Dr. Athanasios Krontiris, Herbstsitzung des AKE in der DPG, Bad Honnef, 20. Oktober 2017

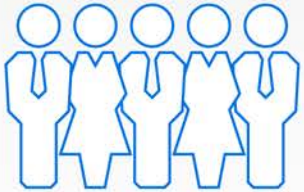
Von HGÜ zu UHGÜ

Entwicklungen und Perspektiven in der großräumigen Gleichstromübertragung

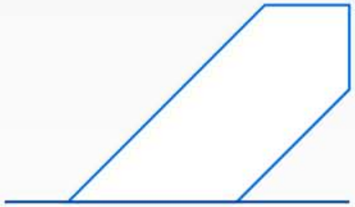
Power and productivity
for a better world™

A global leader in power and automation technologies
Leading market positions in main businesses

~150,000



employees



$42 billion

In revenue (2013)

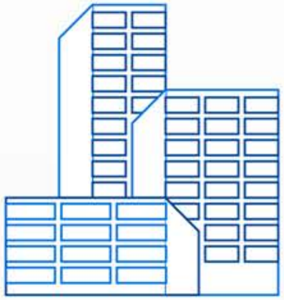
Present in

+100

countries

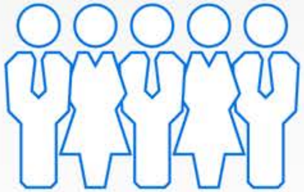
Formed in

1988

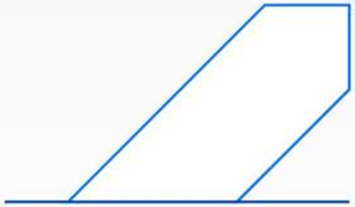


merger of Swiss (BBC, 1891) and Swedish (ASEA, 1883) engineering companies

HVDC at a glance



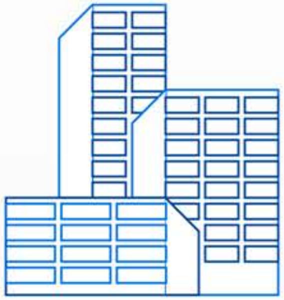
~1,500 employees



$1 billion

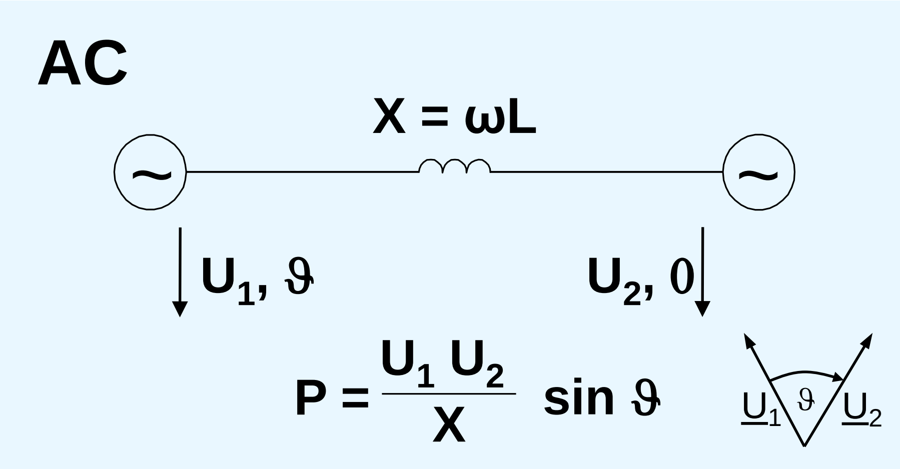
In revenue
(2013)

Projects
Ongoing
13
Delivered
~110



Present in
5 countries
9 countries with
service

Introduction
Drehstrom- versus Gleichstromübertragung



$$P = \frac{U_1 U_2}{X} \sin \vartheta$$

Blindleistung

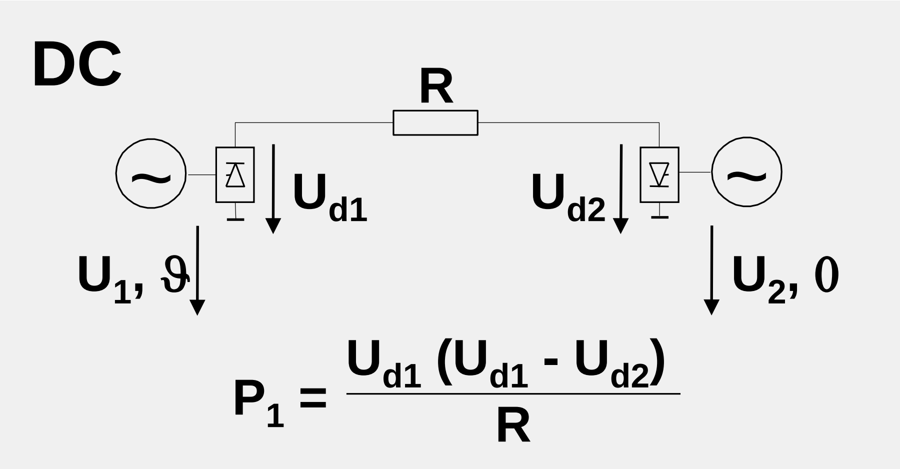
Leistungsübertragung abhängig vom Leitungswinkel ϑ

Stabilität der Wirkleistungsübertragung abhängig vom Leitungswinkel

Kurzschlussstrombegrenzung durch Reaktanzen

Massenträgheit wirksam

Skin-Effekt



$$P_1 = \frac{U_{d1} (U_{d1} - U_{d2})}{R}$$

Keine Blindleistung ⇒ auch Kabel über große Entfernungen einsetzbar

Leistungsübertragung abhängig von Spannungsdifferenz

Stabilität unabhängig vom Leitungswinkel (keine Stabilitätsprobleme)

Kurzschlussstrombegrenzung durch ohmsche Widerstände

Leistungsflussregelung

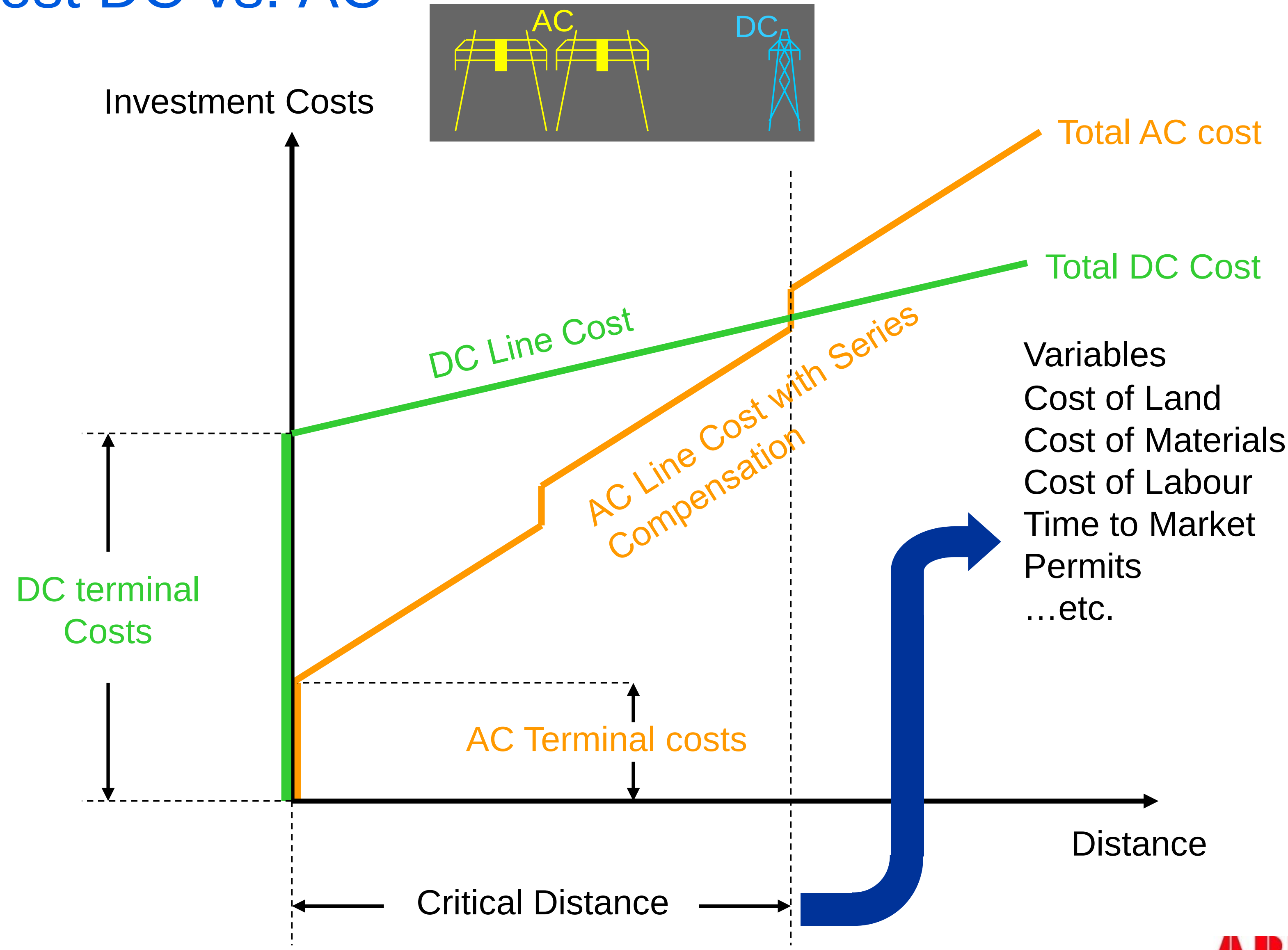
Kein Skin-Effekt

Introduction
Bewährte Technik für effiziente Fernübertragung

Beispiel für eine HGÜ-Ventilhalle.

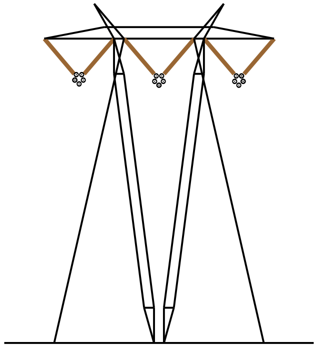
- Bei einer HGÜ wird Drehstrom gleichgerichtet, übertragen und wieder in Drehstrom umgewandelt
- Vorteile:
  - Geringe Verluste (Gleichstrom)
  - Keine Längenbeschränkung, keine Stabilitätsprobleme
  - Kabel über große Entfernung einsetzbar, da kein Blindleistungsbedarf
- Nachteile:
  - Basiskosten für Umrichterstationen → erst bei größeren Entfernungen wirtschaftlich interessant (auf See: ab ca. 80 km, an Land ab mehreren 100 km)

Introduction
Total cost DC vs. AC

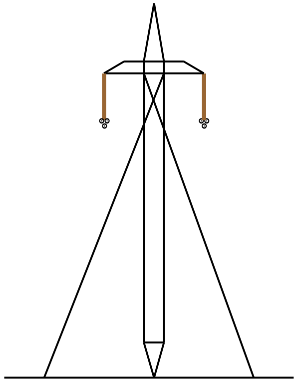


Variables
Cost of Land
Cost of Materials
Cost of Labour
Time to Market
Permits
…etc.

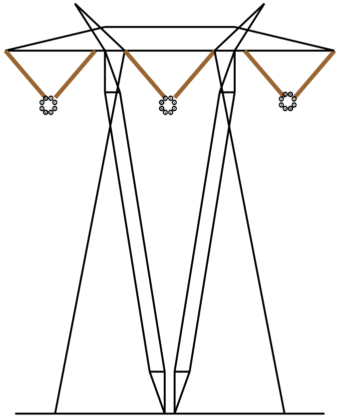
Comparison of overall line design



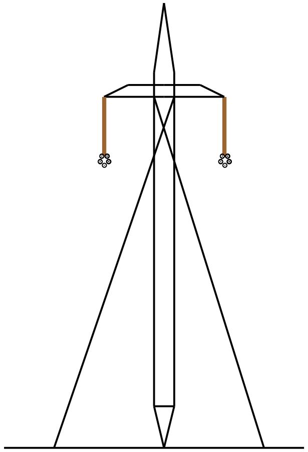
800 kV



±600 kV



1000 kV



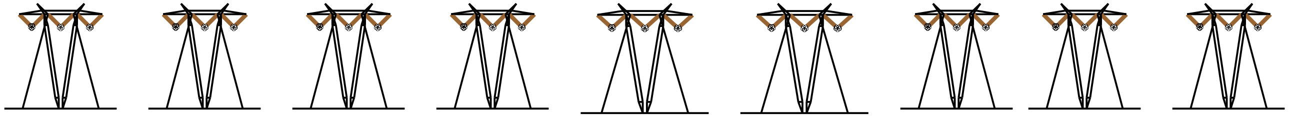
±800 kV

Introduction

Required number of lines in parallel for 18 GW

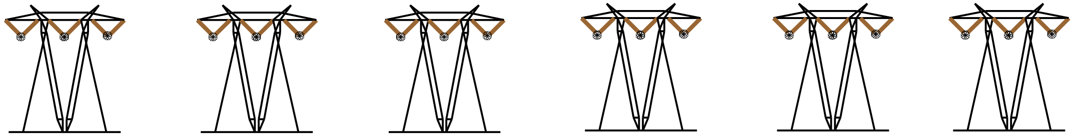
AC 800 kV

(460 kV)



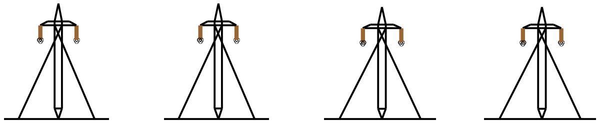
AC 1000 kV

(580 kV)



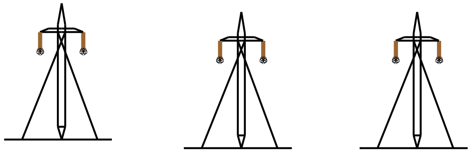
HVDC

600 kV



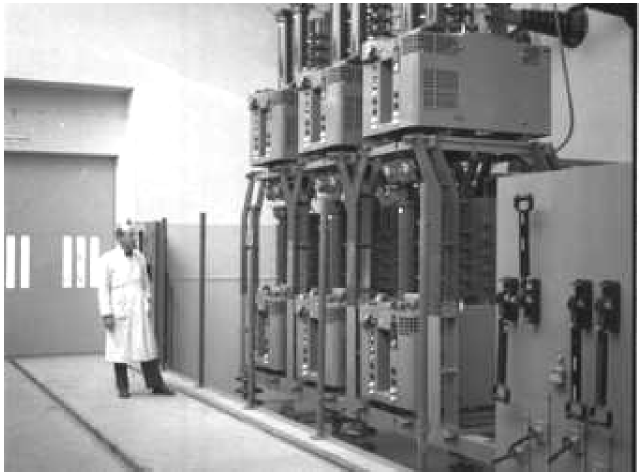
HVDC

800 kV



Note: Above is just indicative. Actual number will vary from specific case to case.

Introduction
60 Jahre HGÜ – Meilensteine



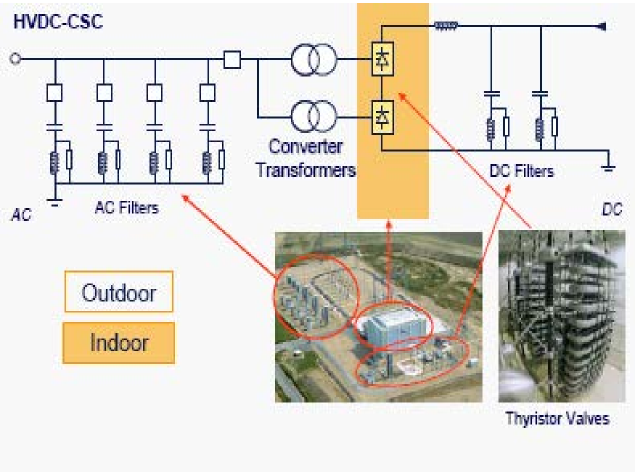

Links: Quecksilberdampfventile in der Gotland-Verbindung von 1954, dem weltweit ersten kommerziellen HGÜ-Projekt.

Rechts: VSC-HGÜ, BorWin1-Projekt 2009

1954 – Erste HGÜ mit Quecksilberdampfgleichrichtern (Gotland)
1970 – Erste Thyristor-Ventile für HGÜ (Skagerrak 1&2)
1980 – Itaipu, mit 6.300 MW die bis dahin weltweit größte Leistung
1997 – Erste kommerzielle VSC-HGÜ-Installation
2007 – 800-kV-UHVDC verfügbar
2008 – NorNed, bis heute längstes Seekabel der Welt
2009 – BorWin1, erste HGÜ-Offshore-Windparkanbindung
2012 – Erster hybrider HGÜ-Leistungsschalter

Technology basics
Klassische, netzgeführte HGÜ

Prinzipschaltbild LCC-HGÜ oder HGÜ Classic. (LCC = Line Commutated Converter)

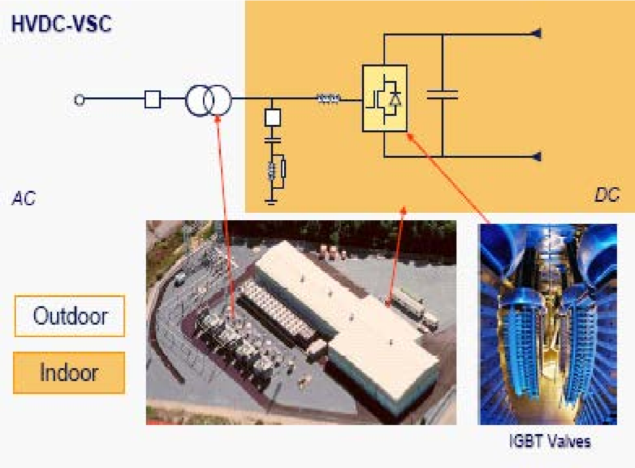


6-Zoll-Thyristor für HGÜ-Anwendungen. Sperrspannung: 8,5 kV Stromtragfähigkeit: 4,5 kA

- Thyristor-Technik (nur einschaltbar)
- 12-Puls-Umrichter
- Kurzschlussleistungsbedarf (Kommutierungsblindleistung, Betrieb nur am spannungsstarren Netz)
- Leistungsbereich: 300 – 8.000 MW (zur Zeit: 10.000 MW bei 1.100 kV)
- Stufenweise Blindleistungsbereitstellung
- Leistungsflussumkehrung durch Umpolung der Spannung (Stromflussrichtung bleibt gleich)
- Freileitung oder Massekabel (Isolation: masseimprägniertes Papier)
- Fernübertragung großer Leistungen

Technology basics
Selbstgeführte HGÜ (VSC-HGÜ)

Prinzipschaltbild VSC-HGÜ.
(VSC = Voltage Source Converter)



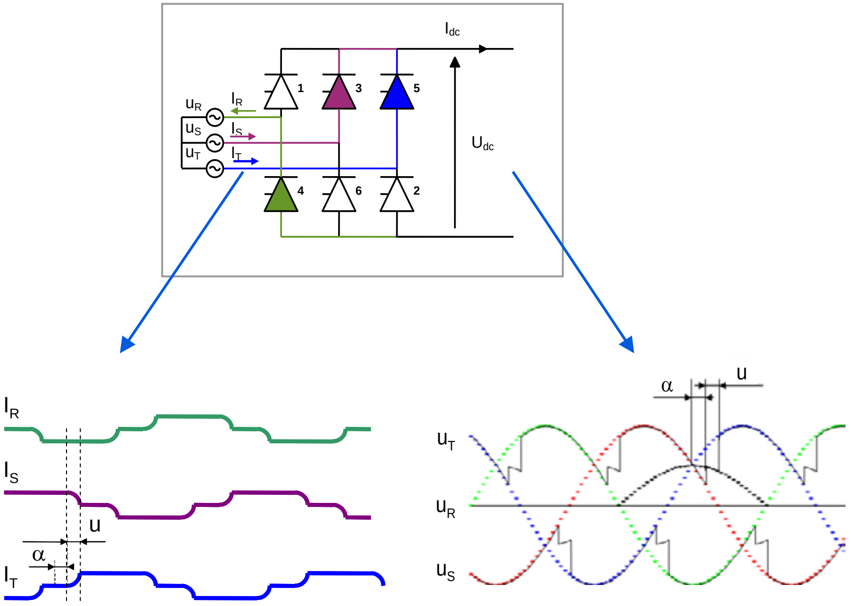
IGBT (Insulated Gate Bipolar Transistor)-StakPak-Module für unterschiedliche Leistungsbereiche.
Sperrspannung: 4,5 kV
Stromtragfähigkeit: 580 bis 1.740 A

- IGBT-Technik (ein- und ausschaltbar)
- Benötigt keine Kommutierungsblindleistung
- Leistungsbereich: 50 – 1.200 MW
- Dynamische Spannungsregelung
- Schwarzstartfähig*
- Leistungsflussumkehrung durch Umkehrung des Stromflusses
- VPE-Kabel (Isolation: vernetztes Polyethylen) oder Freileitung
- Geringer Platzbedarf durch kompakte Stromrichterstationen
- Vielfältige Anwendungen

*Kann nach einem Netzfehler den Betrieb selbstständig, d.h. ohne Stützung durch das umgebende Drehstromnetz wieder aufnehmen.

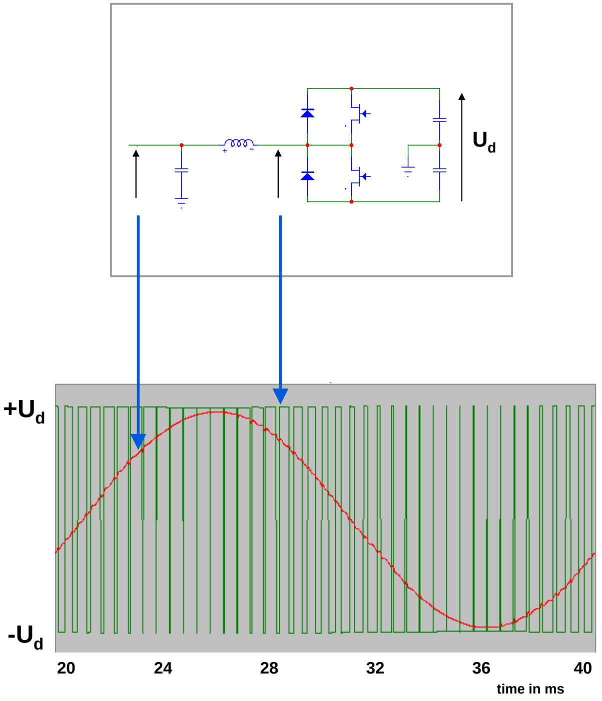
Technology basics
Klassische HGÜ und VSC-HGÜ – Funktionsweise

Klassische HGÜ

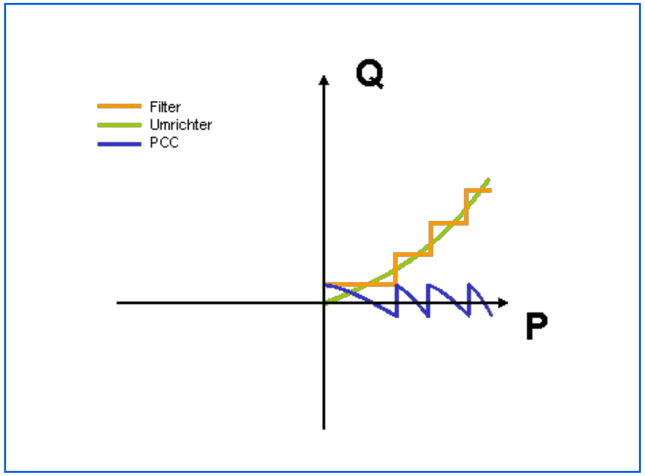


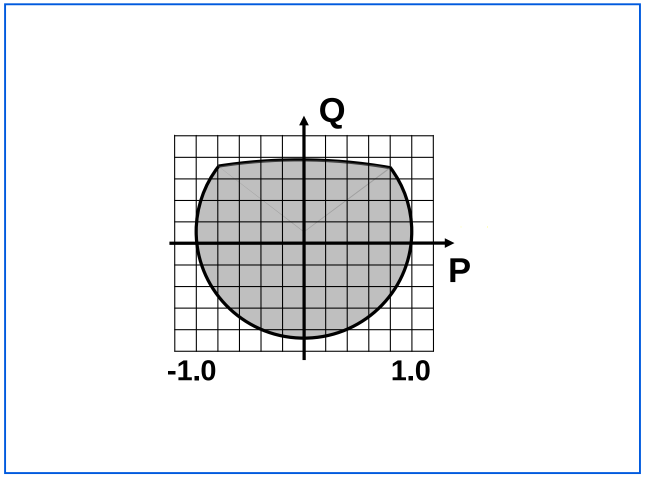
$$U_d = U_{di0}\cos\alpha - d_{xr}\frac{U_{di0r}}{I_{dr}}\, I_d$$

VSC-HGÜ (Beispiel)



Technology basics
Klassische HGÜ und VSC-HGÜ – Funktionsweise





Klassische HGÜ (netzgeführte HGÜ)

- Induktiver Blindleistungsbedarf
- Kurzschlussleistung / spannungsstarres Netz wird benötigt
- Minimaler Leistungsfluss erforderlich
- Leistungsflussumkehr nur mit Ver-zögerung bei Kabelsystemen
- Filterschaltungen notwendig bei sich ändernder Wirkleistung

VSC-HGÜ (selbstgeführte HGÜ)

- Unabhängige Blindleistungsregelung
- Benötigt keine Kurzschlussleistung
- Jeder Wirkleistungsfluss einstellbar
- Sofortige Leistungsflussumkehr
- Keine Filterschaltungen notwendig

References
Application fields

Connecting remote generation

Interconnection grids

Offshore Wind / Power from shore

DC links in AC grids

References

LCC projects by ABB since 1954

1. GOTLAND
2. SKAGERRAK 1 & 2
3. CAHORA BASSA
4. INGA-KOLWEZI
5. CU-PROJECT
6. NELSON RIVER 2
7. ITAIPU
8. GOTLAND 2
9. DÜRNROHR
10. PACIFIC INTERTIE
11. CHATEAUGUAY
12. INTERMOUNTAIN
13. HIGHGATE
14. BLACKWATER
15. VINDHYACHAL
16. BROKEN HILL
17. GOTLAND 3
18. RIHAND-DELHI
19. KONTI-SKAN 2
20. QUEBEC - NEW ENGLAND
21. FENNO-SKAN
22. PACIFIC INTERTIE EXPANSION
23. GEZHOUBA - SHANGHAI
24. NEW ZEALAND DC HYBRID LINK
25. SKAGERRAK 3
26. BALTIC CABLE
27. KONTEK
28. CHANDRAPUR - PADGHE

29. LEYTE-LUZON
30. SWEPOL
31. BRAZIL-ARGENTINA NTERCONNECTION 1
32. ITALY-GREECE
33. THREE GORGES - CHANGZHOU
34. BRAZIL-ARGENTINA INTERCONNECTION 2
35. THREE GORGES - GUANGDONG
36. RAPID CITY DC TIE
37. VIZAG II
38. THREE GORGES - SHANGHAI
39. NORNED
40. SHARYLAND
41.SAPEI
42.OUTAOUAIS
43. XIANGJIABA - SHANGHAI
44. LINGBAO II EXTENSION PROJECT
45. FENNO-SKAN 2
46. HULUNBEIR - LIAONING
47. RIO MADEIRA
48 RIO MADEIRA (Back-to-back)
49. NORTH-EAST AGRA
50. JINPING - SUNAN
51. OKLAUNION (Back-to-back)
52. RAILROAD DC TILE (SHARYLAND)
53. LITPOL
54. JINBEI-NANJING
55. JIUQUAN-HUNAN

55 LCC projects around the world!

References
VSC links in the world

🔵 VSC-HVDC projects by ABB

⚫ VSC-HVDC projects by others

1. Eagle Pass
2. Macinac
3. Cross Sound
4. Maritime
5. East West Interc.
6. CMS
7. NSL
8. Troll 1 & 2
8. Troll 3 & 4
9. DolWin 1
9. DolWin 2
9. BorWin 1
10. Valhall
10. Johan Svedrup
11. Skagerrak
12. Tjæreborg
13. NordLink
13. Kriegers Flak
14. Hällsjön
15. NordBalt
16. Gotland
17. Ål-link
18. Estlink
19. Caprivi
20. Murraylink
21. Terranora

1. Trans Bay
2. INELFE
3. Italy-France
4. NEMO
5. SylWin
6. HelWin 1
6. HelWin 2
6. COBRAcable
7. Ultranet
8. South West Link
9. DolWin 3
9. BorWin 2
9. BorWin 3

Introduction UHVDC

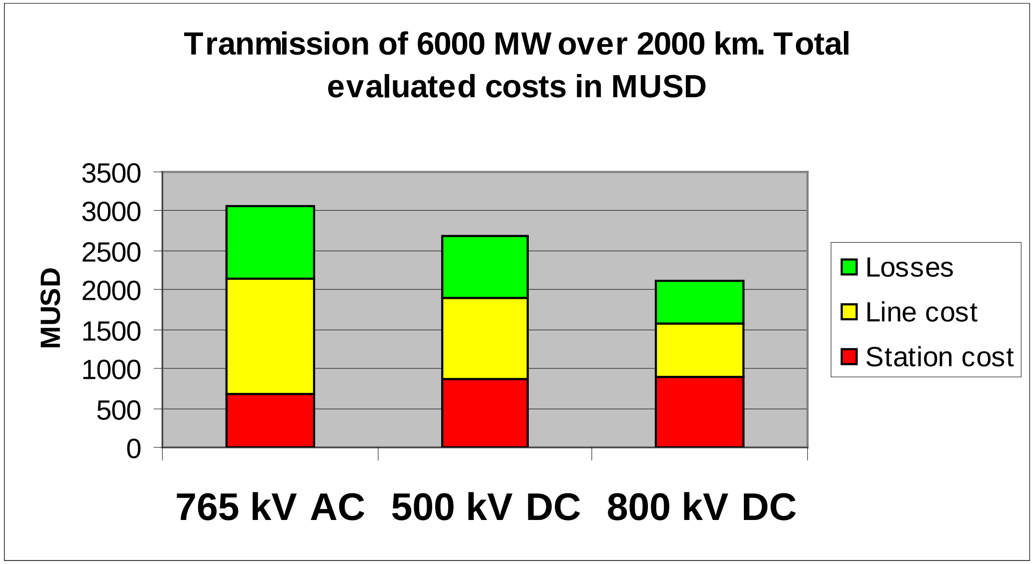
- Itaipu HVDC Transmission in Brazil
  - ± 600 kV
  - Mid 1980s
- Next transmission Voltage
  - 800 kV, UHVDC

Technical Data:

Commissioning year:	1984-1987
Power rating:	3150+3150 MW
DC voltage:	±600 kV
Length of overhead line	785 km + 805 km

Introduction UHVDC

- Bulk Power Transmission
  - Yunnan – Guangdong (China), 5000 MW, ±800 kV
  - Xiangjiaba – Shanghai (China), 6400 MW, ±800 kV
  - NER/ER – NR/WR Interconnector I (India) 6000 MW, ±800 kV (North East – Agra)
  - ….



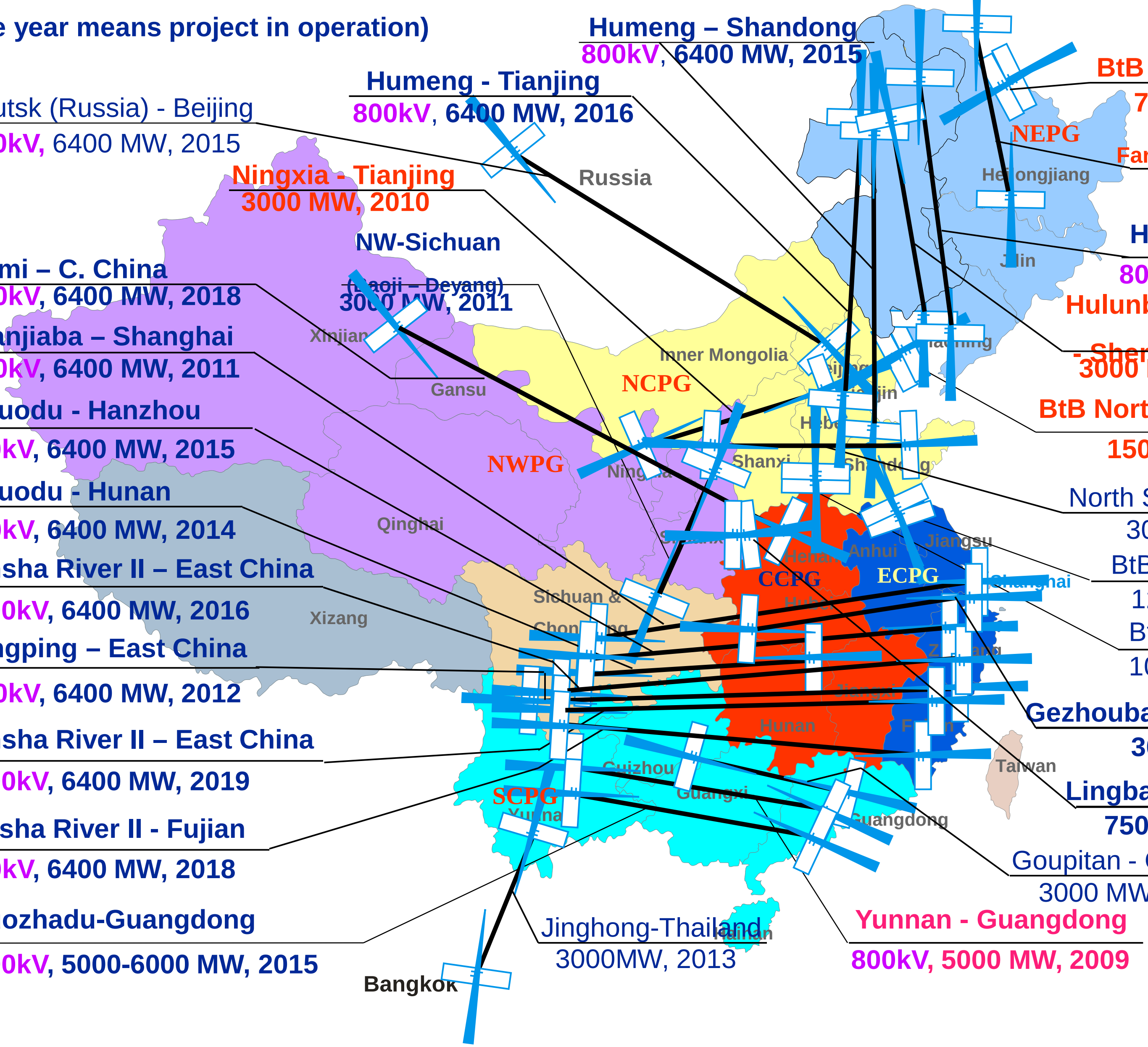
Introduction UHVDC
Step by Step by ABB

600 kVDC	First used in Itaipú (Since 1984-1985)
800 kVDC	First developed on paper in 2002
800 kVDC	Developed with real component design and manufacturing started in 2005 after decision from India for 800 kV
800 kVDC+ (855 kV)	Test circuit with real components energised at full voltage and have been in operation since November 2006
800 kVDC	Projects in Operation - Yunnan - Guangdong (YuG800), CSG - Xiangjiaba - Shanghai (XiS800), SGCC - Jinping - Sunan (JPS800), SGCC - Nuozhadu - Guangdong (or called as Yunnan - Guangdong II), CSG - Hami - Zhengzhou (HZ800), SGCC - Xiluodu - Zhexi (XZ800), SGCC
800 kVDC	Projects in Execution - North East – Agra (Multi-terminal), (NEA800), POWERGRID India - Champa – Kurukshetra, (CK800), POWERGRID India
1100 kVDC	Projects in Execution - Changji-Guquan (12 GW, 3000 km)

Planned Future HVDC Projects by 2020 in China

(The year means project in operation)

2006 forecast



Irkutsk (Russia) - Beijing
800kV, 6400 MW, 2015

Ningxia - Tianjing
3000 MW, 2010

Hami – C. China
800kV, 6400 MW, 2018

Xianjiaba – Shanghai
800kV, 6400 MW, 2011

Xiluodu - Hanzhou
800kV, 6400 MW, 2015

Xiluodu - Hunan
800kV, 6400 MW, 2014

Jinsha River II – East China
800kV, 6400 MW, 2016

Jingping – East China
800kV, 6400 MW, 2012

Jinsha River II – East China
800kV, 6400 MW, 2019

Jinsha River II - Fujian
800kV, 6400 MW, 2018

Nuozhadu-Guangdong
800kV, 5000-6000 MW, 2015

Humeng – Shandong
800kV, 6400 MW, 2015

Humeng - Tianjing
800kV, 6400 MW, 2016

NW-Sichuan
(Baoji – Deyang)
3000 MW, 2011

Jinghong-Thailand
3000MW, 2013

Yunnan - Guangdong
800kV, 5000 MW, 2009

BtB China-Russia (HeiHe)
750 MW, 2008

FarEast (Russia) – NE China
3000 MW, 2010

Humeng - Liaoning
800kV, 6400 MW, 2018

Hulunbeir (Inner Mongolia)
- Shenyang
3000 MW, 2010

BtB Northeast-North (Gaoling)
1500 MW, 2008

North Shaanxi-Shandong
3000 MW, 2011

BtB Shandong - East
1200 MW, 2011

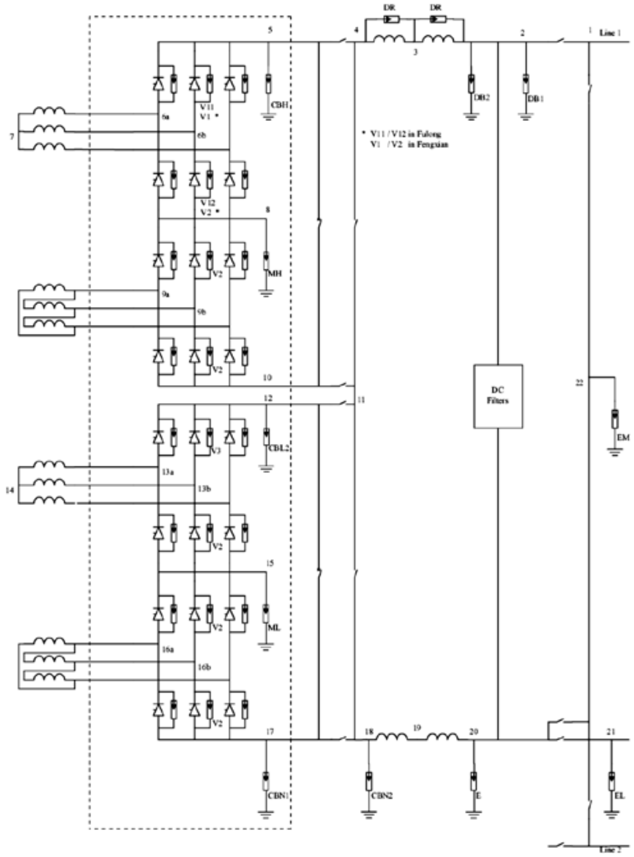
BtB North - Central
1000 MW, 2012

Gezhouba-Shanghai Expansion
3000 MW, 2011

Lingbao BtB Expansion
750 MW, 2009

Goupitan - Guangdong
3000 MW, 2016

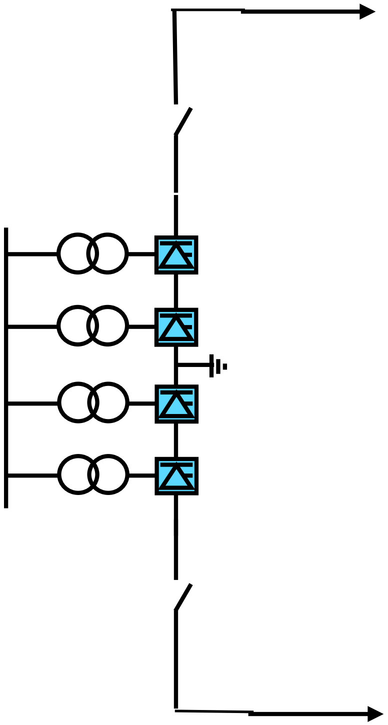
System development
Insulation levels



- Determine the level by system design
  - Not the maximum level over all projects
  - Not a “standard” level
  - Not pre-determined ratio for LI and SI
  - No requirement for inter-changeability
  - Mechanical limitations are close
- Utilize improved arrester properties
- Thorough system simulation and design

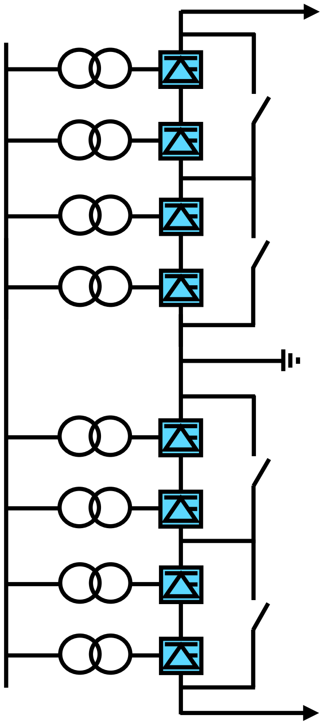
System development
Converter configuration for 800 kV

Single twelve pulse group per pole



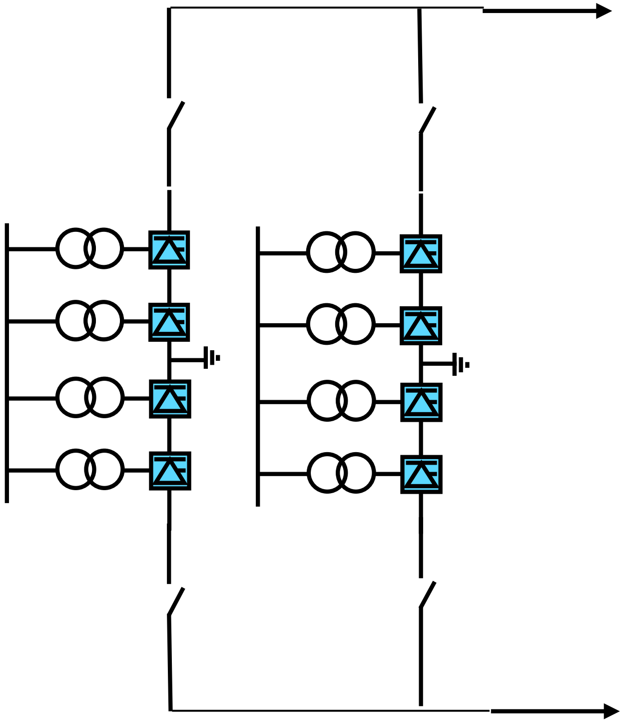
3,000 - 4,500 MW

Series connected twelve pulse groups in each pole



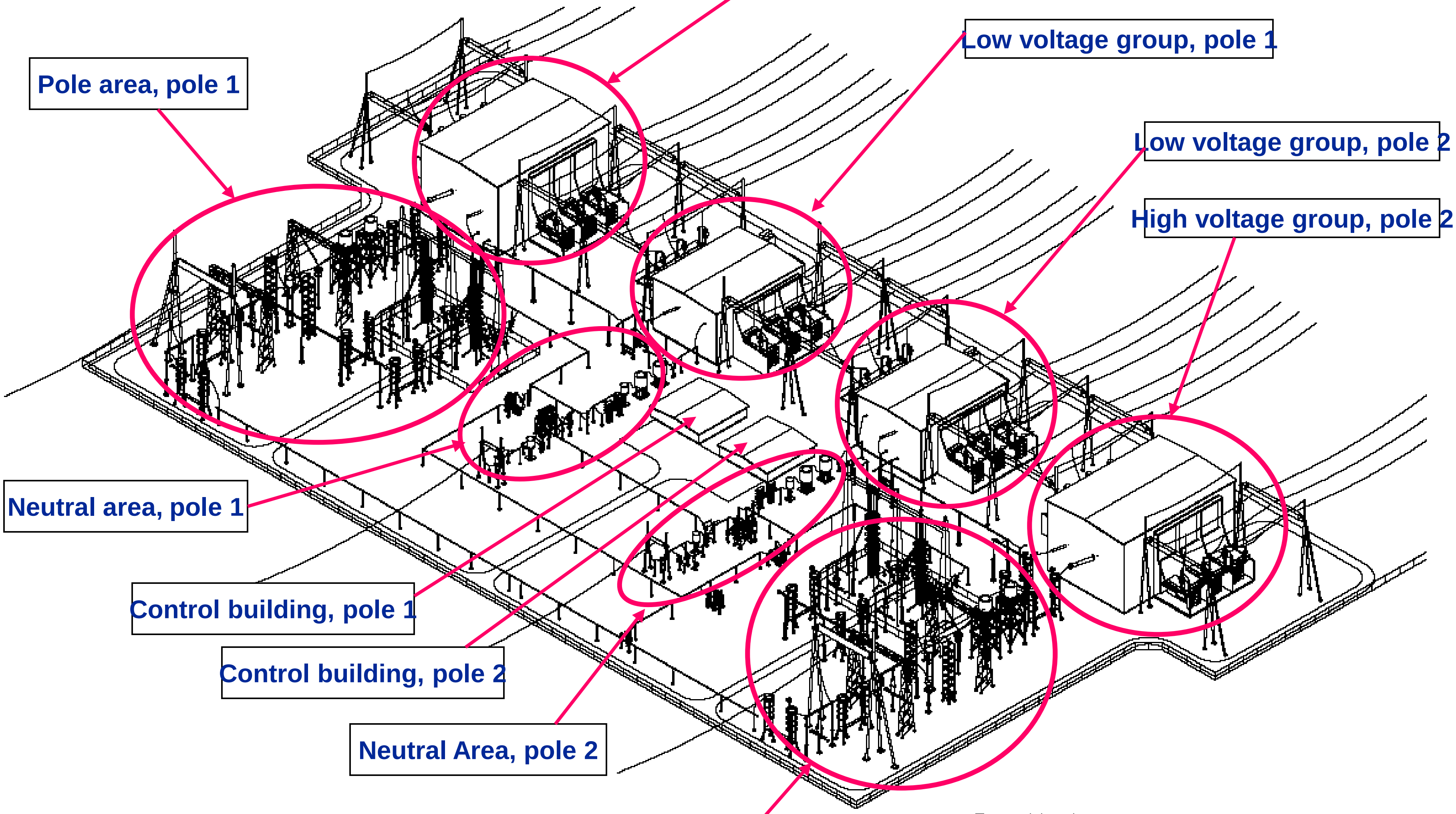
4,500 - 6,400 MW

Parallel twelve pulse groups per pole



6,000 - 9,000 MW

System development
Station layout



High voltage group, pole 1

Low voltage group, pole 1

Pole area, pole 1

Low voltage group, pole 2

High voltage group, pole 2

Neutral area, pole 1

Control building, pole 1

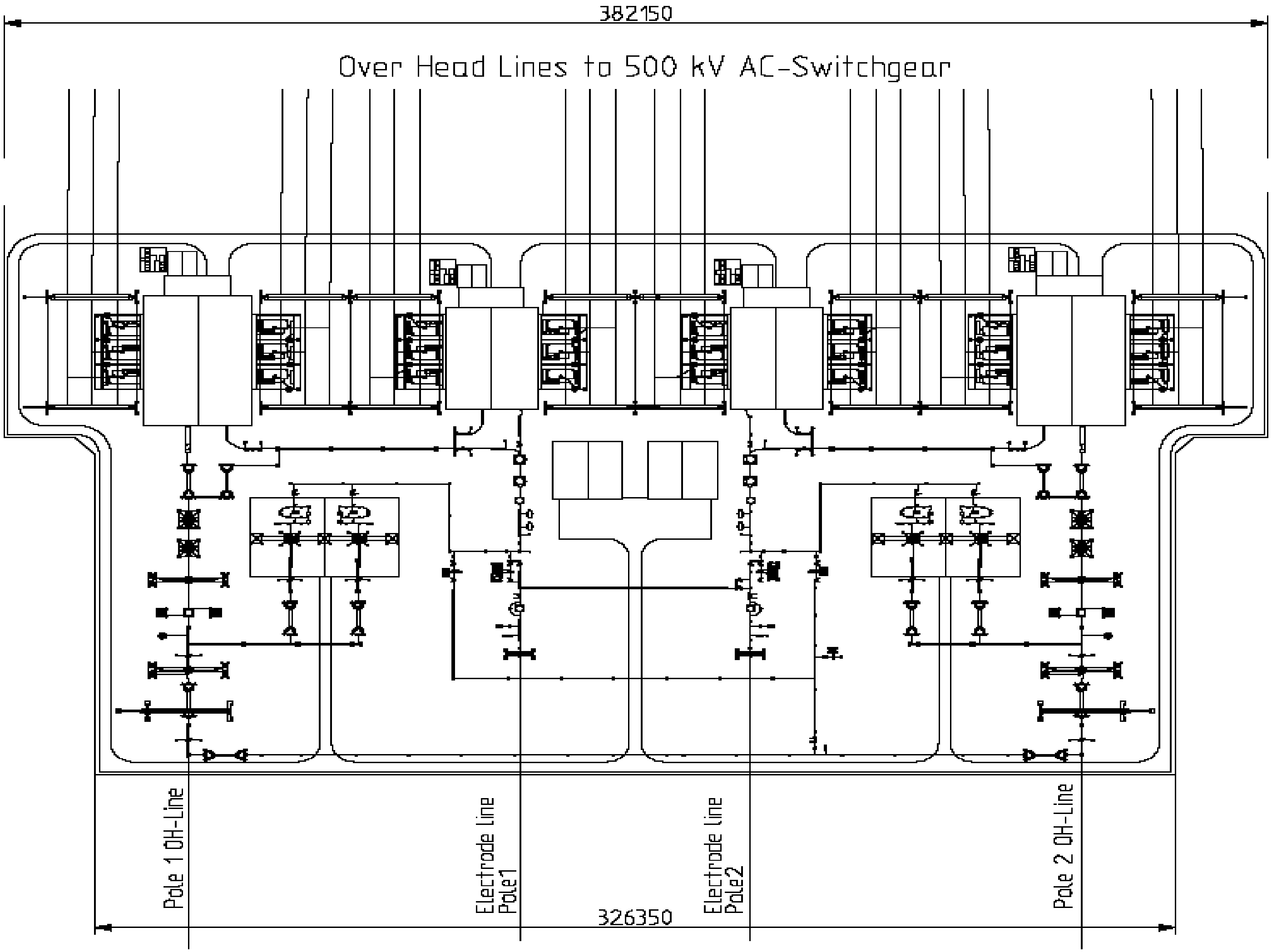
Control building, pole 2

Neutral Area, pole 2

Pole area, pole2

Preliminary
2005-11-02

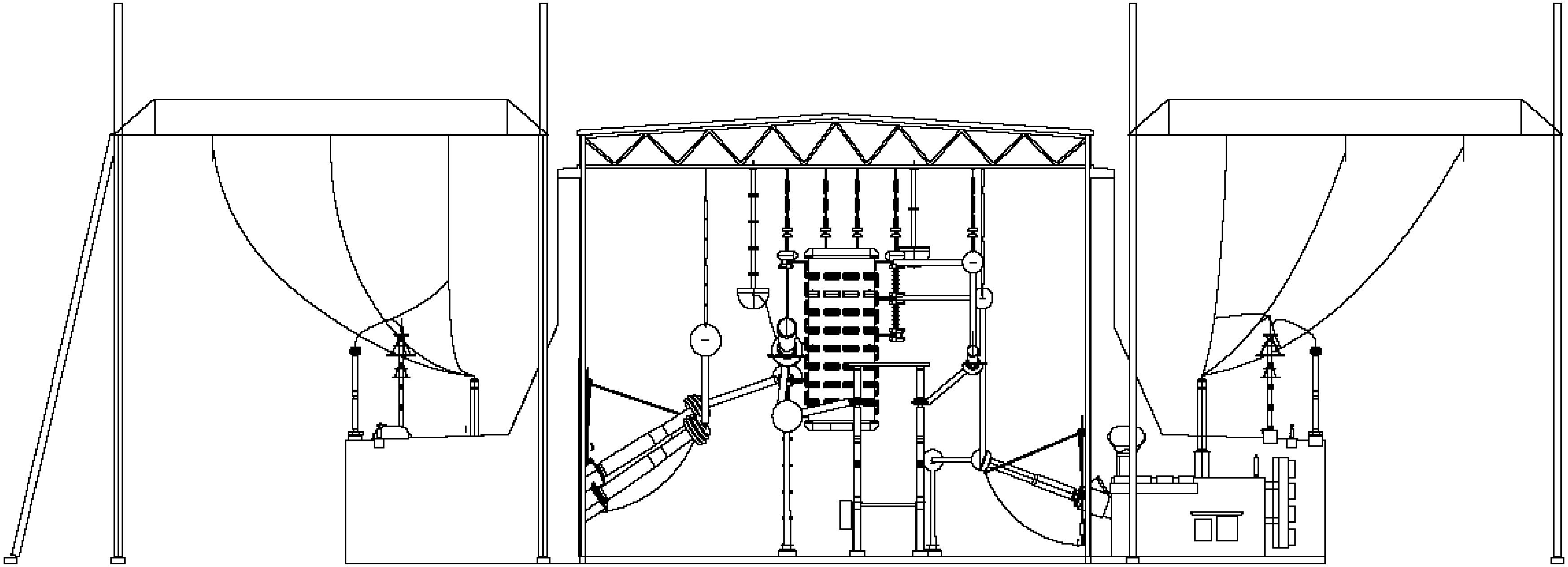
System development
Station layout



System development
Station layout

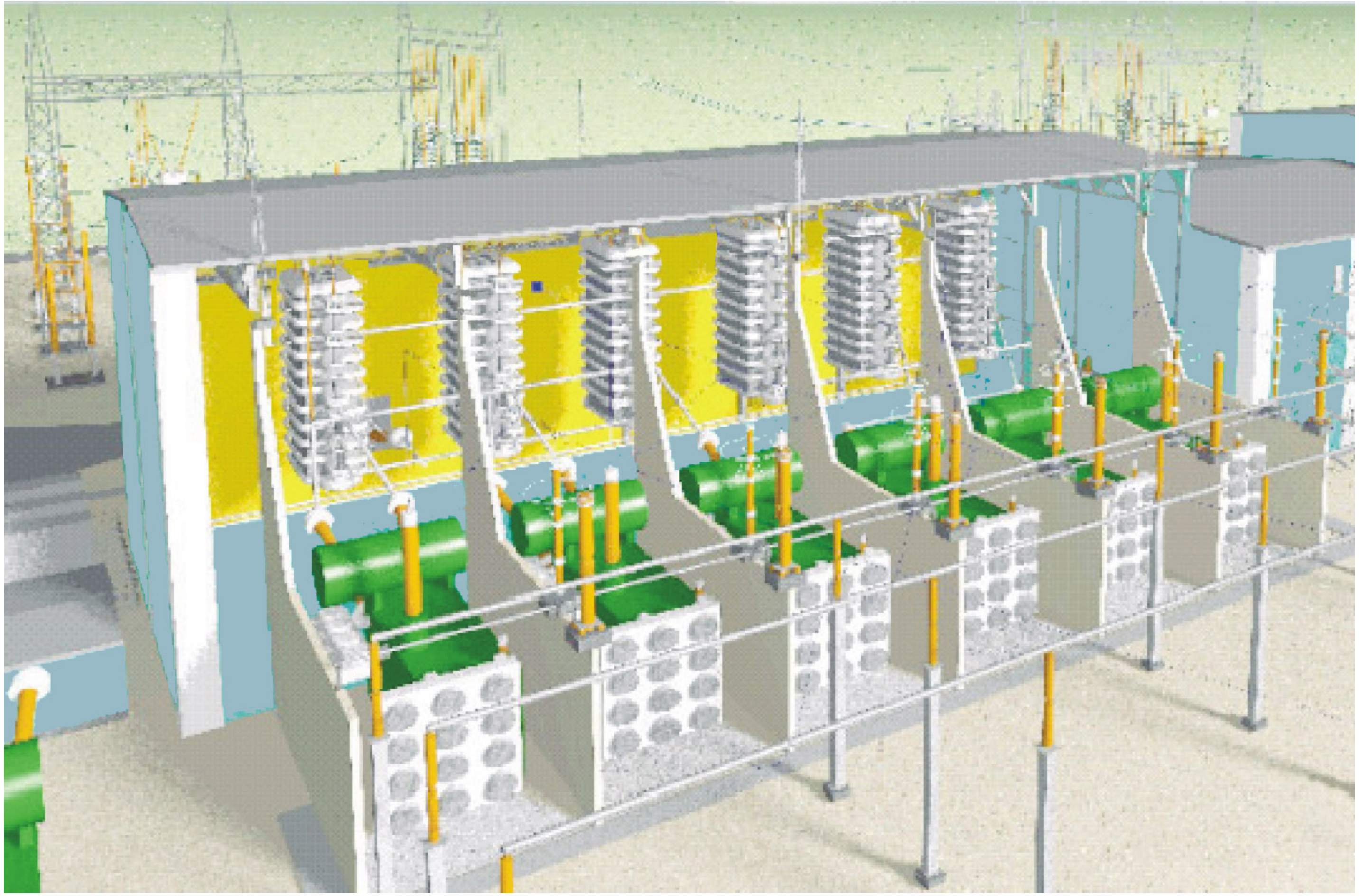
- Complete separation between poles → higher reliability
- Far going separation between groups → higher reliability
- Smaller total valve hall area and volume → lower civil cost
- Built in sound screening of 6/8 of the converter transformers → easier/cheaper to reduce sound level
- By pass switch inside valve hall: Minimizing outdoor insulators pole-ground → reduced risk for external flash overs
- Quadruple valves instead of double valves → cheaper valves
- Fire walls supporting the valve hall on two sides → very rigid civil structure
- Construction, installation and commissioning of pole 2 will not affect operation of pole 1

800 kV Valve Hall

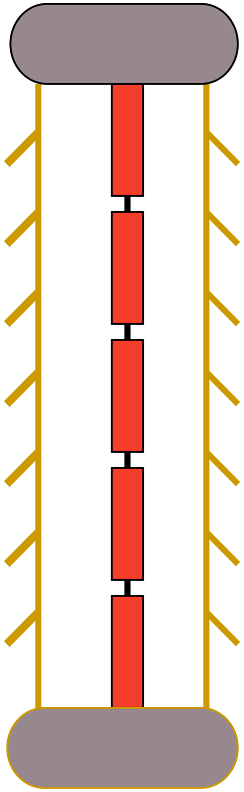


- Dimensions valve halls, LxWxH:
- High voltage group: 46.3x31.8x23.6 m, top of roof 27.3
- Low voltage group: 35.4x26.6x16.6 m, top of roof 20.3

800 kV Valve Hall



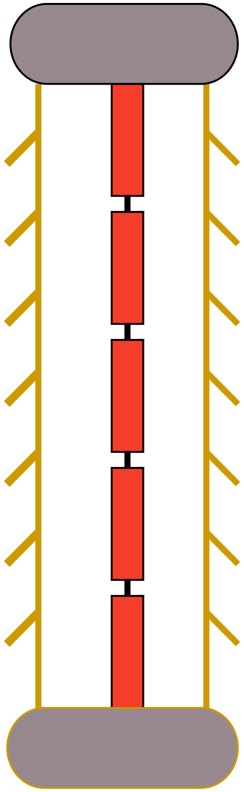
Equipment development
Insulation is critical



- The KEY: voltage distribution
  (for evenness of stresses)
- **<u>The DC component</u>**
- In some components, grading can be done with explicit resistors
  (eg thyristor valves, DC capacitors, etc…)
- In some components this has to be done by modules and geometry
  (eg transformers, bushings)

Important to consider different materials, different resistivities, different temperature dependence, different ageing, etc…

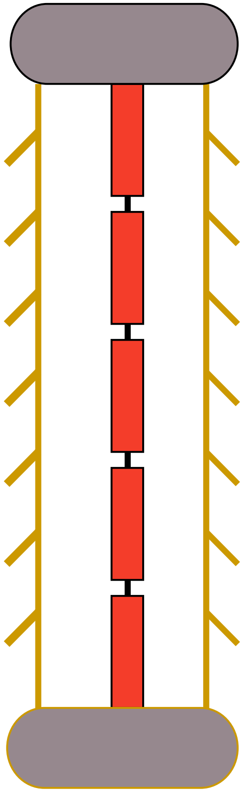
Equipment development
Insulation is critical



- The KEY: voltage distribution
  (for evenness of stresses)
- **<u>The AC and transient components</u>**
- In some components, grading can be done with explicit capacitors
  (eg thyristor valves, DC capacitors, etc…)
- In some components this has to be done by modules and geometry
  (eg transformers, bushings)

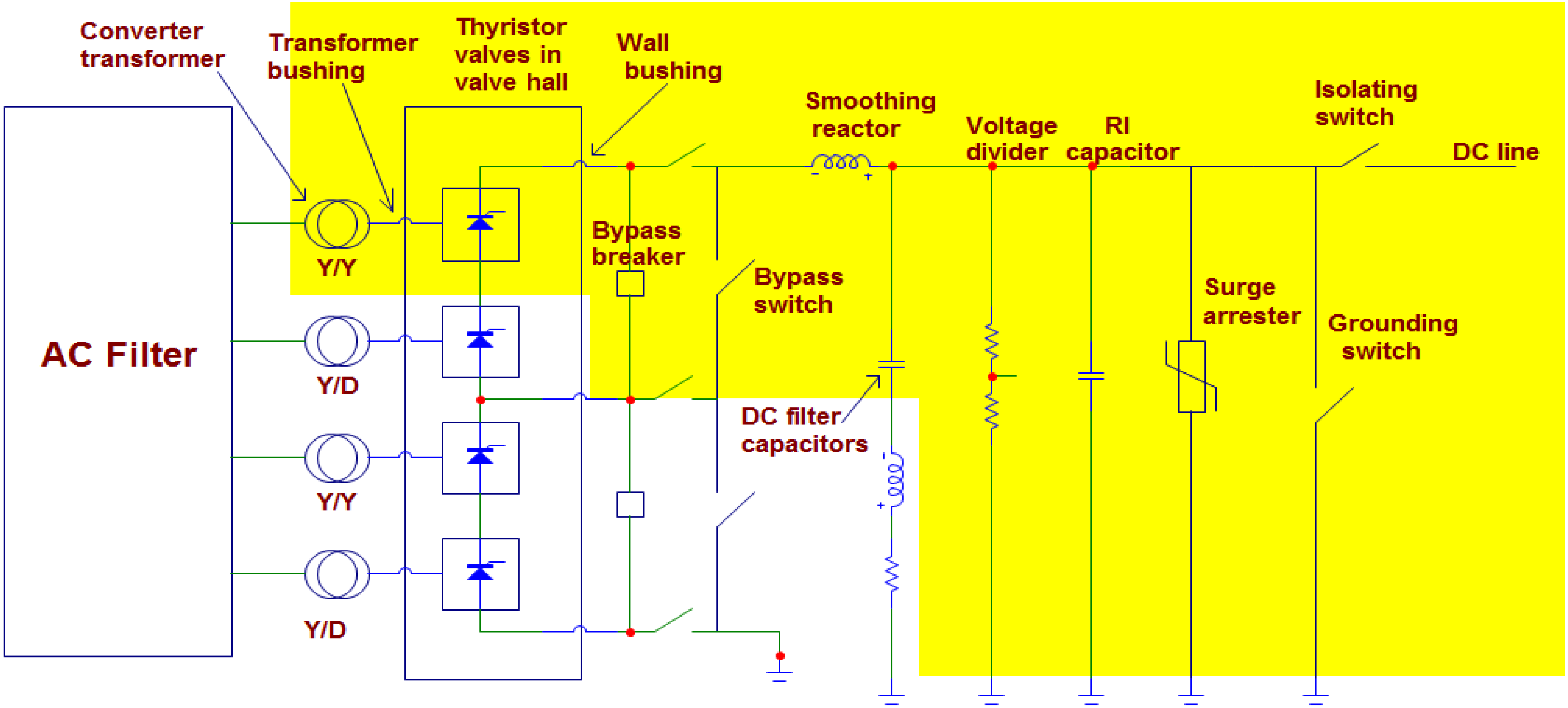
Important to consider: different materials; mainly: different permittivities.

Equipment development
Insulation is critical



- The KEY: voltage distribution
  (for evenness of stresses)
- **Voltage distribution <u>in air and on surfaces</u>**
- By stray capacitances (rings, electrodes)
- By surface resistances
  Pollution and humidity affect them unevenly
  (avoid dry bands, or uneven wetting)
- Coordination of internal and external distribution
  (to avoid high radial stresses)

1100 kV UHVDC
Equipment subject to full DC-voltage



🟨 **Exposed to 1100 kV dc**

Insulation levels

- **Special for UHVDC**
  - Determine the level by system design
    - Not the maximum level over all projects
    - Not a “standard” level
    - Not pre-determined ratio for LI and SI
    - No requirement for inter-changeability
    - Mechanical limitations are close
  - Utilize improved arrester property
  - Thorough system simulation and design

Test margin (factors)

- Why and how much
    - Sometimes depending on who you talk to:
        - Utility, manufacturer, research institute, consultants
- Higher factor ≠ reliable design
    - Correct stress?
    - Exaggerate one parameter of many?
    - Lead to test orientated design

- Good example: 10% for SIWL of single valve sufficient
- Bad example: 1.6 DC for converter valve dielectric tests

External insulation for UHVDC

- Mechanical requirements become limitation
  - No room for over-dimensioning
    - Arbitrary margin on pollution level
    - Overflowing margin on test voltage
    - Over-specified creepage distance
- Utilize the advantage of hydrophobic properties
  - Silicone rubber insulators
  - Hydrophobic coatings
  - Shorter creepage distance
- Full scale pollution tests not realistic

Seismic verification

- Analysis
  - Static analysis for simple or rigid equipment
    - For an initial calculation of the breaker
  - Dynamic analysis
    - Time history analysis
      - Non-linear behaviour of for example seismic dampers can be considered
      - Actual recorded accelerogram
      - Artificial accelerogram created from the specified response spectra
    - Response spectra analysis
- Testing
  - On vibration table

Converter transformer
Prototype testing complete

Prototype tested with:

- AC 900 kV
- DC 1,250 kV
- Switching impulse 1,700 kV

Dimensions:

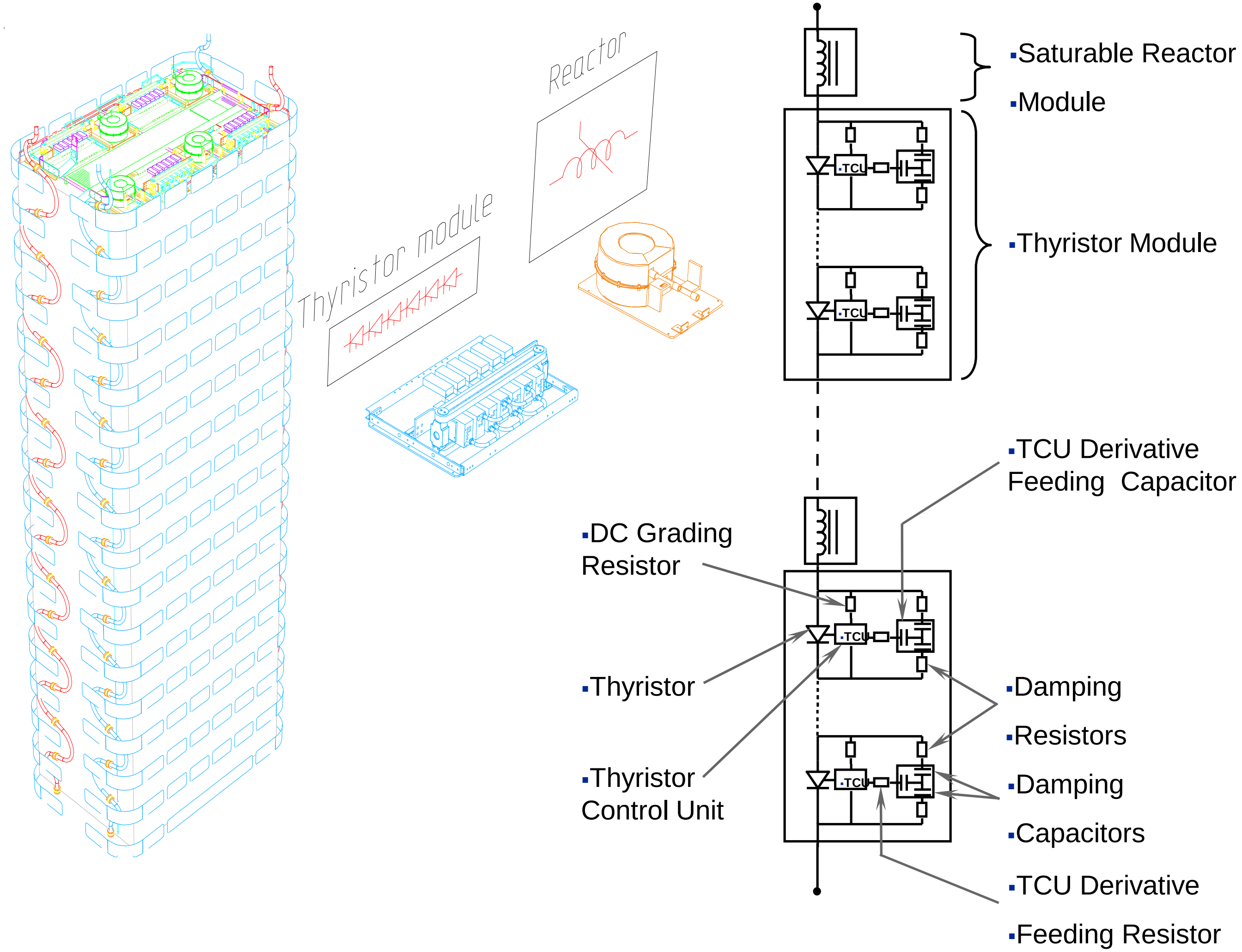
- Length 12.7 m
- Width 3.8 m
- Height 5.0 m

Bushing separately tested with:

- AC 1050 kV
- DC 1450 kV

Bushing for 800 kV UHVDC

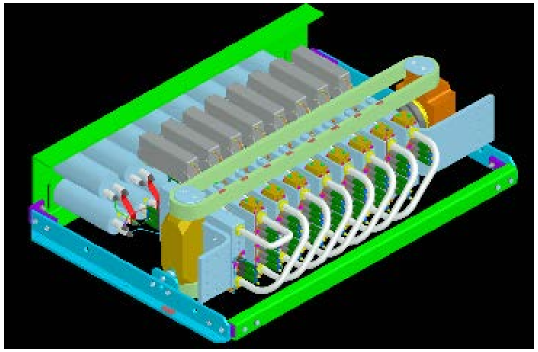
Thyristor Valve Layout

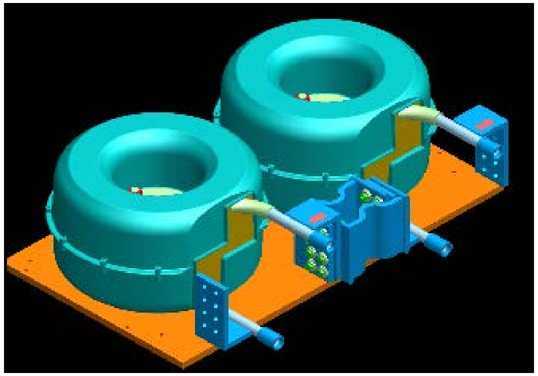


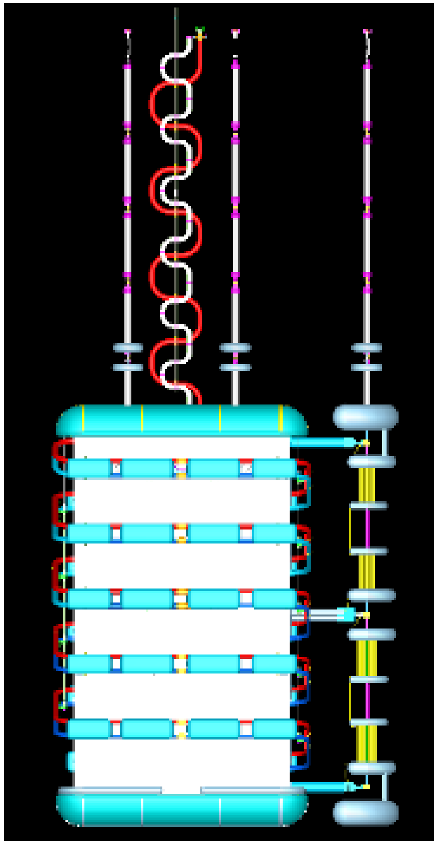
- Saturable Reactor
- Module
- Thyristor Module
- TCU Derivative Feeding Capacitor
- DC Grading Resistor
- Thyristor
- Thyristor Control Unit
- Damping
- Resistors
- Damping
- Capacitors
- TCU Derivative
- Feeding Resistor

Thyristor Valve

- The valve voltage is not decisive for the thyristor. Will be handled by sufficient number of thyristor positions in series. Due to the well defined voltage grading each individual thyristor position has the same electrical stress in an 800 kV valve as in a 500 kV valve!
- The critical parameter for the thyristors is the short circuit current. This is given by the ratio between rated DC current and transformer reactance

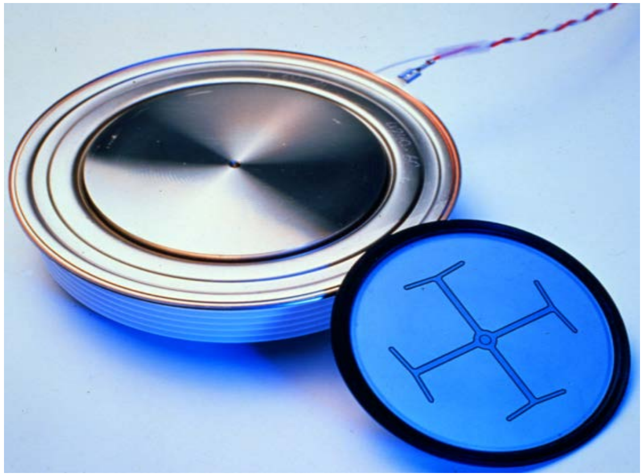


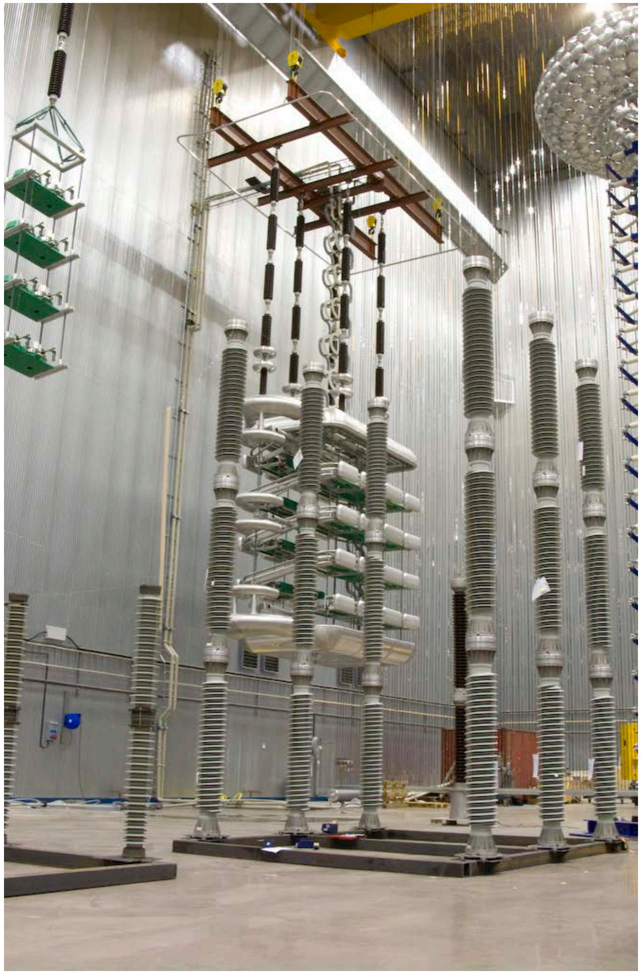




Development of 6 inch thyristors

- Voltage withstand: 8.5 kV
- Short circuit current withstand: 46 kA
- Thyristor valve testing Completed in May 2009





HVDC Arrester Applications

HVDC
Arrester Applications

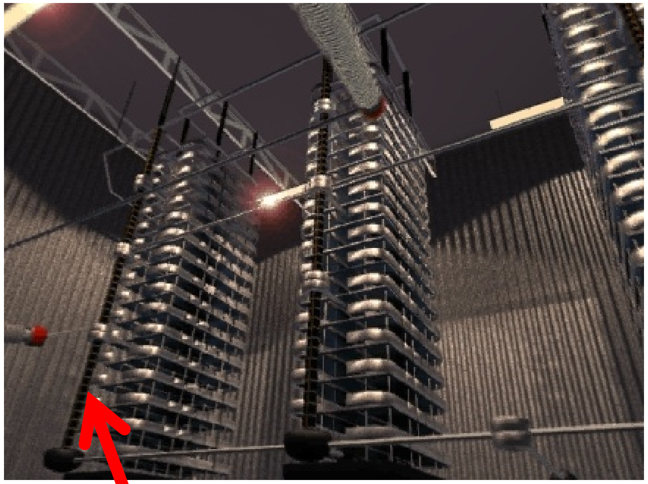
- Valve, 6-12 Pulse
- AC-Bus
- AC-Filter
- DC-Bus
- DC-Breaker
- DC-Filter
- Neutral-Bus

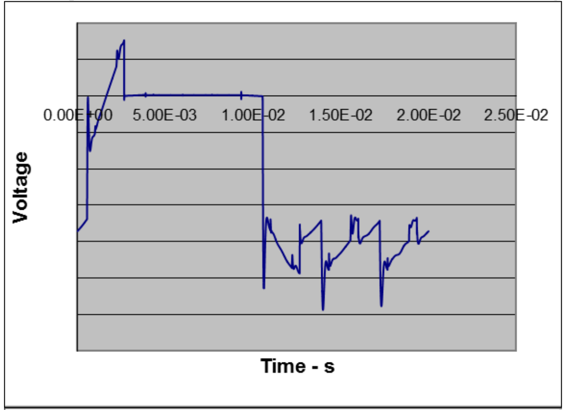
Valve Arresters

Indoor application in controlled environment

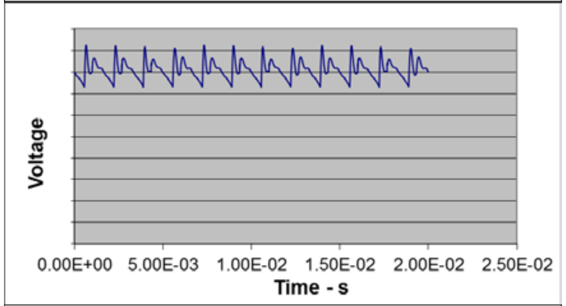
2-12 parallell columns in”open” design

Superior thermal & safety performance

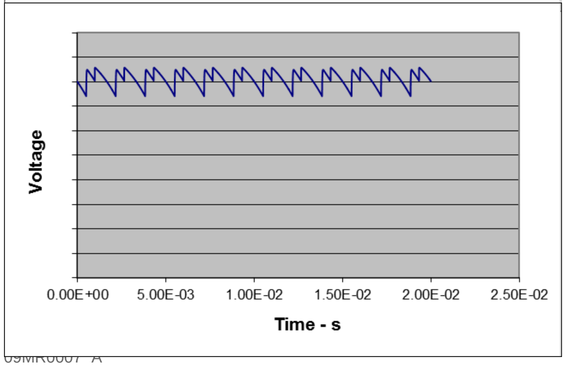




Example of voltage across valve arresters with HF (high-frequency) modelling (arrester V)



Example of voltage across top sixpuls group with HF & LF modelling (arrester B)



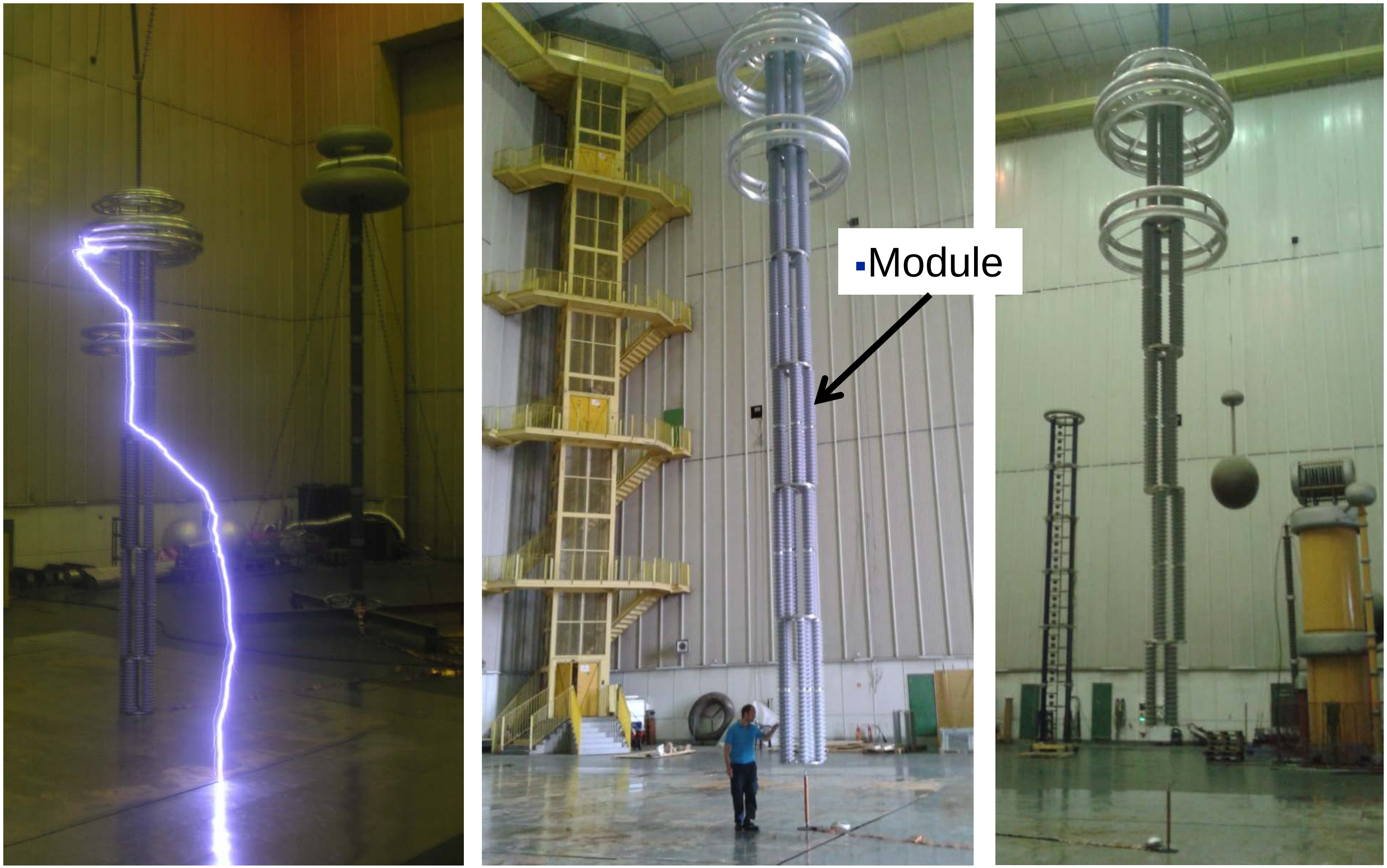
HF gives 7% higher voltage than LF modelling which results in significantly higher power losses for the arrester

Arresters for DC bus

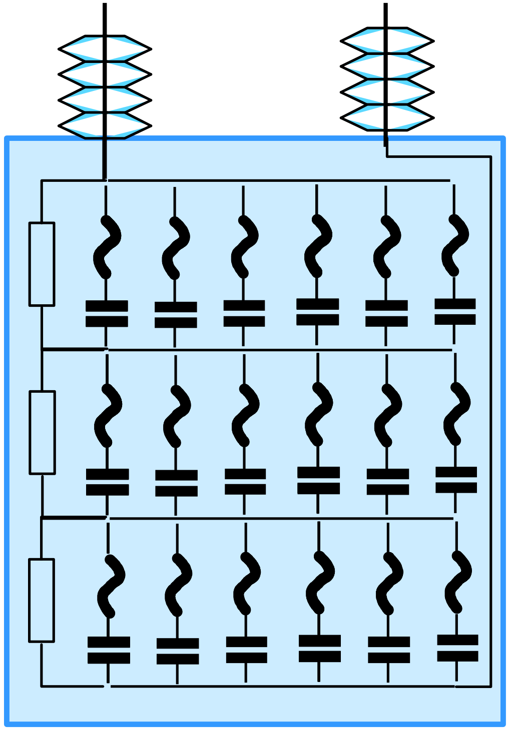
- Prototype fully type tested in 2012
- Technical Specifications fulfilled requirements
  - Ud : 1100 kVDC
  - SIWV : ≥ 2100 kV
  - LIWV : ≥ 2300 kV
  - Creepage: 50750 mm (45 mm/kV)

Modular arrester design

Arresters comprising different number of modules in series and parallel have been tested to determine the insulation withstand for switching and lightning. Design criteria have been determined for outdoor and indoor applications

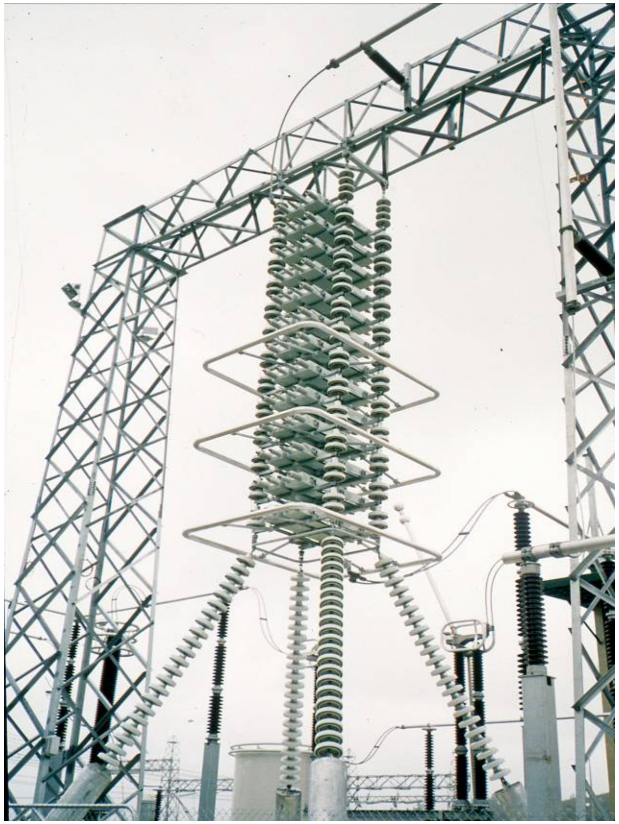


Resistive voltage distribution: DC filter capacitors



- The stresses across the groups of parallel connected elements are controlled by the
- voltage distribution across the grading resistors.
- The grading current is of mA order of magnitude.

DC filter suspended structure to minimize seismic stresses



Insulator chains are fixing the capacitor stack.

Insulator chains are provided with dampers attached to ground foundation to minimize deflection of capacitor stack

1100 kV UHVDC Bypass switch
Development process

- Main concept based on results from long-term outdoor UHVDC testing

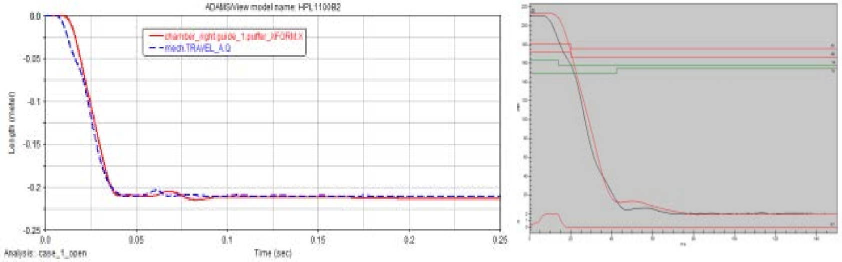
- Dynamical mechanical analysis
  - Contact travel
  - Seismic analysis

- Electric field calculations

- New composite insulator production line
  - Development of enhanced hollow insulators possible

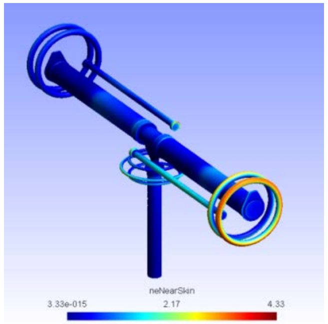
- Grading resistors
  - Improved design and withstand performance

Long-term UHVDC testing after mechanical tests.



Dynamic contact travel simulations vs.

Full scale measurements



Electric field calculations

HPL 1100TB4,
800 and 1100 kV SF$_6$ gas circuit breaker

1100 kV	Rated voltage
40/50/63 kA	Breaking current
5000--6300 A	Continuous current
1100 kV	PF 1 minute
2550 kV	LIWL
1800 kV	SIWL
2400 kV	CRV
800 ohm	Pre-insertion resistor when needed
- 40/+50 ^{o}C	Ambient temperature
0,3g	Seismic withstand
M2	Mechanical withstand
Spring operated	
Porcelain or composite insulators	

Long Term Test Circuit
First 800 kV UHVDC

1. Transformer prototype
2. Wall bushing
3. Optical current transducer
4. Voltage divider
5. Pole arrester
6. Smoothing reactor prototype
7. RI Capacitor
8. Disconnector
10. By pass breaker

UHV testing facility
Dielectric testing of bushings and HVDC valves

Technical data of UHV testing facility

- **Voltage levels**:

DC	**2000 kV**	(100mA)
AC	**1700 kV**	
LI	**3300 kV**	
SI	**2500 kV**	

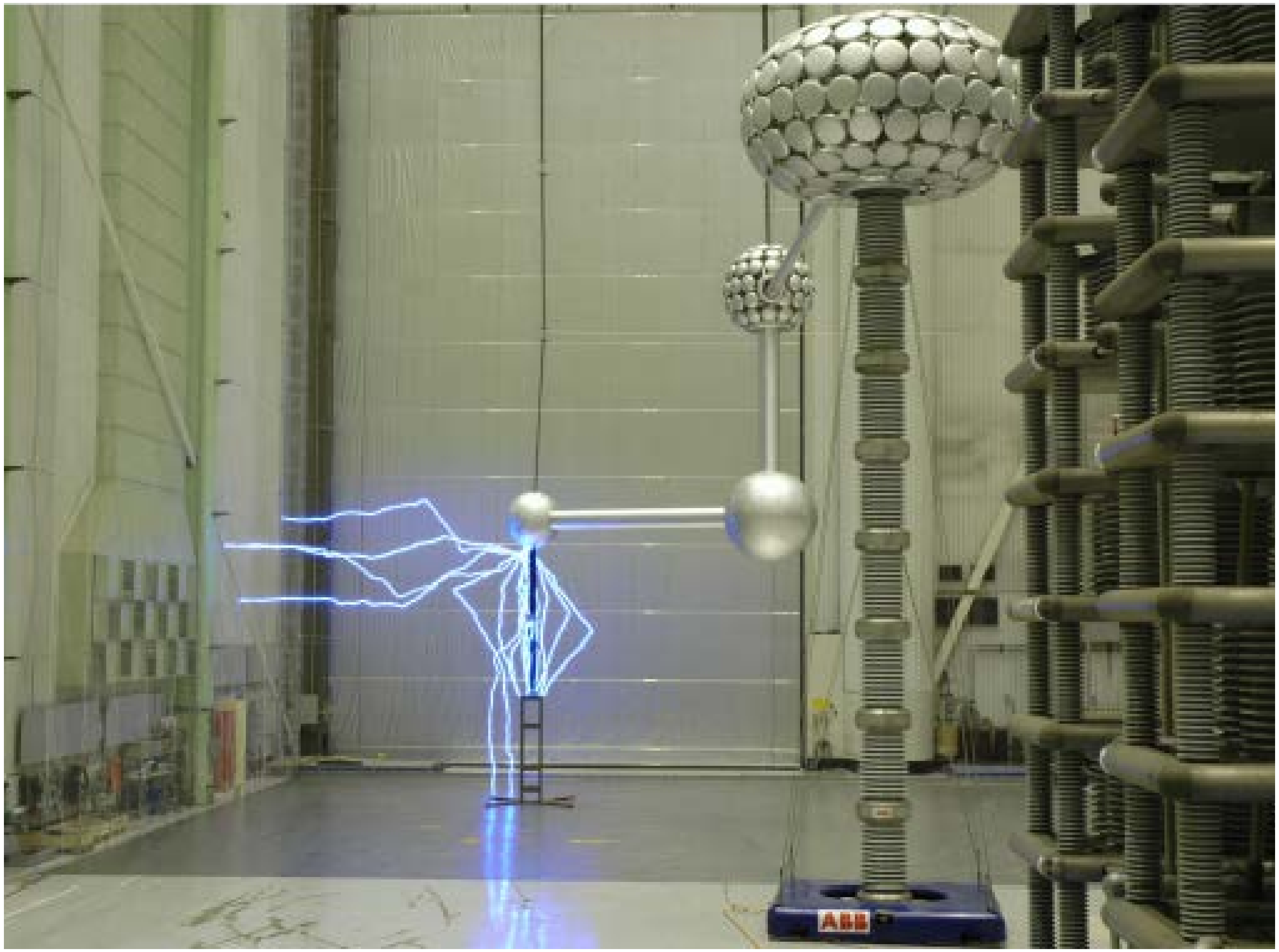
- Dimensions, based on voltage levels:
  - Inner size **60 x 40 x 35 m** (l w h)
  - Outer size **63 x 43 x 37 m**

These voltage levels and dimensions facilitate development and type- and routine testing of HV equipment for the highest rated power transmission systems in the world, today and tomorrow, such as 1,100 kV DC and 1,200 kV AC

Testing for valve hall clearances

Flashovers are up to 10 m long.

Voltage level is up to 2 million volts



The Hydroelectric Development Behind Xiangjiaba – Shanghai

- Four hydro plants on the Jinsha River (Xiangjiaba/Xiluodu)
- Total power 18,600 MW
- 26 generators @ 750MVA
- A significant part is meant to feed Shanghai
- Being hydro-electric, this generation is environmentally very good: it displaces coal fired generation, with concurrent CO_2

The Transmission Project:

Xiangjiaba – Shanghai: a real project

- Nominal transmission data:
  6,400 MW, ±800 kV UHVDC, 4 kA
- Transmission line: 1935 kM
- Sending end station: Fulong.
  In the YiBin area of the Sichuan province.
  Connected to 500 kV_{AC}, 50 Hz.
- Receiving end station: Fengxian.
  In Hengqiao town, within Shanghai.
  Connected to 500 kV_{AC}, 50 Hz.

Xiangjiaba – Shanghai ± 800 kV UHVDC
China

Customer: SGCC

Year of commissioning:
2010

Customer's need

- Development of renewable hydro power 2,000 km from load center

ABB's response

- World's longest and largest transmission system
- ± 800 kV UHVDC, 6,400 MW

Customer's benefits

- High efficiency - 93 %
- Compact - land use 40 % less than conventional technologies
- Reliable transmission – forced unavailability < 0.5 %
- Delivered one year ahead of time

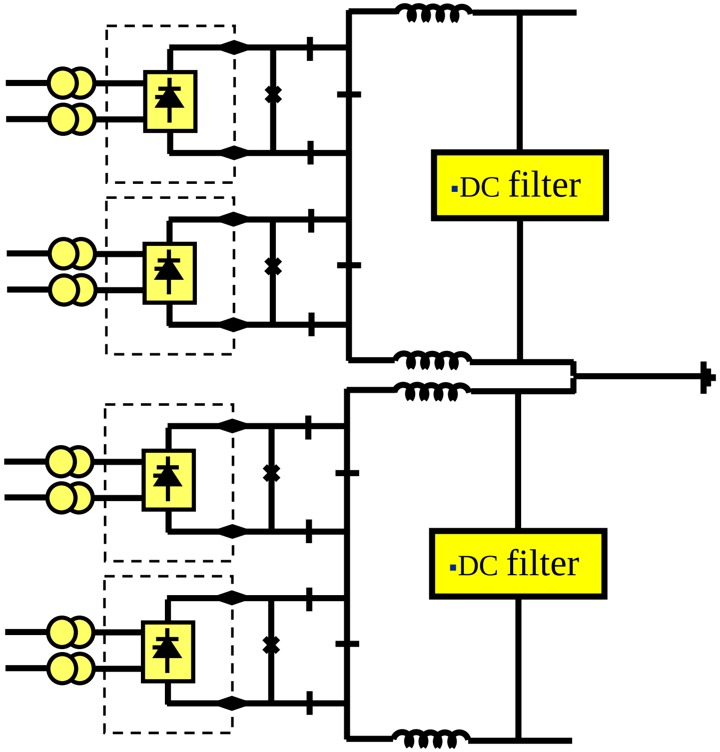
How far is 2,000 km ?

How much power is 6,400 MW?

- In 2009 26,000 MW new generation was installed in Europe – of which 10,163 MW was wind power
- More the 1 ton coal per second

The Transmission Project:
Xiangjiaba – Shanghai: a real project

- 6400 MW, 800 kV$_{DC}$, 4 kA
- Two converters per pole
- Two smoothing reactors per pole
- Lower ripple in key points means
  - Lower arrester Uref voltage
  - Lower SIPL
  - **Lower <u>SIWL</u>**



The Transmission Project: Xiangjiaba – Shanghai: a real project

- 6400 MW = 100 %
  at maximum ambient, no redundant cooling
- Overload is available:
  - At maximum ambient, with redundant cooling:
    105% continuous, 113% for 2 hours
  - At 20ºC, with redundant cooling:
    115% continuous, 131% for 2 hours
- NB: these are POWER figures, not current.

The Transmission Project:
Xiangjiaba – Shanghai: a real project - Fulong

From Drawing Board

To Reality

The Transmission Project:
Xiangjiaba – Shanghai: a real project

Control & Protection

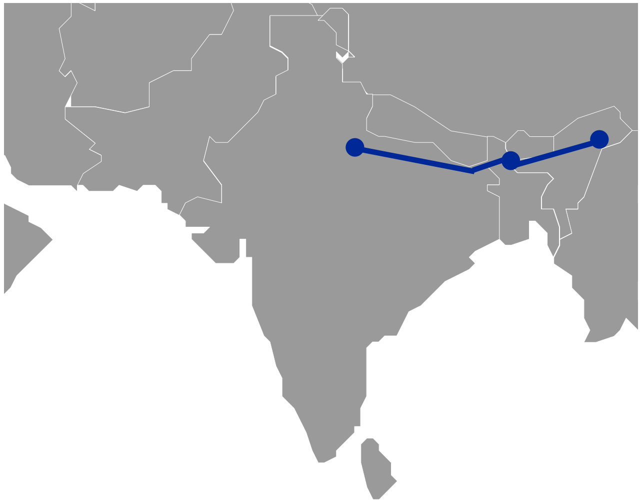
Factory System Test

- All the Control and Protection cubicles are energized and loaded with related Software
- Transmission with full power is simulated

North-East Agra
India

Customer:
POWERGRID

Years of commissioning:
2014 - 2015



Customer's need

- Transmission of 6,000 MW hydropower from the north-eastern parts of India to the region of Agra – over 1,700 km

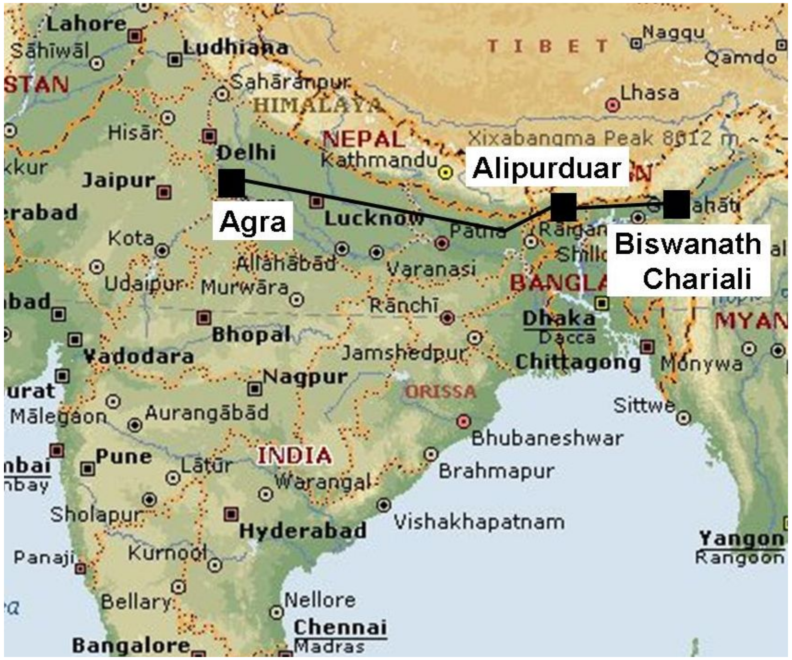
ABB's response

- Turnkey 6,000 MW ±800 kV UHVDC system
- Multiterminal – three converter stations

Customer's benefits

- Low losses – 6 %
- 8,000 MW converter capacity, providing redundancy for loss of one converter with retained transfer capacity
- Effective use of right-of-way

The Transmission Project
North East Agra: a real project



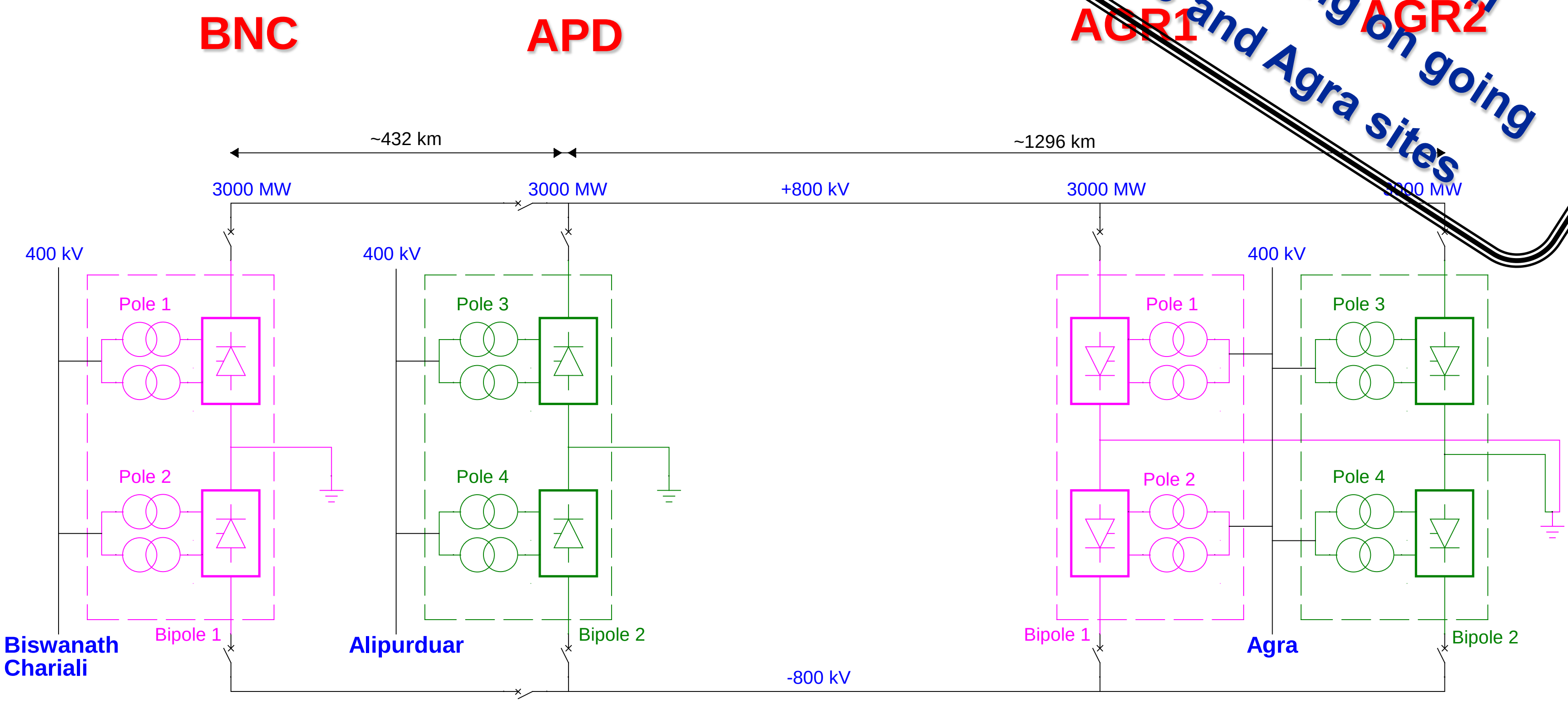
First Multi-terminal at 800 kV

POWERGRID CORPORATION OF INDIA

- **3 stations, 4 terminals**
- **800 kV, 12 pulse converter**
- **2000 MW each converter = 8000 MW**

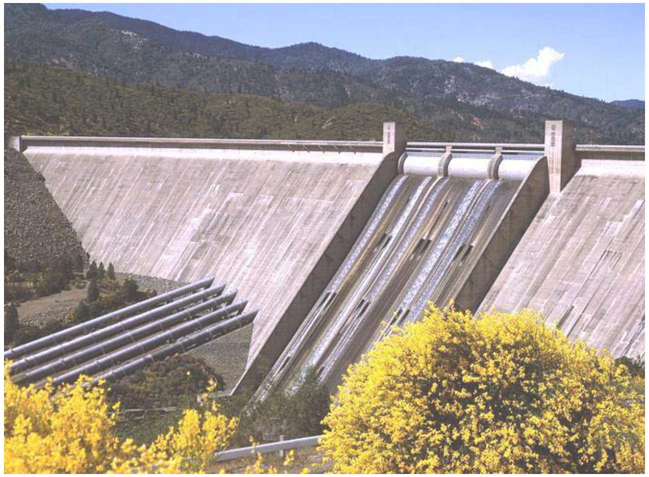
The Transmission Project:
North East Agra: a real project

Under Execution
Commissioning on going
at BNC and Agra sites



800 kV HVDC station

Conclusion



- The world needs more renewable power, such as remote hydro and solar
- 800 kV UHVDC makes it technically and economically feasible
- The next step – 1,100 kV is being developed

Conclusions

- UHVDC is environmentally very attractive for **bulk**, **long distance** transmission.
- UHVDC is economically very attractive for bulk, long distance transmission.
- **800 kV UHVDC is a mature, qualified technology**:
  Several projects are either in
  - Test Installation: since November 2006
  - Commercial Operation:
    5+ projects: up to 7200 MW, all in China, with 400 kV + 400 kV series converters
- **1100 kV is type tested** and currently under installation/commissioning

HVDC development steps towards UHVDC 1100 kV

2009: Preliminary long term test of components at 1050 kV (Ludvika)

2010: Design criteria, standards, basic material research to establish foundation for design, system design

2011: Detailed equipment development

2012: Long term testing, contract

Next Step - UHVDC 1,100 kV
Challenges

- We consider that 1,100 kV is feasible and we also understand the difficulties associated with.

- Significant increase in voltage level from 800 kV
  - 1,100/800 > 800/600
  - Non-linear increase of the difficulties
- Increased current at the same time

- Added complexity caused by transport limitation