High Power Converters for Efficient Transmission Solutions

Dr. Le Tang

VP & Head of Corporate Research Center

ABB Inc.

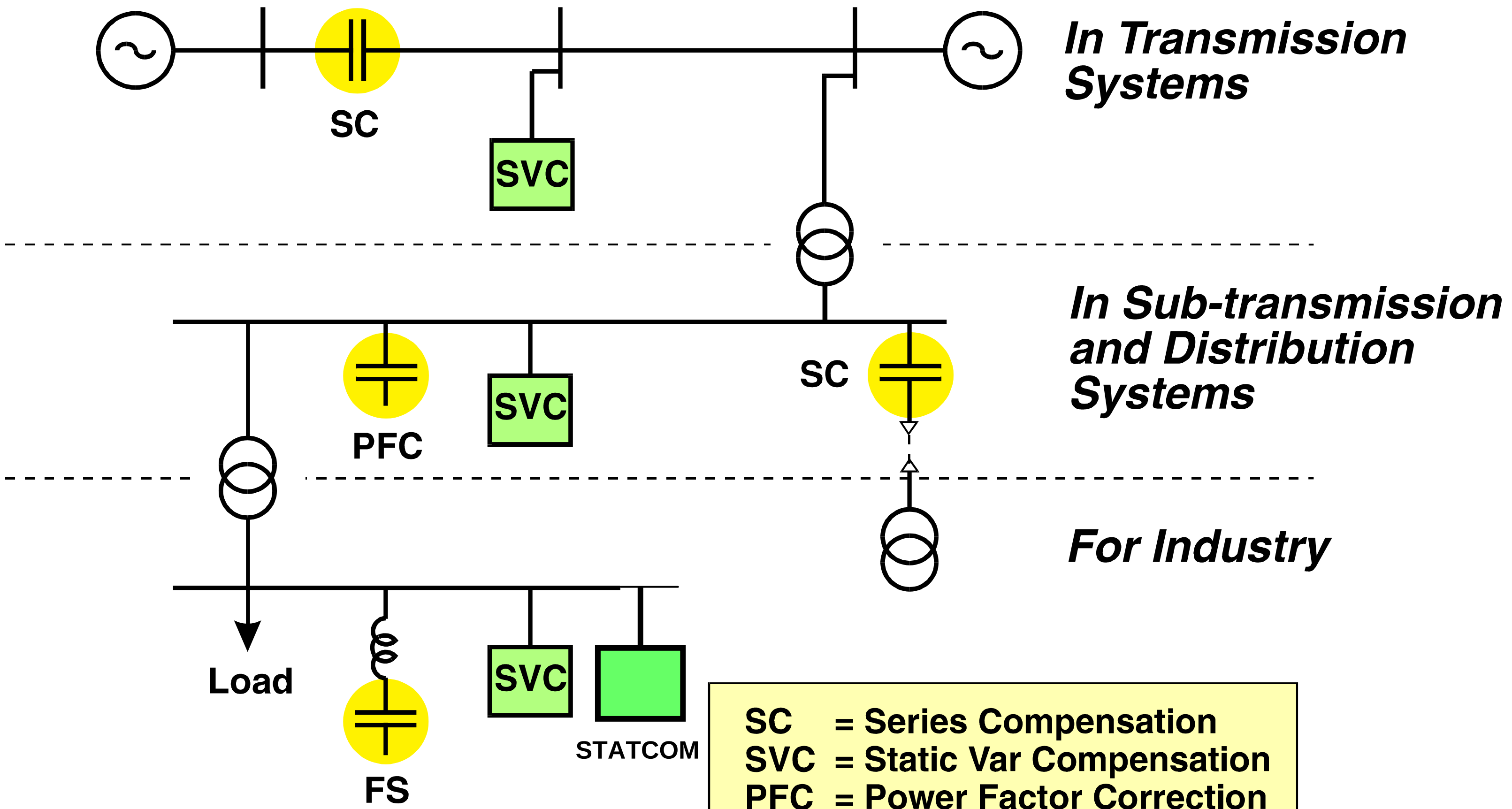
High Megawatt Power Converter Technology R&D Roadmap Workshop

April 8, 2008

FACTS Topics

- FACTS Technologies
  - Static Var Compensators - SVC
  - Series Capacitors - SC
  - Thyristor Controlled Series Capacitors - TCSC
  - Static Synchronous Compensator - STATCOM
- Selected FACTS Projects
  - STATCOM with Energy Storage

Basic FACTS Devices



SC = Series Compensation
SVC = Static Var Compensation
PFC = Power Factor Correction
FS = Filter Systems

FACTS Portfolio – Two main areas

Shunt Compensation

- SVC
- **STATCOM (SVC Light)**

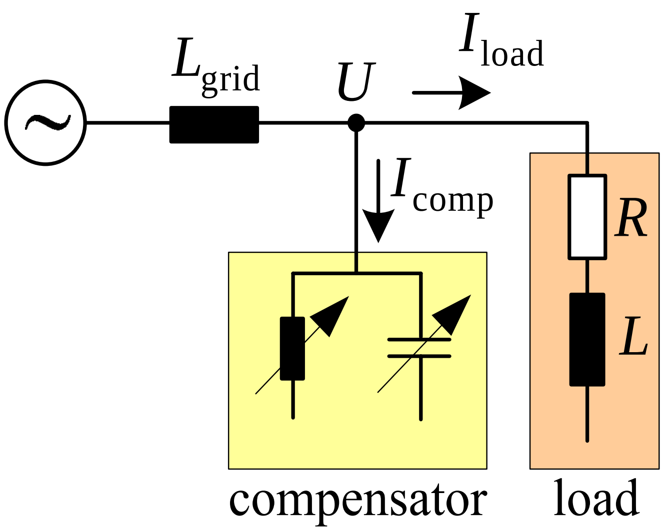
Series Compensation

- Fixed
- Controllable

Basic Controller Function

Classic SVC

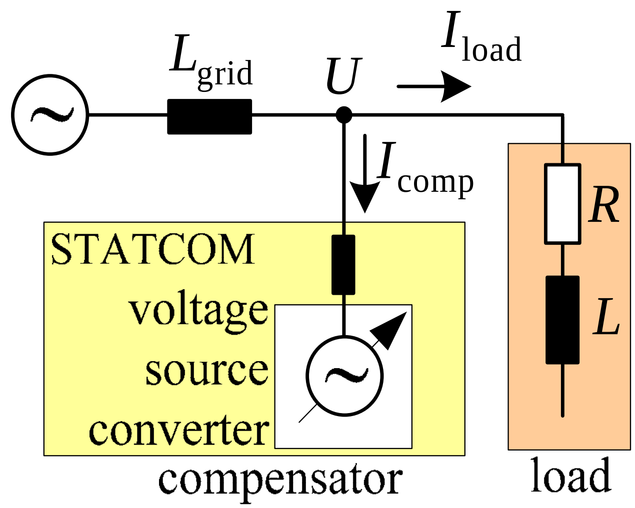
- Variable inductors and capacitors obtained by thyristors



- Q~U²
- Load balancing

STATCOM (Static Compensator)

- VSC (Voltage Source Converter) controls current through inductor



- Q~U
- High bandwidth => quicker control
- Active filtering
- Load balancing
- Flicker mitigation
- Low content of harmonics

History of ABB's SVC Light

- Manufactured 10 SVC Light

SVC Light Pilot

Hällsjön	*1997*	*3 MW*	*(pilot HVDC Light)*
Hagfors	1999	±22 MVAr	(Flicker mitigation for EAF)
Mosel	2000	±38 MVAr	(Flicker mitigation for EAF)
Eagle Pass	2000	±36 MW	(B2B with SVC priority)
Evron	2003	±16 MVAr	(Traction power supply conditioner, load balancing, harmonic filtering)
Polarit	2003	164 MVAr	(Flicker mitigation for EAF)
Holly	2004	±95 MVAr	(Utility, voltage regulation)
ZPSS	2006	164 MVAr	(Flicker mitigation for EAF)
Ameristeel	2006	64 MVAr	(Flicker mitigation for EAF)
Mesney	2007	±13 MVAr	(Traction power, load balancing, filtering)

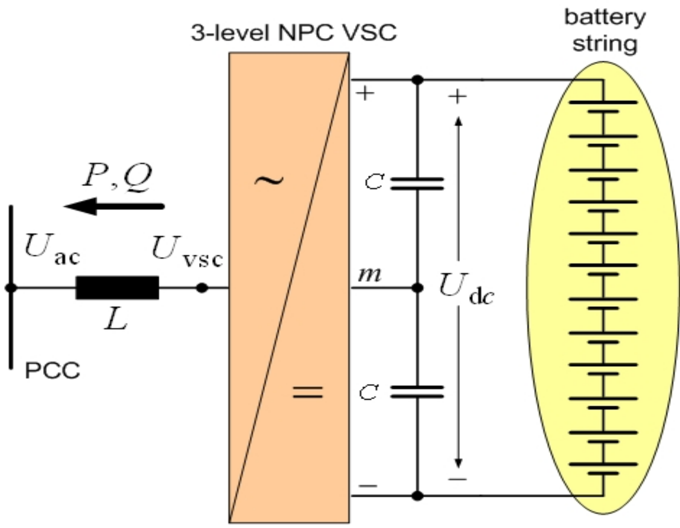
steelworks **utility** **EAF = electric arc furnace**

FACTS with Energy Storage

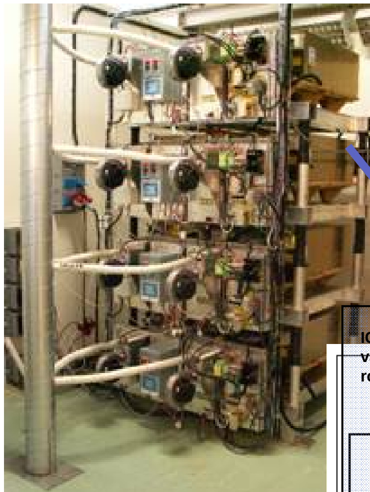
SVC Light → flicker compensation, harmonic filtering, power-factor correction, voltage regulation, load balancing

SVC Light + energy storage → **load leveling (energy)**, flicker compensation, harmonic filtering, power-factor correction, voltage regulation, load balancing, DIP mitigation

Increased functionality

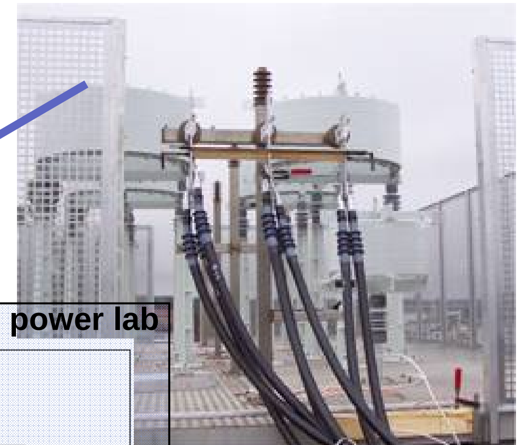


Laboratory Demonstration 2005/2007

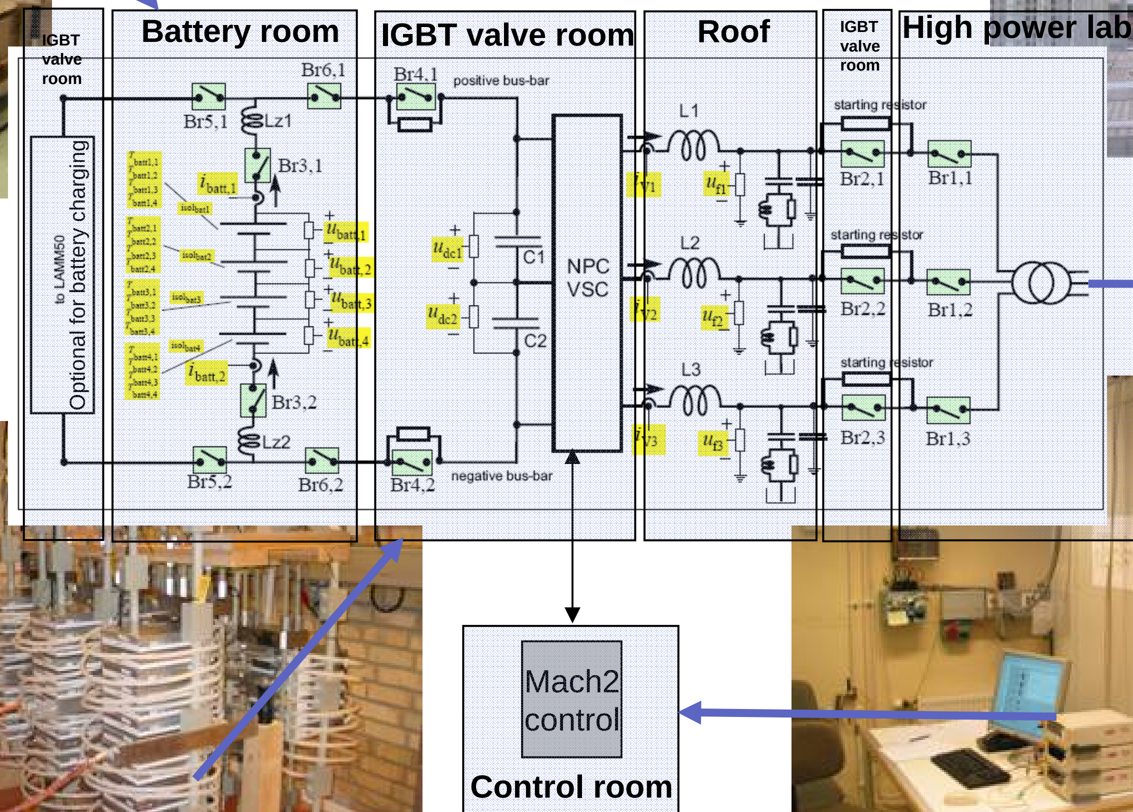


Udc=6 kV

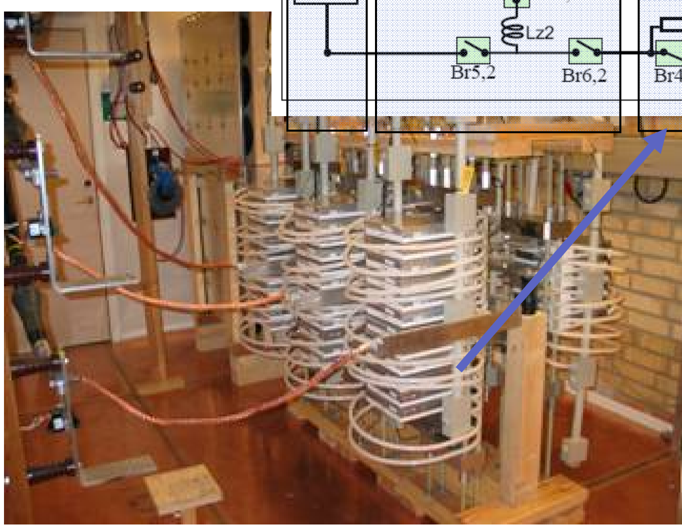
world record in battery voltage

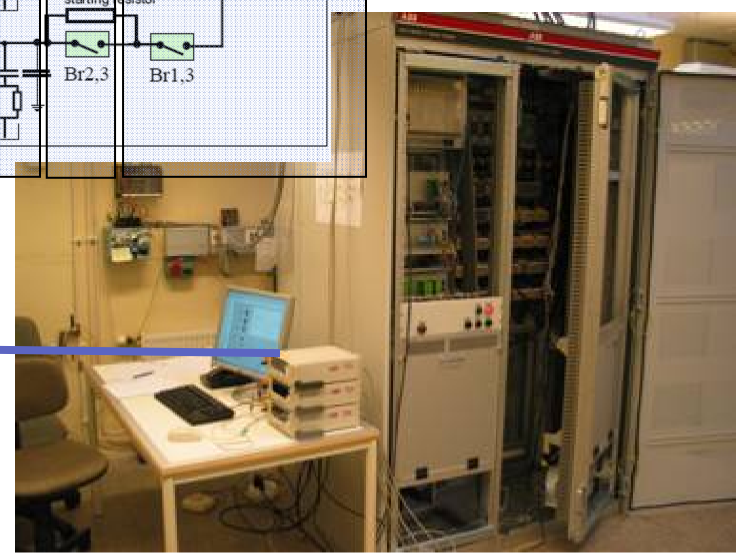


4 ZEBRA batteries á 1500V, 32Ah



6.3 kV net

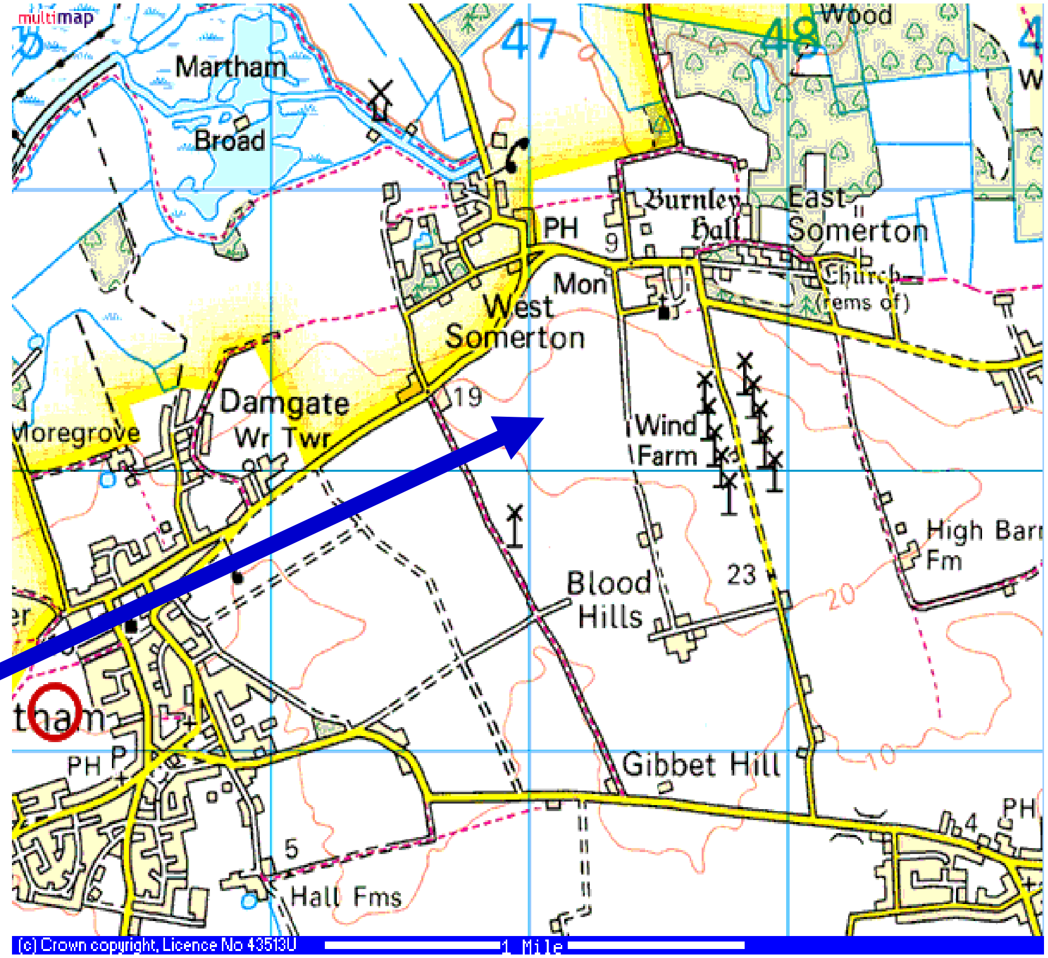




SVC Light Energy Storage R&D Project

- The SVC Light Energy Storage will be located in UK.
- In close vicinity to the SVC Light Energy Storage two Wind Farms are connected to the 11 kV distribution system.

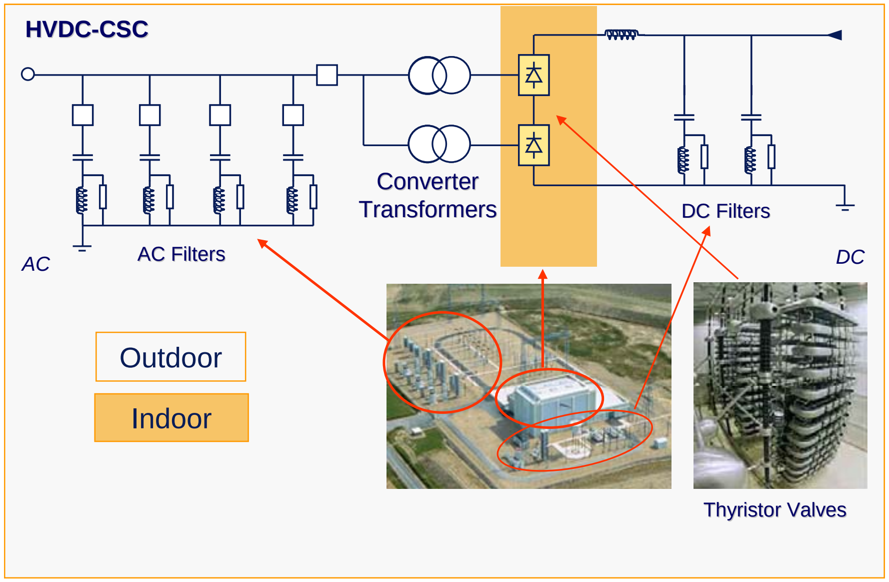
SVC Light Energy Storage

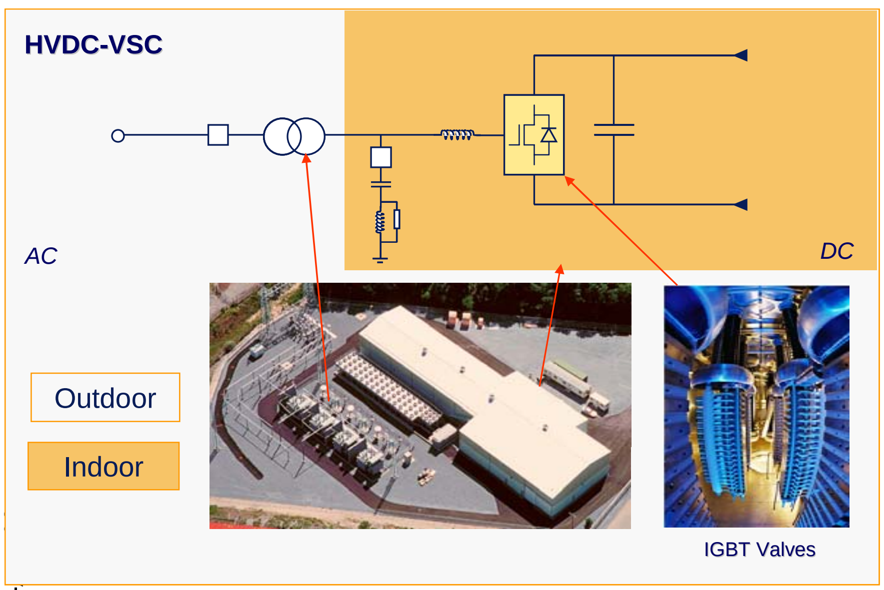


HVDC Topics

- HVDC Technologies
  - Converter Stations
  - Cables
- Selected HVDC Projects
  - Estonia – Finland (Estlink) black start field tests
  - Norway – Netherlands (Norned)
  - Outaouais
  - E.ON, Borkum 2 - 400 MW Offshore Wind
  - Caprivi Link
  - Xiangjiaba – Shanghai, ± 800 kV, 6400 MW
- Vision
  - What's New

Core HVDC Technologies





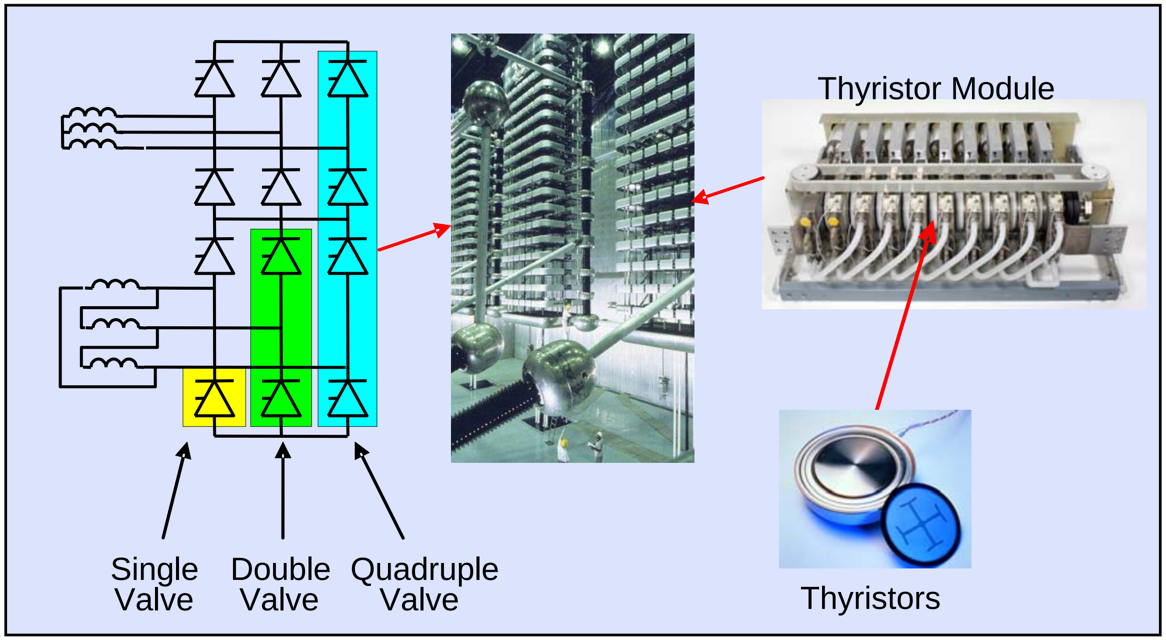
HVDC Classic

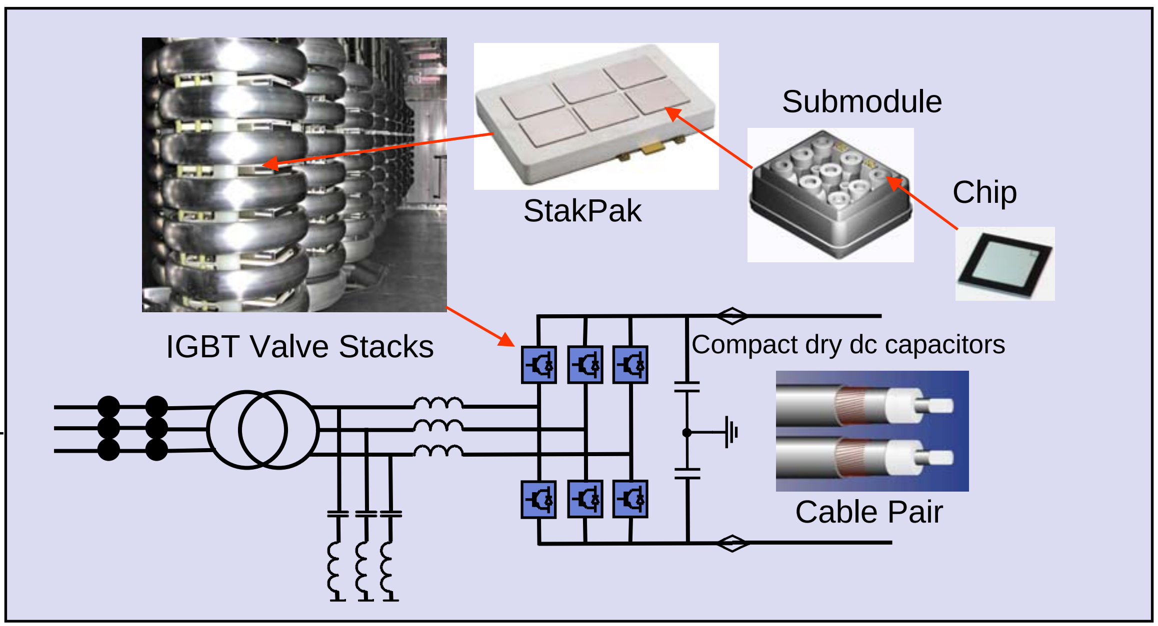
- Current source converters
- Line-commutated thyristor valves
- Requires 50% reactive compensation (35% HF)
- Converter transformers
- Minimum short circuit capacity > 2x converter rating, > 1.3x with capacitor commutation

HVDC Light

- Voltage source converters
- Self-commutated IGBT valves
- Requires no reactive power compensation (~15% HF)
- Standard transformers
- Weak system, black start
- U/G or OVHD
- Radial wind outlet regardless of type of wind T-G

HVDC Converter Arrangements





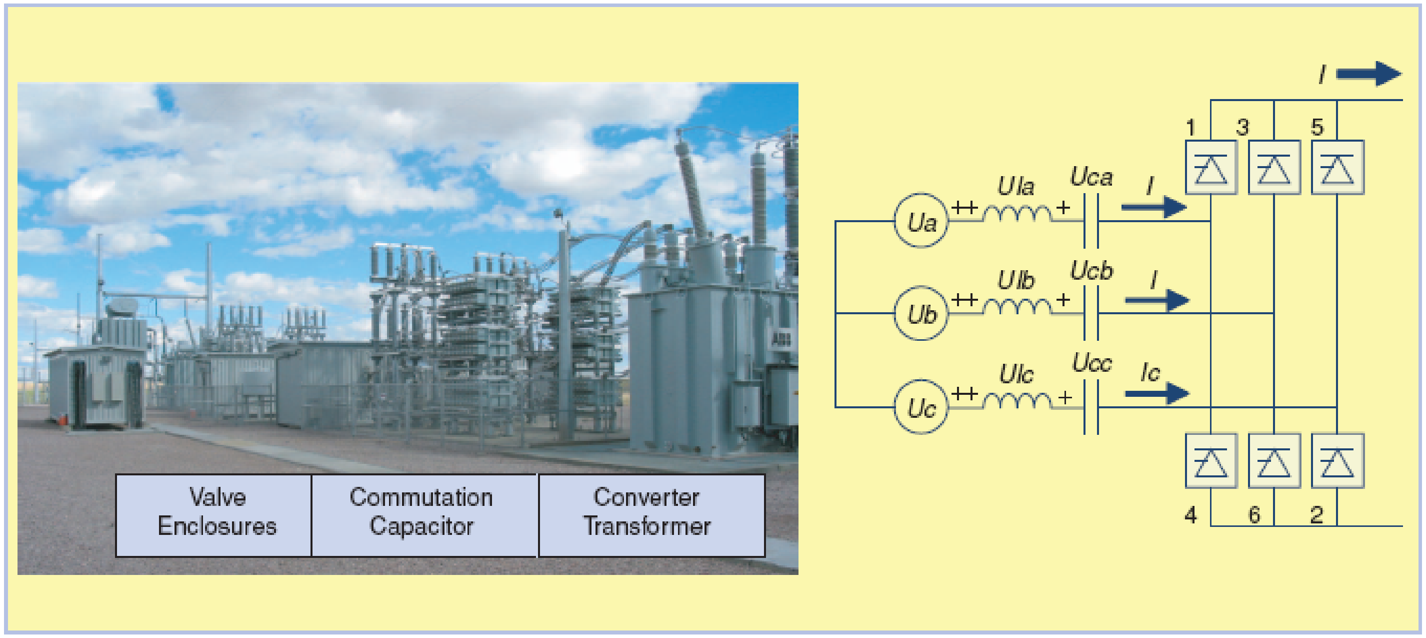
HVDC Classic

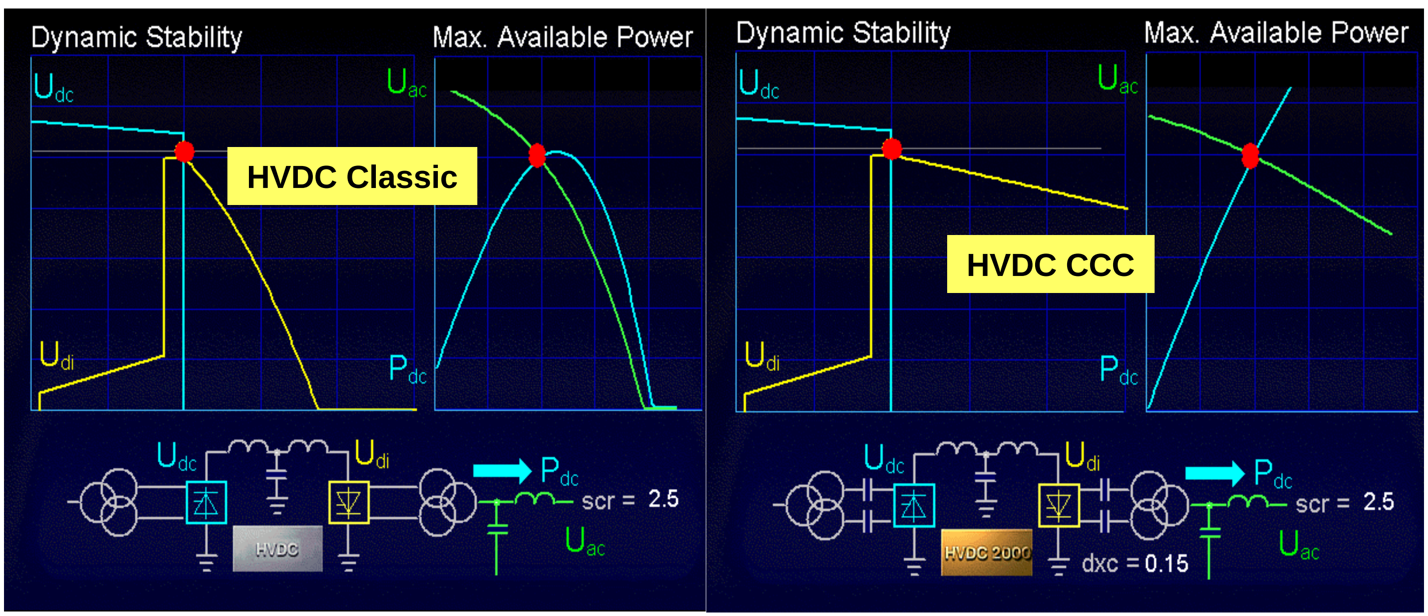
- Thyristor valves
- Thyristor modules
- Thyristors
- Line commutated

HVDC Light

- IGBT valves
- IGBT valve stacks
- StakPaks
- Submodules
- Self commutated
- Compact dry dc capacitors

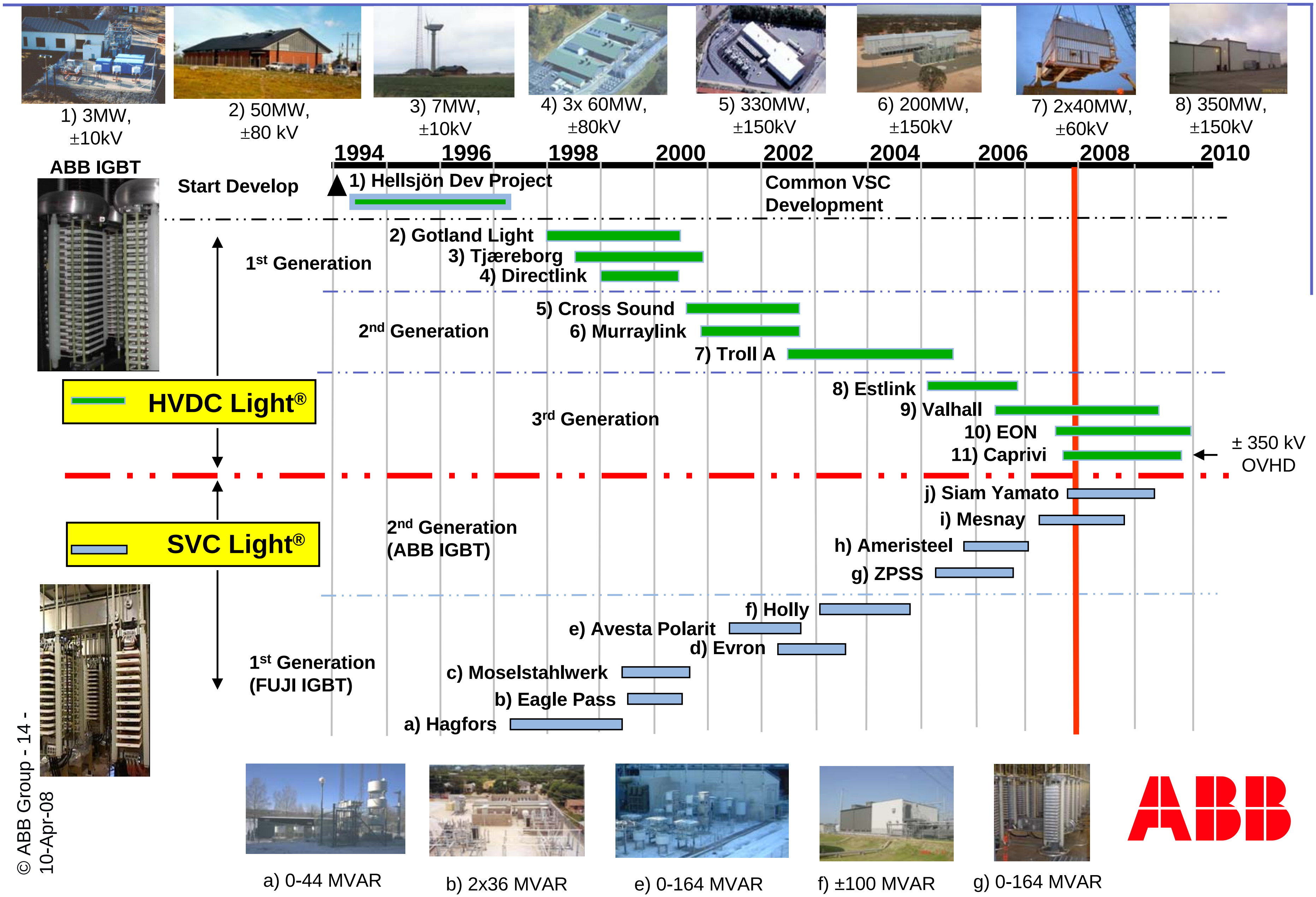
Modular Back-to-Back CCC Asynchronous Tie



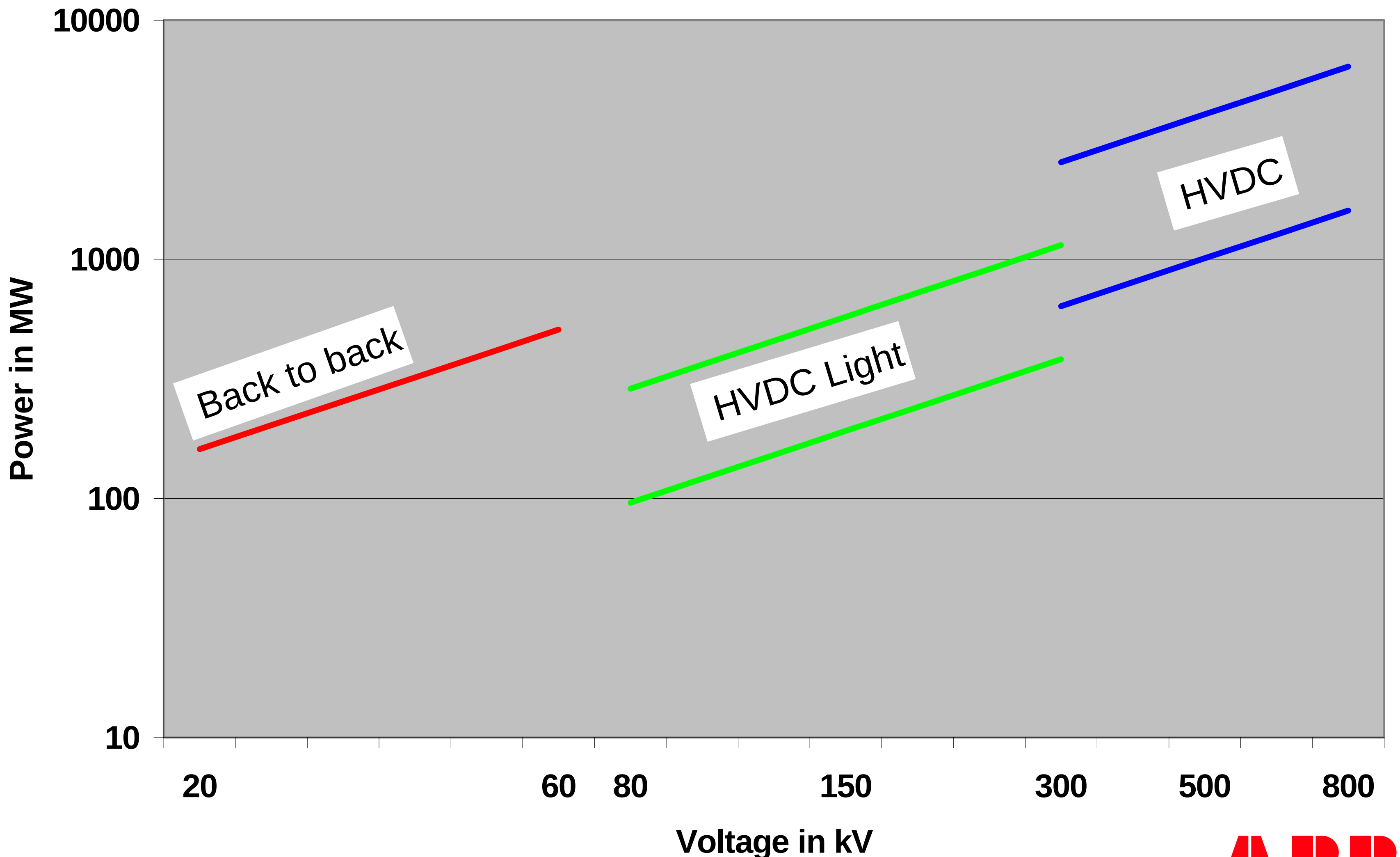


- Improved stability for weak systems due to commutation capacitor
- Higher power for given location
- Simplified reactive power control
- Garibi: 4x550 MW
- Rapid City Tie: 2x100 MW
- Modular design for shorter construction time
- Least expensive, most efficient asynchronous tie technology

Maturation of HVDC & SVC Light



Power Ranges HVDC-Classic and HVDC-Light



Mass-Impregnated Paper & Solid Dielectric XLPE Cables

HVDC Classic

- Type tested to 500 kV
- Insulation, lapped mass-impregnated oil paper
- Medium/high weight
- Tailored joints (5 days/joint handcrafted in field, impractical for long distance land cable installation)

HVDC Light

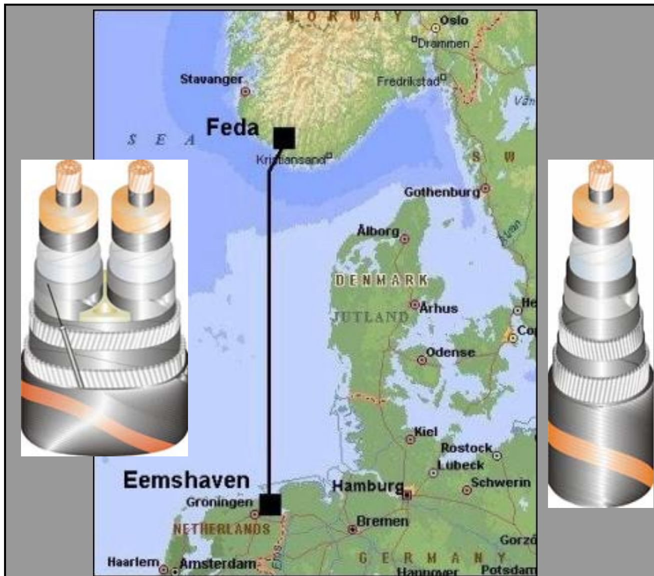
- Type tested to 320 kV
- XLPE insulation
- Low/medium weight
- Pre-molded joints (practical for long distance land cable installation)

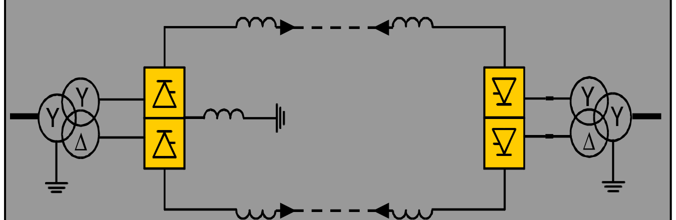
ABB's cable factory in Sweden

Estlink – HVDC Light between Estonia & Finland

Client:	Nordic Energy Link, Estonia
Contract signed:	April 2005
In service:	November 2006
Project duration:	19 months
Capacity:	350 MW, 365 MW low ambient
AC voltage:	330 kV at Harku
	400 kV at Espoo
DC voltage:	±150 kV
DC cable length:	2 x 105 km (31 km land)
Converters:	2 level, OPWM
Special features:	Black start Estonia, no diesel
Rationale:	Electricity trade
	Asynchronous Tie
	Long cable crossing
	Dynamic voltage support
	Black start

Submarine Cable: NorNed Cable HVDC Project





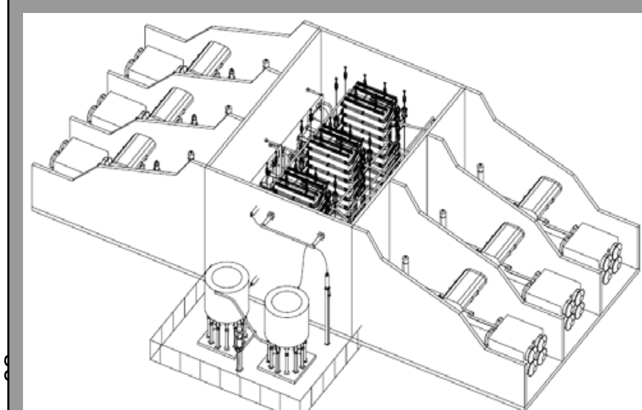
Scope

- 700 MW HVDC cable interconnection Norway - Netherlands
- ± 450 kV monopole mid-point ground (900 kV converters)
- Cable length: 2 x 580 km
- Sea depth: up to 480 meters
- 400 kV ac voltage at Eemshaven
- 300 kV ac volgage at Freda

Project Basis

- Customer: Statnett (NOR), Tennet (NLD)
- Asynchronous networks, long cable
- Power control suits markets
- Project start: January 2005
- Project duration: ~ 3 years

Outaouais Asynchronous Tie- Summary



Scope

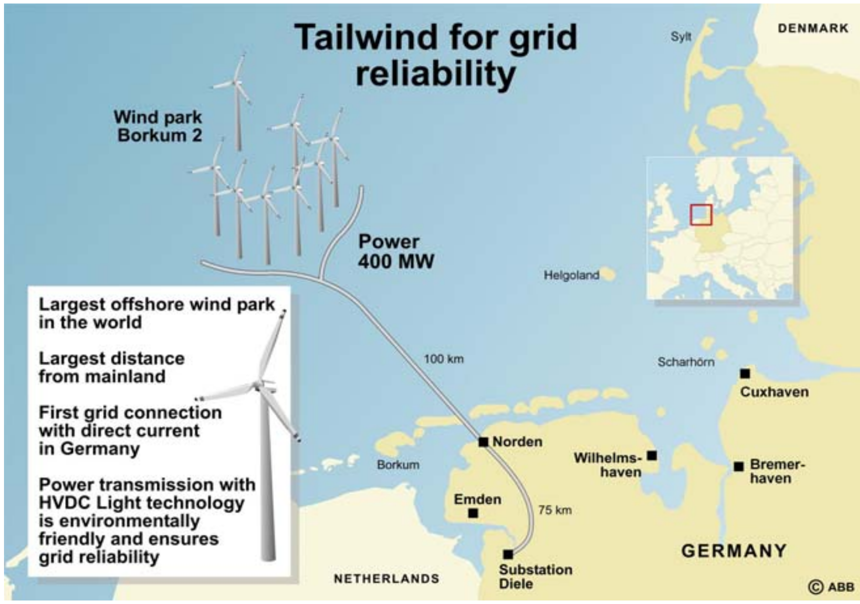
- 1250 MW HVDC B t B Interconnection Québec-Ontario
- Two independent converters of 625 MVA
- Includes 14 x 250 MVA 1-phase converter transformers

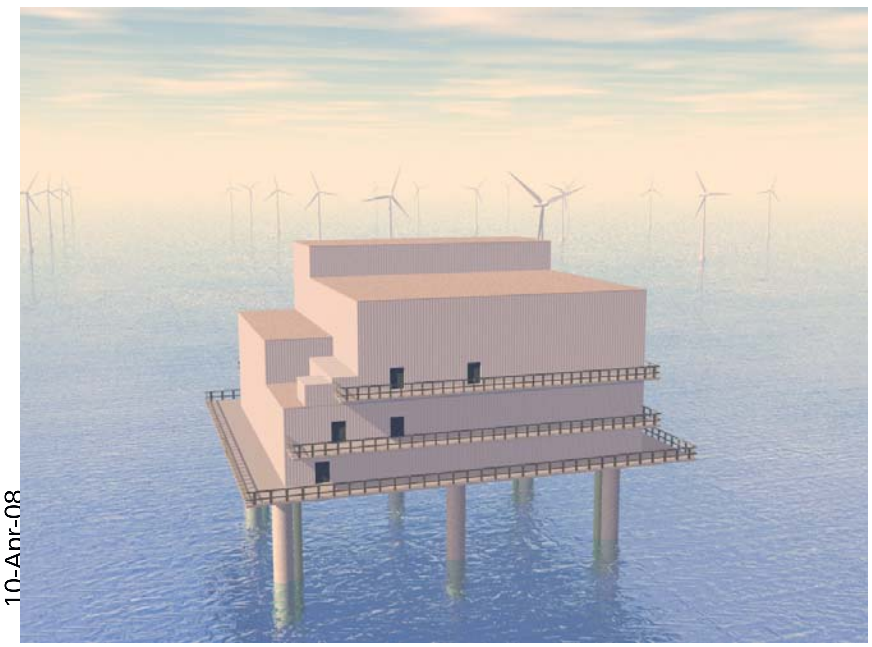
Project Basis

- Customer: Hydro-Québec (HQ)
- Project to export power from Québec to Ontario (Hydro Québec and Hydro One)
- Ontario gets access to clean hydroelectric power during peak times and decreases dependency on coal from US
- HQ sells at peak and buys at low (pump storage)
- Provides stability and reliability to both grids

ABB

Borkum 2, E.ON Netz





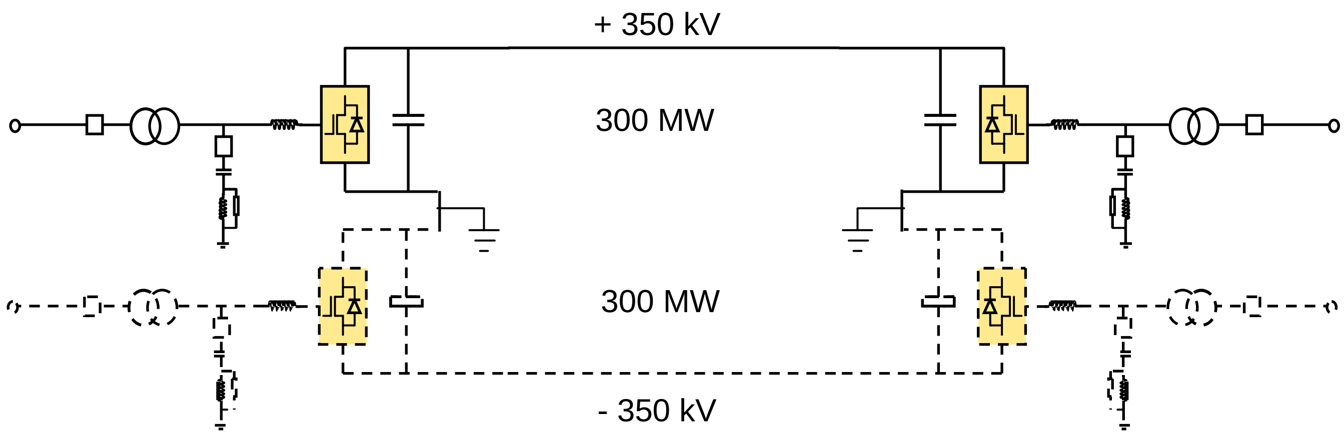
Scope

- 400 MW HVDC Light Offshore Wind, North Sea - Germany
- ±150 kV HVDC Light Cables (route = 130 km by sea + 75 km by land)
- Serves 80 x 5 MW offshore wind turbine generators
- Builds upon HVDC Light experience with wind generation at Tjaerborg and Gotland
- Controls collector system ac voltage and frequency

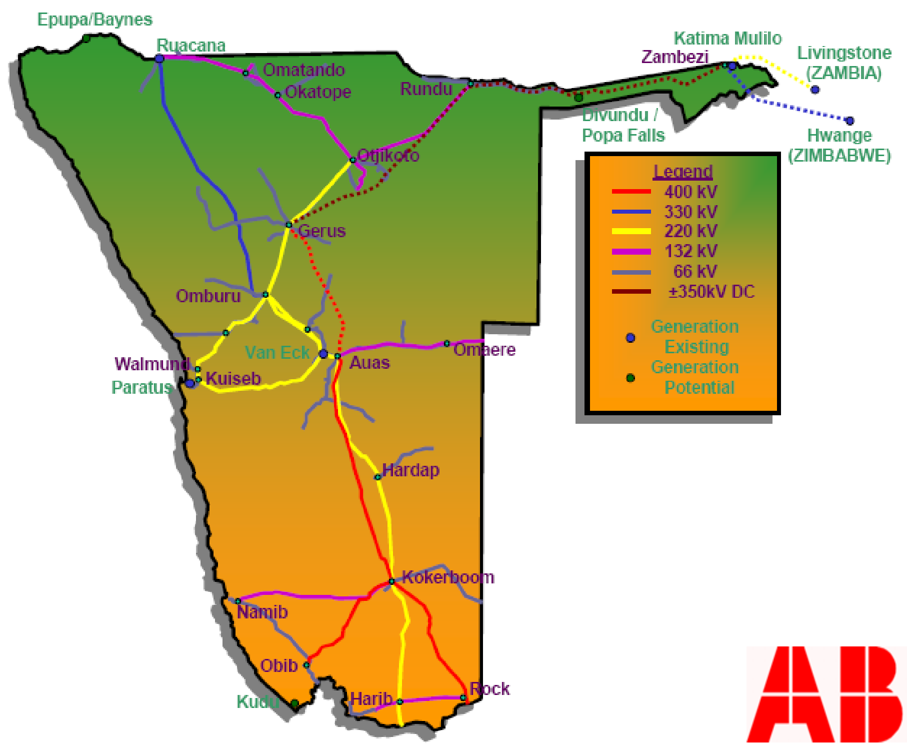
Project Basis

- Customer: E.ON Netz GmbH
- Project serves 80 x 5 MW offshore wind turbine generators
- Germany gets access to clean wind power with higher capacity factor than land based wind generation
- Provides stability and reliability to receiving system
- 24 month delivery time
- Saves 1.5 M tons CO_2/year

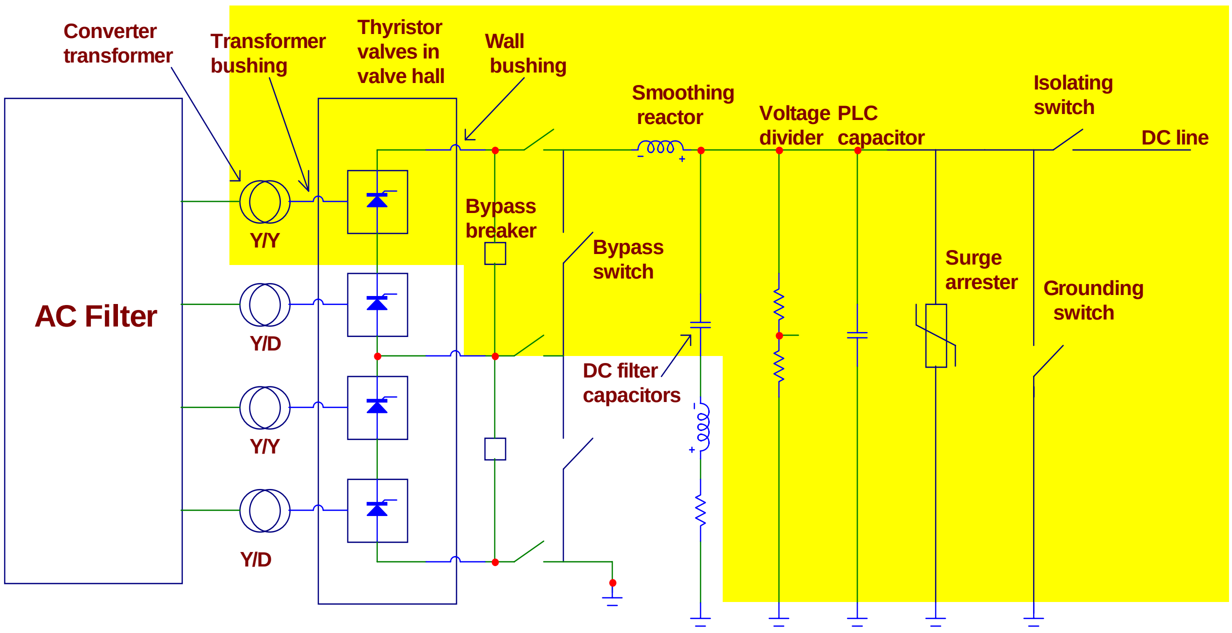
Caprivi Link, NamPower



- 300 MW, 350 kV HVDC Light Monopole with ground electrodes
- Expandable to 600 MW, ± 350 kV Bipole
- ± 350 kV HVDC Overhead Line
- Links Caprivi region of NE Namibia with power network of central Namibia and interconnects with Zambia, Zimbabwe, DR Congo, Mozambique
- Improves voltage stability and reliability
- Length of 970 km DC and 280 km (400kV) AC



800 kV HVDC Transmission

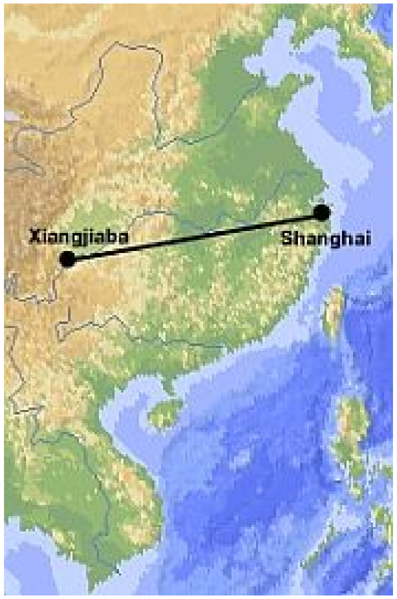


Pole equipment exposed to 800 kV dc

Long term test circut for 800 kV HVDC

± 800 kV, 6400 MW (4 x 1600) HVDC Link

Xiangjiaba - Shanghai ± 800 kV UHVDC Project



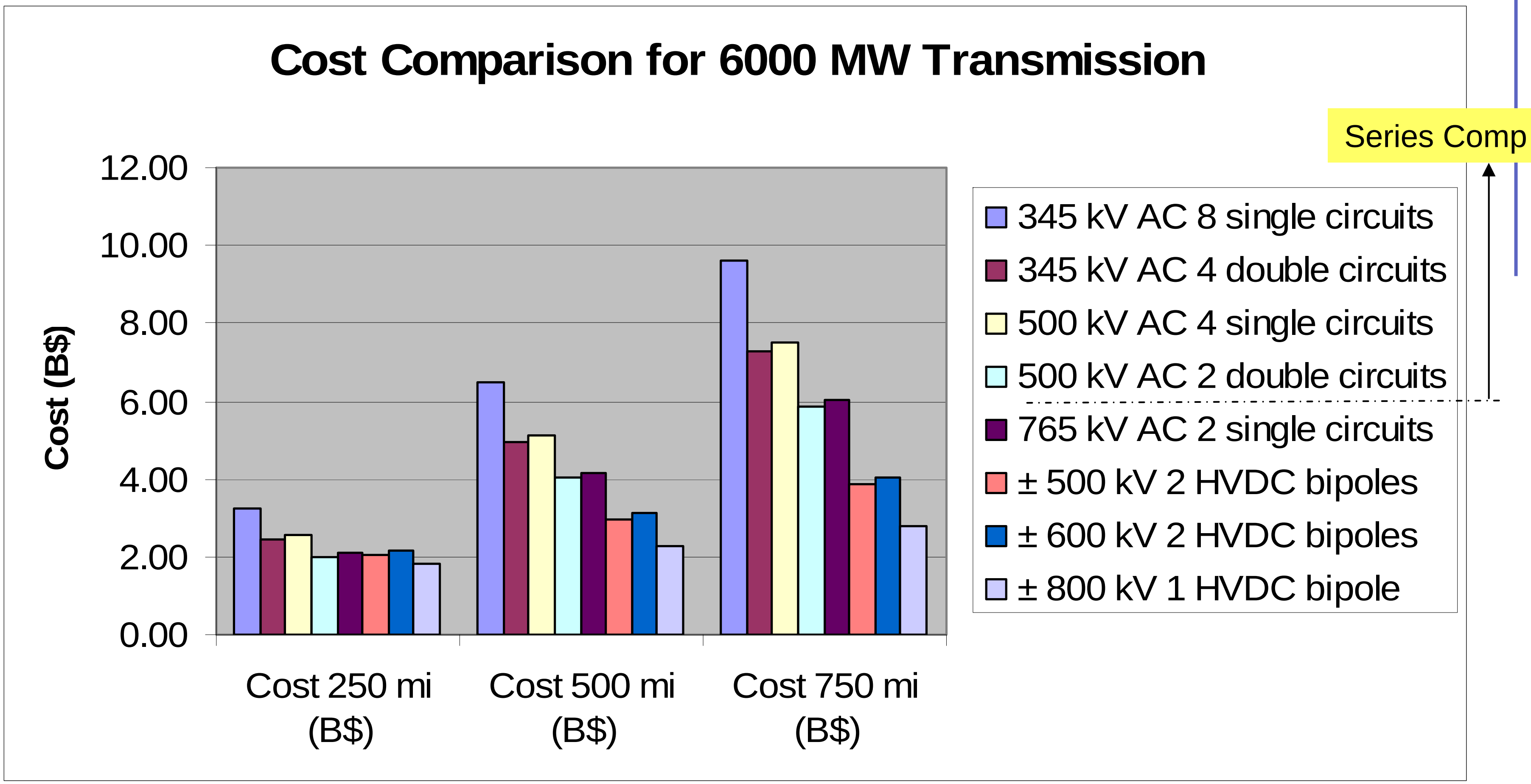
Scope

- Power: 6400 MW (4 x 1600 MW converters)
- ± 800 kV DC transmission voltage
- System and design engineering
- Supply and installation of two ± 800 kV converter stations including 800 kV HVDC power transformers and switchgear
- Valves use 6 inch thyristors and advanced control equipment

Project Basis

- Customer: State Grid Corporation of China
- Project delivers 6400 MW of Hydro Power from Xiangjiaba Power Plant in SW China
- Length: 2071 km (1286 mi), surpasses 1700 km Inga-Shaba as world's longest
- Pole 1 commissioned in 2010, pole 2 in 2011
- AC voltage: 525 kV at both ends

Cost of 6000 MW Transmission Alternatives



Note: Transmission line and substation costs based on Frontier Line transmission subcommittee and NTAC unit cost data.

Summary of Power Conversion Requirements

- High rating semiconductor devices
- High reliability
- Modularity
  - Flexible for reconfiguration and expansion
  - Spare parts
- Small footprint
- Transformer less connection
- Controllability, dynamic response (4Q operation), and black start
- Less filtering requirement
- Low losses
- Self-diagnostic/Self-healing
- Cost

Power and productivity
for a better world™