High Power Converters for Efficient Transmission Solutions

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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

In Transmission Systems

In Sub-transmission and Distribution Systems

For Industry
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~U^2
- 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
- **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)*

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### steelworks  utility  EAF = electric arc furnace
FACTS with Energy Storage

- flicker compensation
- harmonic filtering
- power-factor correction
- voltage regulation
- load balancing

SVC Light

Increased functionality

SVC Light + energy storage

load leveling
(energy)
- flicker compensation
- harmonic filtering
- power-factor correction
- voltage regulation
- load balancing
- DIP mitigation

3-level NPC VSC

battery string

PCC

$U_{ac}$

$U_{vsc}$

$L$

$P, Q$

$U_{dc}$
Laboratory Demonstration 2005/2007

- 4 ZEBRA batteries à 1500V, 32Ah

- Udc=6 kV, world record in battery voltage

- 6.3 kV net

- Control room

- Mach2 control

- Battery room
- IGBT valve room
- Roof
- High power lab
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.
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

ABB IGBT

Start Develop

1st Generation

2nd Generation

3rd Generation

Common VSC Development

1) 3MW, ±10kV
2) 50MW, ±60kV
3) 7MW, ±10kV
4) 3x 60MW, ±80kV
5) 330MW, ±150kV
6) 200MW, ±150kV
7) 2x40MW, ±60kV
8) 350MW, ±150kV

3MW, ±10kV
50MW, ±60kV
7MW, ±10kV
3x 60MW, ±80kV
330MW, ±150kV
200MW, ±150kV
2x40MW, ±60kV
350MW, ±150kV

HVDC Light®

SVC Light®


1) Hellsjön Dev Project
2) Gotland Light
3) Tjæreborg
4) Directlink
5) Cross Sound
6) Murraylink
7) Troll A
8) Estlink
9) Valhall
10) EON
11) Caprivi
8) Estlink
9) Valhall
10) EON
11) Caprivi

± 350 kV

±350 kV
OVHD

1) 3MW, ±10kV
2) 50MW, ±60kV
3) 7MW, ±10kV
4) 3x 60MW, ±80kV
5) 330MW, ±150kV
6) 200MW, ±150kV
7) 2x40MW, ±60kV
8) 350MW, ±150kV

ABB IGBT

1st Generation (FUJI IGBT)

2nd Generation (ABB IGBT)

3rd Generation

± 350 kV

±350 kV
OVHD

1st Generation

2nd Generation

3rd Generation

± 350 kV

±350 kV
OVHD

a) Hagfors
b) Eagle Pass
c) Moselstahlwerk
d) Evron
e) Avesta Polarit
f) Holly
g) ZPSS
h) Ameristeel
i) Mesnay
j) Siam Yamato

a) 0-44 MVAR
b) 2x36 MVAR
e) 0-164 MVAR
f) ±100 MVAR
g) 0-164 MVAR
Power Ranges HVDC-Classic and HVDC-Light

- Voltage in kV
- Power in MW

- HVDC
- Back to back
- 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 voltage at Freda

Project Basis
- Customer: Statnett (NOR), Tenet (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
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 CO2/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

Long term test circuit 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
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