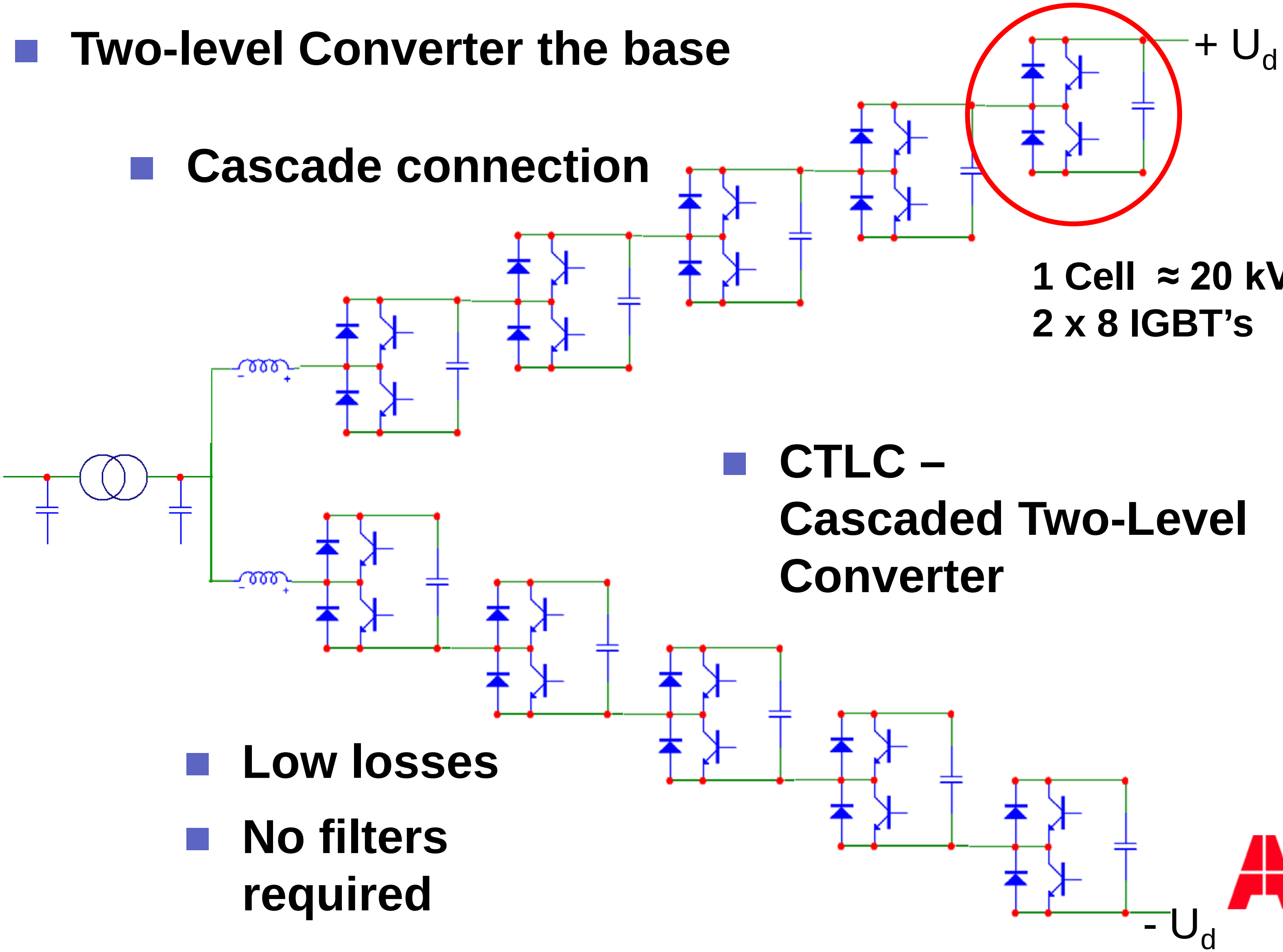




Two-level converter phase-to-neutral voltage

Generation 3 evolution into Generation 4

- **Two-level Converter the base**
  - **Cascade connection**



1 Cell ≈ 20 kV
2 x 8 IGBT's

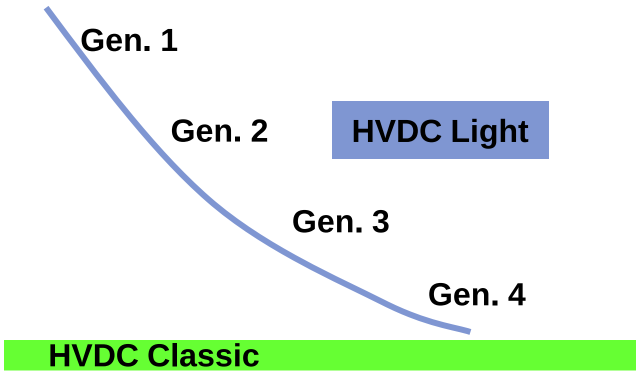
- **CTLC – Cascaded Two-Level Converter**

- **Low losses**
- **No filters required**

Black start and synchronizing

- An important feature of VSC is the ability for black start
- HVDC black start is easy, synchronizing is more complicated
- After a power system has gone down power sources very soon start up in different “islands” of the power grid
- These islands are not in synchronism
- Islands will automatically interconnect by means of synchronizers if stipulated criteria are met
- Synchronizers need typically a window of phase angle ±30 ° and ΔU within ±6 % of Un simultaneously to interconnect
- HVDC converters have no inertia but can withstand synchronizing by temporarily operating in current-control mode

HVDC Light losses



Optimized the switching pattern has reduced the station losses from 3 % ~ 0,6 %

HVDC Light, technical development 1997 - 2019

From pioneering to a main stream product

1997→ 2019 1000 times

3MW/10kV to 3000MW/535kV

LCC vs VSC station size

Pacific Intertie, Celilo Station

Approx. 310 m x 310 m

Nordlink, Wilster station

Approx. 230 m x 180 m

Station size relation VSC / LCC 50 %

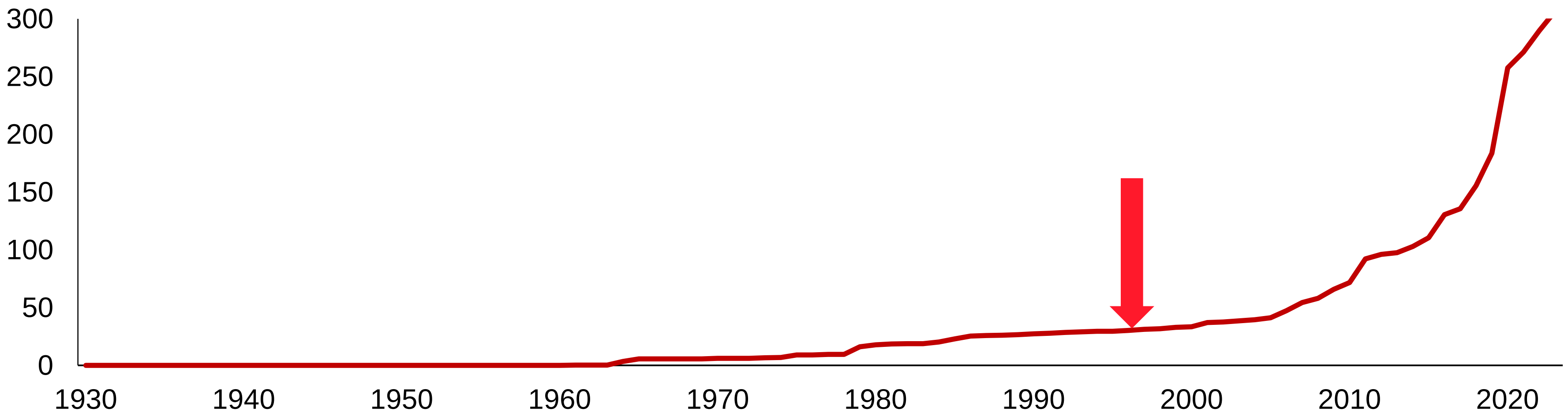
500 kV bipole up to 3 GW

From an idea to global industrialization

HVDC is the solution for today's grid challenge

HITACHI
Inspire the Next

Cumulated GW installed



1928
Dr Uno Lamm began developing HVDC in Ludvika, Sweden

1954
The world's first commercial HVDC link at Gotland, Sweden

1960s
Mercury arc valves replaced with thyristor semiconductor valves

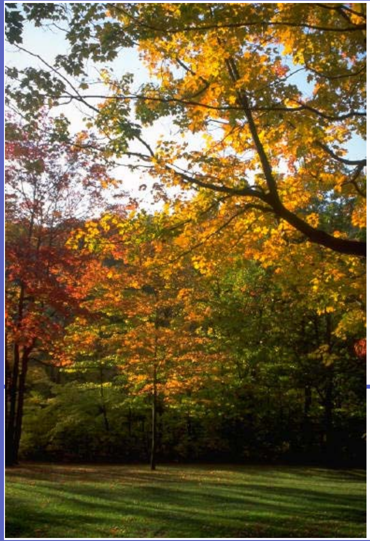
1997
The world's first VSC[1] HVDC installation

2017
VSC HVDC highest performance ever – 3,000 MW, 640 kV, 2,000 km

Exponential growth has been driven by Technical developments and Grid transformation needs

Hitachi Energy

Thank you for the attention!



Homepage: www.hitachienergy.com/hvdc