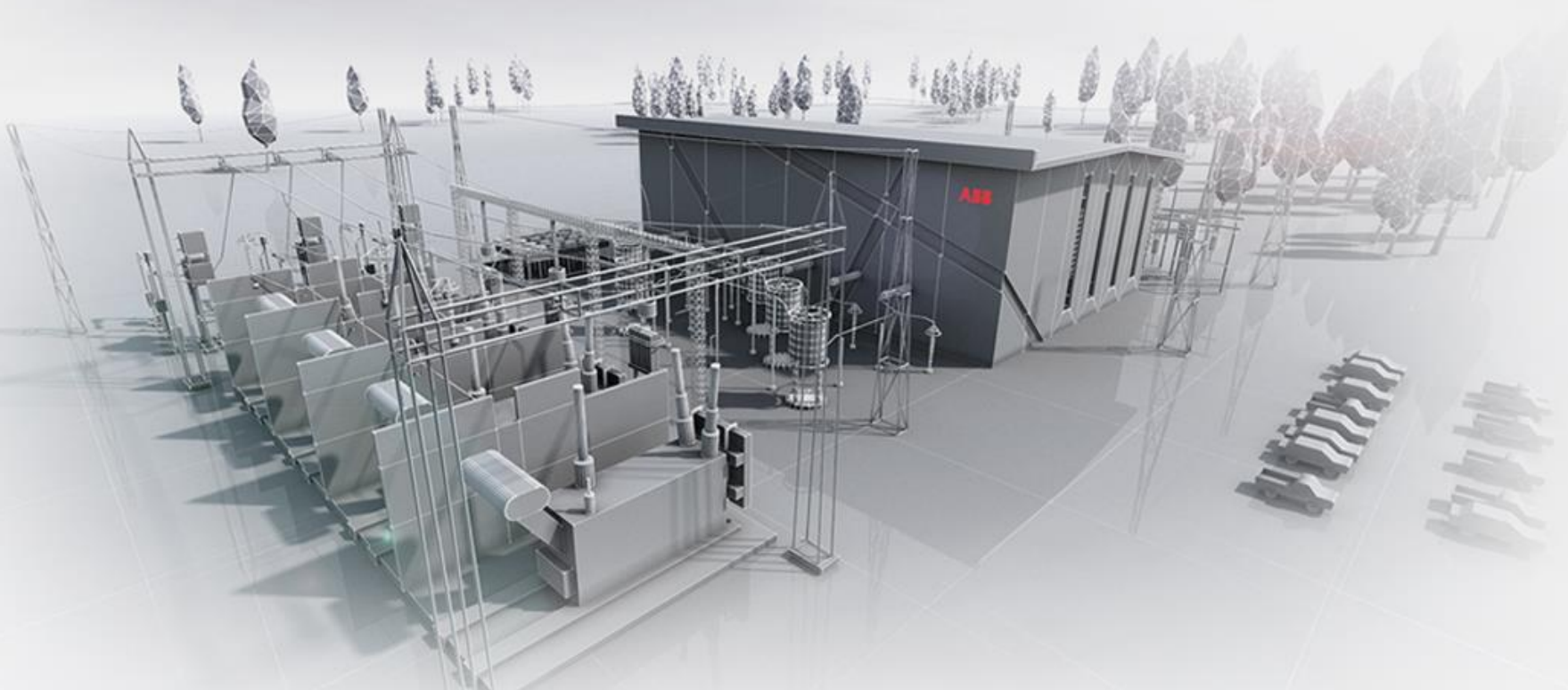


US DEPT OF ENERGY SOLID STATE POWER SUBSTATION ROADMAPPING WORKSHOP, JUNE 27-28, 2017, NORTH CHARLESTON, SC

HVDC Light ®

An example of a current application of solid state technology on the grid

Sandeep Bala, ABB Corporate Research

Outline

HVDC Light – Background & Status

Challenges

Opportunities

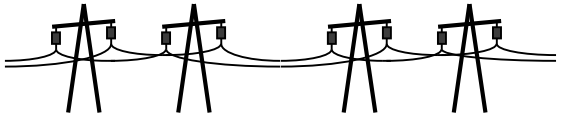
What is an HVDC transmission system ?

Customer's Grid

HVDC converter station
> 300 MW, Classic

Submarine cables

Overhead lines
Two conductors

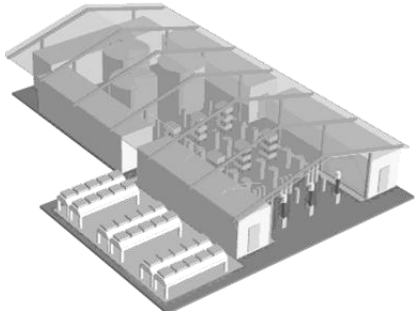


HVDC converter station
> 300 MW, Classic

Customer's Grid

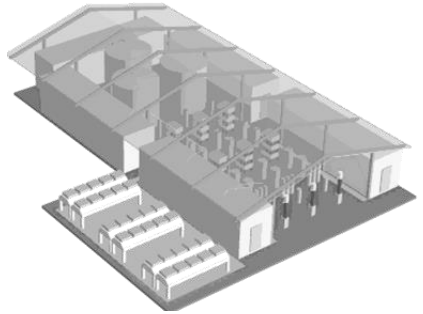
Customer's Grid

HVDC converter station
< 3,600 MW, Light



Land or submarine cables

HVDC converter station
< 3,600 MW, Light



Customer's Grid

Power / energy direction

HVDC is a growing technology

Applications

Connecting remote generation

Interconnecting grids

Offshore wind connections

DC links in AC grids

Power from shore

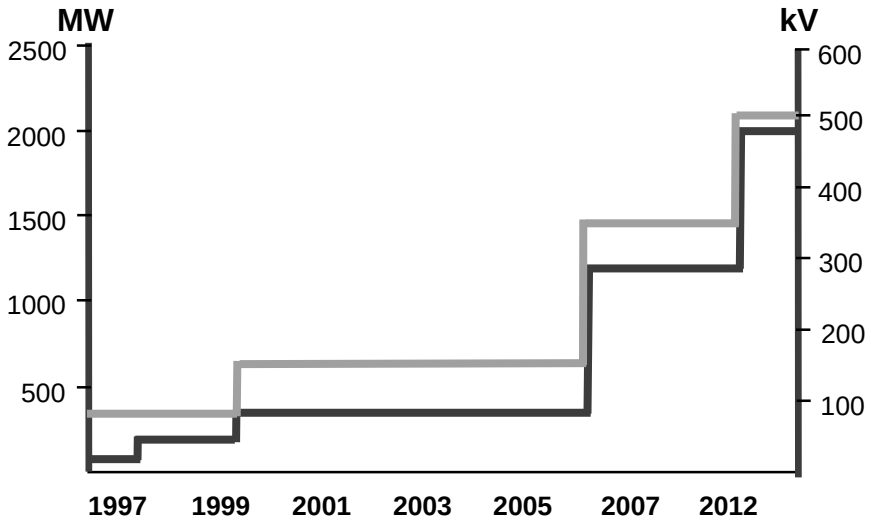
City center infeed

Connecting remote loads

Upgrades

HVDC Light

Technical development



Hällsjön
3 MW
± 10 kV

Gotland
50 MW
± 80 kV

Cross Sound
330 MW
± 150 kV

Estlink
350 MW
± 150 kV

BorWin1
400 MW
± 150 kV

Caprivi
300 MW
+ 350 kV

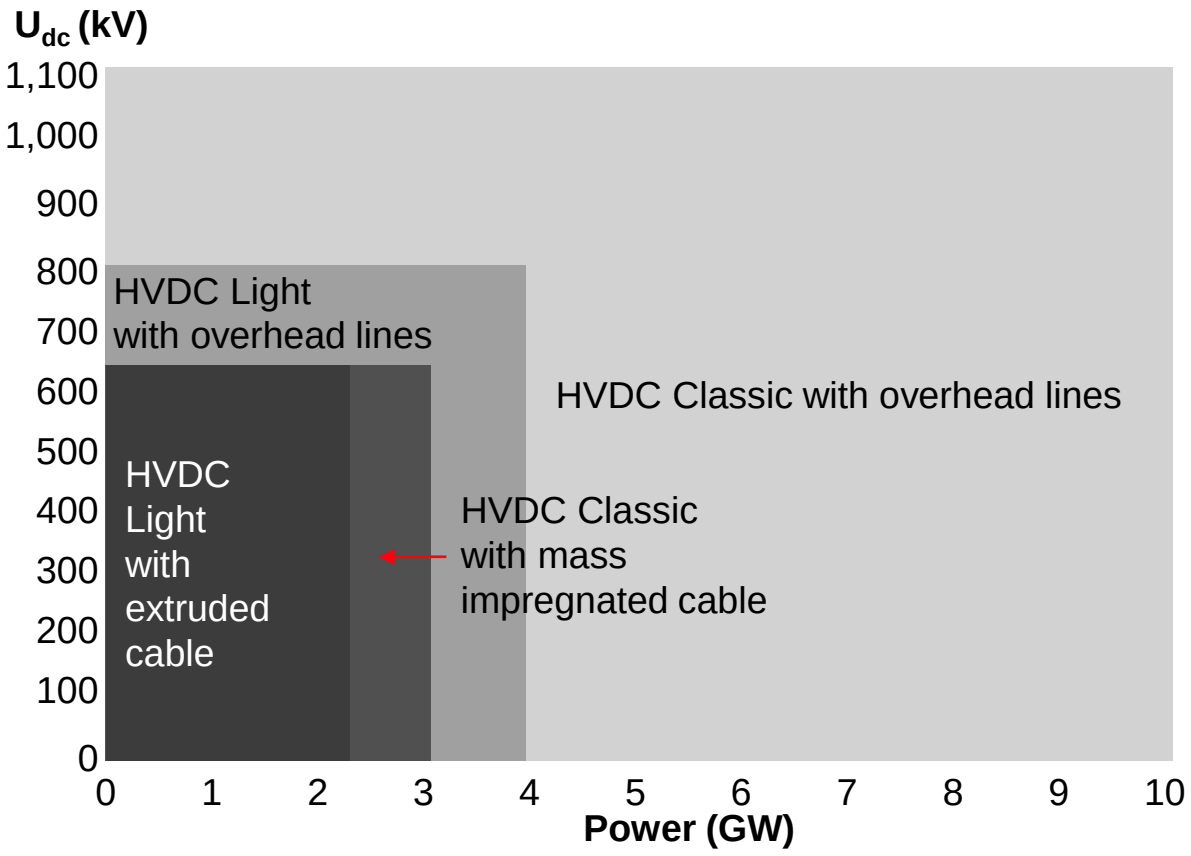
East-West
Interconnector
500 MW
± 200 kV

DolWin1
800 MW
± 320 kV

Skagerrak 4
700 MW
500 kV

HVDC technologies

Transmission capacity



Power transmission with HVDC Light

HVDC Light conceptual modules		DC Currents (I_v)			
		617 A_{dc}	1233 A_{dc}	1850 A_{dc}	2775 A_{dc}
DC Voltages (U_d)	80 kV_{dc}	M1 99 MW	M2 197 MW	M3 296 MW	M3x 444 MW
	150 kV_{dc}	M4 185 MW	M5 370 MW	M6 555 MW	M6x 833 MW
	320 kV_{dc}	M7 395 MW	M8 789 MW	M9 1184 MW	M9x 1776 MW
	500 kV_{dc}	M10 617 MW	M11 1233 MW	M12 1600 MW	M12x 2775 MW
	640 kV_{dc}	M13 789 MW	M14 1579 MW	M15 2368 MW	M15x 3552 MW

Outline

HVDC Light – Background & Status

Challenges

Opportunities

Performance

Environmental aspects

Objectives for system design

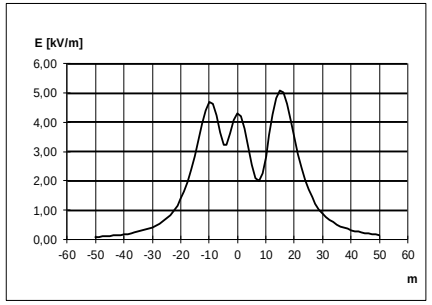
Health, safety and operational flexibility

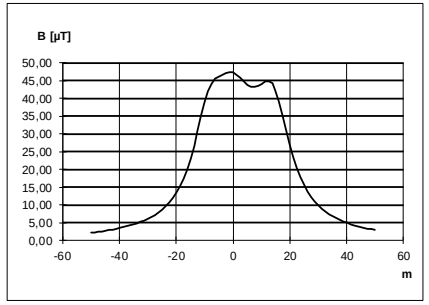
Maintainability (long maintenance-free intervals)

Low converter losses

Environmental impact: minimum impact regarding

- Field emissions
- Interference
- Noise emissions





Typical requirements

Total losses of a HVDC converter station (calculation according to IEC 61803)	<0.8%
Total availability (forced and scheduled unavailability considered)	>98.5%
Maintenance-free interval	1 – 2 years
Telephone interference (TIF)	<40
Electromagnetic compatibility (EMC)	According to Cigré TB391
Electric and magnetic fields	According to applicable standards and regulations [1]

[1)] Minimum requirements: Directive 2013/35/EU and ICNIRP Guidelines for limiting exposure to time

Outline

HVDC Light – Background & Status

Challenges

Opportunities

Mackinac

USA

Main data

Customer	ATC
Customer needs	• 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 benefits	• Enhanced network stability • Islanded operation possible • Black-start – restarting the grid after a black-out • Automatic power reduction at disturbances
Year	• 2014

Operational flexibility

Field experience from reference projects

Caprivi Link Interconnector

“The field experience in Caprivi link project shows that HVDC Light can not only operate in extremely weak AC system with SCR below one and down to zero, but also enhance the stability of the weak AC system significantly.”

“Stability enhancement and blackout prevention by VSC based HVDC”, Cigré Symposium, Bologna

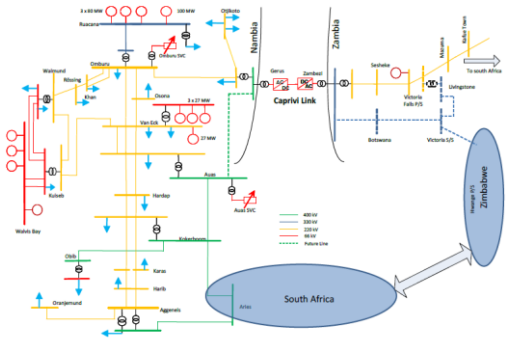


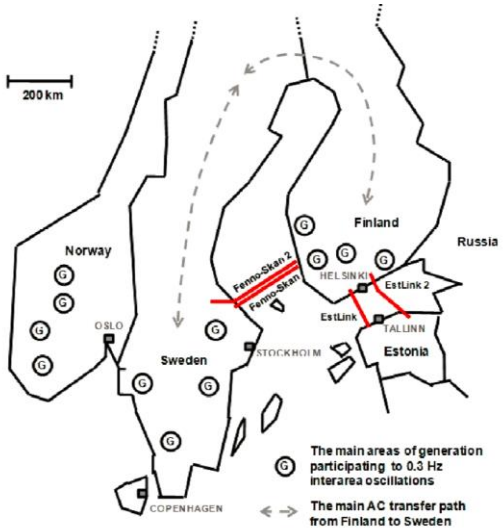
Fig. 1 Caprivilink Project and surrounding AC network configuration

Fenno-Skan

Stationary load flow optimization between Sweden and Finland

POD control for small-signal stability

In operation for over 20 years



Pacific Intertie

The ability to damp depends on the converter station location and the feedback control signals used

Most favorable with parallel connection of AC ties with an HVDC link

The Pacific HVDC Intertie – Significant improvement of the damping of the Western interconnected power system

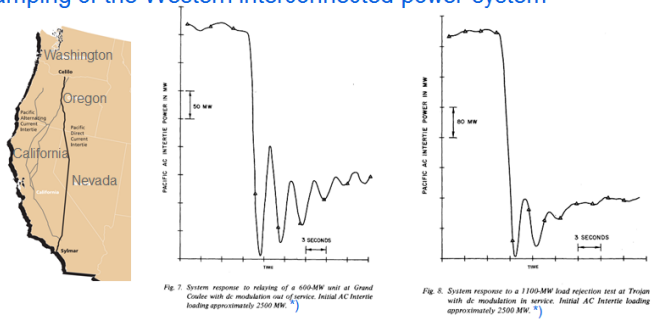


Fig. 7. System response to relaying of a 600-MW unit at Grand Coulee with dc modulation out of service. Initial AC Intertie loading approximately 2500 MW. *)

Fig. 8. System response to a 1100-MW load rejection test at Trojan with dc modulation in service. Initial AC Intertie loading approximately 2500 MW. *)

“The succesful operation of dc modulation was a key factor in permitting an increase in the rating of the Pacific AC Intertie from 2100 MW to 2500 MW”*)

*)Reference: IEEE TRA-PAS-97, No. 4, July/Aug 1978

HVDC Light an intelligent transmission device

- HVDC Light is an intelligent link for transmitting electrical power
  - Active Power can be changed
    - Very quickly – the interfacing grid sets the limits
    - A variety of static and dynamic schemes
  - Reactive Power can be changed
    - Very high dynamic response
  - Add-on features possible
    - Black start, active filtering and power oscillating damping
- VSC converters are highly controllable