US Department of Energy's Grid Tech Team Workshop

Applications for High Voltage Direct Current (HVDC) Transmission Technologies

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NRECA Conference Center

Arlington, VA 22203

Keynote Speaker: Nari Hingorani

HVDC Overview

Today's HVDC

- **Power System in general has to be AC, because there is no DC Transformers**
- **Therefore Today's HVDC involves conversion of AC to DC and back to AC**
- **To justify HVDC, there needs to be enough cost or performance benefit to pay for the converters.**

Applications for HVDC

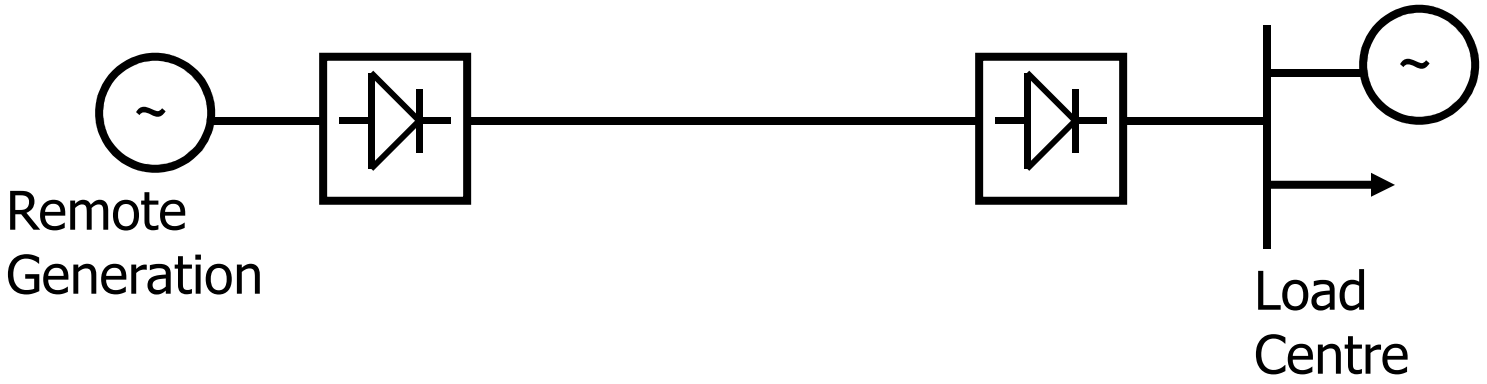
- **Moving large amounts of power over long distances.**
- **Moving power by cable over moderate to long distances.**
- **Moving power between asynchronous systems.**
- **Forcing ordered power into an area**

Advantages of HVDC

- **Lower Cost than AC for Long Distance (600 miles for overhead and 30 miles for Underground/Submarine)**
- **Controlled Power Flow (Owner has control)**
- **Limitation of Short Circuit Currents**
- **High speed electronic clearance of temporary faults**
- **Transmission at reduced voltages when line insulation is damaged**

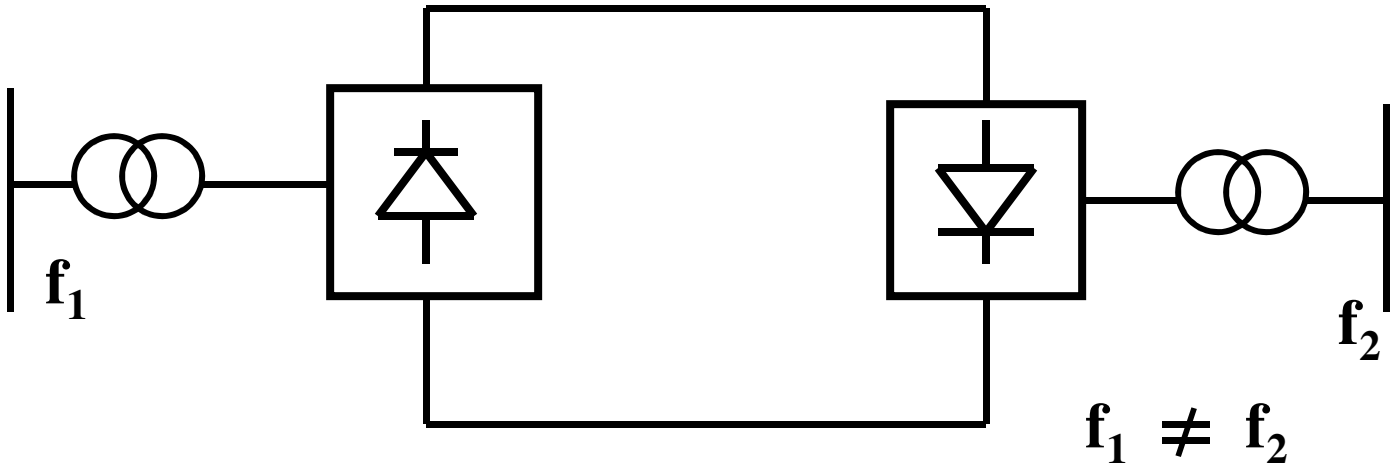
Applications for HVDC

Transmission of bulk power from remote generation

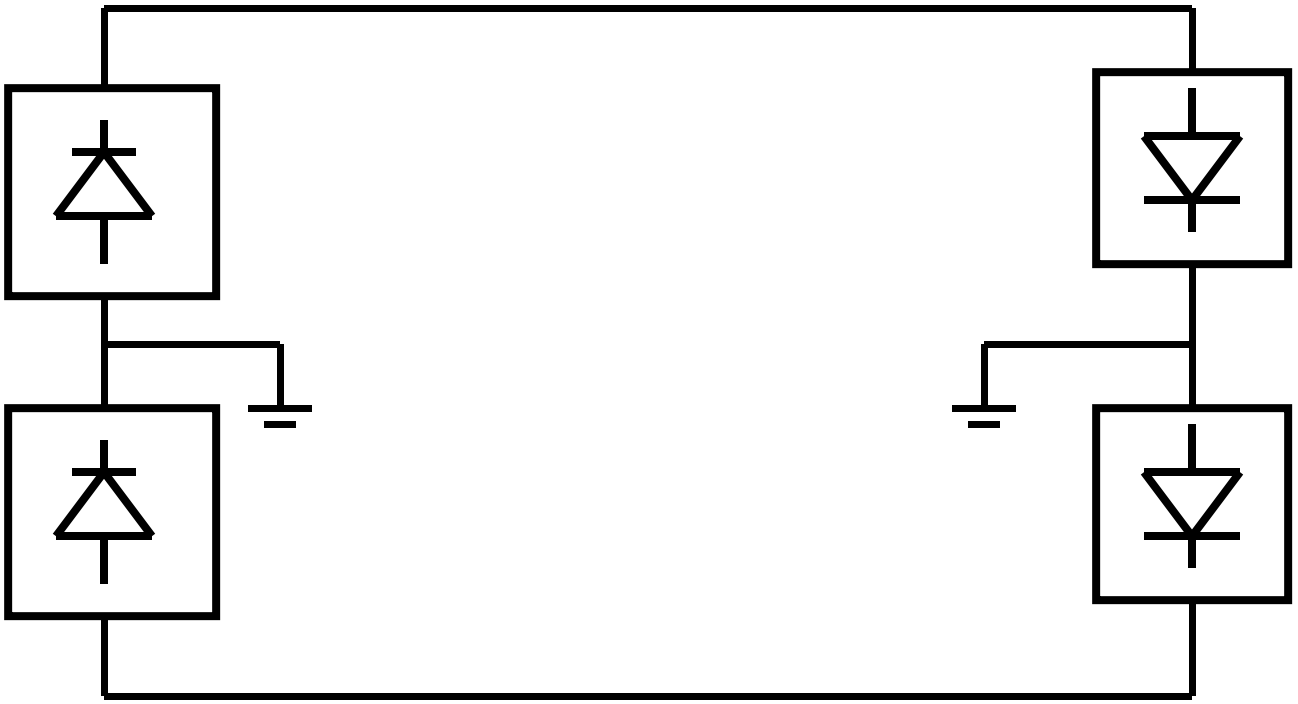


Applications for HVDC

Asynchronous Interconnection (Back-Back)

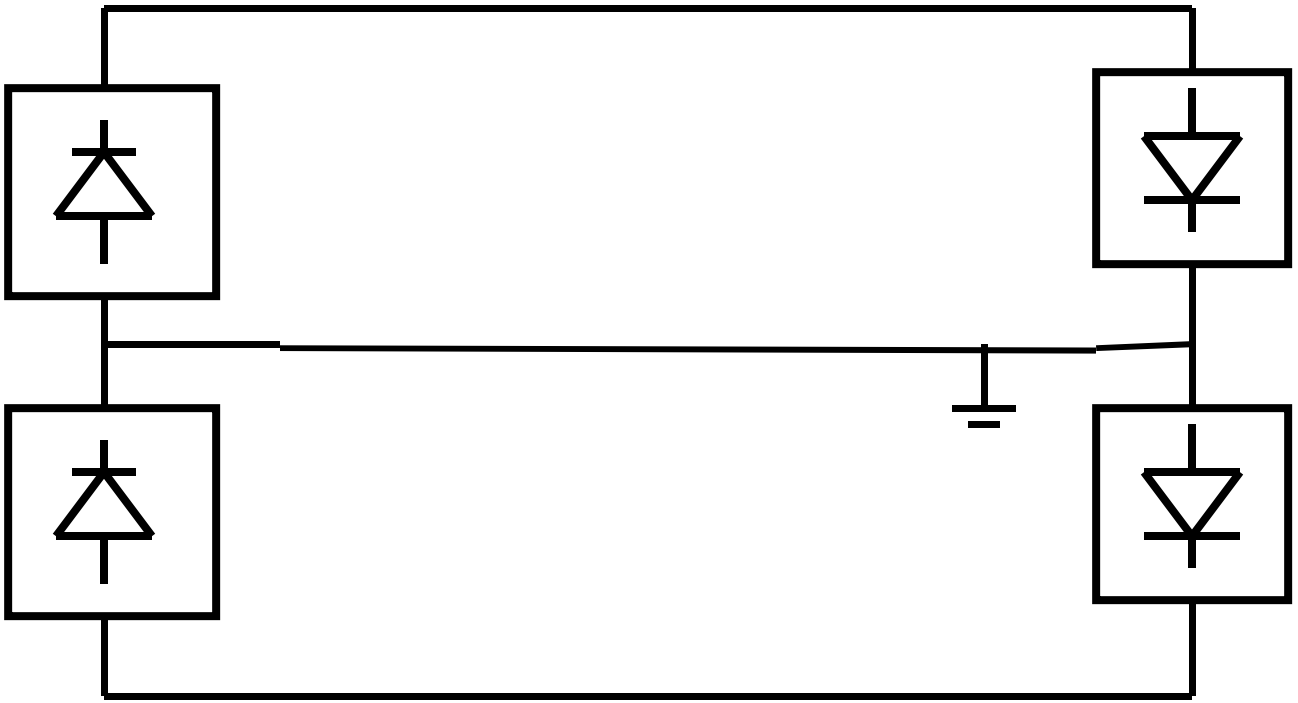


Two Terminal Bipolar System

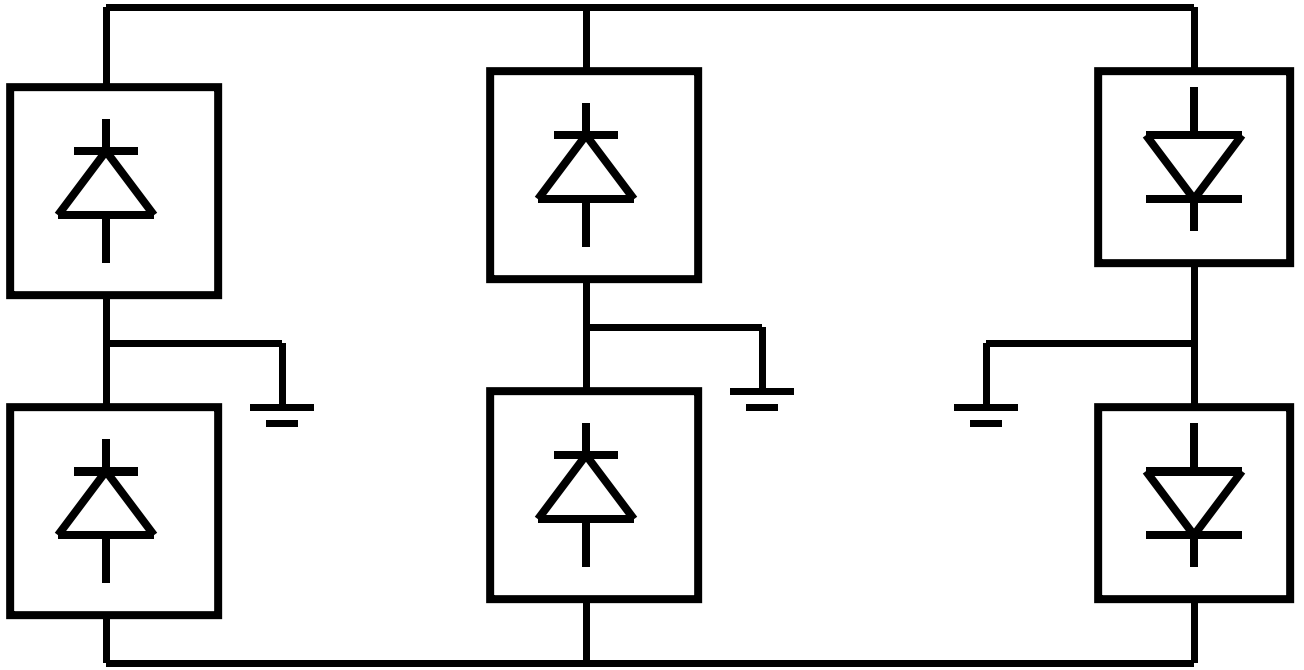


Two Terminal Mono-polar System Ground Return

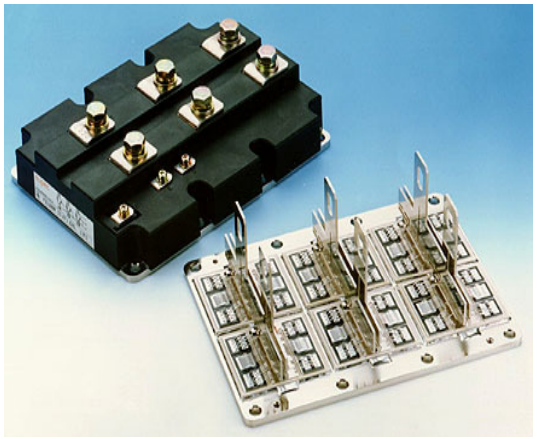
Two Terminal Bipolar System



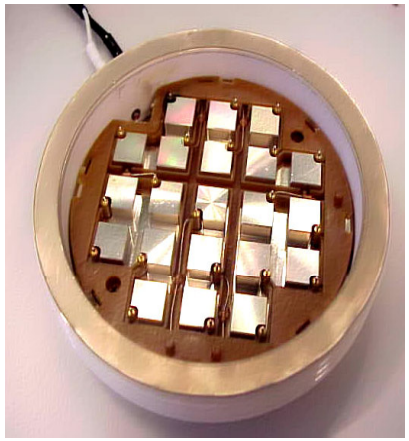
Multi-Terminal Parallel Tap



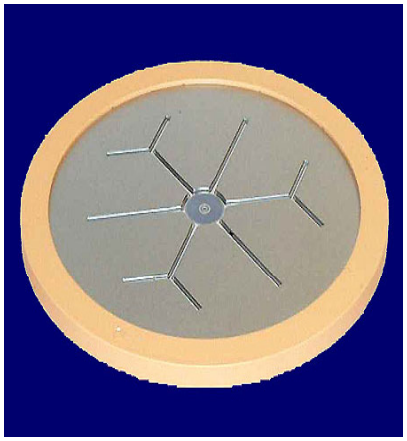
Choice of Power Devices



IGBT Module (wire bonded)



IGBT (presspack)



Thyristor

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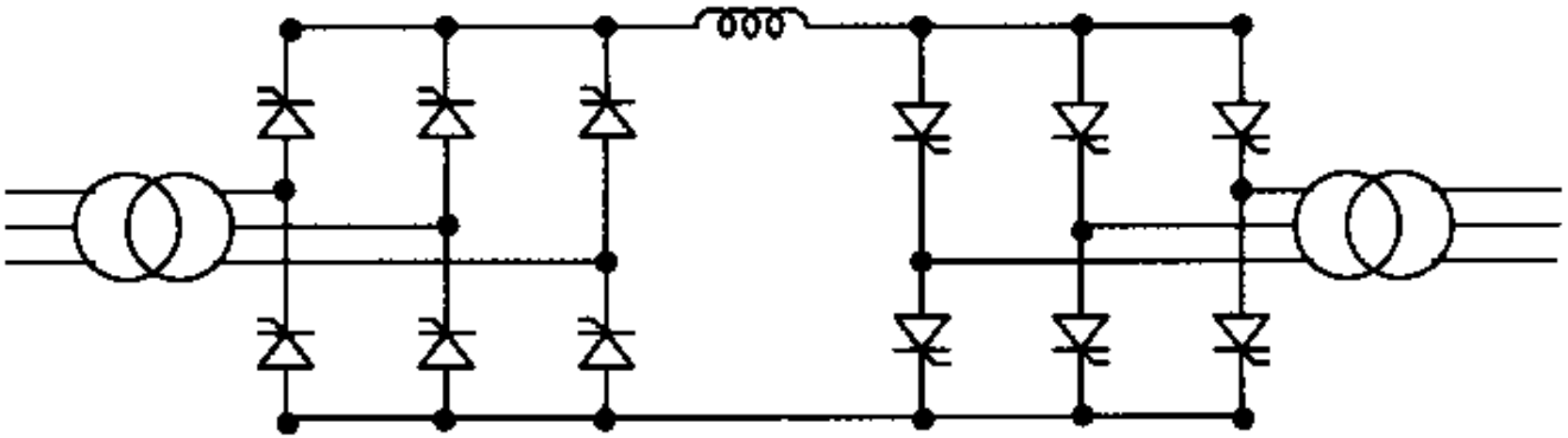
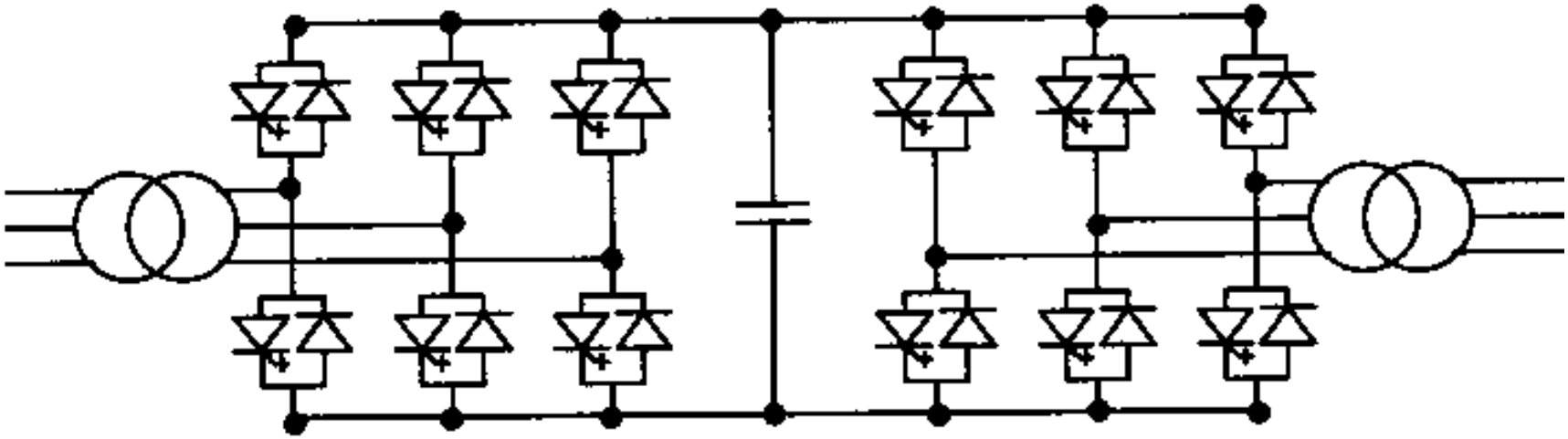
Types of HVDC Converters

- **Line Commutated Converters (LCC) Using devices with no turn-off capability (Thyristors)**

- **Voltage Source Converters (VSC) Using devices with turn-off capability, Insulated Gate Bipolar Transistors (IGBT)**



Line Commutated Converter (LCC) System, which requires unidirectional current flow



Voltage Sources Converter (VSC) System which requires unidirectional dc voltage

Advantages of Voltage Source Converter Compared to Thyristor Based HVDC Technology

- **With phase angle control of ac voltage, converters can independently supply leading and lagging reactive power along with real power**
- **There are no commutation failures**
- **With same polarity voltage (no voltage reversal) cable is much cheaper**
- **Site area required is half that for thyristor-based HVDC converters**
- **Black start capability**
- **Can operate in a passive ac system.**
- **Since there is no voltage reversal, VSC system is suitable for multi-terminal system and future expansion**

Disadvantages of Voltage Source Converter Compared to Thyristor Based HVDC Technology

- **Need many more devices in series and also diodes in parallel with each controlled device**
- **Higher cost (50% more)**
- **Higher losses (50% more)**
- **IGBT Devices not as high power and robust as thyristor technology**
- **Can not yet electronically clear temporary dc line faults with multiple and low voltage restarts for HVDC with overhead line**

Applications HVDC Transmissions
Three Different Worlds

- **Developing Countries: China, India, Brazil --- Doing the way it should be done**
- **Europe - Mostly underground and Submarine**
- **USA - Need transmission for Renewables but NIMBY and BANANA for Overhead Lines, Underground Cable is too expensive**

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UHVDC and HVDC in China

All Overhead Medium and Long Distance Transmission

11 ±500kV HVDC Lines,1 ±660kV HVDC Line,2 ±800kV UHVDC lines in operation.

9 ±800kV projects in 5 years.

and more in the future.

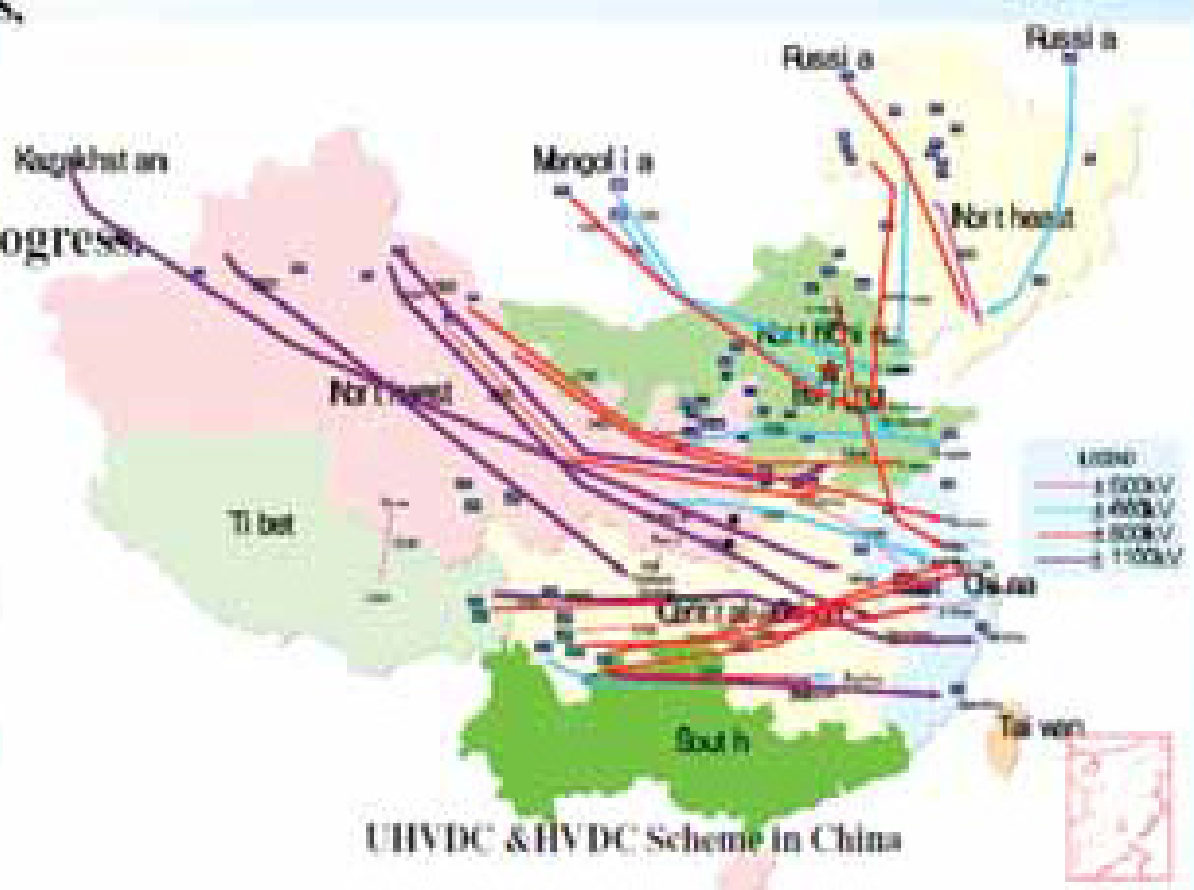
± 1100kV UHVDC under progress.

2 projects in 5 years.

±660kV in green

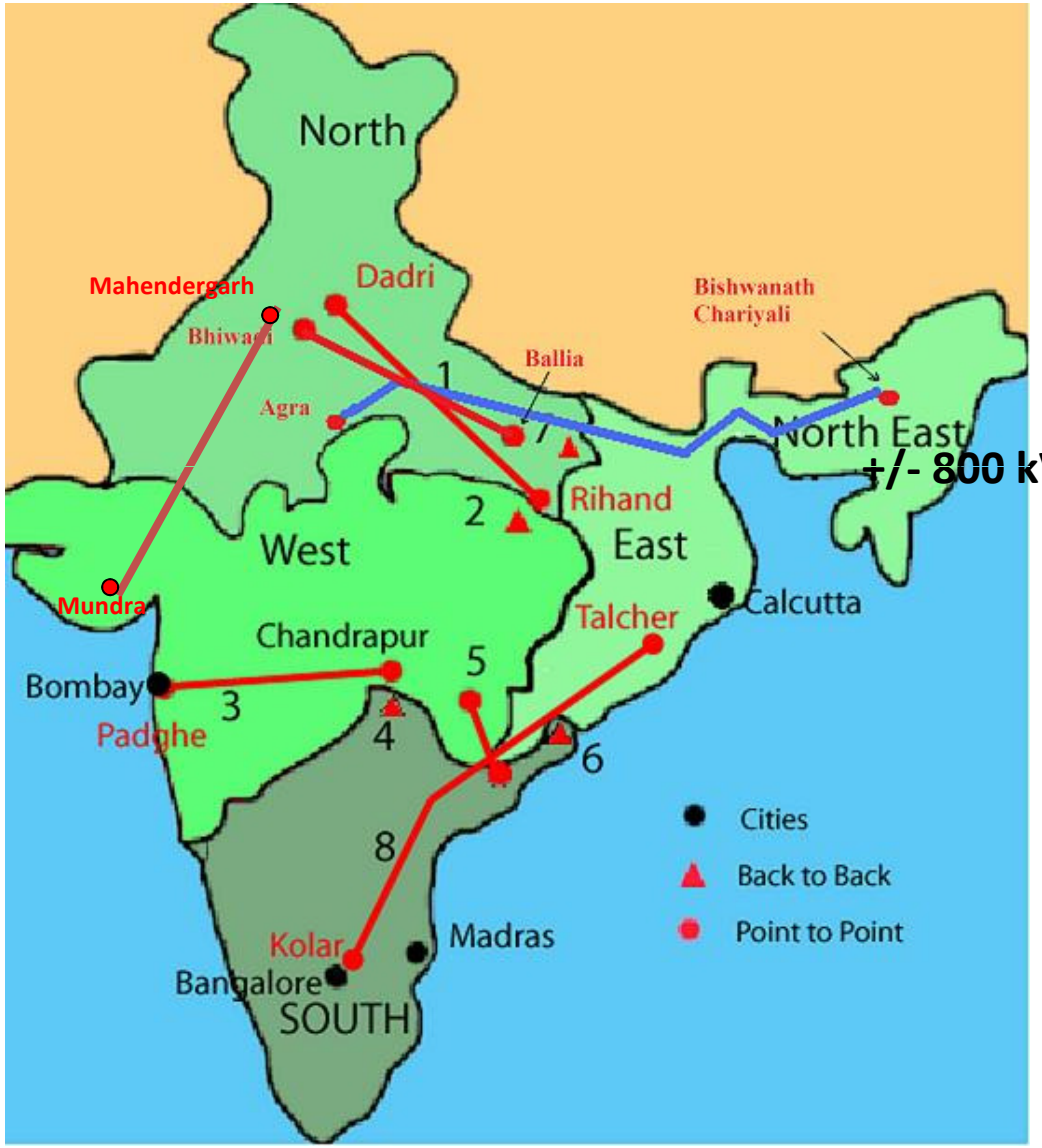
±800kV in red

±1100kV in purple



UHVDC &HVDC Scheme in China

HVDC Projects in INDIA



1 – Rihand-Dadri (+/- 500 kV,1500MW)

2 - Vindyachal (2 X250 MW)

3 - Chandrapur-Padghe (+/- 500kV,1500 MW) MSTCL

4 - Chandrapur-Ramagundam (2 X 500MW)

5 – Barsoor-Lower Sileru (100 kV,100MW)

6 – Gajuwaka (1 X 500 MW + 1 X 500 MW)

7 - Sasaram (1 X 500 MW)

8 - Talcher-Kolar ((+/- 500 kV, 2000MW, upgraded to 2500 MW)

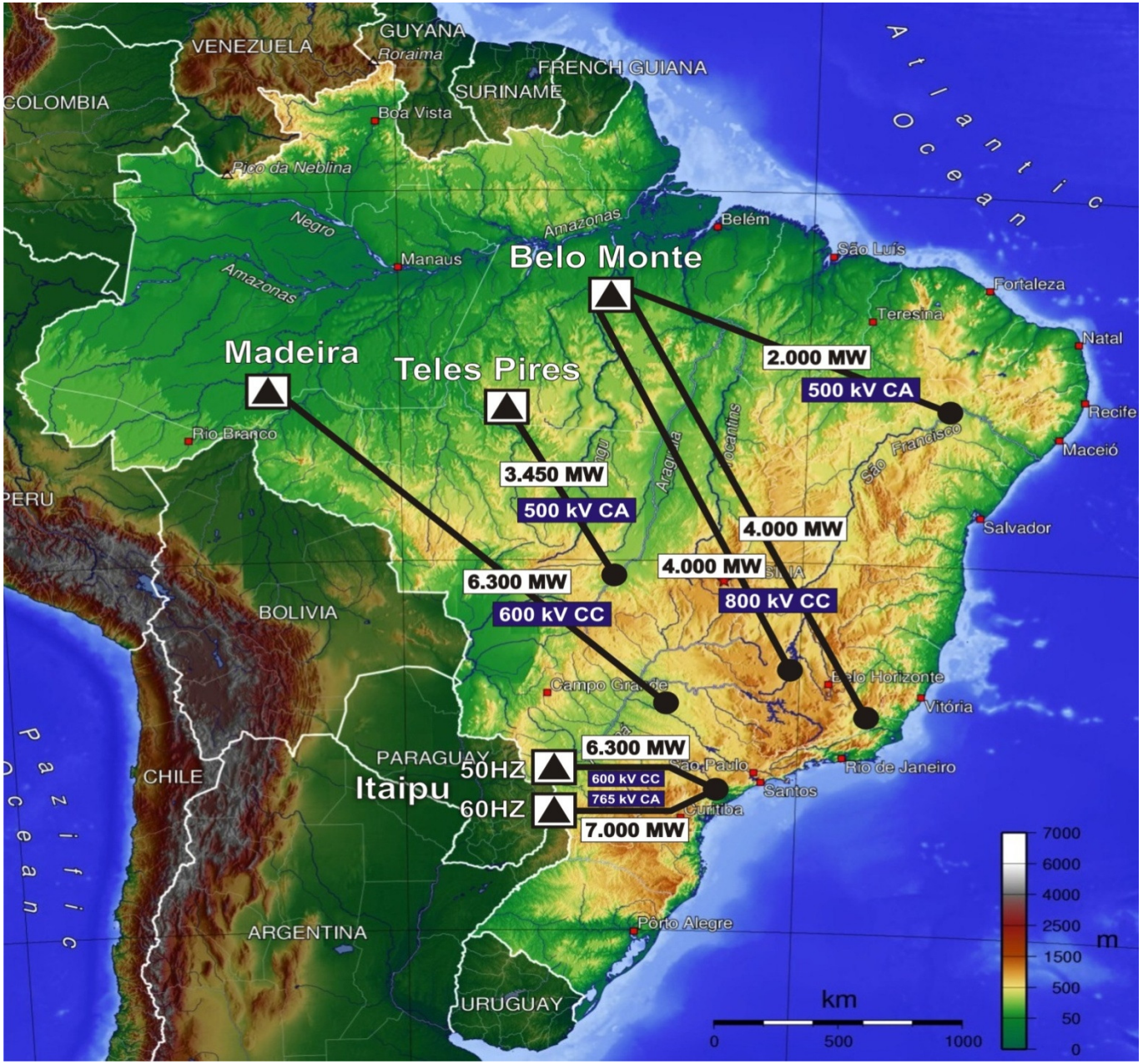
9- Ballia-Bhiwadi (+/- 500 kV, 2500MW)

10- NER-Agra (+/- 800 kV, 6000 MW , Multi-Terminal ,under execution)

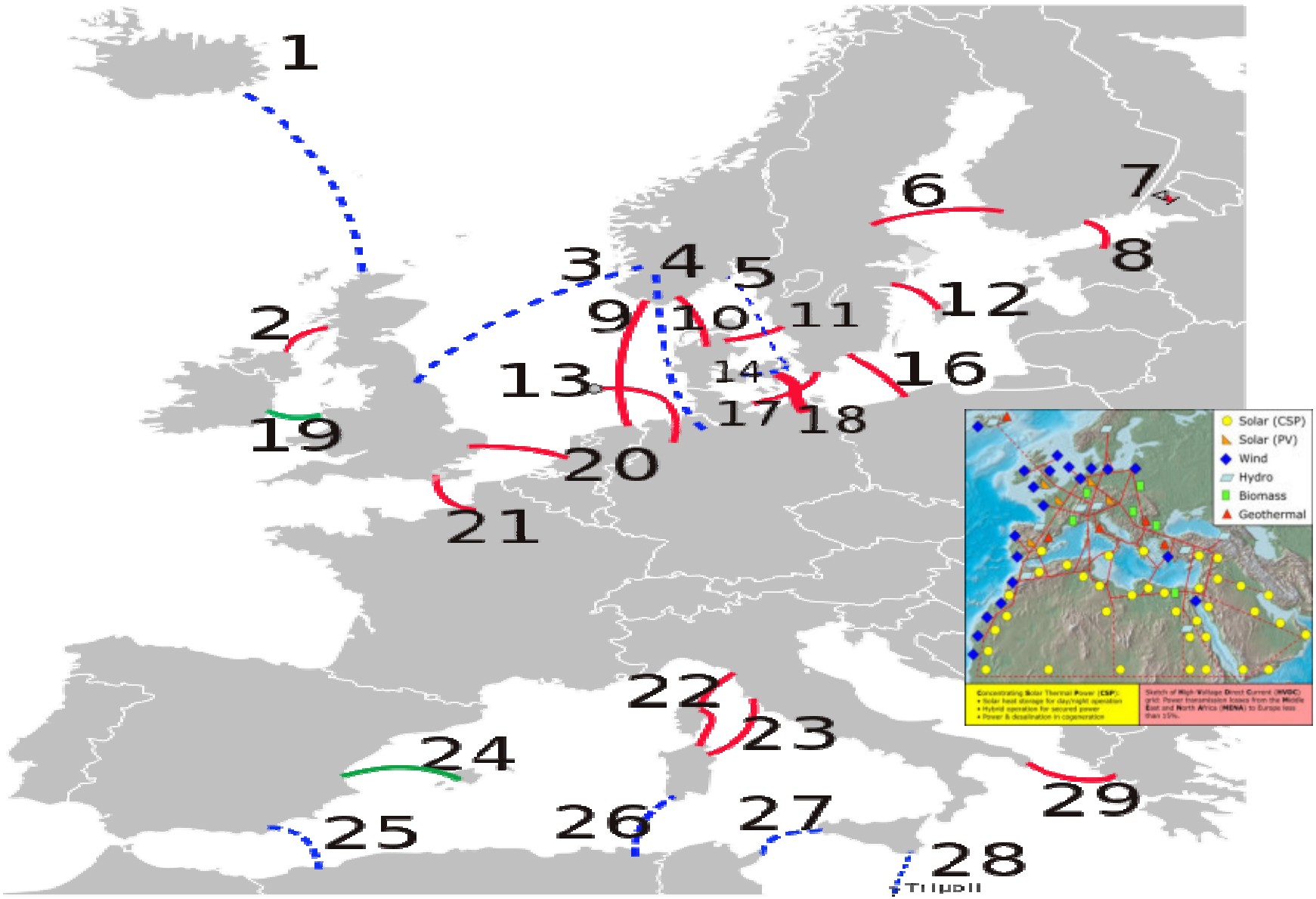
11. Mundra- Mahendergarg (+/- 500 kV, 2500MW) Adani

12. Champa -Kurukhshetra (3000MW +/- 800 kV)

HVDC/AC in Brazil: Present and Future Projects



HVDC in Europe



USA Scenario

- **In USA, we need transmission AC or DC**
  particularly for moving power from large
  wind (land and offshore) and solar Farms
  that exist at long distance from the load centers

- **We have permitting, and siting problems**
  for AC Overhead Lines

- **Like Europe, UHVAC or UHVDC seems to be out of question**

- **Can a case be made for HVDC Underground and Submarine Cables?**

Latest Example:

Swedish HVDC VSC Converters and Underground Cable
1440 MW (2x720MW) 300kV South-West Link
Ordered by Svenska Kraftnät, the national grid operator
for completion in 2014

- **ABB HVDC Cable complete turnkey cost: 1440 MW (2x720MW) 300kV, 125 miles for $160 M ($1.28 per mile)**

- **Alstom Grid's MaxSineTM Voltage Source Converters (VSC) , complete turnkey for Euros 240M ($320M)**

For 125 miles total cost $472M=$3.7M/mile
For 200 miles Total Cost would be $568M= $2.84/mile
For 250 miles Total Cost would be $632M= $2.5/mile
For 400 miles Total Cost would be $824M= $2.1M/mile **Hingorani**

Thank You