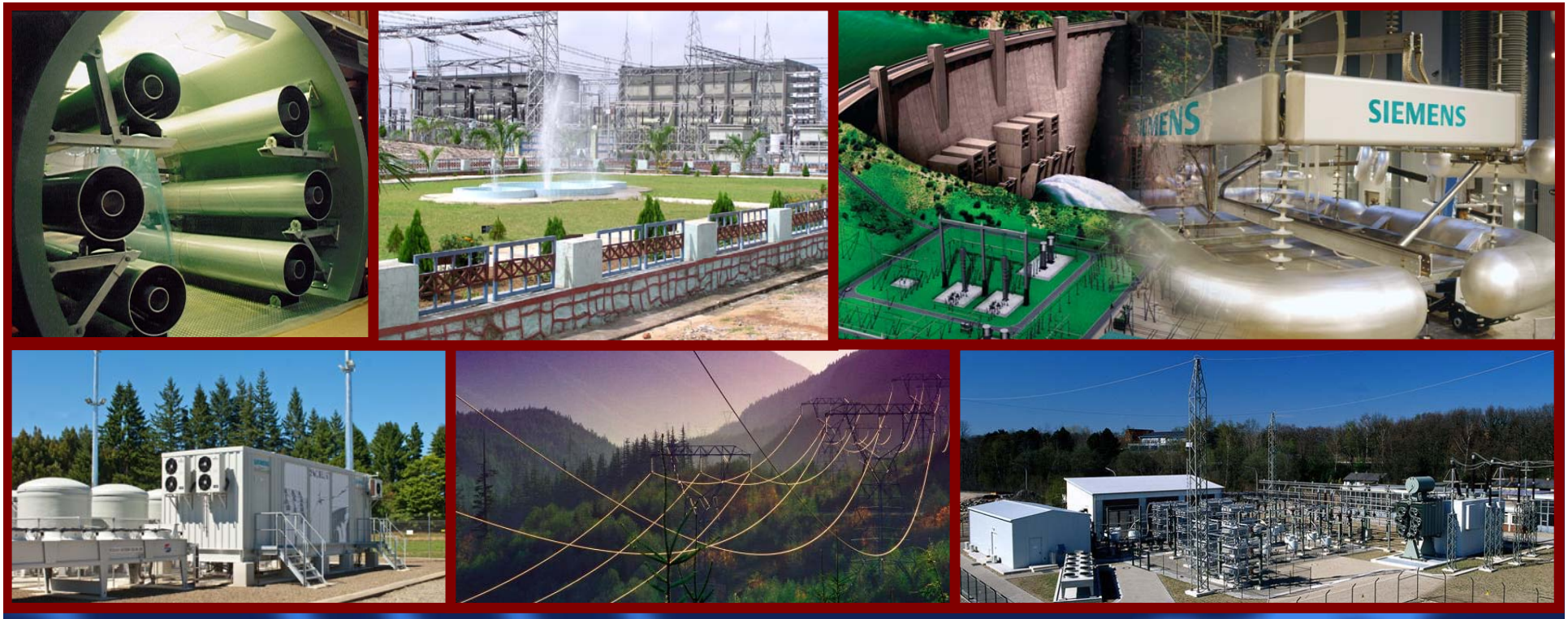


IEEE PES Substations Committee, Montreal, May 16-21, 2010

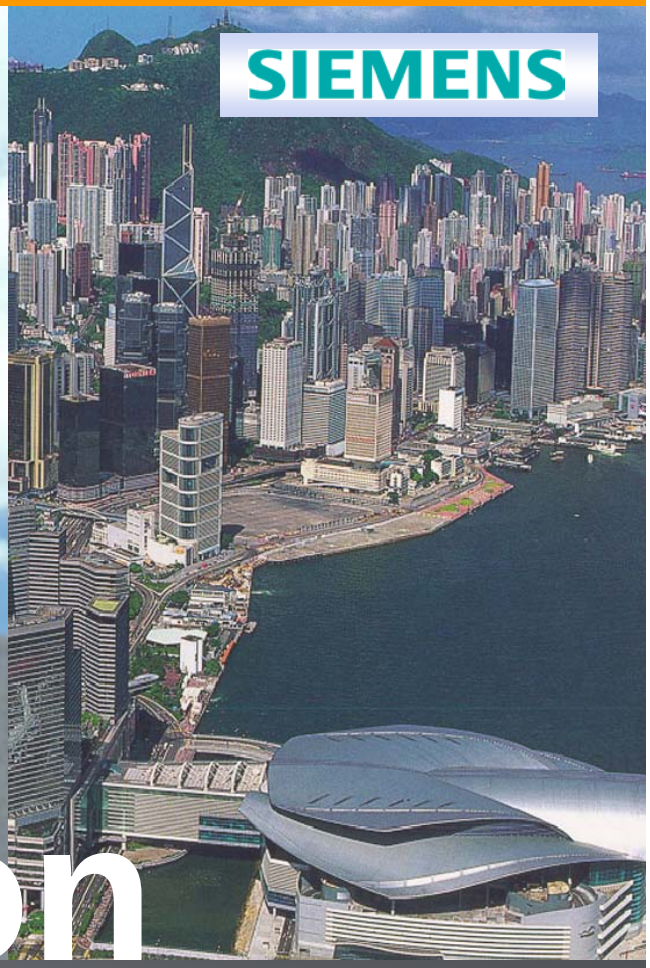
Prospects of Integrated AC/DC Systems for Power Transmission Enhancement

Matthias Luther Rafael Mihalic Dusan Povh D. Retzmann

transpower stromübertragungs gmbh

University of Ljubljana

SIEMENS



Introduction

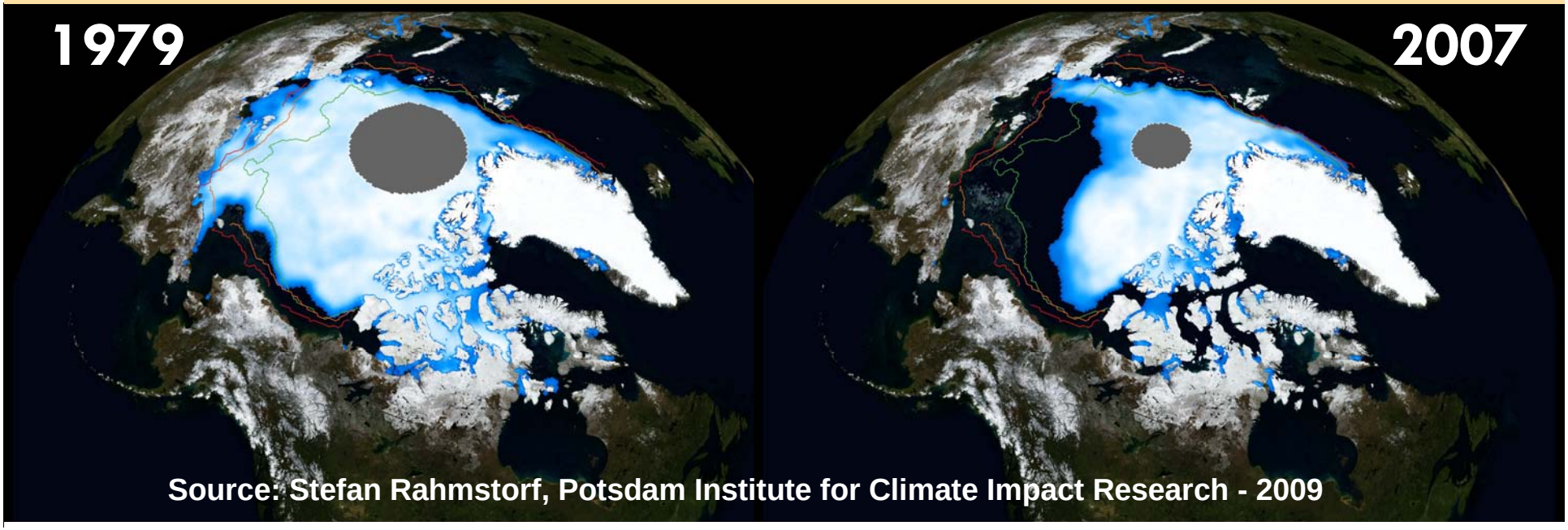
CO_2 Reduction – Green Energy

Megacities – Security of Supply

Greenland Melt-Down has accelerated: Reality – from 1979 to 2007 !

SIEMENS

***Sustainability** of **Power Supply** – highly important, today and in Future!*



EWEA's * three Wind Power Scenarios (in GW)

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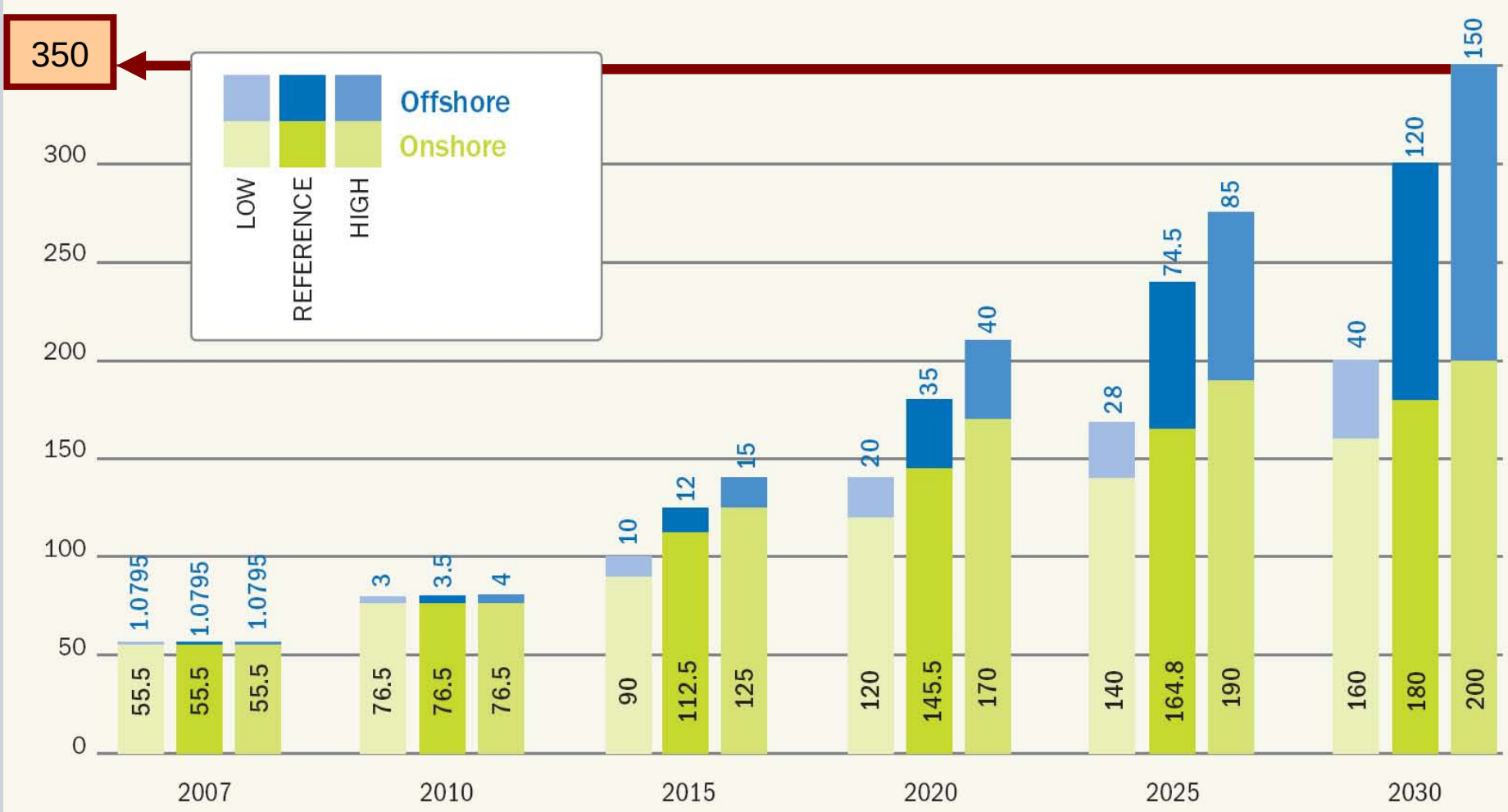

*** EWEA: European Wind Energy Association – Pure Power® Wind Energy Scenarios up to 2030 (Report 03-2008)**

Prospects of Solar Power from Deserts

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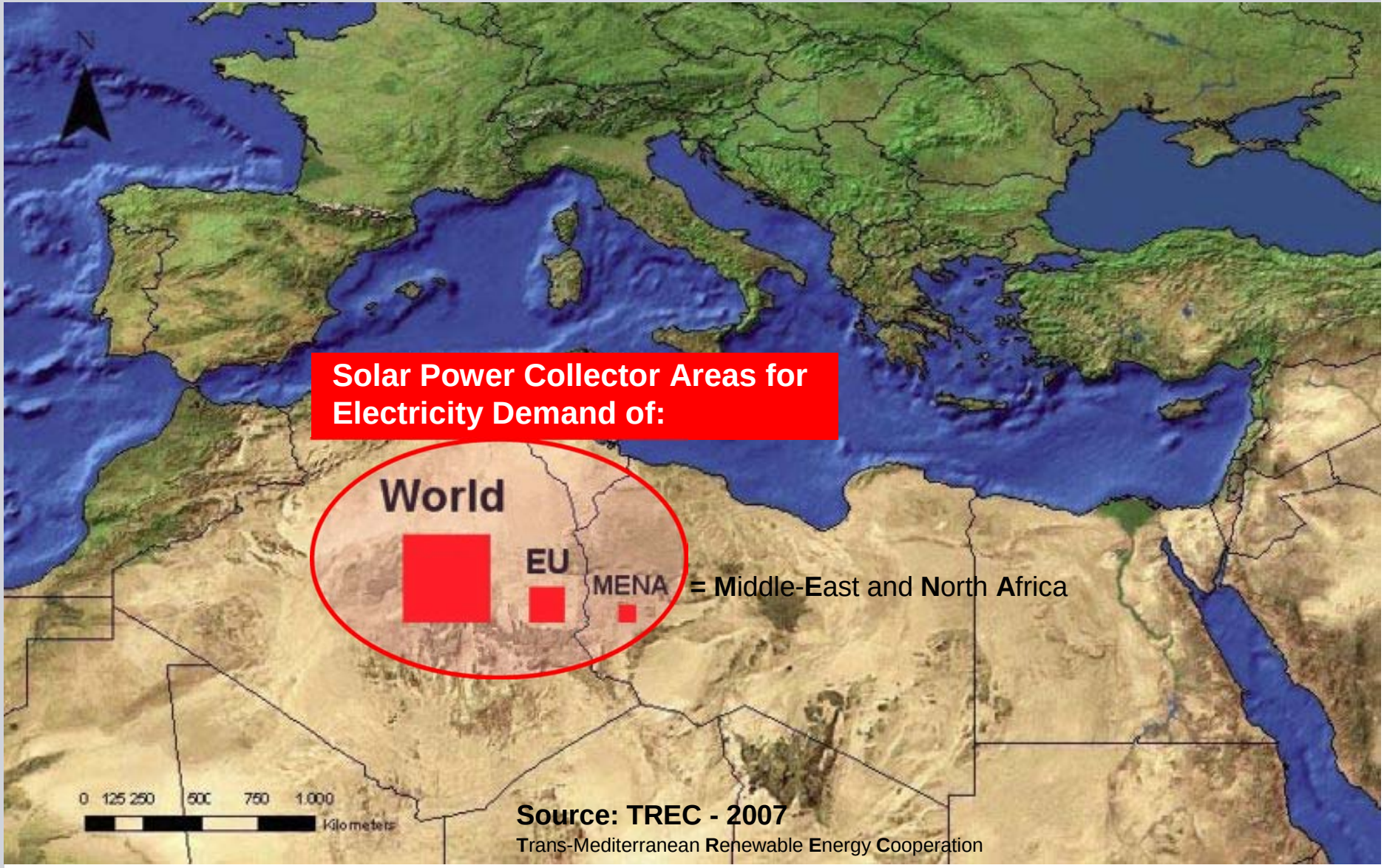

Hydro Power for Supply of Megacities …

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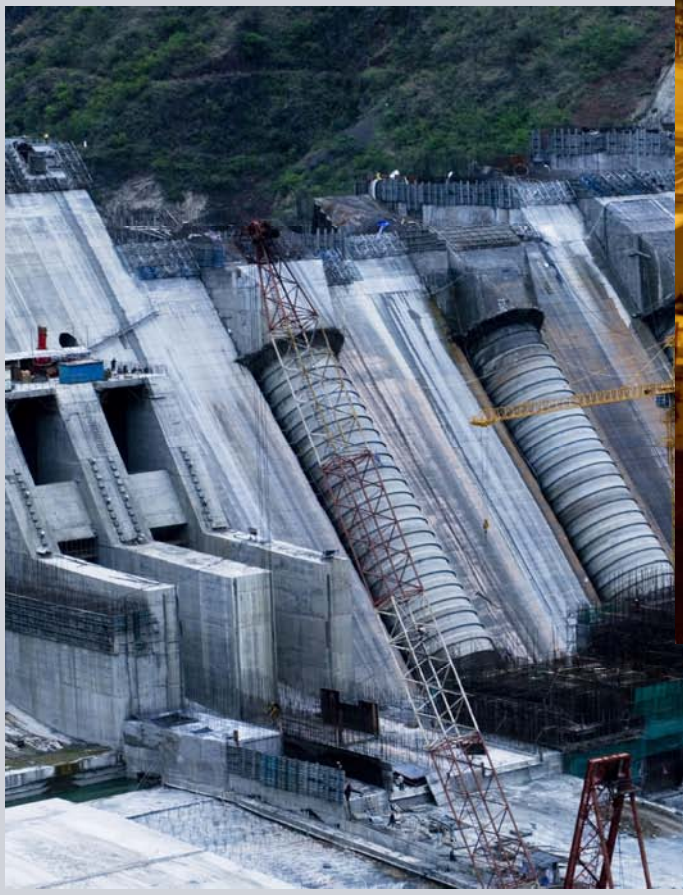
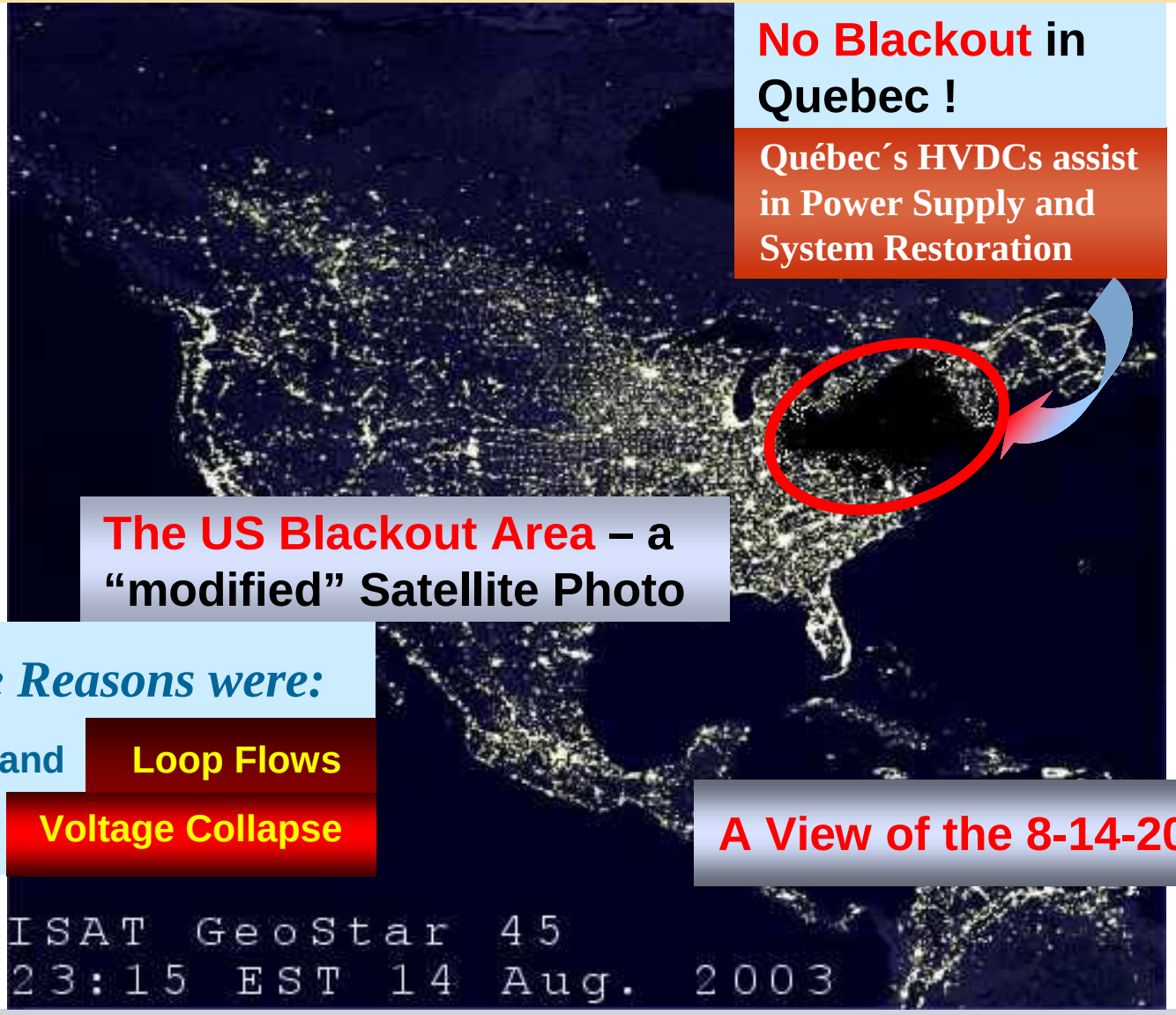
with 800 kV Bulk Power UHV DC



Security of Supply – HVDC protected Québec

SIEMENS



No Blackout in Quebec !

Québec´s HVDCs assist in Power Supply and System Restoration

The US Blackout Area – a "modified" Satellite Photo

A View of the 8-14-2003 Event

Some of the Reasons were:

- Overloads and **Loop Flows**
- Leading to **Voltage Collapse**

Options of HVDC & Hybrid AC-DC Interconnections

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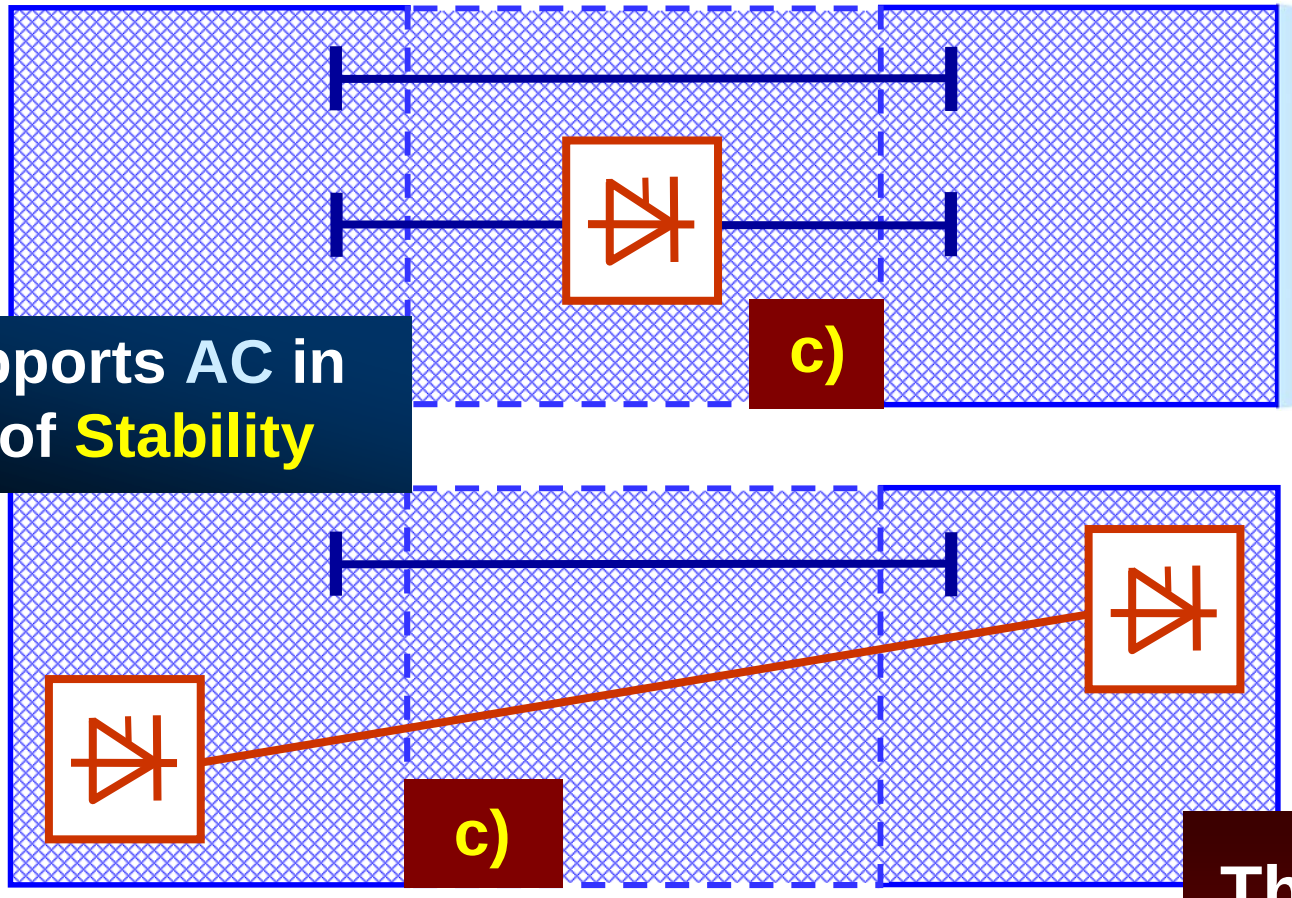

Can be connected to long AC Lines

DC supports AC in Terms of Stability

a) Back-to-Back Solution

b) HVDC Long-Distance Transmission

c) Integration of HVDC into the AC System

The Firewall for Blackout Prevention

Benefits of Hybrid System Interconnections

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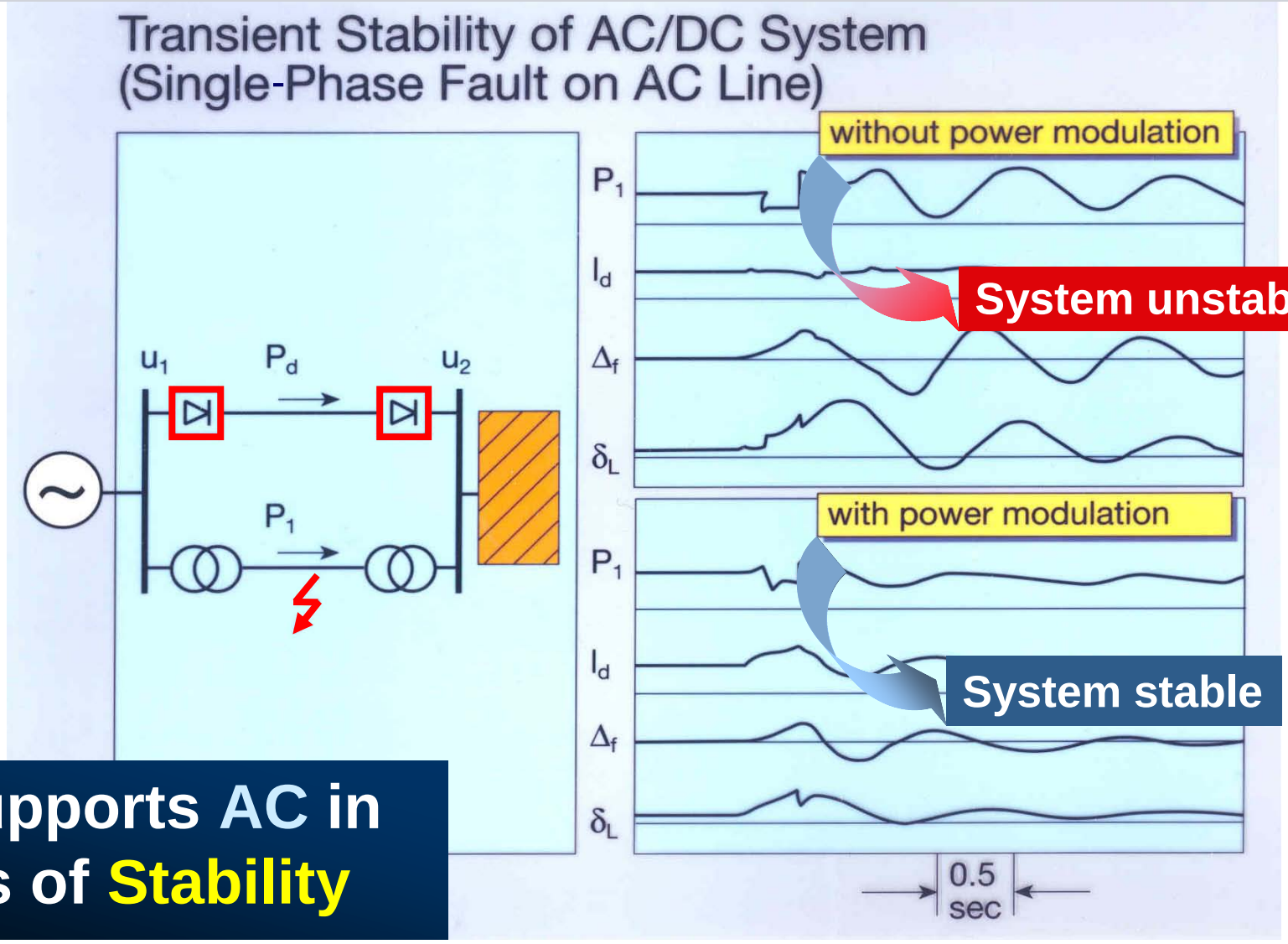

DC supports AC in Terms of Stability

Global Trends

on Power Markets

Power System Development: The Key-Issue – How to avoid Bottlenecks

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Globalisation/ Liberalisation

Deregulation – Privatization: Opening of the Markets, Independent Transmission Companies ITCs, Regional Transmission Organisations RTOs

Bottlenecks in Transmission

Problem of uncontrolled **Loop Flows**
Overloading & **Excess of allowed SCC* Levels**
System **Instabilities & Outages**

The Grids are "close to their Limits"

Investments in Power Systems

Increase in System **Security** & **Sustainability**:

- **Higher Voltage Levels ****
- **New Transmission Technologies**
- **Renewable Energies** for CO_2 Reduction

* SCC = Short-Circuit Current

** Example of CE: 400 kV is in fact too low

Development of Power Systems

SIEMENS

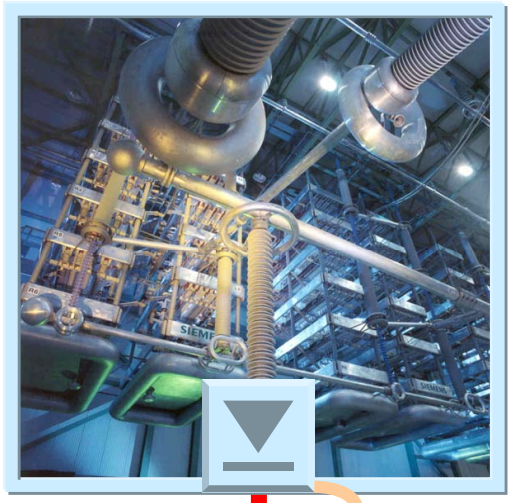
- **Extensions** of **Interconnected Systems**
- **Increased Power Exchange** among the **Interconnected Systems**
- Transmission of **large Power Blocks** over **long Distances** (Hydro, **Wind** * and Solar Energy)
- **Renewable Energy Resources** at favorable Locations *

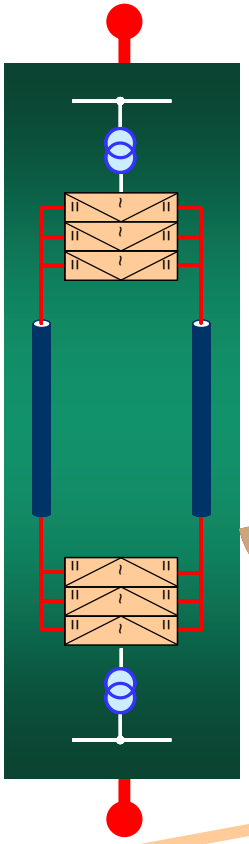
* A big Issue for Grid Developments – in all Countries

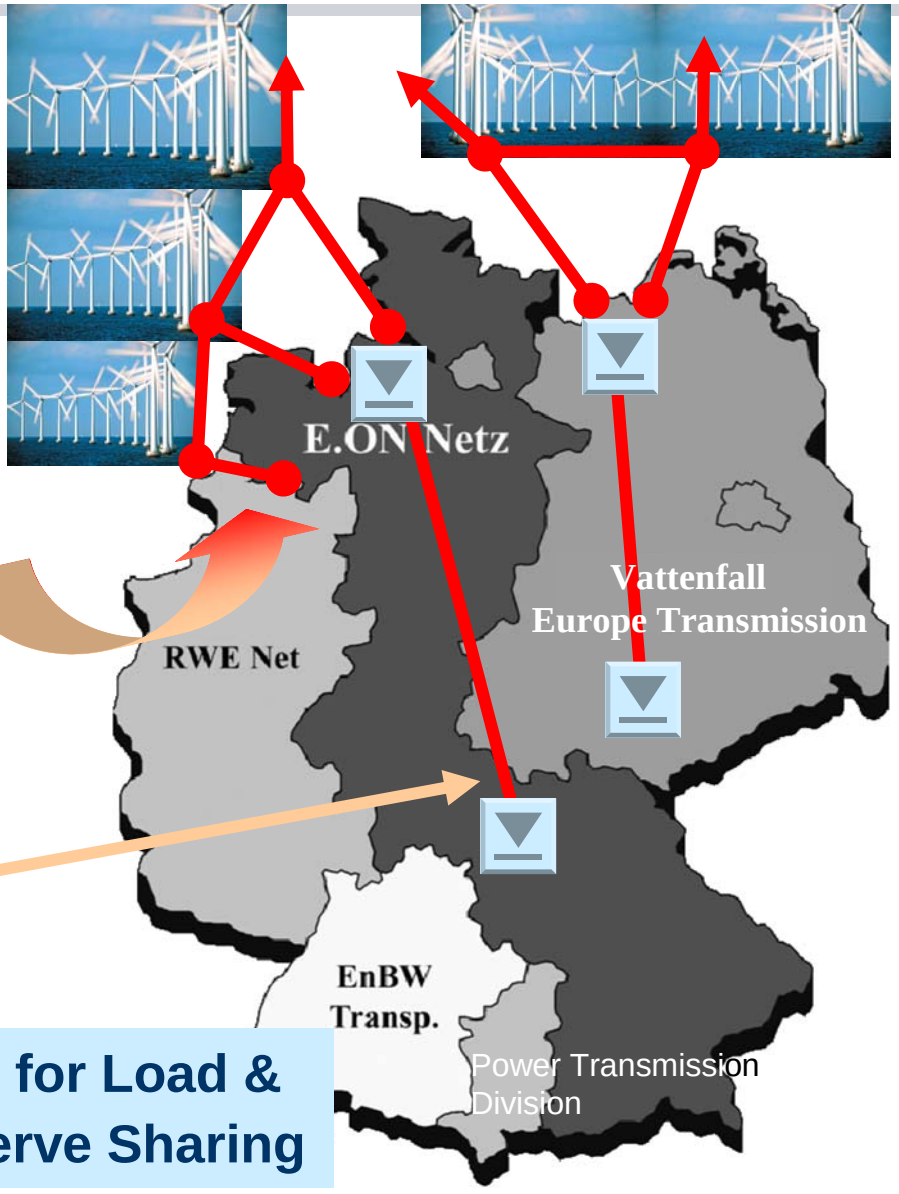
Integration of large Offshore Wind Farms into the Main Grid – the German Prospects

SIEMENS

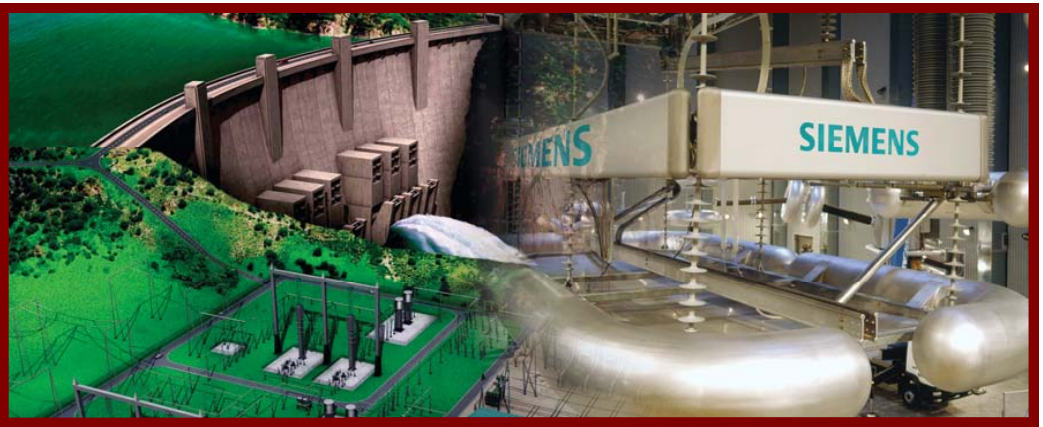
VSC HVDC – for Onshore Grid Access & Offshore DC Multiterminal

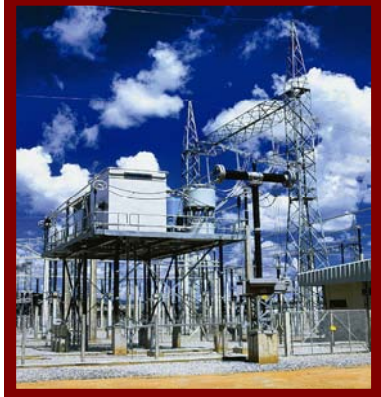






HVDC Classic – for Load & Generation Reserve Sharing





Getting more Power out of the Grid

Prospects of Grid Extension *and* System Interconnection

Many Concepts: MAINSTREAM, SEATEC …

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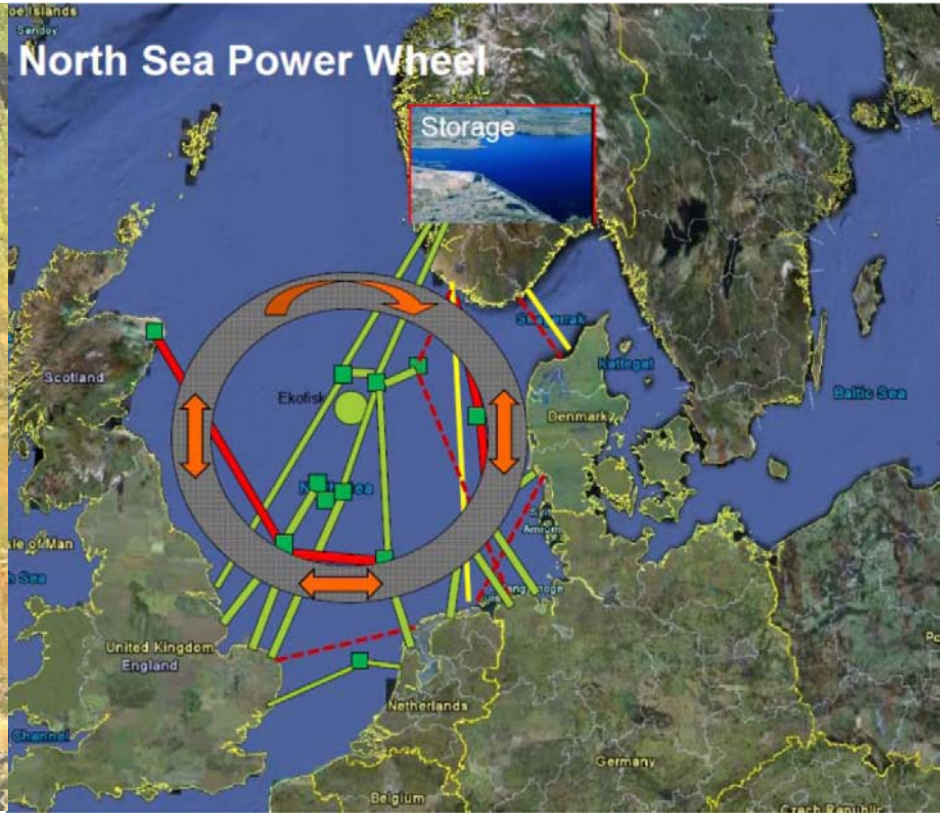
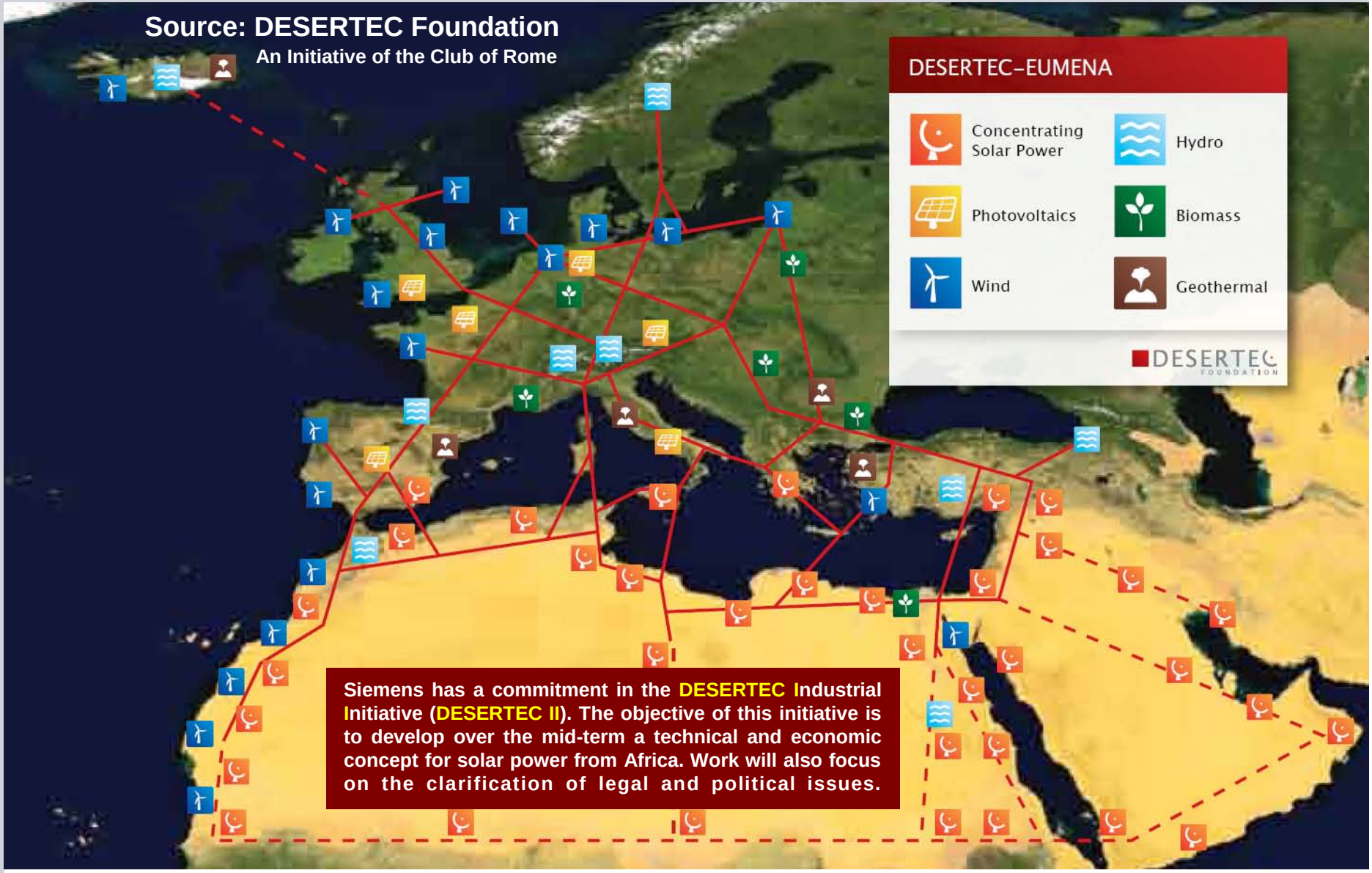


… and DESERTEC, the Super Grid

SIEMENS



UCTE*-IPS/UPS Interconnection Study

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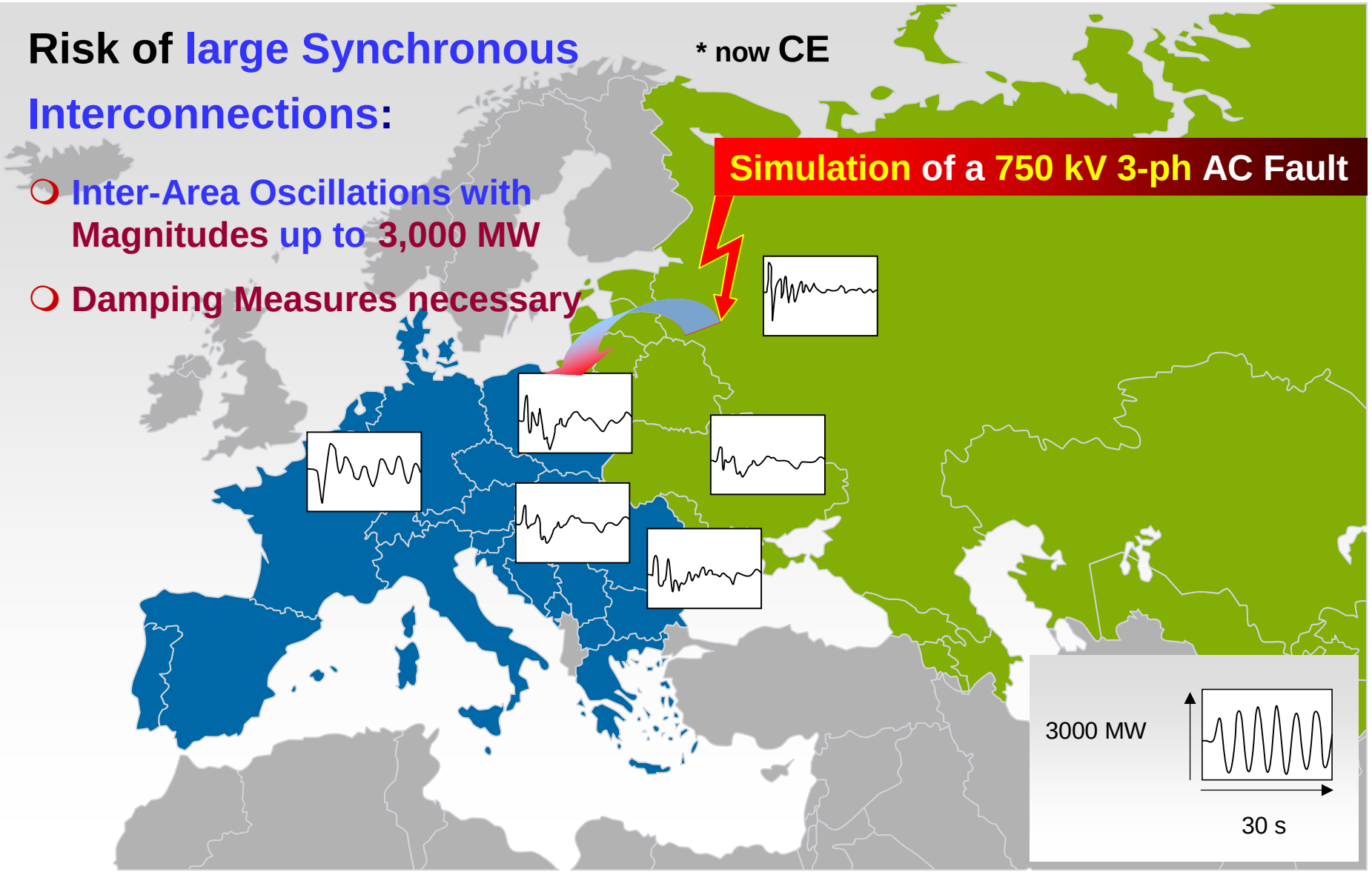
Risk of large Synchronous Interconnections:

* now CE

- Inter-Area Oscillations with Magnitudes up to 3,000 MW
- Damping Measures necessary



Studies for Integrated AC/DC Systems

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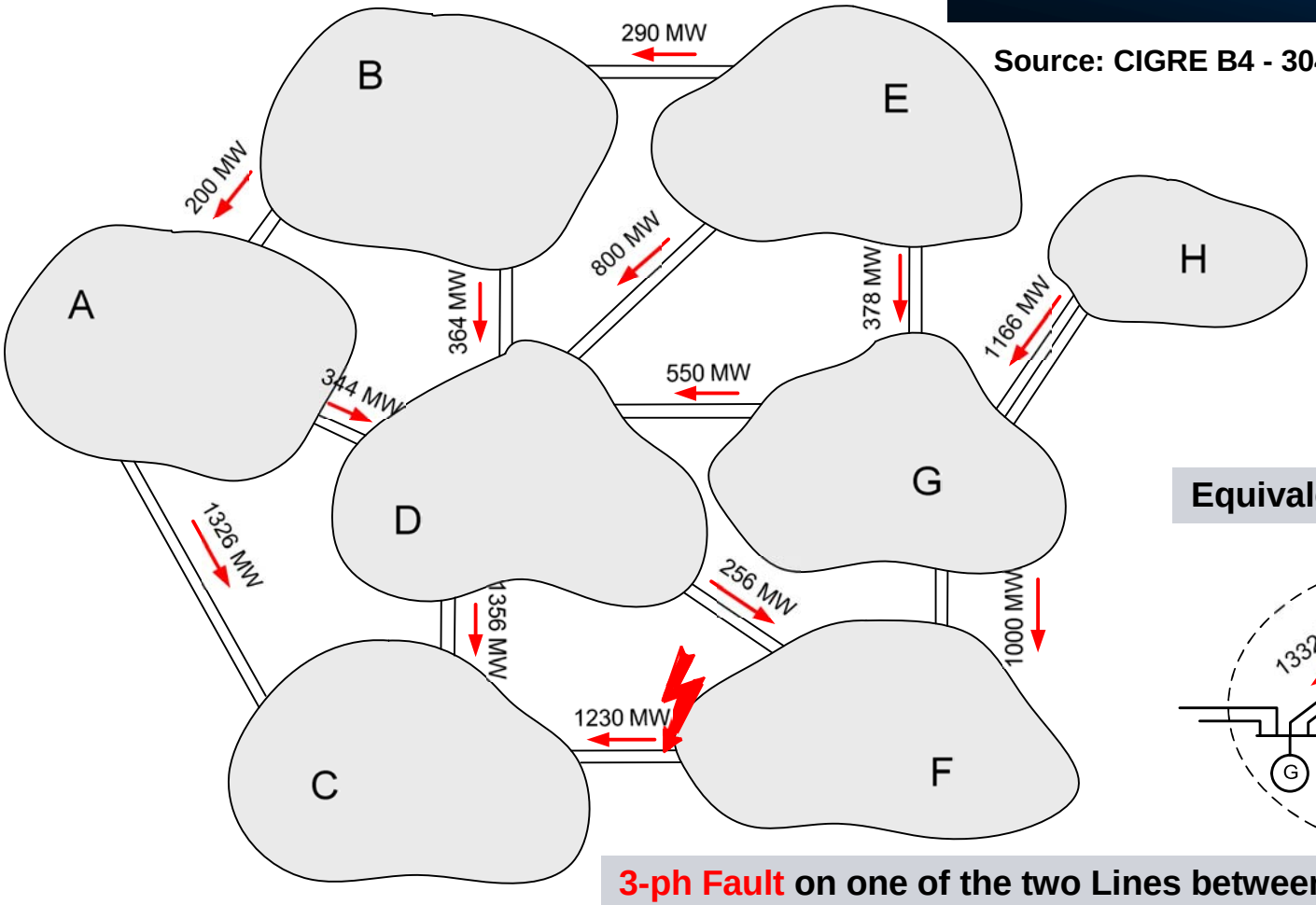
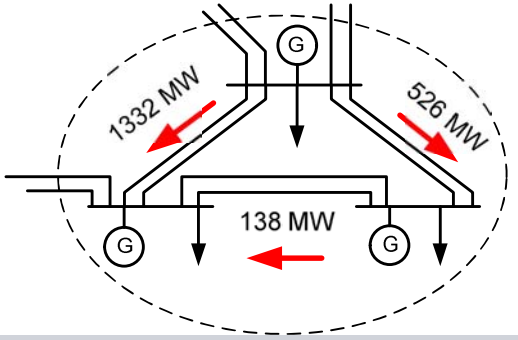
AC Reference System:

Network Structure similar to the European CE System

Source: CIGRE B4 - 304, Paris Session 2006



Equivalent of a Subsystem:



3-ph Fault on one of the two Lines between Subsystems F and C, followed by Disconnection of the Faulty line after 300 ms

Now 2,000 MW additional Power from H to C

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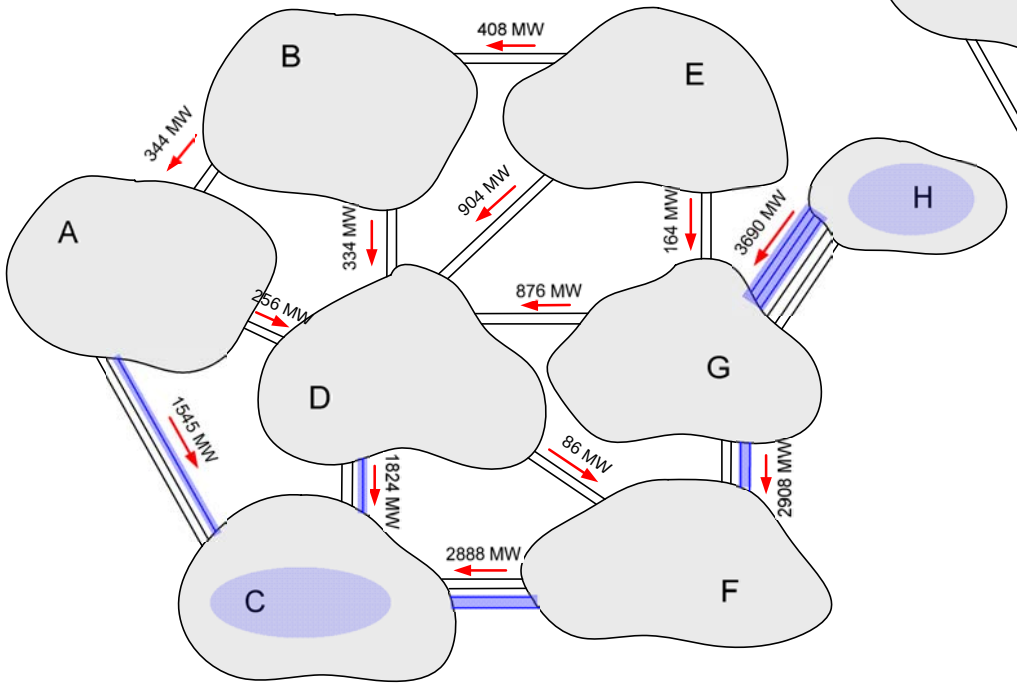
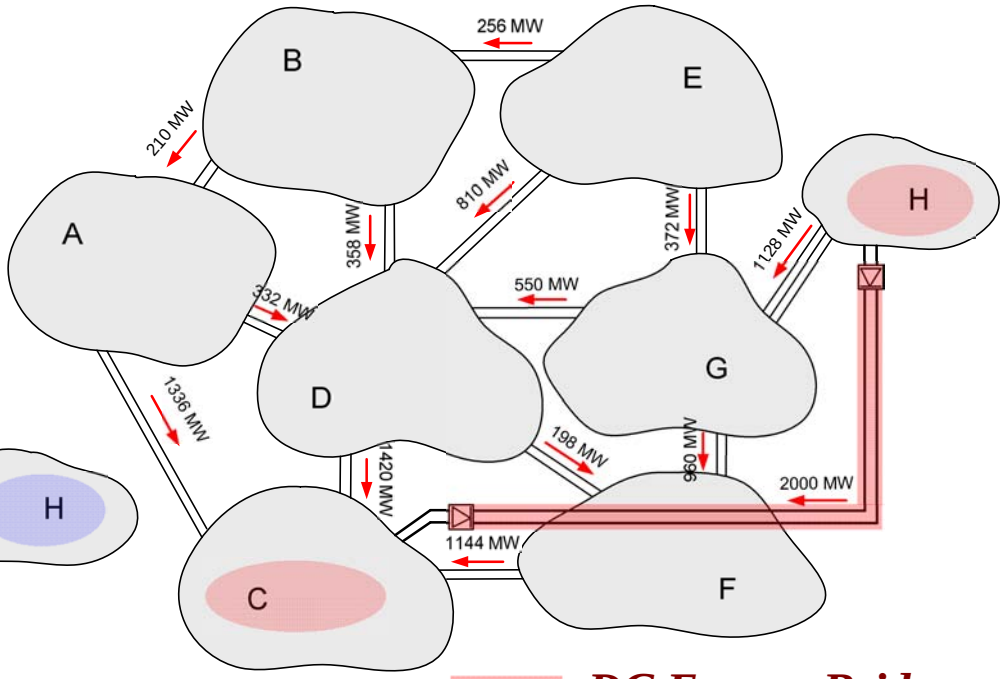
System with AC Extension:

Load Flow for the System strengthened to transmit additional 2,000 MW from Subsystem H to Subsystem C



Additional AC Lines



DC Energy Bridge

System with DC Extension:

Load Flow for the Reference System with an additional 2,000 MW HVDC Transmission from Subsystem H to Subsystem C

Studies for Integrated AC/DC Systems

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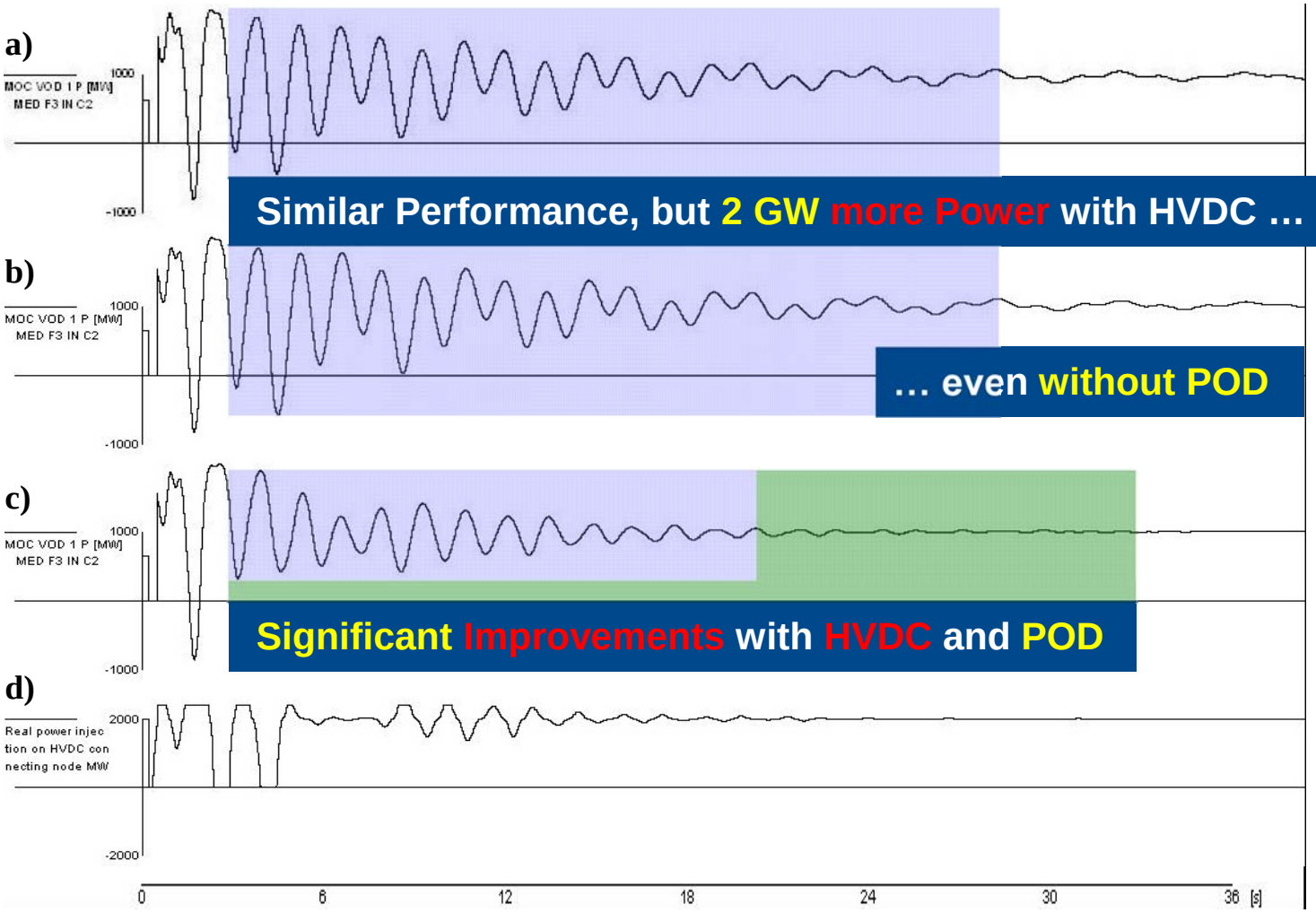
Reference System with initial Power Flow:

2 GW System Extension with HVDC, POD blocked:

System Extension with HVDC, POD enabled:

POD Output Signal HVDC:



The Vision: DC Energy Highway – why not in Europe too ?

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Connecting:

- Wind Power
- Hydro Plants
- Solar Fields

Trends in AC & DC Transmission, EHV *and* UHV

Prospects of UHV AC & UHV DC

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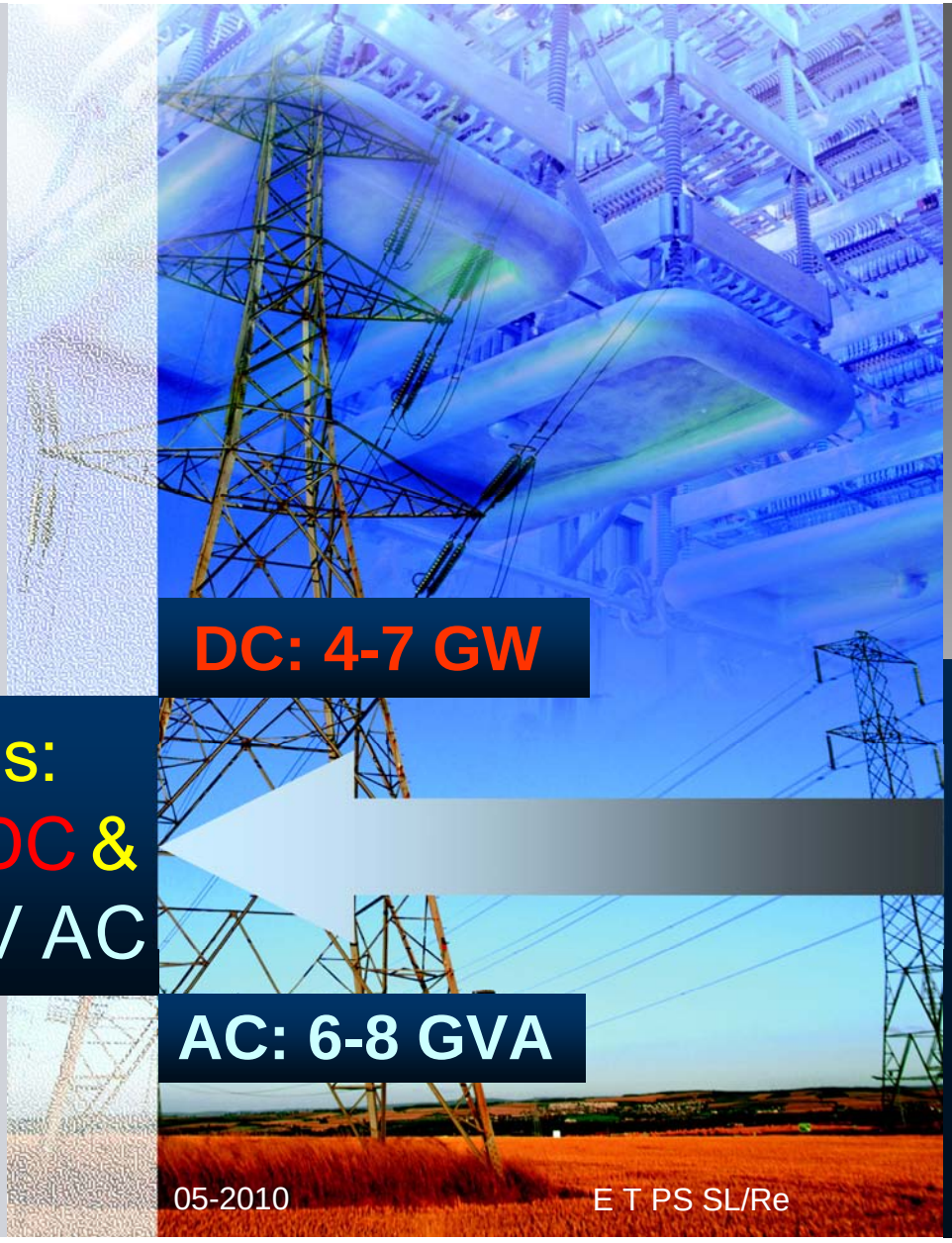

Some Countries will need **Bulk Power Transmission Corridors …**

Solutions:
800 kV DC &
1,000 kV AC

… Increase in Transmission Distance – and Reduction in Losses

UHV AC Transmission Towers

SIEMENS

China: over 217 GW * of additional HVDC Transmission Capacity are expected between 2010 and 2020

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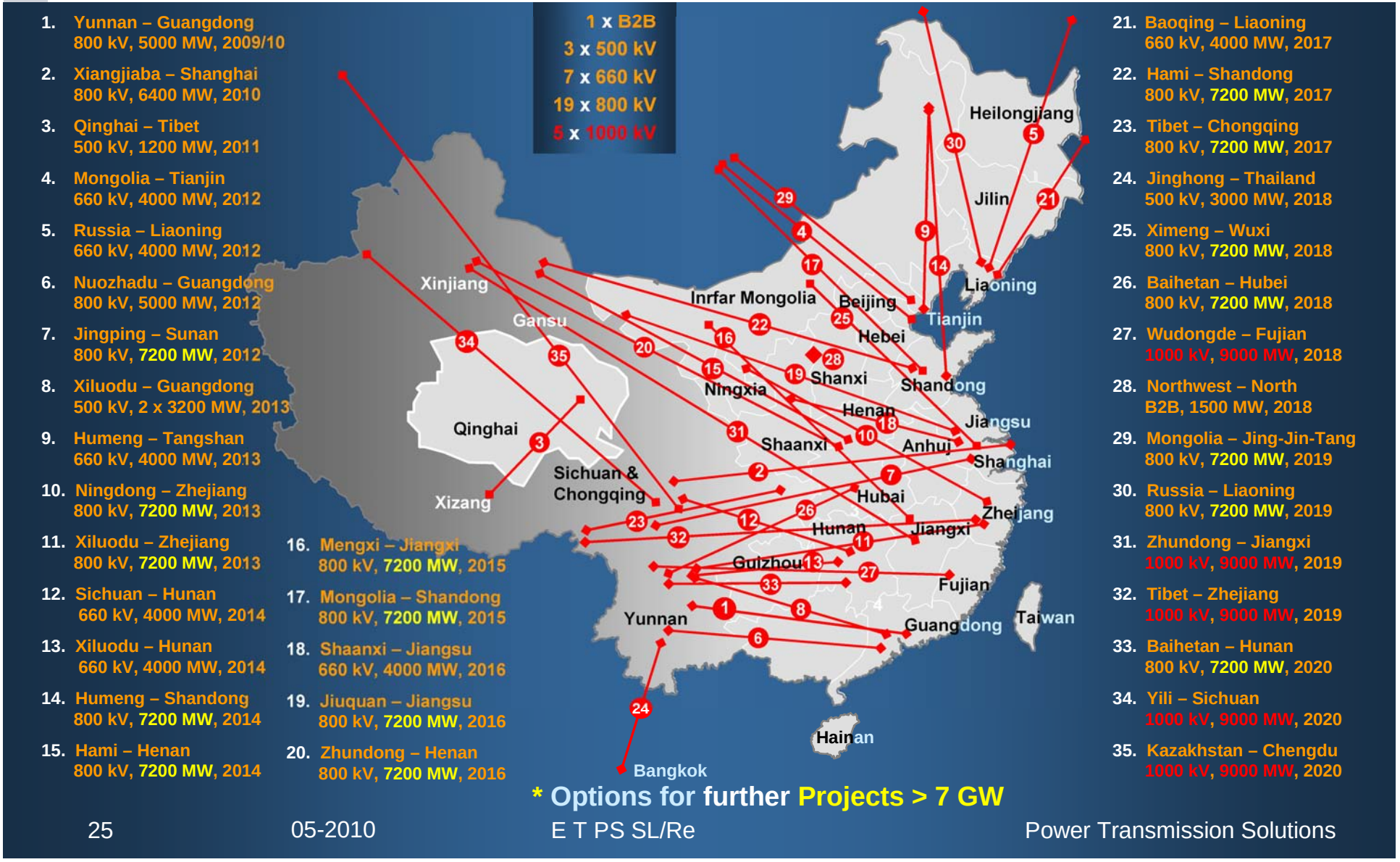


1. Yunnan – Guangdong
   800 kV, 5000 MW, 2009/10
2. Xiangjiaba – Shanghai
   800 kV, 6400 MW, 2010
3. Qinghai – Tibet
   500 kV, 1200 MW, 2011
4. Mongolia – Tianjin
   660 kV, 4000 MW, 2012
5. Russia – Liaoning
   660 kV, 4000 MW, 2012
6. Nuozhadu – Guangdong
   800 kV, 5000 MW, 2012
7. Jingping – Sunan
   800 kV, 7200 MW, 2012
8. Xiluodu – Guangdong
   500 kV, 2 x 3200 MW, 2013
9. Humeng – Tangshan
   660 kV, 4000 MW, 2013
10. Ningdong – Zhejiang
    800 kV, 7200 MW, 2013
11. Xiluodu – Zhejiang
    800 kV, 7200 MW, 2013
12. Sichuan – Hunan
    660 kV, 4000 MW, 2014
13. Xiluodu – Hunan
    660 kV, 4000 MW, 2014
14. Humeng – Shandong
    800 kV, 7200 MW, 2014
15. Hami – Henan
    800 kV, 7200 MW, 2014
16. Mengxi – Jiangxi
    800 kV, 7200 MW, 2015
17. Mongolia – Shandong
    800 kV, 7200 MW, 2015
18. Shaanxi – Jiangsu
    660 kV, 4000 MW, 2016
19. Jiuquan – Jiangsu
    800 kV, 7200 MW, 2016
20. Zhundong – Henan
    800 kV, 7200 MW, 2016
21. Baoqing – Liaoning
    660 kV, 4000 MW, 2017
22. Hami – Shandong
    800 kV, 7200 MW, 2017
23. Tibet – Chongqing
    800 kV, 7200 MW, 2017
24. Jinghong – Thailand
    500 kV, 3000 MW, 2018
25. Ximeng – Wuxi
    800 kV, 7200 MW, 2018
26. Baihetan – Hubei
    800 kV, 7200 MW, 2018
27. Wudongde – Fujian
    1000 kV, 9000 MW, 2018
28. Northwest – North
    B2B, 1500 MW, 2018
29. Mongolia – Jing-Jin-Tang
    800 kV, 7200 MW, 2019
30. Russia – Liaoning
    800 kV, 7200 MW, 2019
31. Zhundong – Jiangxi
    1000 kV, 9000 MW, 2019
32. Tibet – Zhejiang
    1000 kV, 9000 MW, 2019
33. Baihetan – Hunan
    800 kV, 7200 MW, 2020
34. Yili – Sichuan
    1000 kV, 9000 MW, 2020
35. Kazakhstan – Chengdu
    1000 kV, 9000 MW, 2020

* Options for further Projects > 7 GW

Advanced Power Transmission Solutions

SIEMENS

HVDC

integrated into the

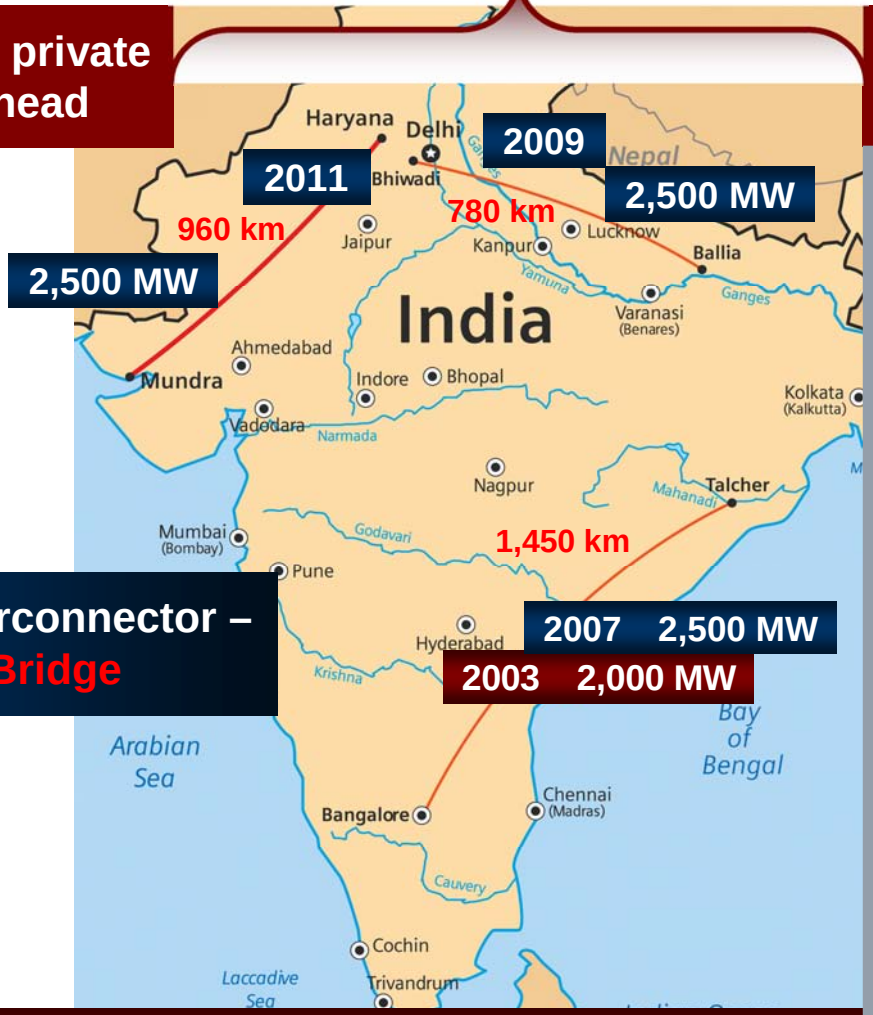
AC Systems

India – Three "Classic" HVDCs at 500 kV of which Adani and Ballia-Bhiwadi are fully integrated into the AC Grid

SIEMENS

Adani HVDC – a private Investor goes ahead

Ballia-Bhiwadi – Power Grid Corporation of India Ltd



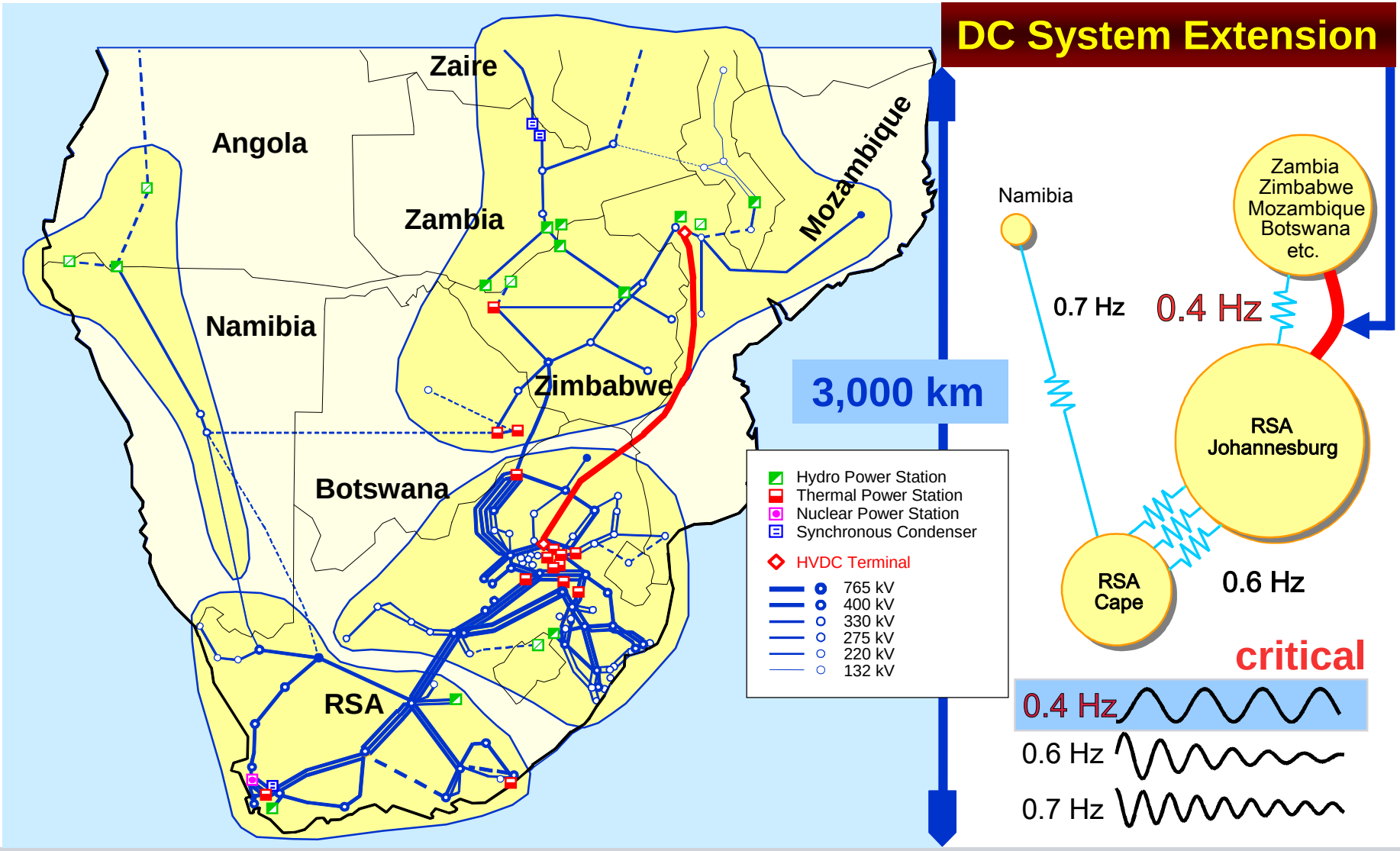
East-South Interconnector – the DC Energy Bridge

Examples of Integrated AC/DC Systems

Further Examples of Projects with Integrated AC/DC Transmission:

- Cahora Bassa, Mozambique-South Africa, 1977-79, 1920 MW, 533 kV, 1400 km
- Gezhouba-Shanghai, China, 1989/1990, 1200 MW, 500 kV, 1040 km
- Tianshengqiao-Guangzhou, China, 2000, 1800 MW, 500 kV, 960 km
- Guiguang I, China, 2004, 3000 MW, 500 kV, 940 km
- Guiguang II, China, 2007/2008, 3000 MW, 500 kV, 1230 km
- Neptune, New York, 2007, 660 MW, 500 kV, 105 km Cable
- Yunnan-Guangdong, 2009/2010, 5000 MW, 800 kV, 1420 km
- Trans Bay Cable, HVDC PLUS, San Francisco, 2010, 400 MW, 200 kV, 88 km Cable
- Xiangjiaba-Shanghai, 2011, 6400 MW, 800 kV, 2071 km

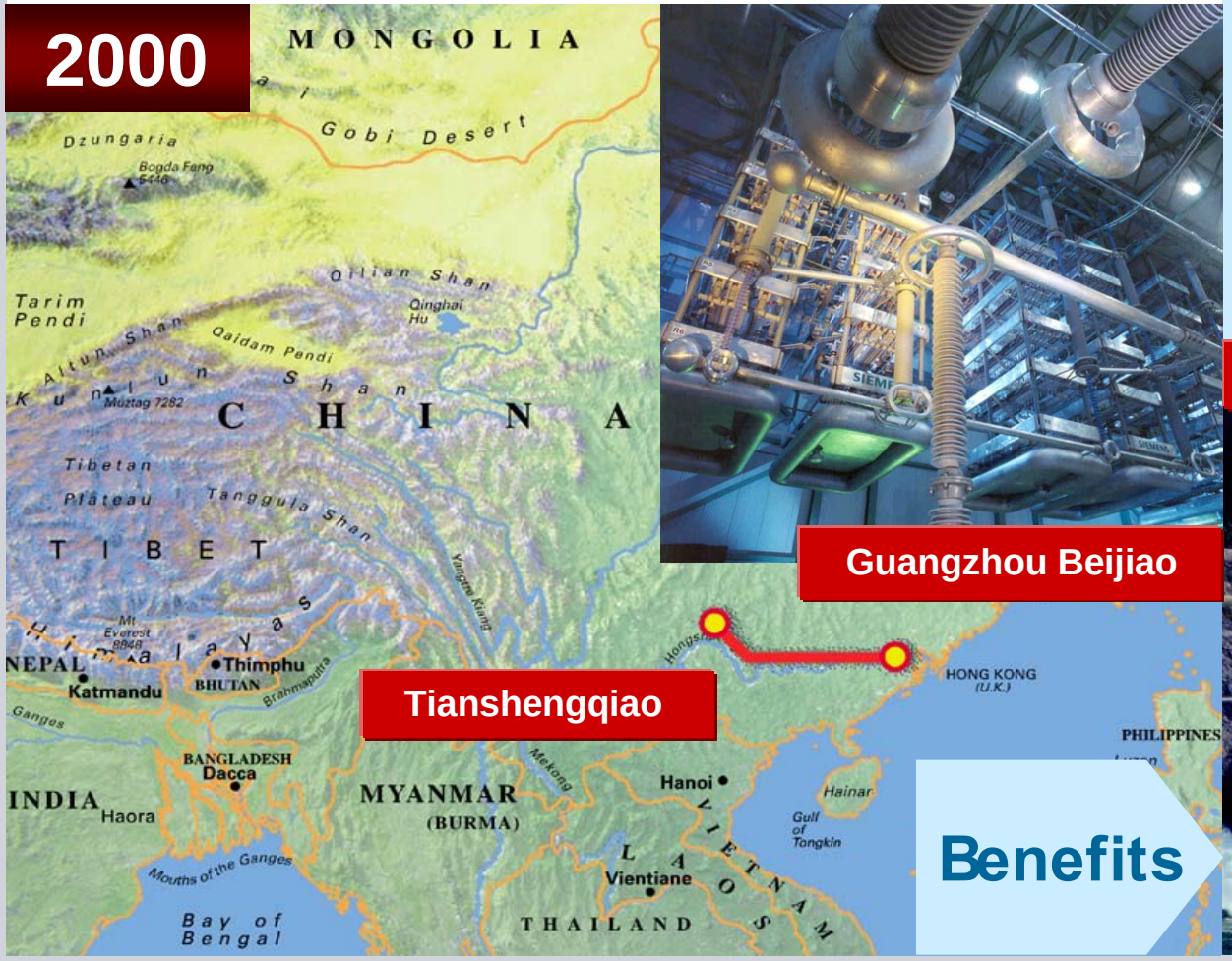
South Africa: Stability Improvement with HVDC SIEMENS



HVDC Long-Distance Transmission Tian-Guang

SIEMENS

The Task: Connection of Hydro Generation to Remote Load Centers



- **Operated by:**
  South China Electric Power JVC (SCEP)
- **System Data:**

Rating	1,800 MW
Voltage	+/-500 kVDC
Thyristor	8 kV
Line Length	960 km

Tian Hydro Station

Benefits

Use of Clean & Low Cost Energy

China: Benefits of active Damping with HVDC & FACTS in a Hybrid AC-DC System

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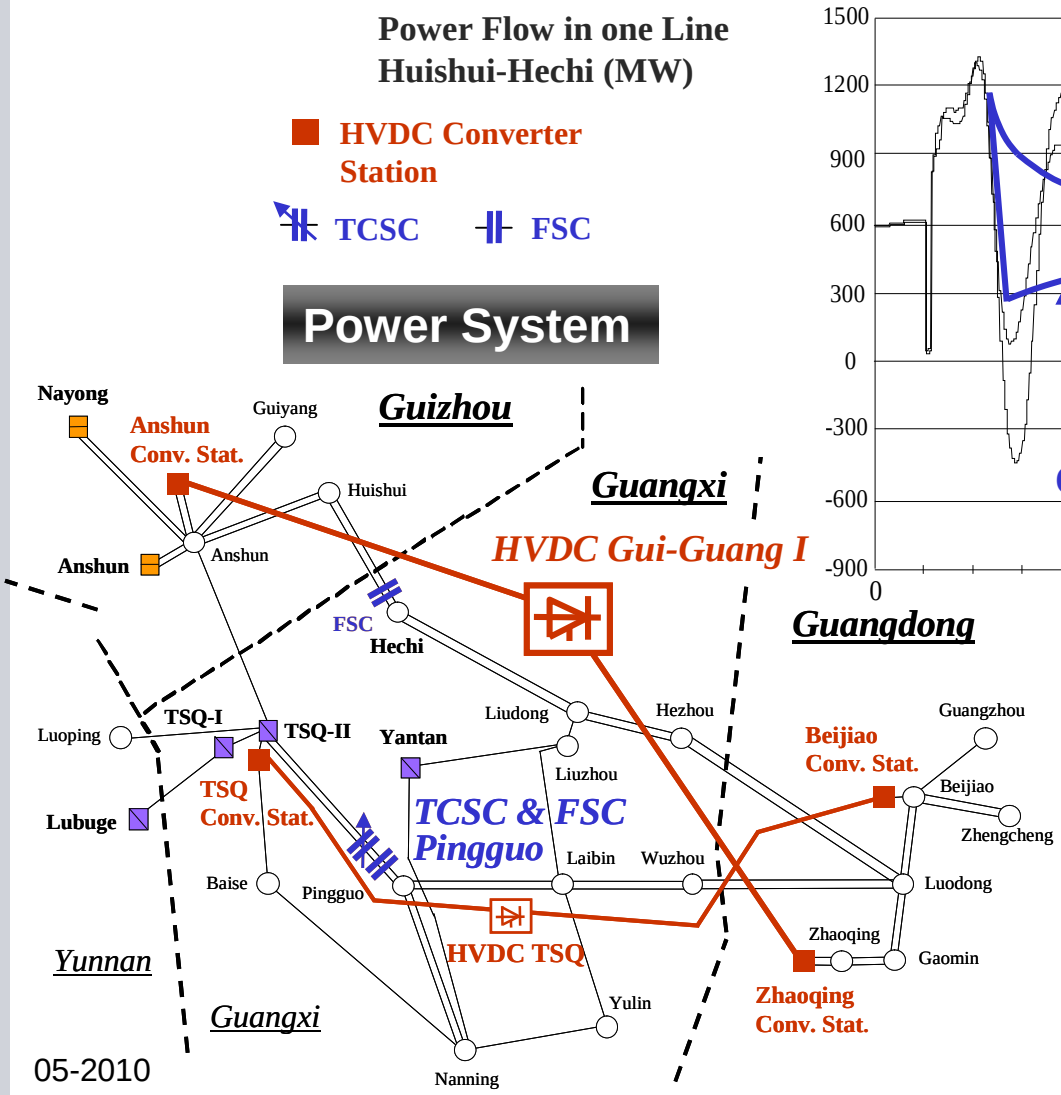

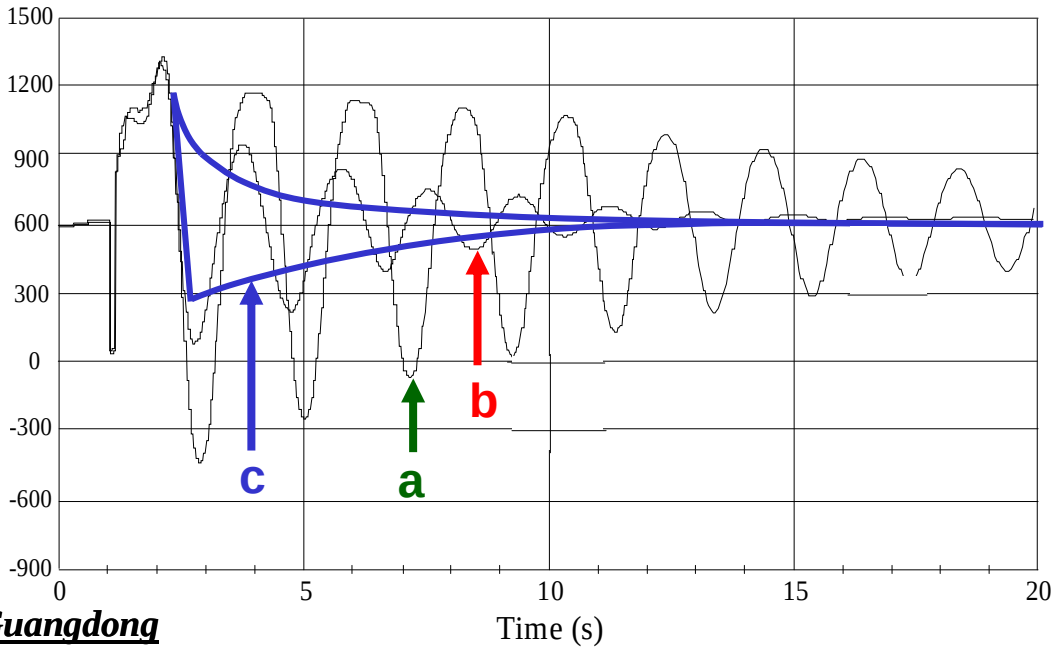

Dynamic Results

a – without Power Modulation

b – with Power Modulation of HVDC Control

c – further Improvements with Pingguo TCSC/FSC

More Power out of the Grid …

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云南至广东±800kV特高压直流输电工程
投 产 仪 式
2009.12.28 广州

Yunnan-Guangdong

plus CO_2 Reduction

World's first 800 kV HVDC – 5,000 MW

In China Southern Power Grid

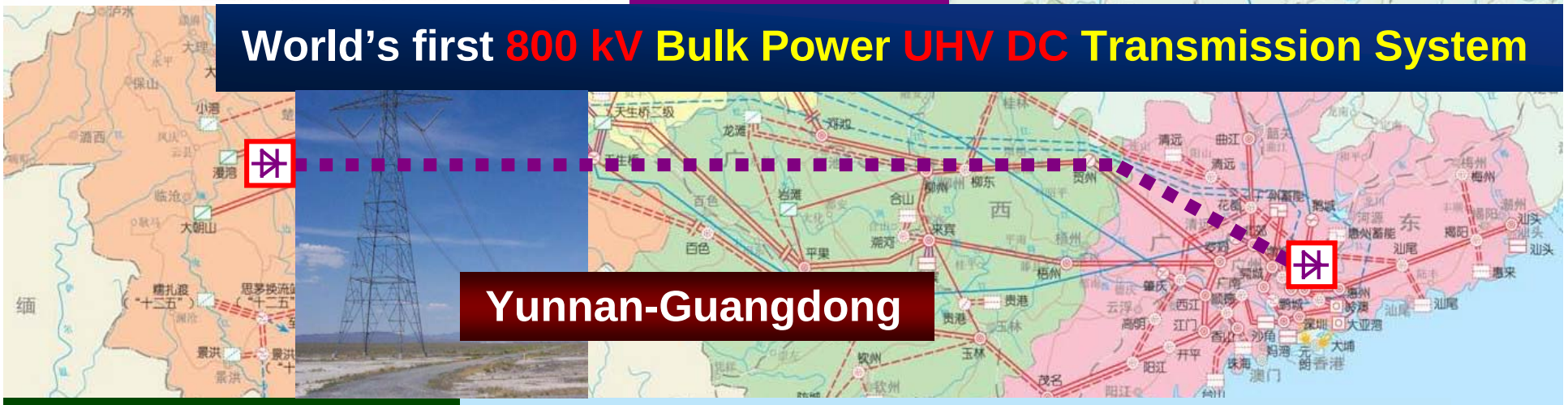
Siemens received an Order for the World's first 800 kV UHV DC in China Southern Power Grid

SIEMENS

Commercial Operation:

- 2009 – Pole 1
- 2010 – Pole 2

World's first 800 kV Bulk Power UHV DC Transmission System



Reduction in CO_2 → versus local Power Supply with Energy-Mix

32.9 m tons p.a. – by using Hydro Energy and HVDC for Transmission

Yunnan-Guangdong – from '3D Models' …

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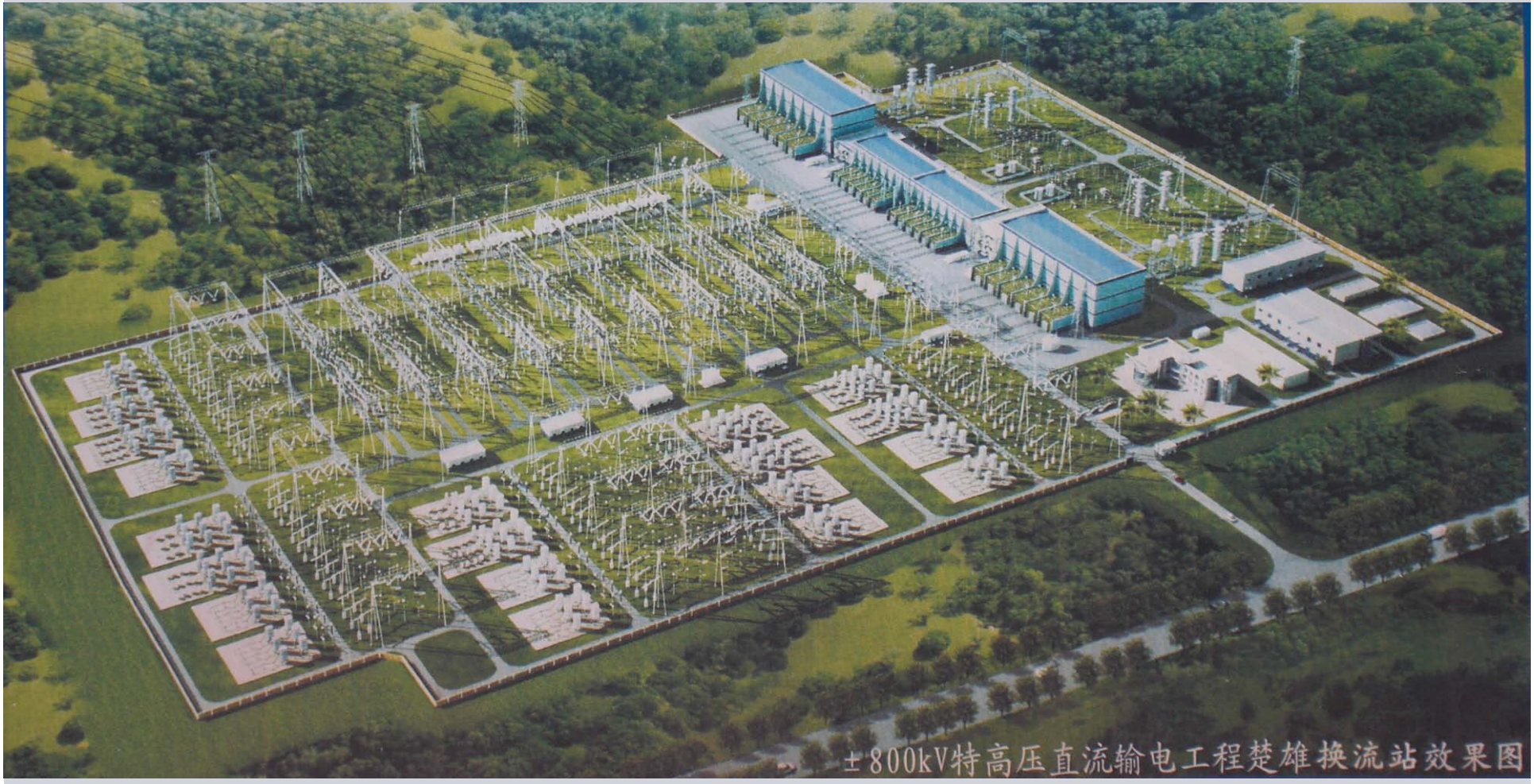

… to Reality: Sending Station Chuxiong

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Yunnan-Guangdong: UHV DC – 'Welcome'

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Yunnan-Guangdong – UHV DC Converter

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800 kV DC

Yunnan-Guangdong: UHV DC – Inauguration Pole 1

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More Power out of the Grid …

SIEMENS

In Co-Operation with

西安西电电力整流器有限责任公司
XIAN XD POWER RECTIFIER CO., LTD.

Fulong Converter Station – HVDC Transformers & Thyristor Valves with new 6-inch Thyristors

plus CO_2 Reduction

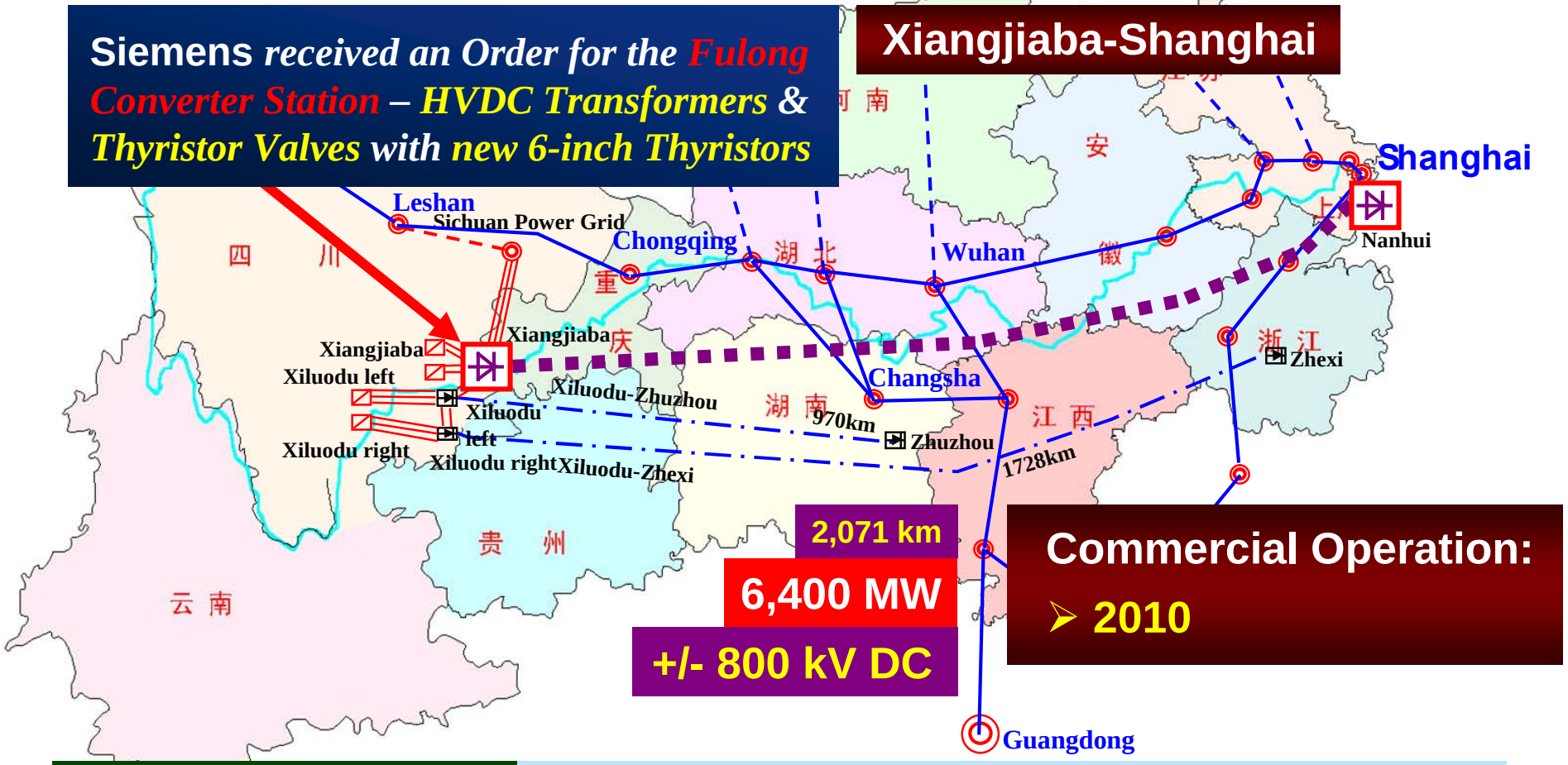
Xiangjiaba-Shanghai

World's biggest and longest 800 kV HVDC

World's biggest and longest 800 kV UHV DC Transmission Project – State Grid Corporation of China

SIEMENS

Siemens *received an Order for the Fulong Converter Station – HVDC Transformers & Thyristor Valves with new 6-inch Thyristors*



Reduction in CO_2 ⟶ versus local Power Supply with Energy-Mix

41 m tons p.a. – by using Hydro Energy and HVDC for Transmission

Arrangement of 800 kV Converters for Fulong Station

SIEMENS

Two HV and two LV Valve Towers for Fulong Converter Station during Erection for the dielectric Type Tests in Xihari HV Test Field in Xi'an, China (Arresters not yet connected)

SIEMENS

HVDC

and

FACTS

in parallel

Operation

SVC Siems – the 1st HV SVC in Germany

SIEMENS

HVDC and FACTS in parallel Operation

HVDC: Power Increase – from 450 MW to 600 MW → *Reduction in CO_2: 634,000 tons p.a.*

The Solution

More Hydro Power from NORDEL to Germany

The Problem: no Right-of-Way for 400 kV AC

Grid Access of Baltic Cable HVDC – only 110 kV

2004

Prospects of Power Electronics

Super Grid Solutions for Bulk Power Transmission

SIEMENS

Solutions with Overhead Lines

Note: Power AC – 1 System 3 ~, DC – Bipole +/-

- High-Voltage DC Transmission:
  - HVDC "Classic" with 500 / 660 kV (EHV) – up to 4 GW
  - HVDC "Bulk" with 800 kV (UHV) – 5 GW to 7.2 GW

  Option UHV DC 1,000 kV: 9 GW
- AC Transmission:
  - 800 kV AC (EHV) – 3 GVA
  - 1,000 kV AC (UHV) – 6 to 8 GVA

The Winner is HVDC !

Solutions with DC Cables *

* Distances over 80 km: AC Cables too complex

- 500 / 600 kV DC – 1 GW to 2 GW (with Mass Impregnated Cables; actual - prospective)

Solutions with GIL – Gas Insulated Lines

- 400 kV AC (HV) – 1.8 GVA / 2.3 GVA (directly buried / Tunnel or Outdoor)
- 500 kV AC (EHV) – 2.3 GVA / 2.9 GVA (directly buried / Tunnel or Outdoor)
- 550 kV AC (EHV) – Substation: Standard 3.8 GVA / Special 7.6 GVA **
- 800 kV AC (EHV) – Tunnel: 5.6 GVA ***

** Reference: Bowmanville, Canada, 1985 - Siemens

*** Reference: Huanghe Laxiwa Hydropower Station, China, 2009 - CGIT (USA)

Summary: Features and Benefits of HVDC

SIEMENS

HVDC – High-Voltage DC Transmission: It makes P flow

- Three HVDC Options available: PLUS (VSC), "Classic" and Bulk
- With DC, Overhead Line Losses are typically 30-40 % less than with AC
- For Cable Transmission (over 80 km), HVDC is the only Solution
- HVDC can be integrated into the AC Systems
- HVDC supports AC in Terms of Stability
- System Interconnection with HVDC:
  - DC is a "Firewall" against Cascading Disturbances
  - Bidirectional Control of Power Flow – quite easy
  - Frequency, Voltage and POD Control available
  - Staging of the Links – with DC quite easy
  - No Increase in Short-Circuit Power
  - DC is a Stability Booster

The Future ? Global Link for Green Energy

SIEMENS

with HVDC – including DESERTEC & Seatec

Thank You for Your Attention !