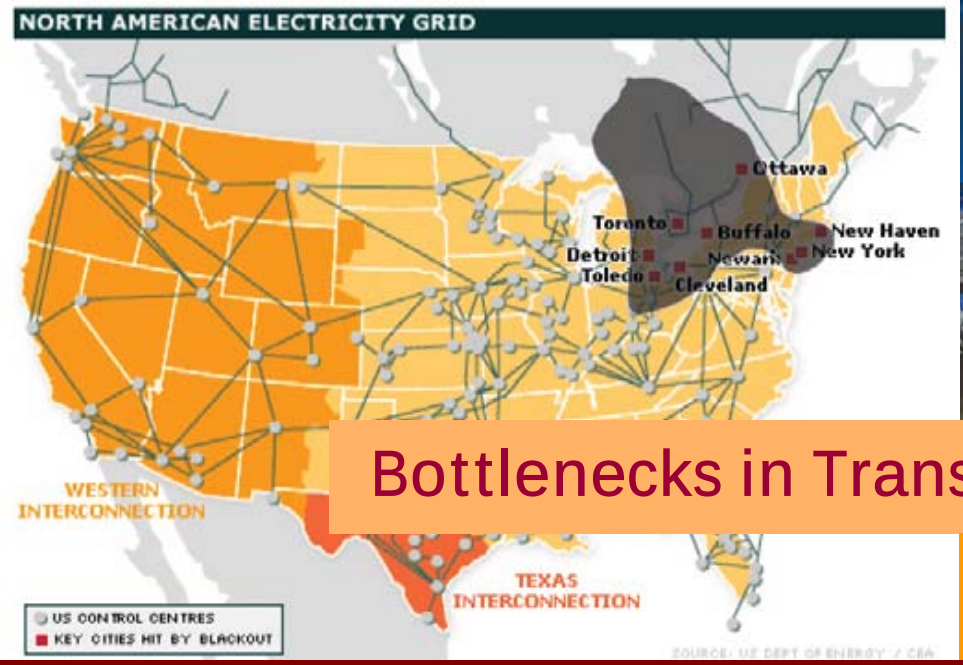

Bottlenecks in Transmission Systems

The reliable Grid -

From Blackout towards a "Smart Gird"

Das sichere Netz -

vom Blackout zum "Smart Gird"

Power Transmission and Distribution

S

High Voltage

Dusan Povh - Dietmar Retzmann

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

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 SCC* Levels**
System **Instabilities & Outages**

Investments in Power Systems

System **Enhancement** & **Interconnections**:

- **Higher Voltage Levels ****
- **New Transmission Technologies**
- **Renewable Energies**

** Example UCTE: 400 kV is actually too low

* SCC = Short-Circuit Current

Development of Power Systems

- Extensions of Interconnected Systems
- Increased Power Exchange among Interconnected Systems
- Transmission of large Power Blocks over long Distances (Hydro Resources)
- Decentralized Power Generation

High Voltage

Problems in large Power Systems

- **Increasing loading at low investment into the system**
- **Complex configuration**
- **Change of transmission directions due to new generation locations (wind generation) and system interconnections**
- **Weak interconnections among the systems**
- **Stability and oscillation problems because of long transmission distances**
- **Distributed and not coordinated system controls**

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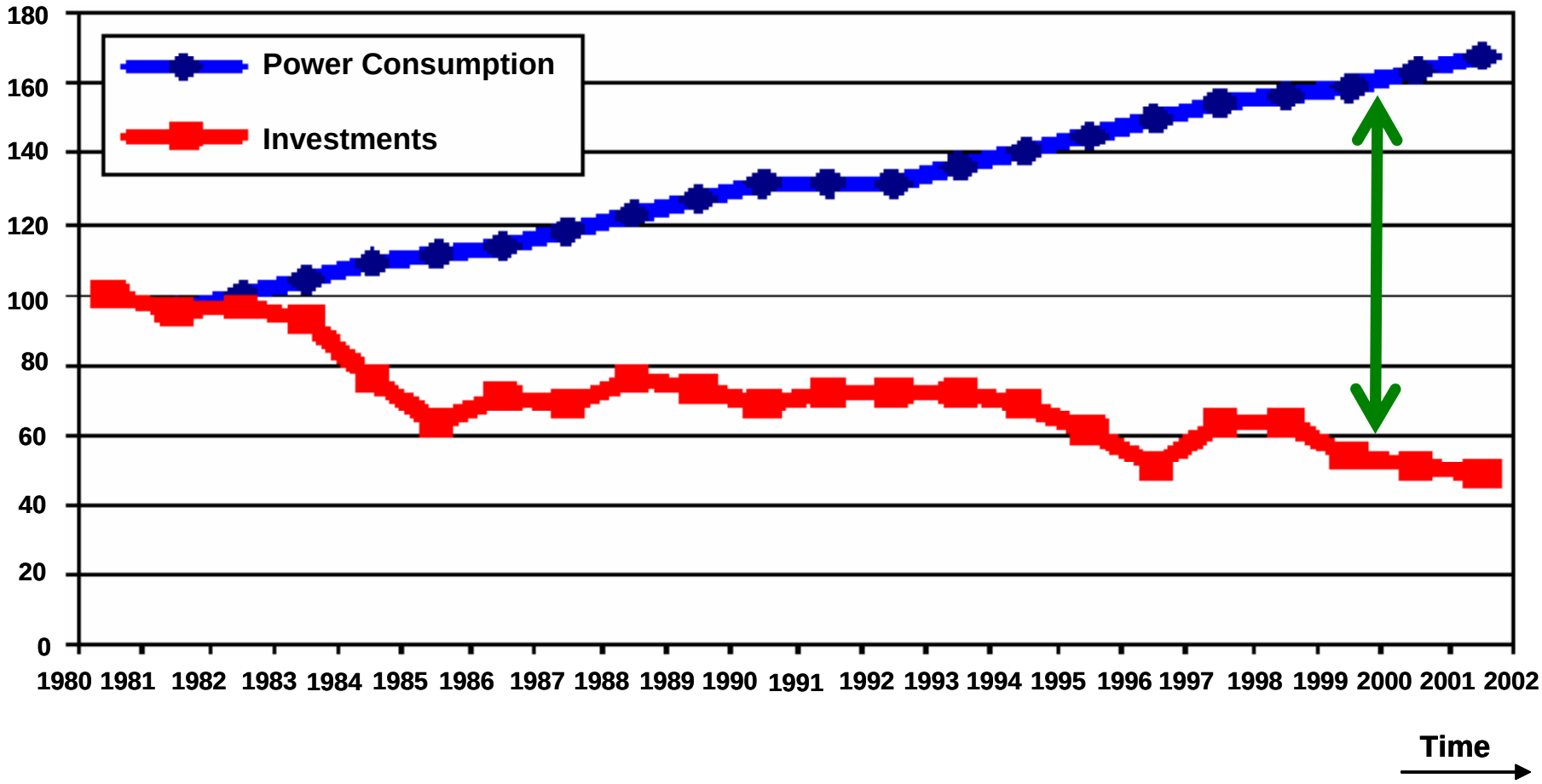
The Gap – between Consumption & Investments

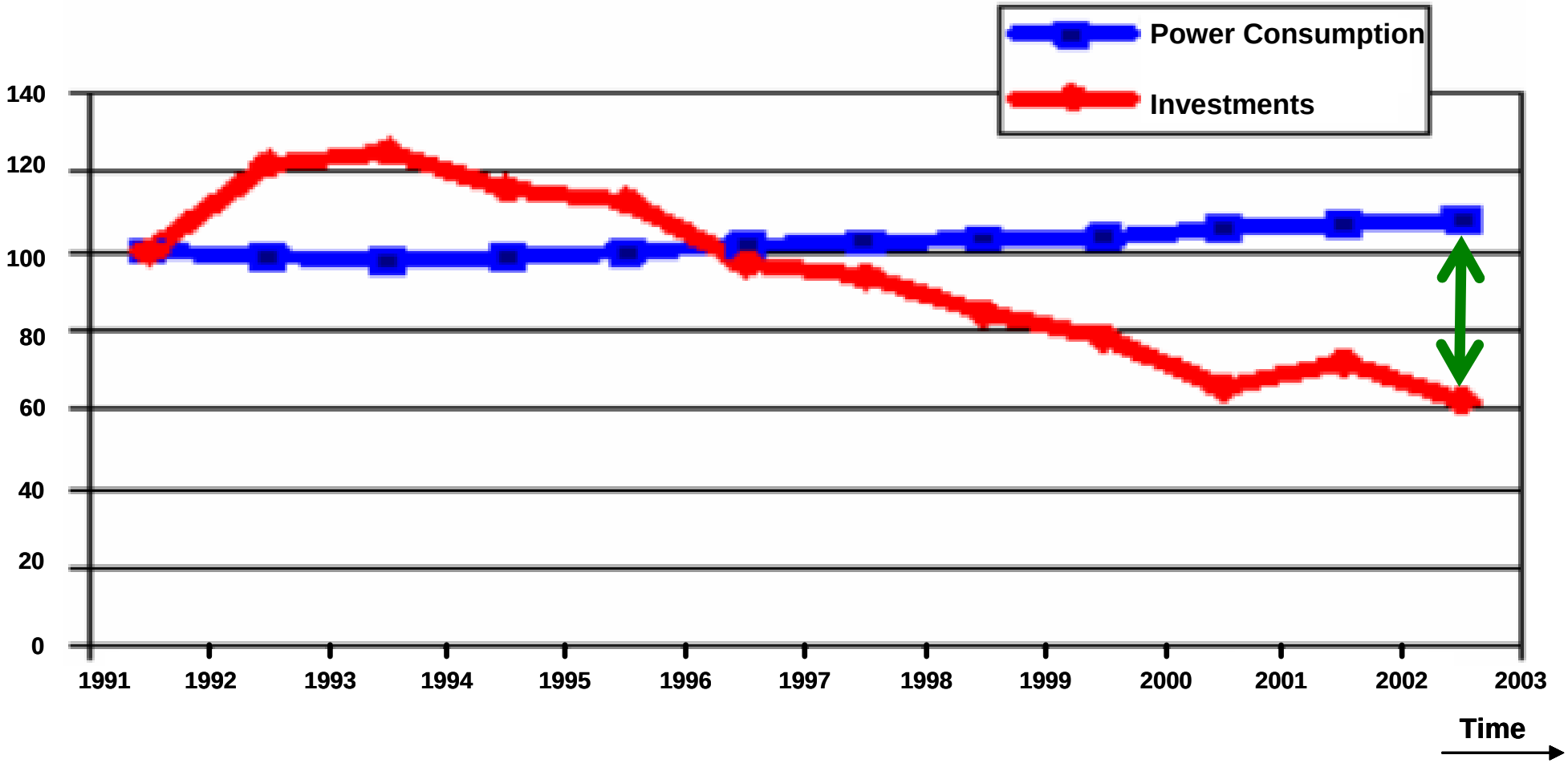
Example 1: United States



Source: VDN/ETG Fachtagung 10-11 Feb. 2004 Jena, Germany

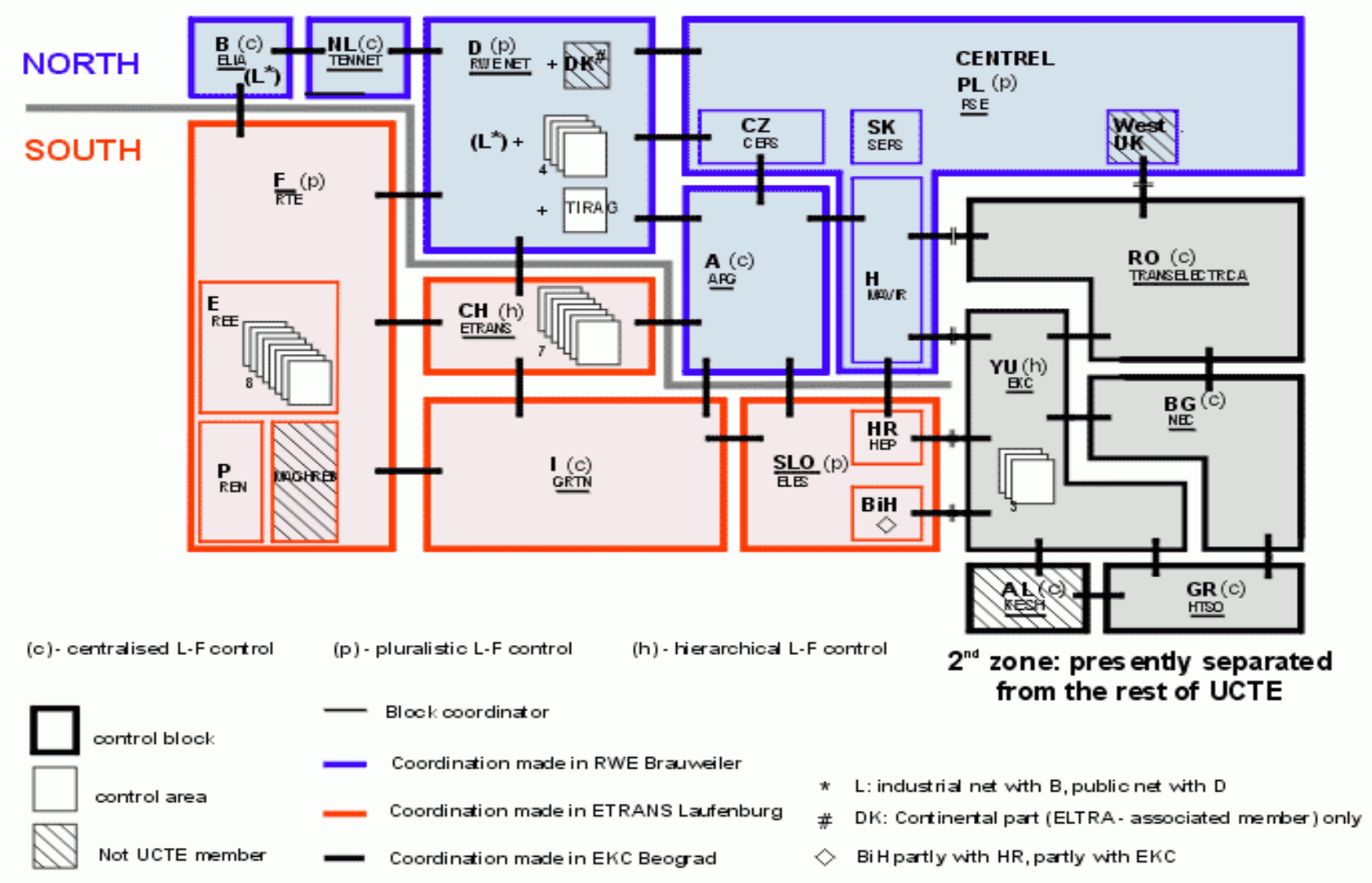
The Gap – between Consumption & Investments

Example 2: Germany – similar Tendency, just “later” and “smoother”

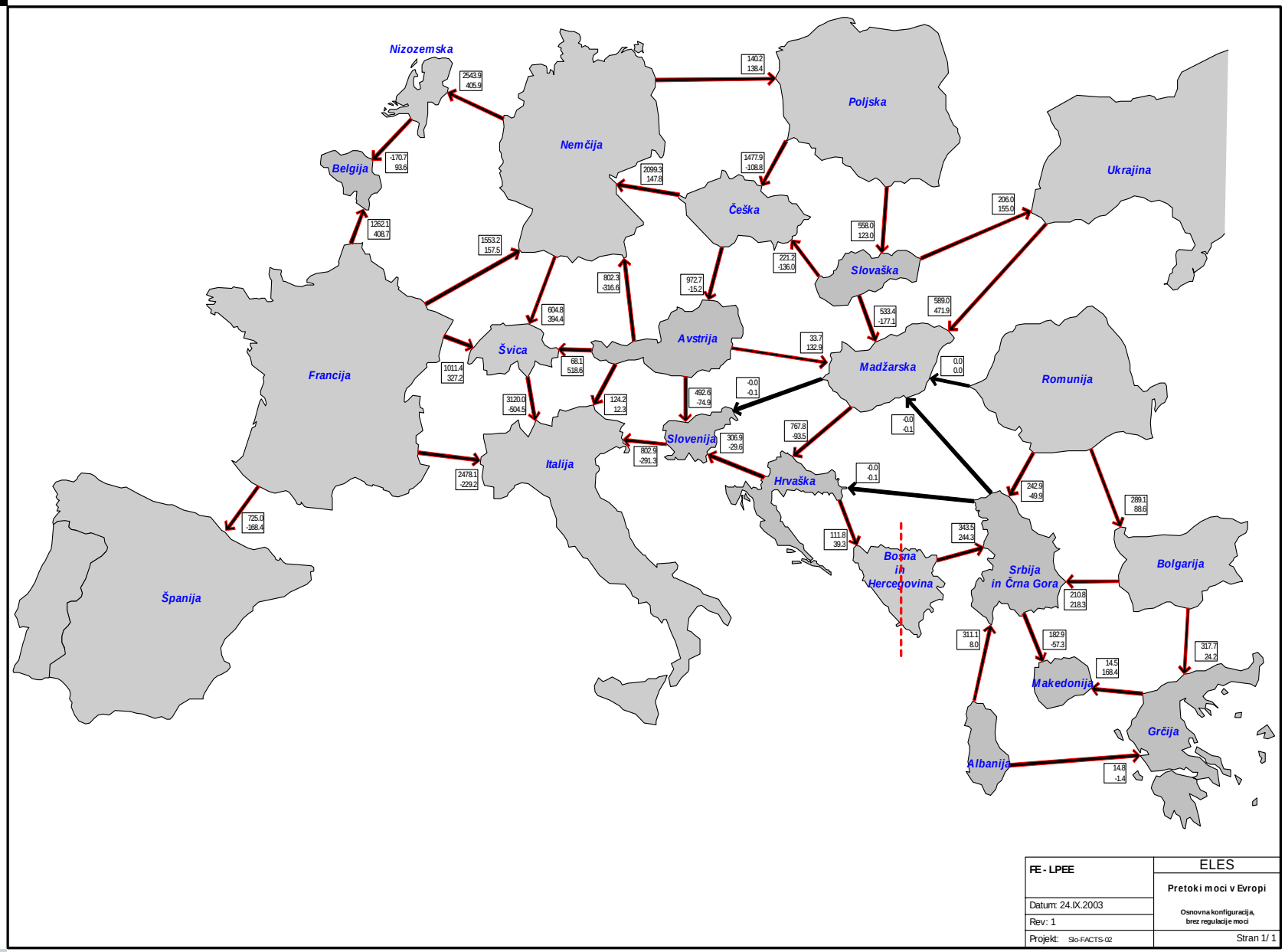


Source: VDN/ETG Fachtagung 10-11 Feb. 2004 Jena, Germany

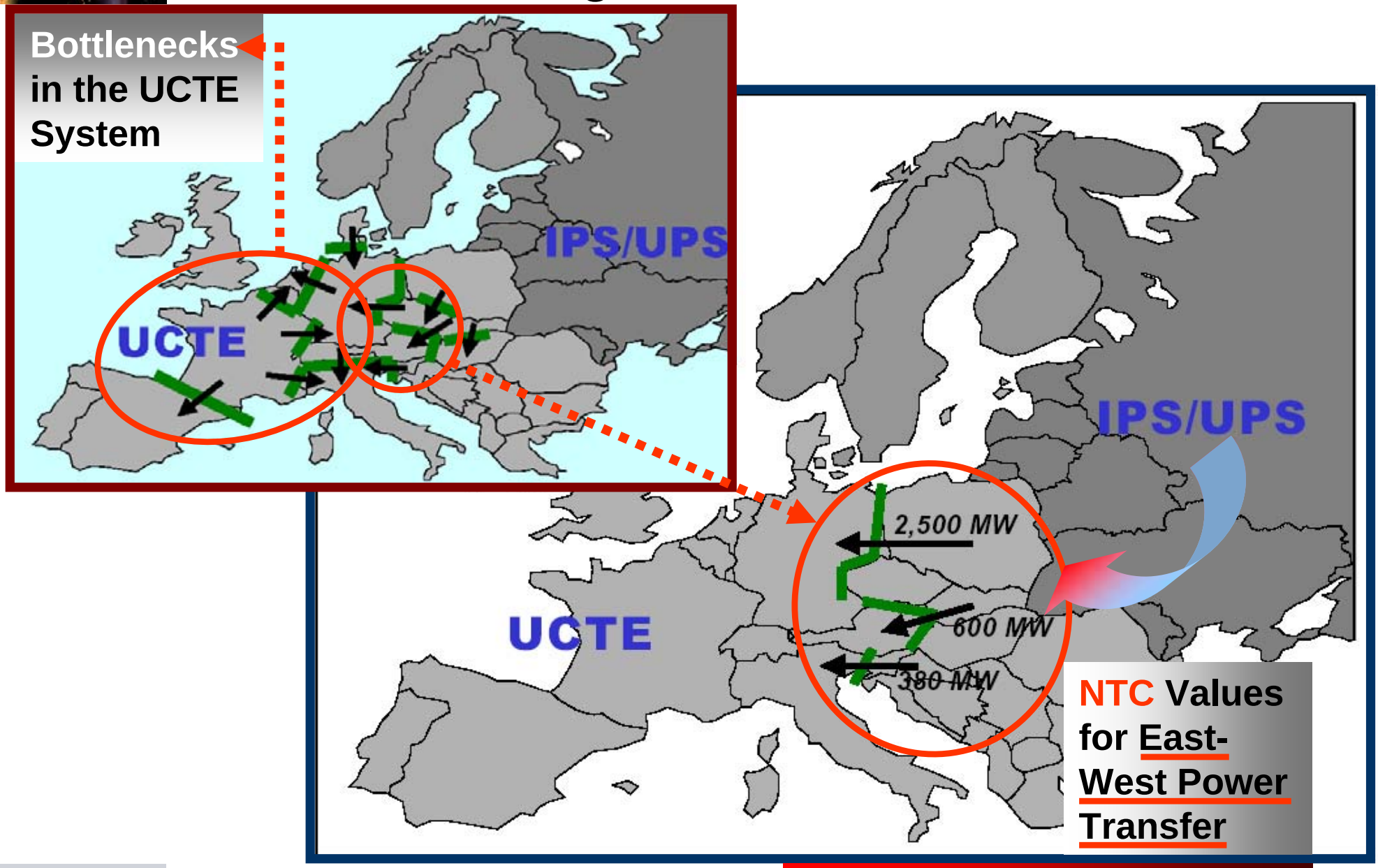
The UCTE Structures – in Details



European Grids – in Details



Congestion also in West-Europe (UCTE): 400 kV AC Voltage is too low !

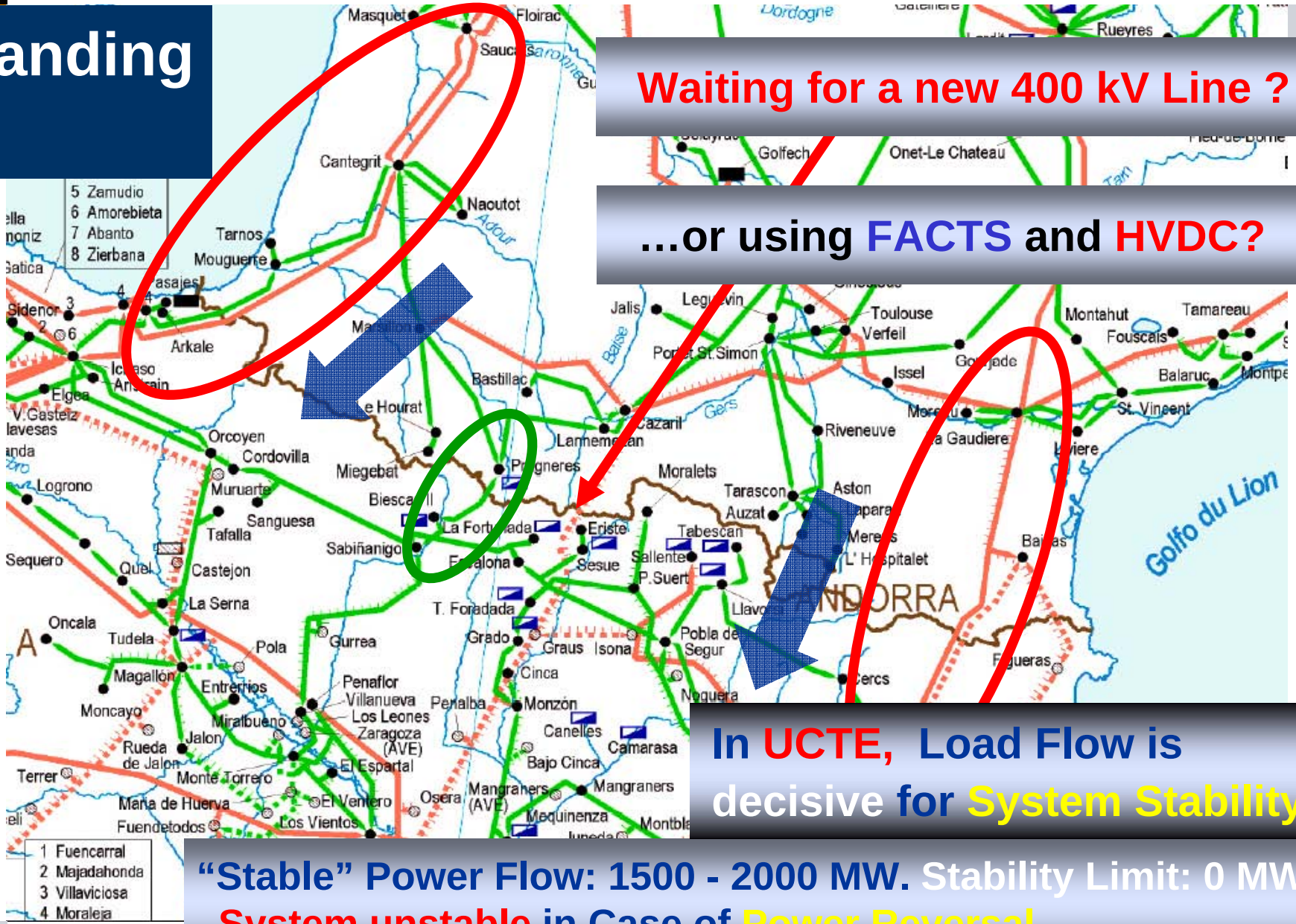


Source: UCTE - 5 / 2003

NTC = Net Transfer Capacity

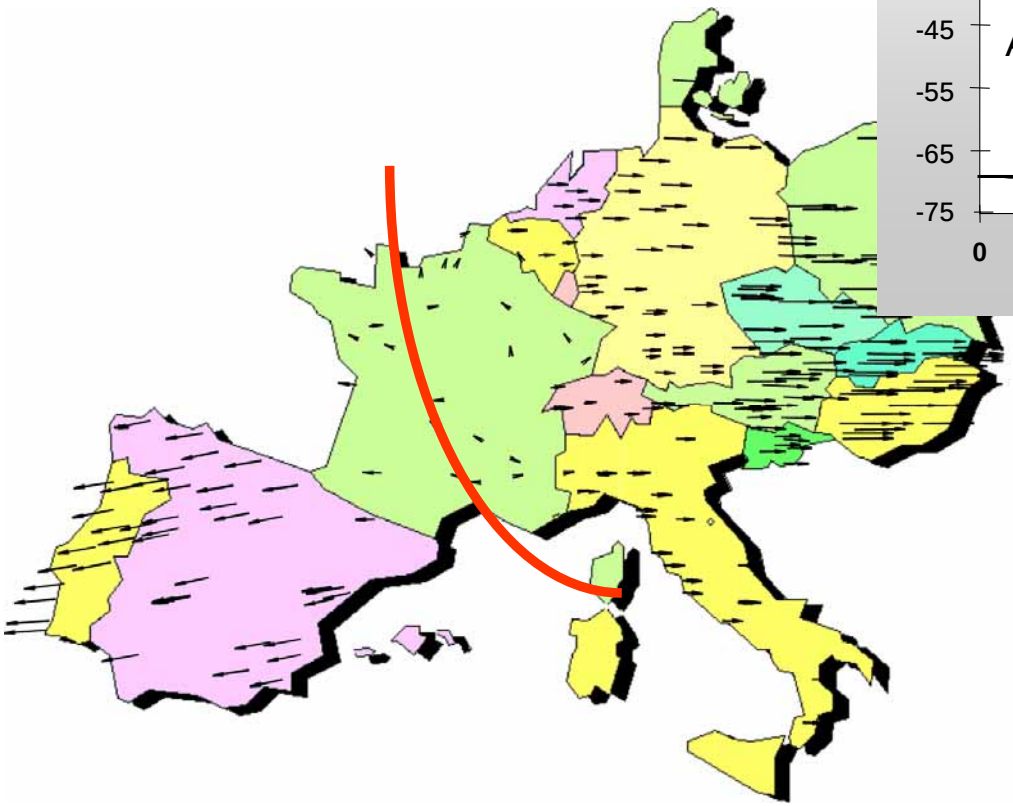
Interconnection Spain-France: a weak Link

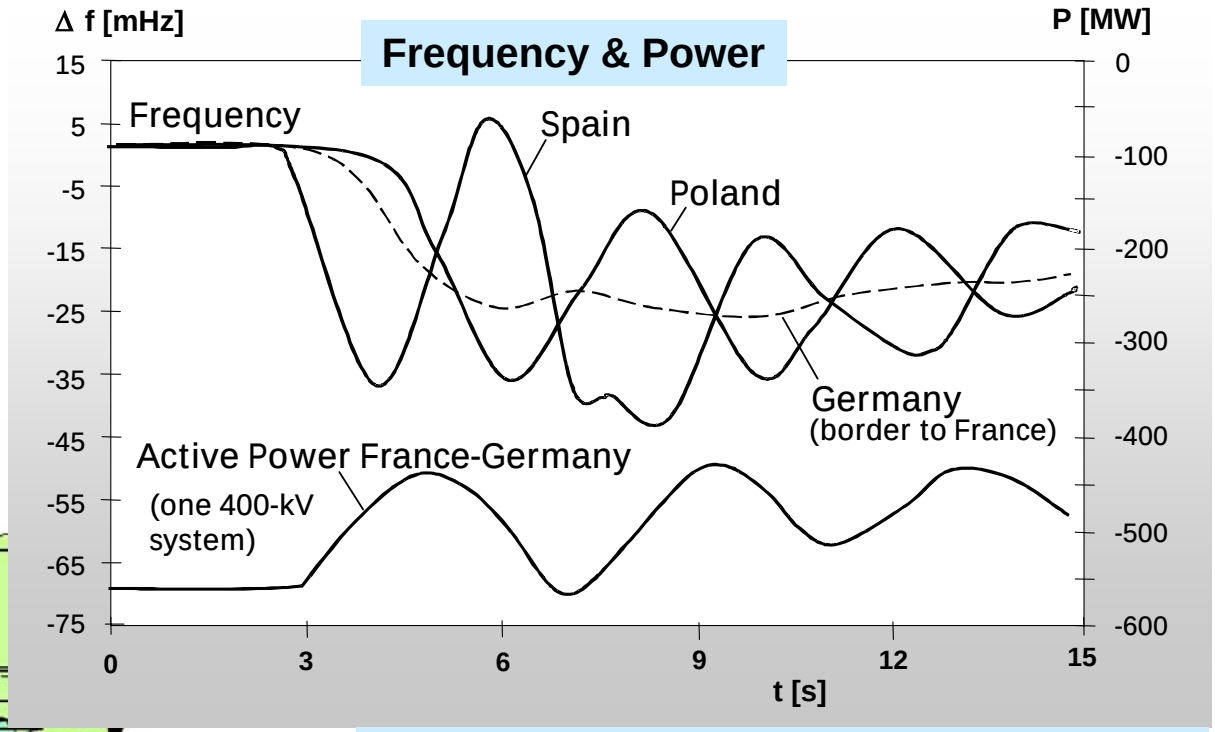
Understanding UCTE …



The Risk: Inter-Area Oscillation in UCTE

An Example:
Trip of 300 MW Power Station
in Spain





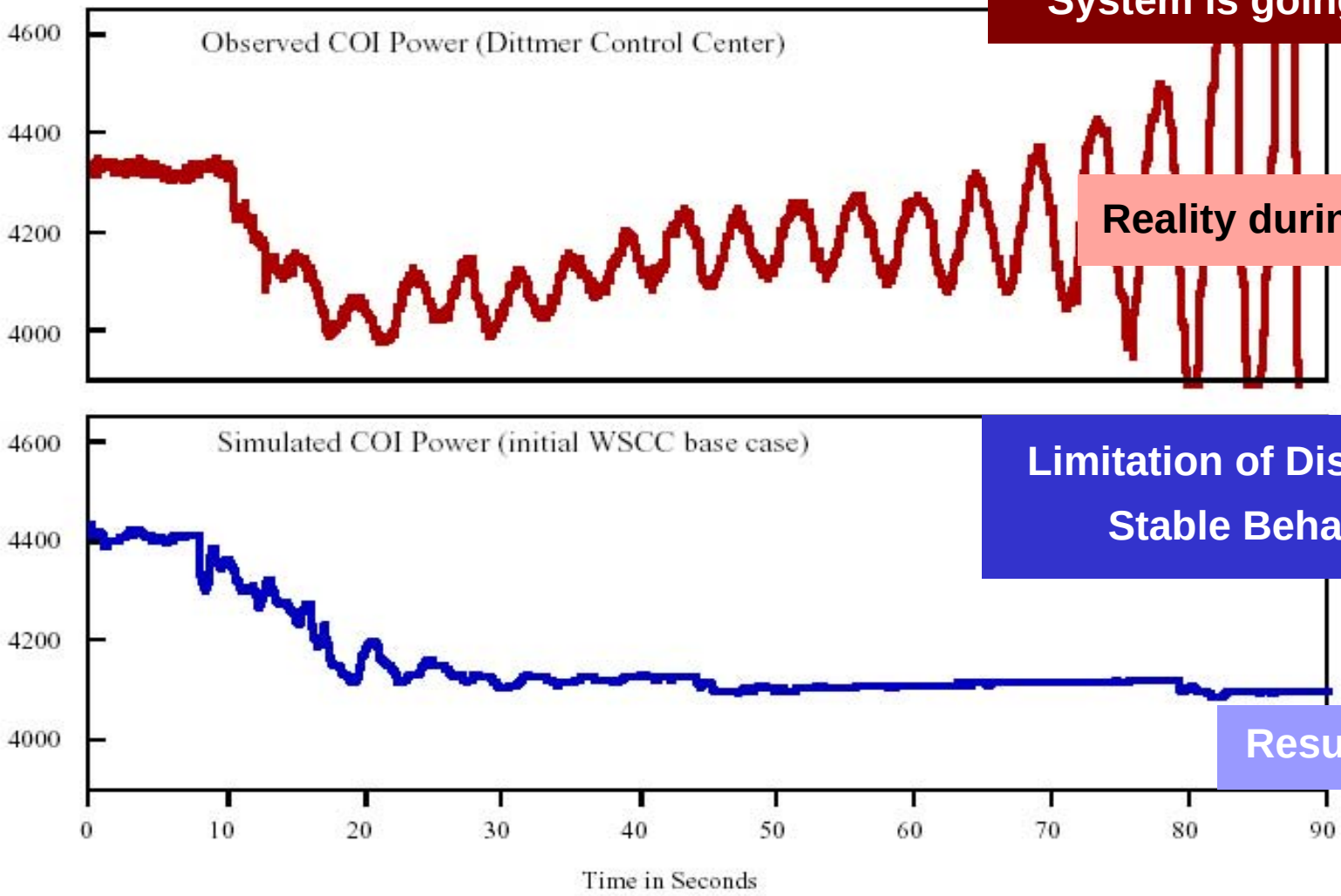
Signals: simulated & measured by WAMS

<u>Mode 1:</u> f = 0.21 Hz, Damping ζ = -3.7 %

Source: E.ON - RWE Net - Siemens 11-2002

Large Synchronous Systems - Risk of Spread of Disturbances

Figure 5. Modeling failure for Western System breakup of August 10, 1996. (MW on California-Oregon Interconnection)



Increasing Power Oscillations: System is going to collapse

Reality during Blackout 1996

Limitation of Disturbances: Stable Behaviour

Results of Simulation

Source: National Transmission Grid Study; U.S. DOE 05-2002

High Voltage

Classification of Stability Problems in Power Systems

Overview about basic Problems in Terms of Physics, which are related to a high Loading of Transmission Systems by Transport of electrical Energy.

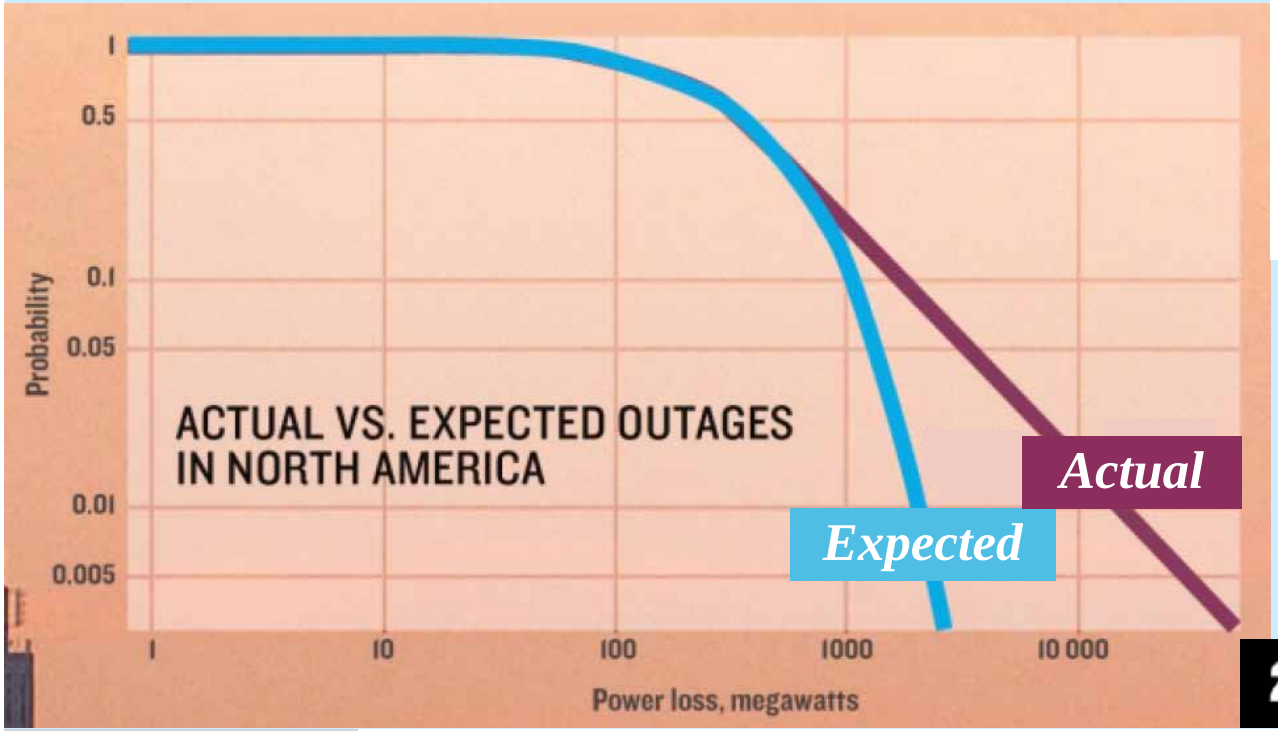
The main Types of Instability Concerns are:

- Cascading Line Tripping by Overload or wrong Protection Settings
- Loss of Synchronism due to Angle Instability
- Oscillatory Instability causing self exciting Inter-Area Oscillations
- Exceeding of the allowed Frequency Range (Over- and Under-Frequency), causing Generator Trips
- Voltage Collapse

Source: UCTE Interim Report 10-27-2003

High Voltage

Reasons for high Probability of large Blackouts



- Systems too complex to be tested properly (Protection, Controls)
- Insufficient Investments into the System (heavily loaded Network Elements)
- Lack in Maintenance
- Insufficient Training
- Human Errors

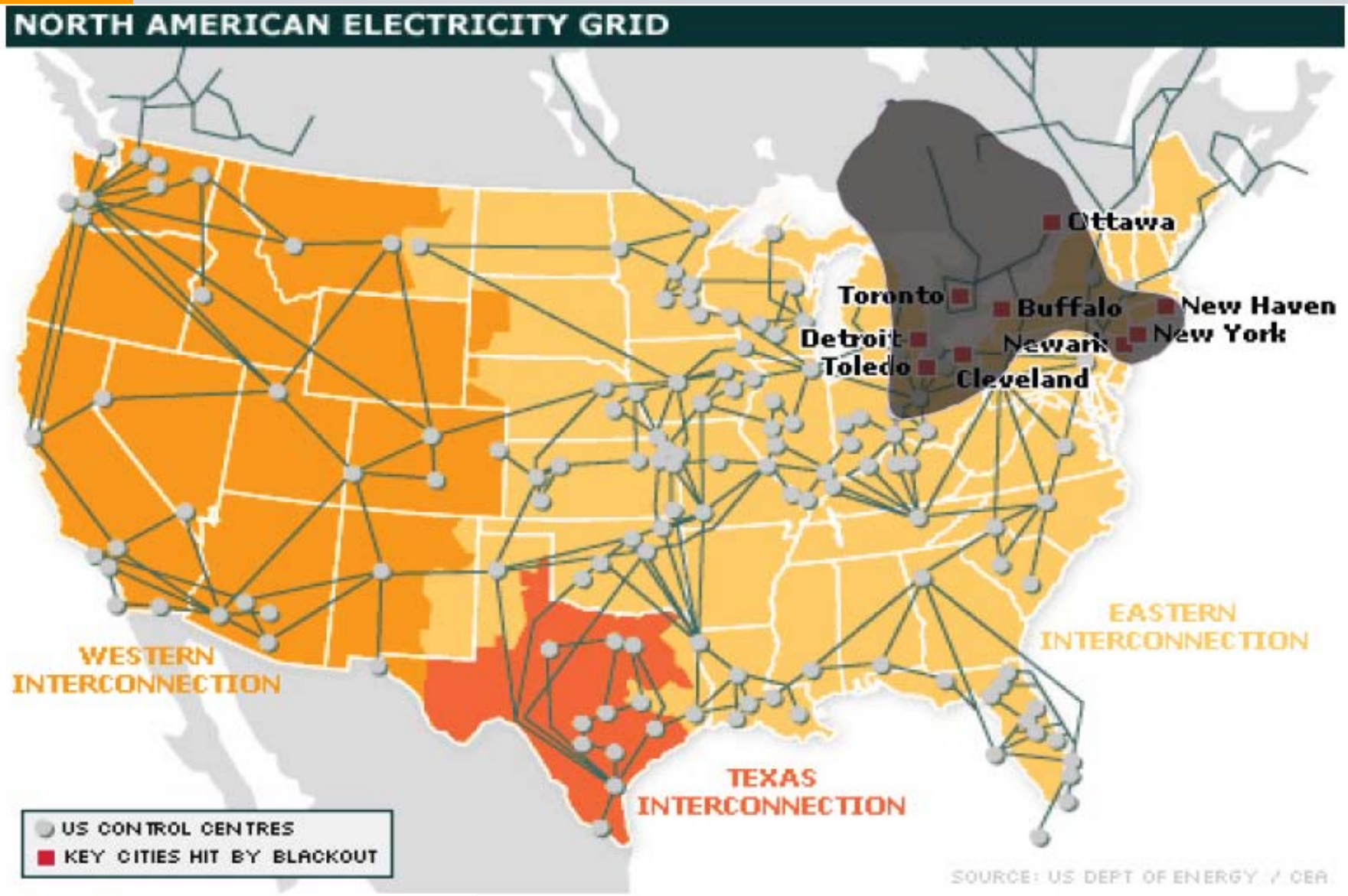
Source:

22 IEEE Spectrum | August 2004 | NA

ADVANCED MATHEMATICAL MODELING SUGGESTS THAT BIG BLACKOUTS ARE INEVITABLE BY PETER FAIRLEY

High Voltage

The Blackout Area - a “Daylight” View



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Source: hydro one Cigré Paris Session 2004

The US-Canada Blackout - from 12 to 4 PM

4:13 PM – Cascading sequence essentially complete

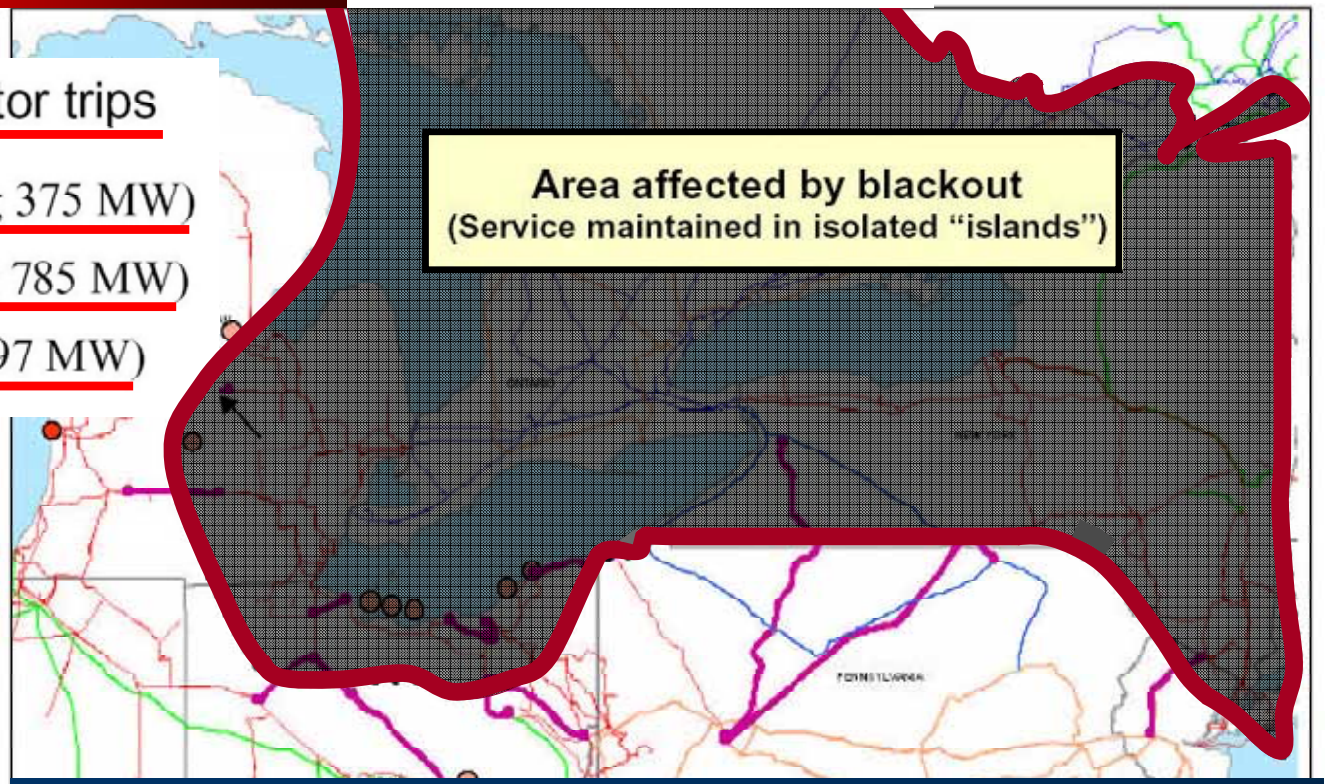
the "Result"

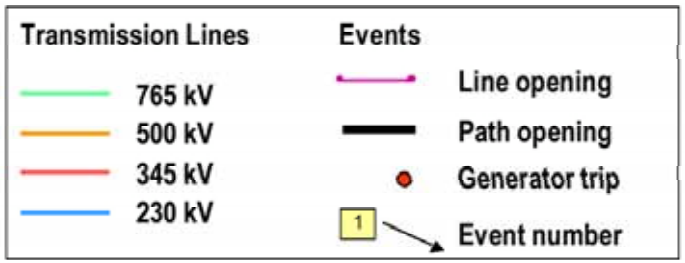
4 hrs. – a very long Time

12:05:44 – 1:31:34 PM – Generator trips

1. 12:05:44 – Conesville Unit 5 (rating 375 MW)
2. 1:14:04 – Greenwood Unit 1 (rating 785 MW)
3. 1:31:34 – Eastlake Unit 5 (rating: 597 MW)

How it "started"





Now some Details - the Sequence of Events …

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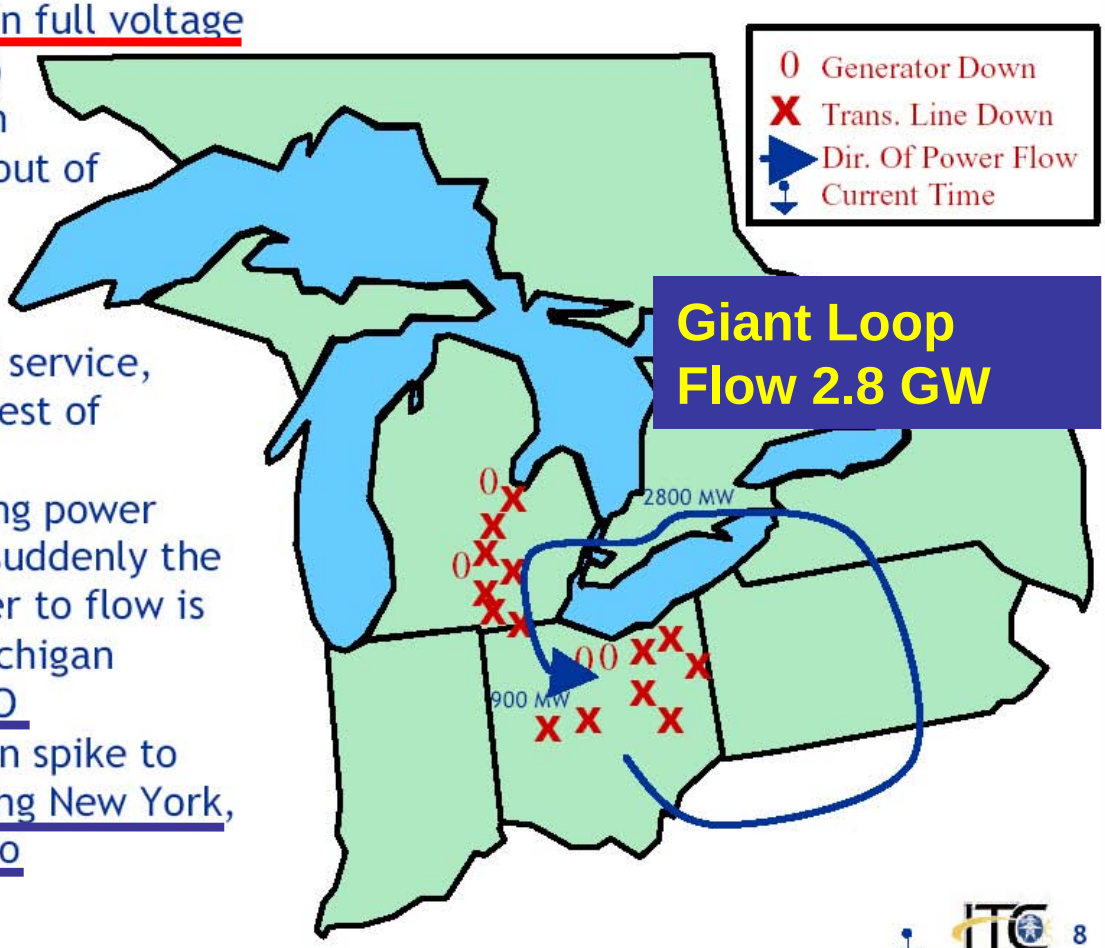
Source: Blackout Summary, U.S./Canada Power Outage Task Force 9-12-2003

High Voltage

Event 18 in the ITC-Analysis: 30 s to Blackout

About 1 Minute Later... 4:10:40 - 4:10:46 PM

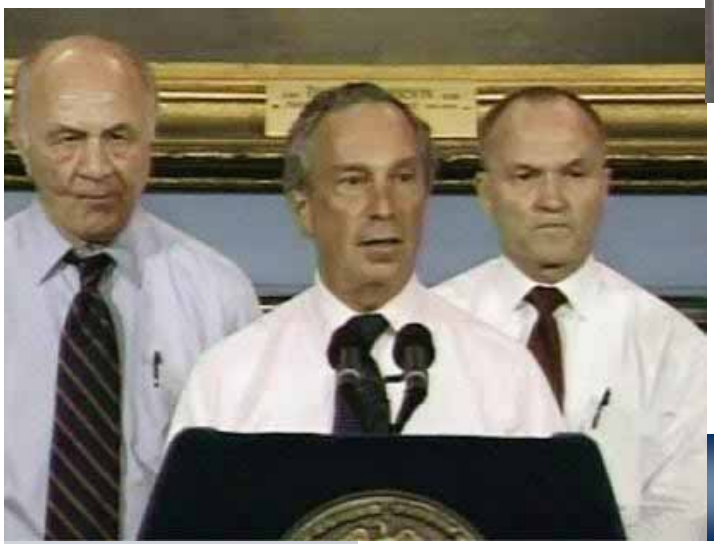
- The ITC system is now in full voltage collapse (rapid decline) causing 30 Transmission lines in Michigan to go out of service in less than 8 seconds
- Connections between METC and ITC go out of service, isolating ITC from the rest of Michigan
- FirstEnergy is still pulling power through Michigan, but suddenly the only route for the power to flow is through Ontario and Michigan
- Flows over the ITC - IMO international connection spike to nearly 2800 MW affecting New York, other states and Ontario



Source: Blackout Summary, U.S./Canada Power Outage Task Force 9-12-2003

High Voltage

The Blackout – Breaking News ...



… the Leaders are concerned

Source: Web/Google

High Voltage

The Blackout - some more "Daylight" Views

Transportation, however, goes on …

… just by different Means

… Traffic Jam

"Activities" in New York City …

Communication - highly important

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Source: Web/Google

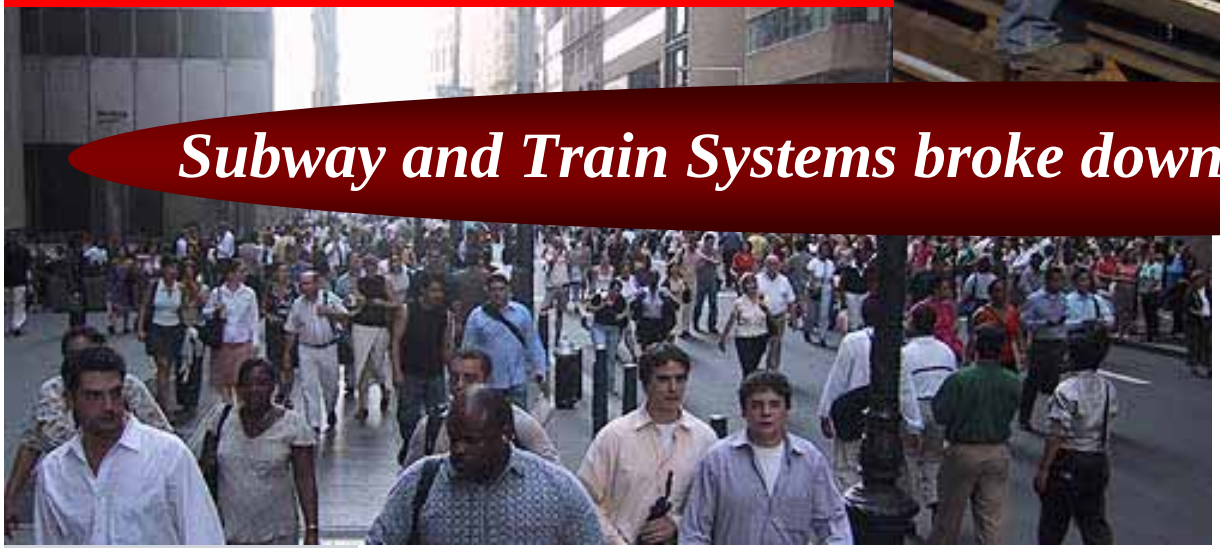
High Voltage

The Blackout - some more “Daylight” Views

In spite of this …

many Helpers

and a high Degree of Discipline everywhere !



Subway and Train Systems broke down, but Streets keep on moving

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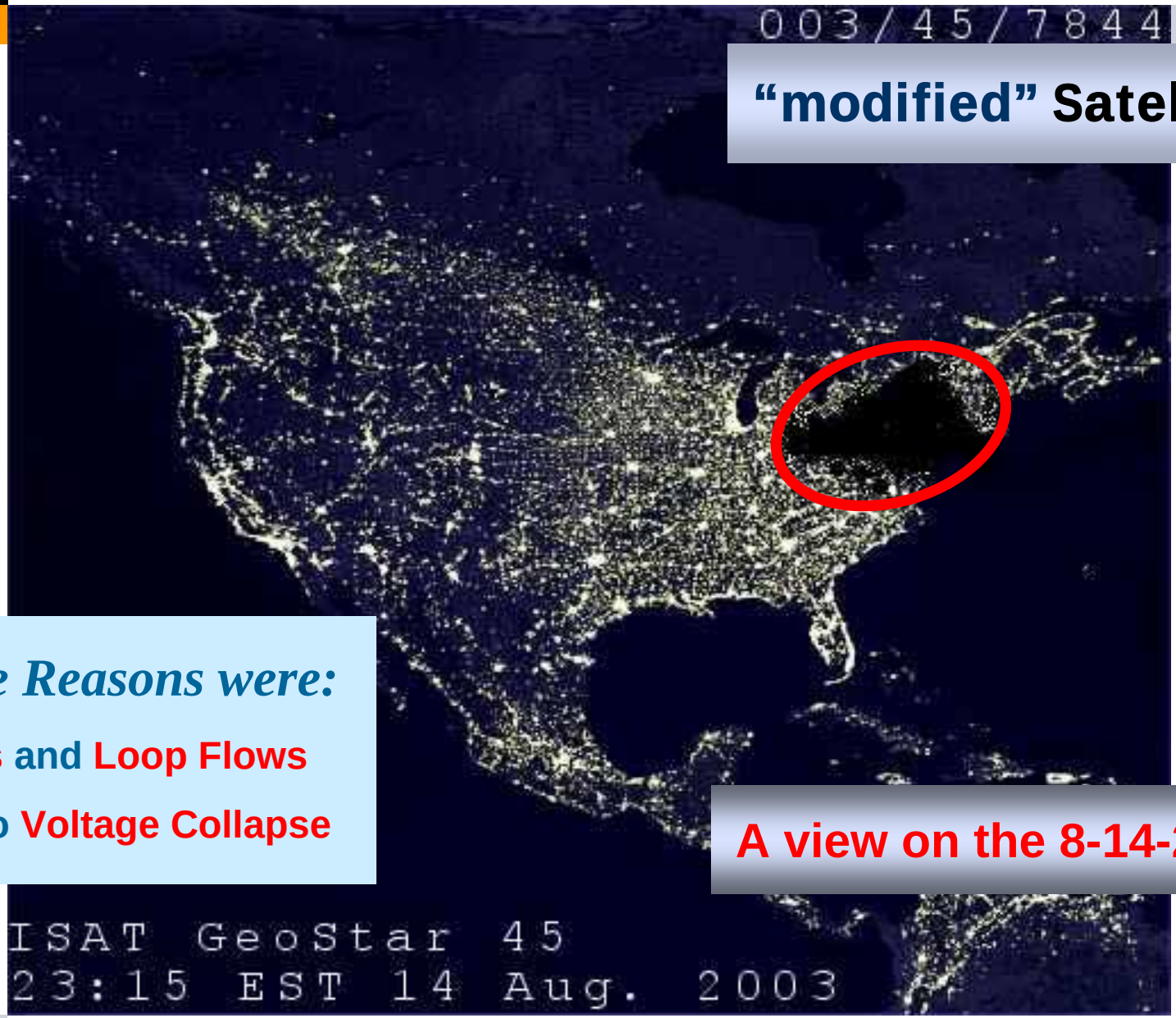
Source: Web/Google

High Voltage

The Blackout Area - a “Nightlight” View



“modified” Satellite Photo

A view on the 8-14-2003 Event

Some of the Reasons were:

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

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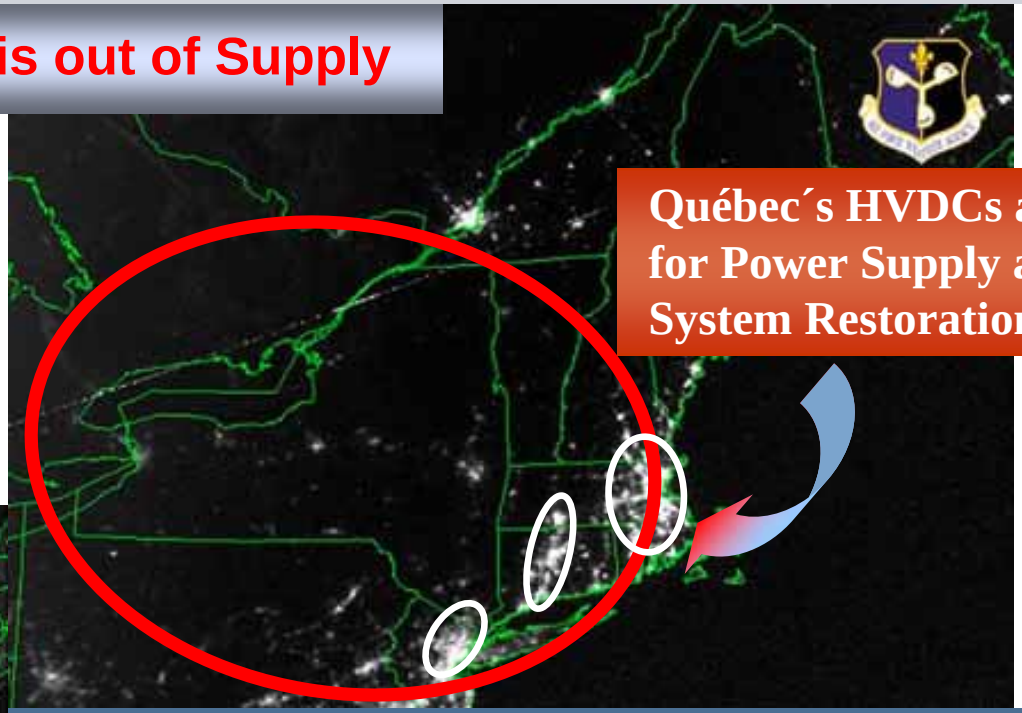
High Voltage

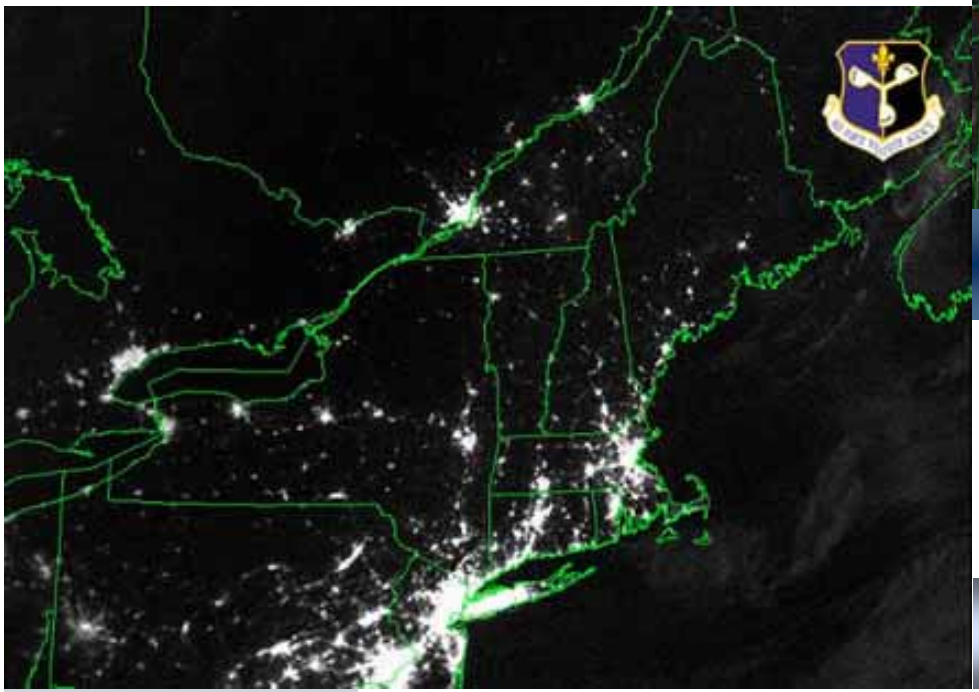
The Area of the Blackout - the "real" Photos

Blackout: a large Area is out of Supply



Québec´s HVDCs assist for Power Supply and System Restoration

However, some Islands still have local Supply



Before the Blackout

Source: EPRI 2003

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The Blackout: some more “Nightlight” Views

When Night falls - Skylines in Toronto and New York

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Source: Web/Google

6 Weeks after the US Blackout - a large Blackout in Italy ...

... the Risk for a Spread of Disturbance to UCTE was high

Europe needs Enhancements, too

... Similar Events and Root Causes

From "White Night" to "Black Night"

Source: VDN/ETG Fachtagung 10.-11.-2-2004 Jena, Germany

UCTE: Sequence of Events on the Interconnections

Sunday 28.09.2003: Sequence of events (line trippings)

starting at 03:01 a.m

20 min. after the 1st Line Trip: Loss of a 2nd Line … and then a very fast cascading Sequence

Blackout in Italy

1. 380 kV Lavorgo-Mettlen (CH)
2. 380 kV Sils-Soazza (CH)
3. 220 kV Airolo-Mettlen (CH)
4. 220 kV Lienz-Soverzene (A-I)
5. 380 kV 2xAlbertville-Rondissone (F-I)
6. 220 kV Riddes-Avise/Valpelline (CH-I)
7. 380 kV Divacia-Redipuglia (SLO-I)
8. 380 kV Praz-La Coche (F)
9. 220 kV Robiei-Bavona (CH)
10. 220 kV Innertkirchen-Robiei (CH)
11. 380 kV Villarodin-Venaus (F-I)
12. 380 kV Soazza-Bulciago (CH-I)

Timeline: Initial UCTE Press Release 09-29-2003

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A view on the 380 kV Lukmanier Line ...

Lessons Learned: **Power Systems have not been designed for "wide-Area" Energy Trading with daily varying Load Patterns**

... near the Tree Flashover

Event 1

Source: Cigré Paris Session 2004

A Key-Issue in many Power Systems today:

The Grids are "close to their Limits"

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Effect of System Loading on Stability Margin

The transmission distance of considerable power transfer of 6.7 GW from the generation located in Central Europe to the consumers in Italy led to a relatively high phase angle difference in the stationary parallel operation between the UCTE main grid:

- **the immediate reconnection of the line tripping first was not possible because of a steady state phase angle difference higher than expected**
- **the cascading line tripping evolved into a much more severe angle stability problem.**

Source: UCTE Interim Report 10-27-2003

High Voltage

The “Blackout-Story” *goes on …*

When Ice, Snow and Storm exceed the “Design Criteria”

Münsterland, Germany, Nov. 25-30, 2005:

600,000 People without Electricity initially,

250,000 for 3 Days und 90,000 up to 4 Days

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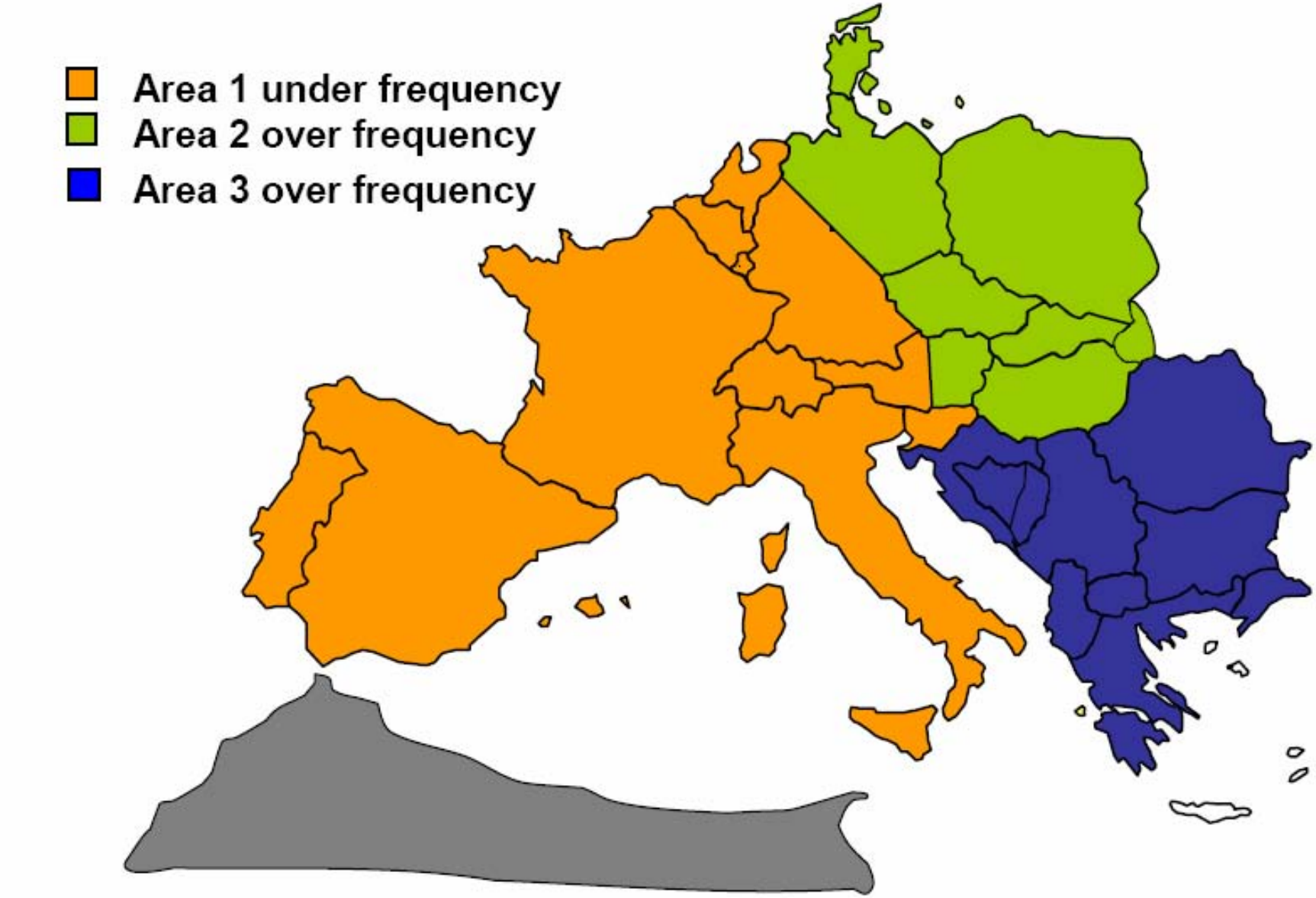
System fully restored after 6 Days


Area 1 under frequency
Area 2 over frequency
Area 3 over frequency

Sequence of events:

At 21:38h, both circuits of a 380-kV-line were switched off in order to secure the passing of the Ems river by a ship.

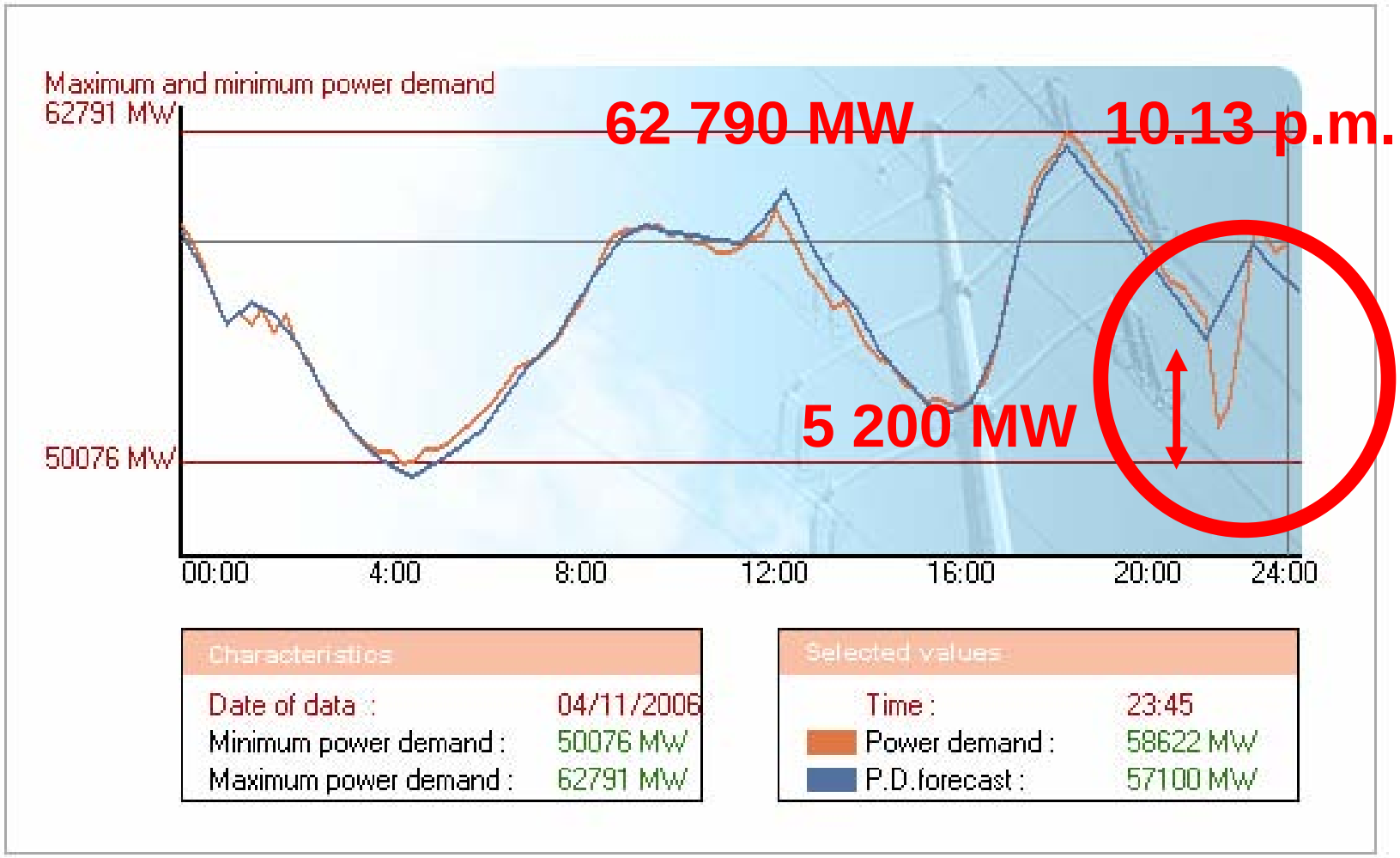
A routine simulation of the switching-off of the a.m. line was computed in advance and did not bring up concerns about this switching maneuver.

Following the switching-off of the said line, the energy flow was transferred to other lines in the South.

This situation was still stable.

The outage as seen from RTE, the French TSO

Power demand graph of day : 04/11/2006



High Voltage

What can actually be done ? Are other large Systems in the World Safe ?

- Improvement of System Protection and Enhancement of Communication and Monitoring with IT (EMS & DSM)
- Review of Generator and Load Trip Strategy (Under-Voltage and Under-Frequency Trip Levels and Times)
- Use of FACTS & HVDC for Reactive-Power Compensation, Power-Flow Control and Prevention of Voltage Collapse
- Active Damping of Power Oscillations with FACTS & HVDC
- Possibly more HVDC in the interconnected US-Canada Areas: HVDC is a Firewall against cascading events (Voltage Collapse and Frequency decline): Québec was not affected !
- Increase of Reserve Capacity (HVDC, new Generations)

Task Forces were “looking into” their own Systems all over the World

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High Voltage

Getting more Power out of the Grid

Our Solutions:

HVDC – High Voltage DC Transmission Systems

FACTS – Flexible AC Transmission Systems

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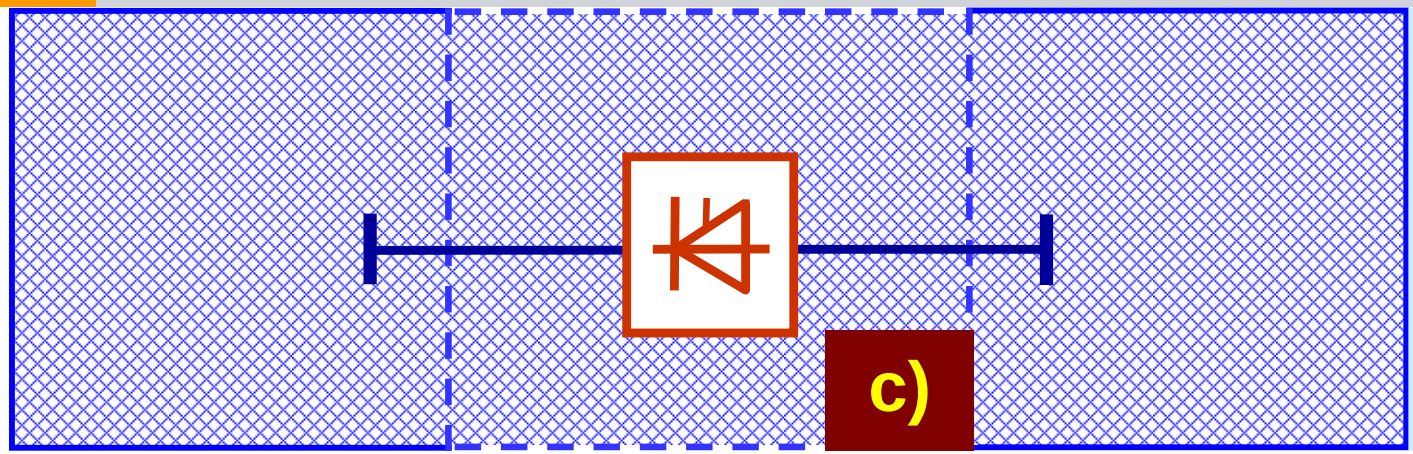
High Voltage

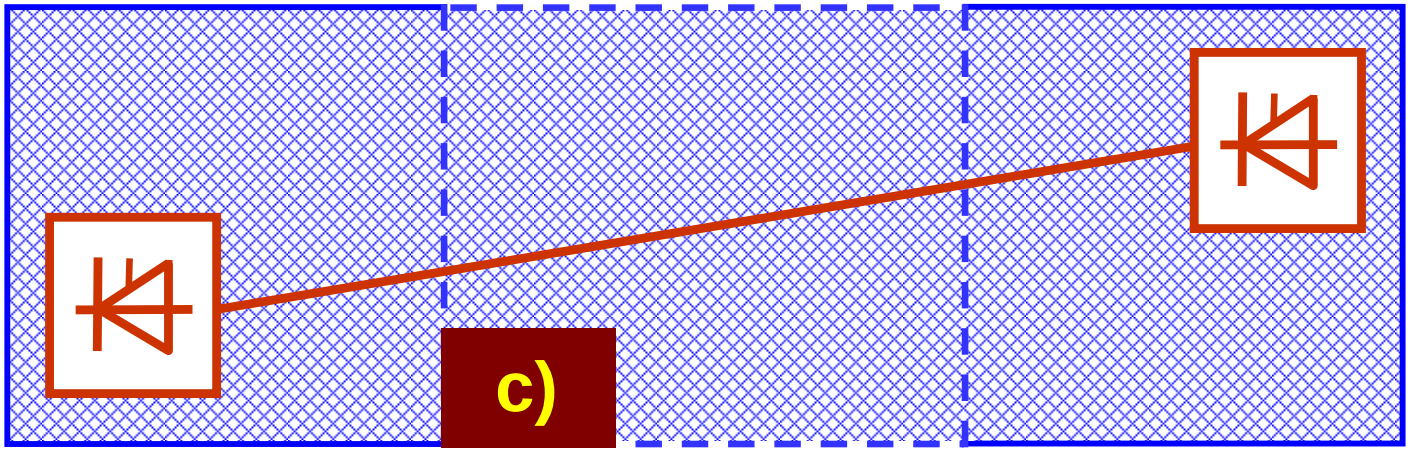
Options of HVDC Interconnections

a)



Can be connected to long AC Lines

b)



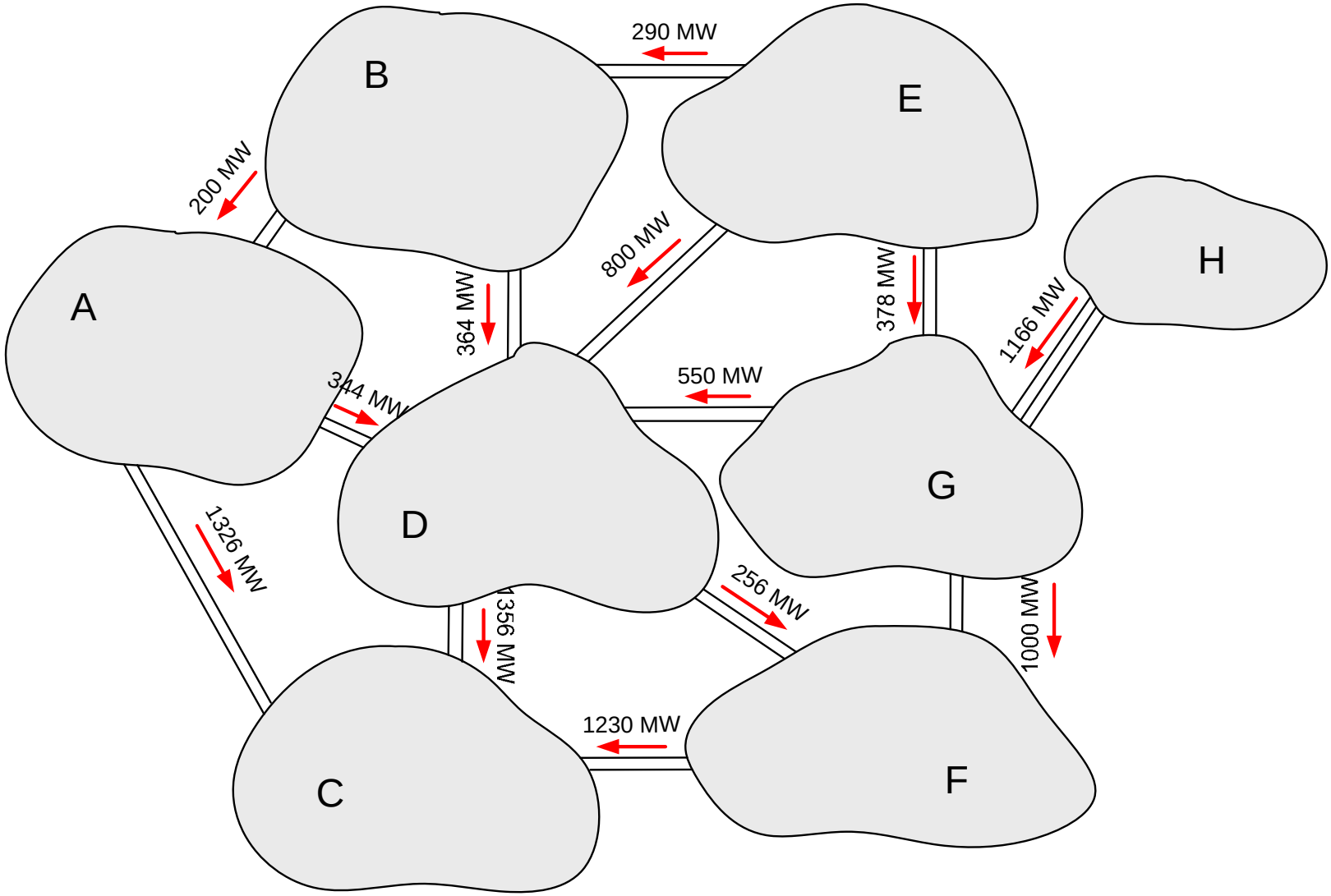
a) Back-to-Back Solution

b) HVDC Long Distance Transmission

c) Integration of HVDC into the AC System

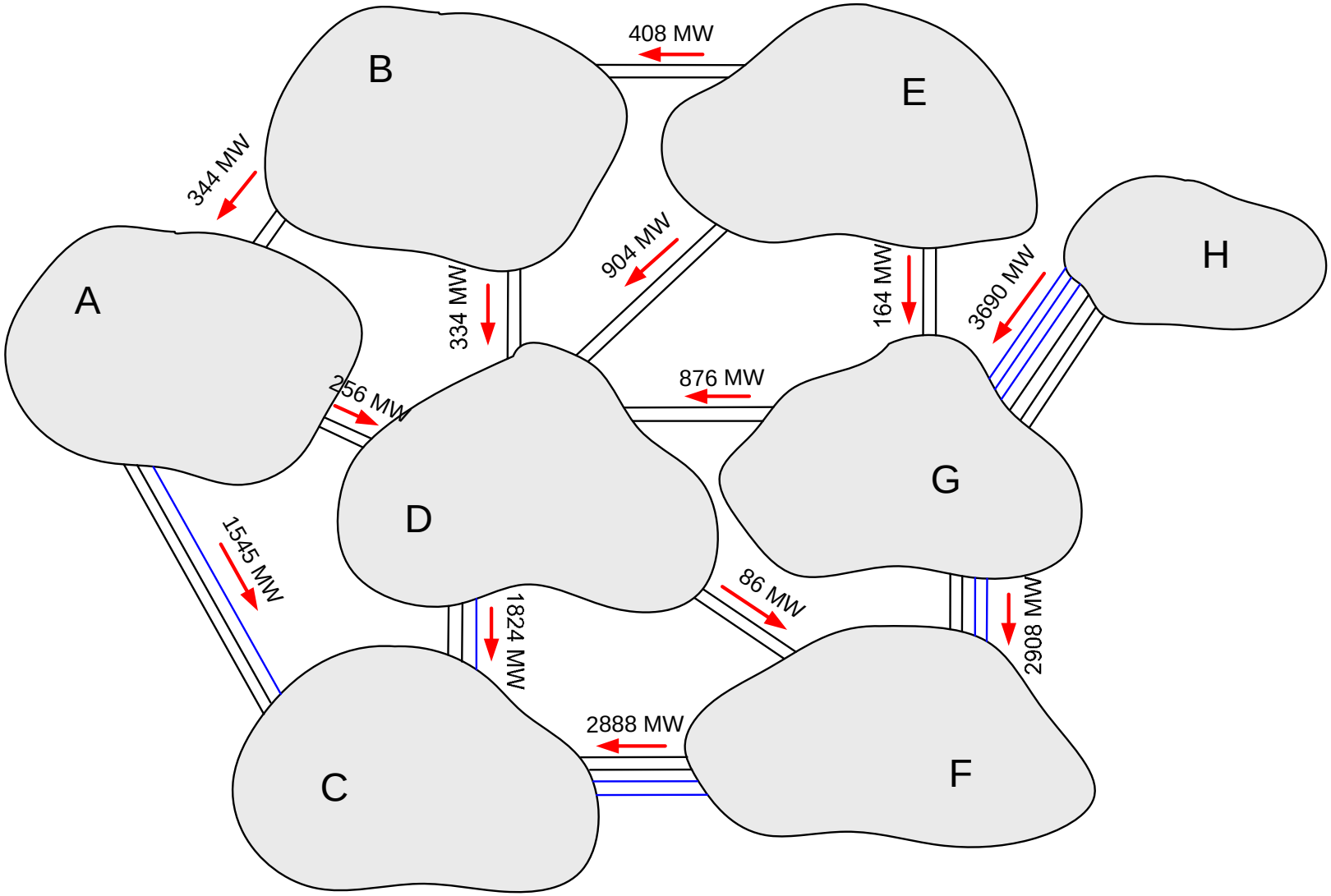
High Voltage

Interconnected system configuration



High Voltage

Transmission of additional 2000 MW through the system



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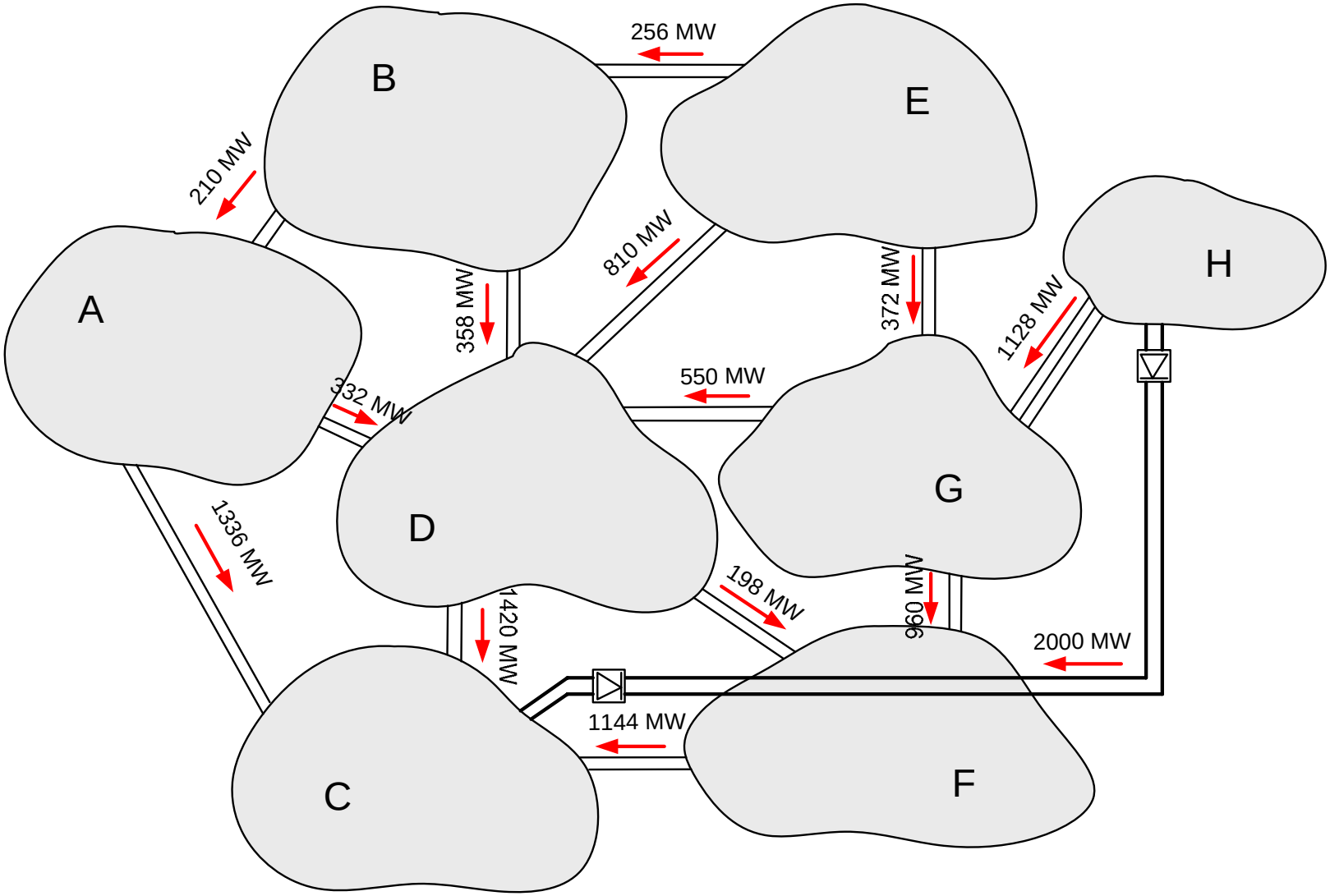
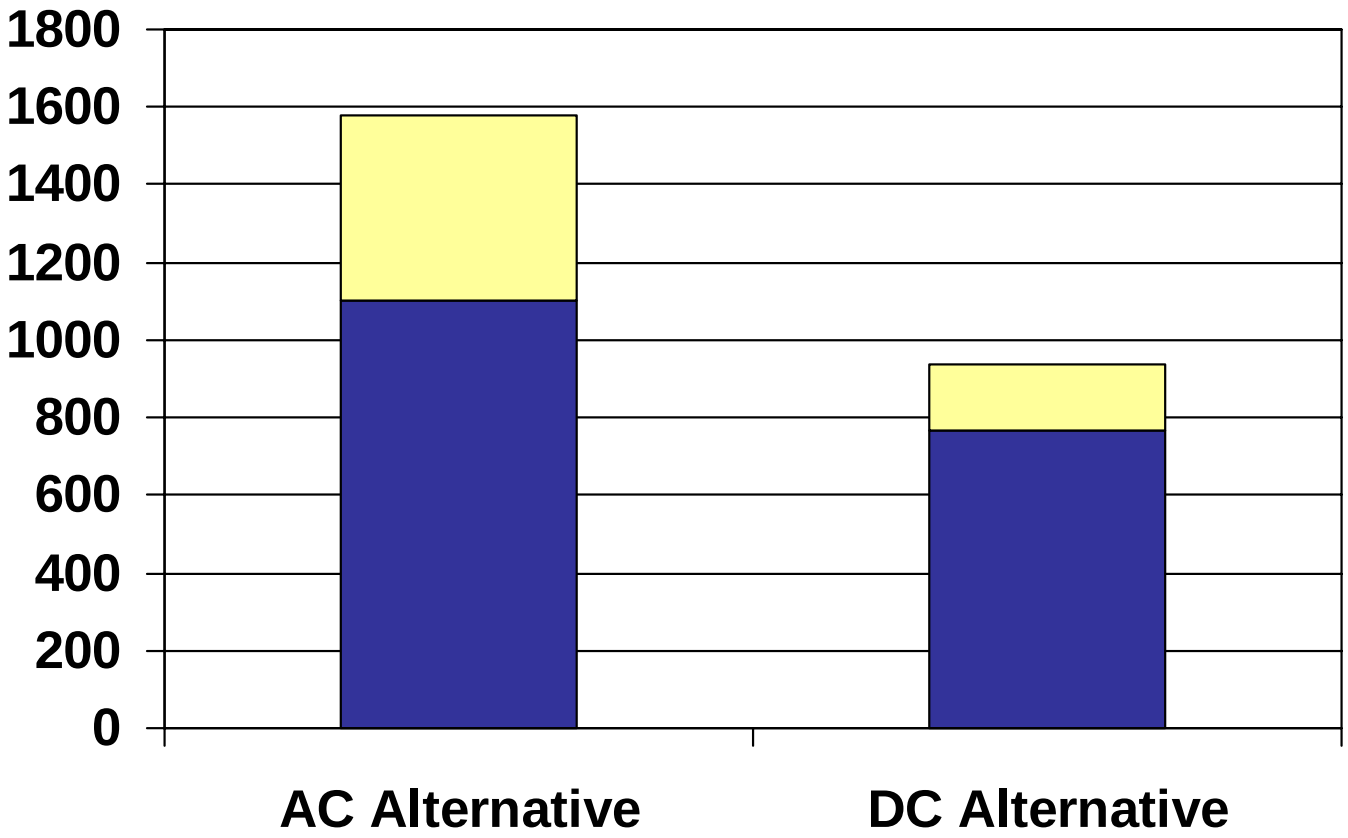
High Voltage

Transmission of additional 2000 MW by HVDC



High Voltage

Cost Comparison



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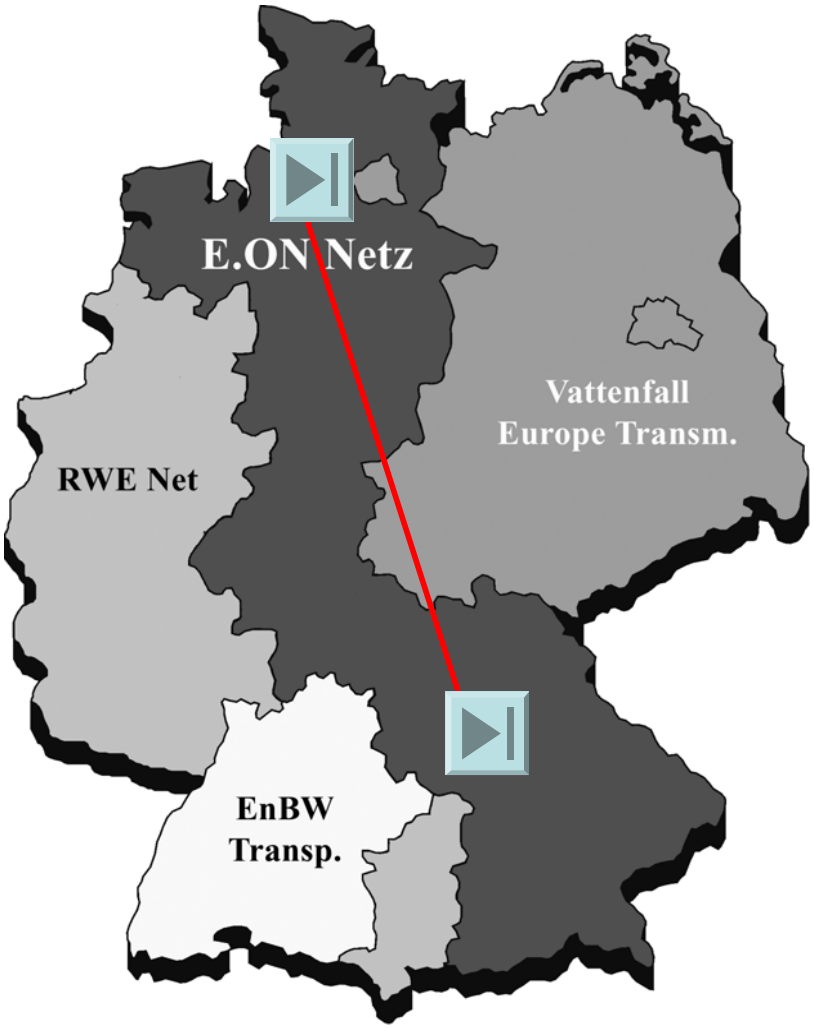
High Voltage

Integration of HVDC into the system (example)



Share in installed wind energy of 12,223 MW

E. ON Netz:	48 %
Vattenfall Europe Transmission:	37 %
RWE Net:	14 %
EnBW Transportnetze:	1 %

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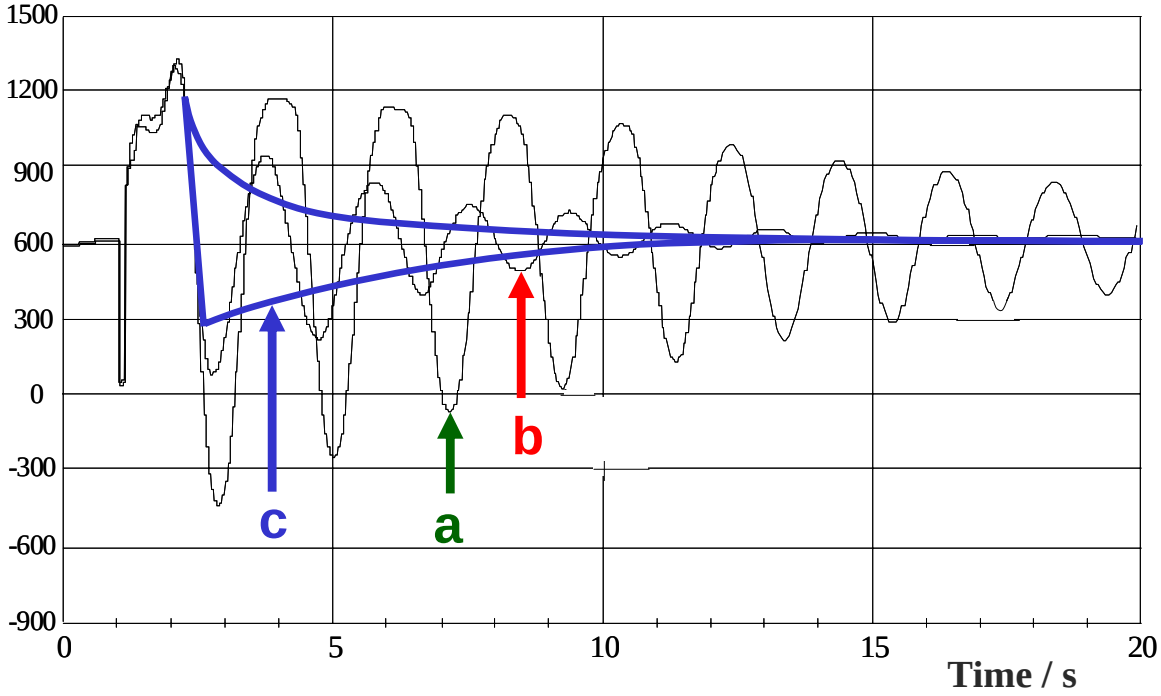
High Voltage

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

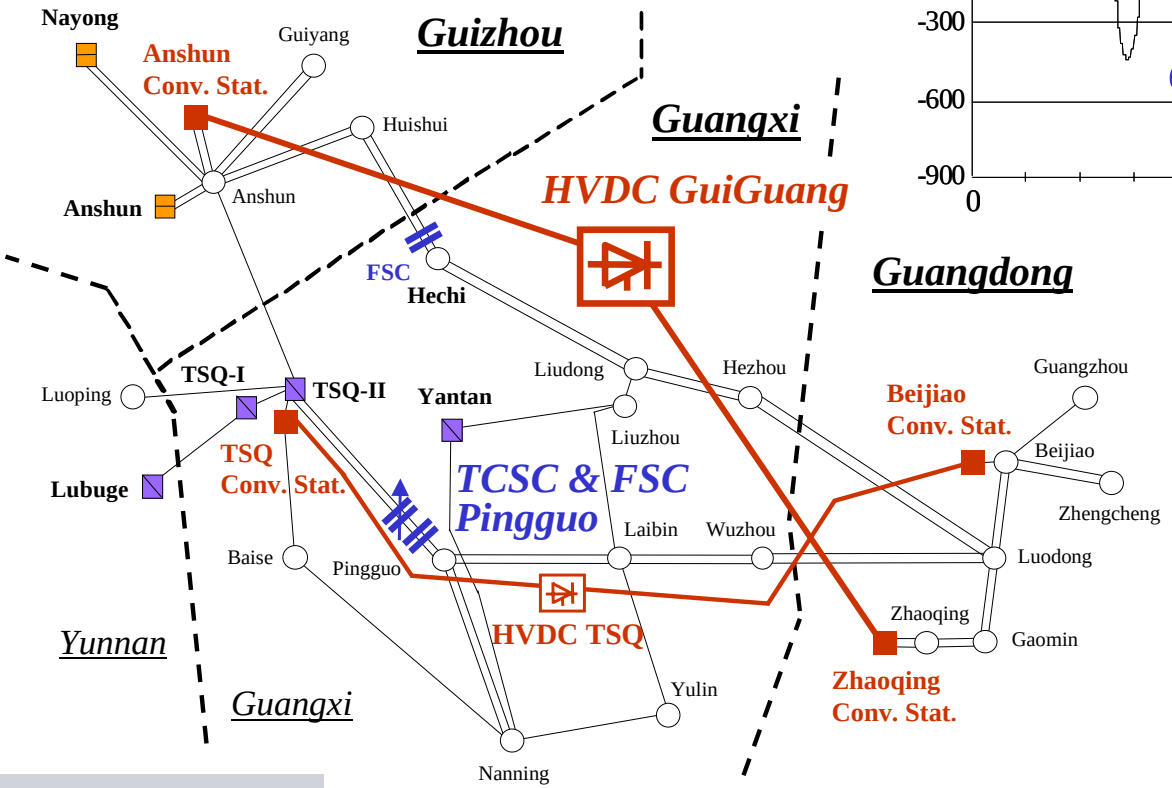
Power Flow in one Line
Huishui-Hechi (MW)



HVDC Converter Station

TCSC FSC

Power System

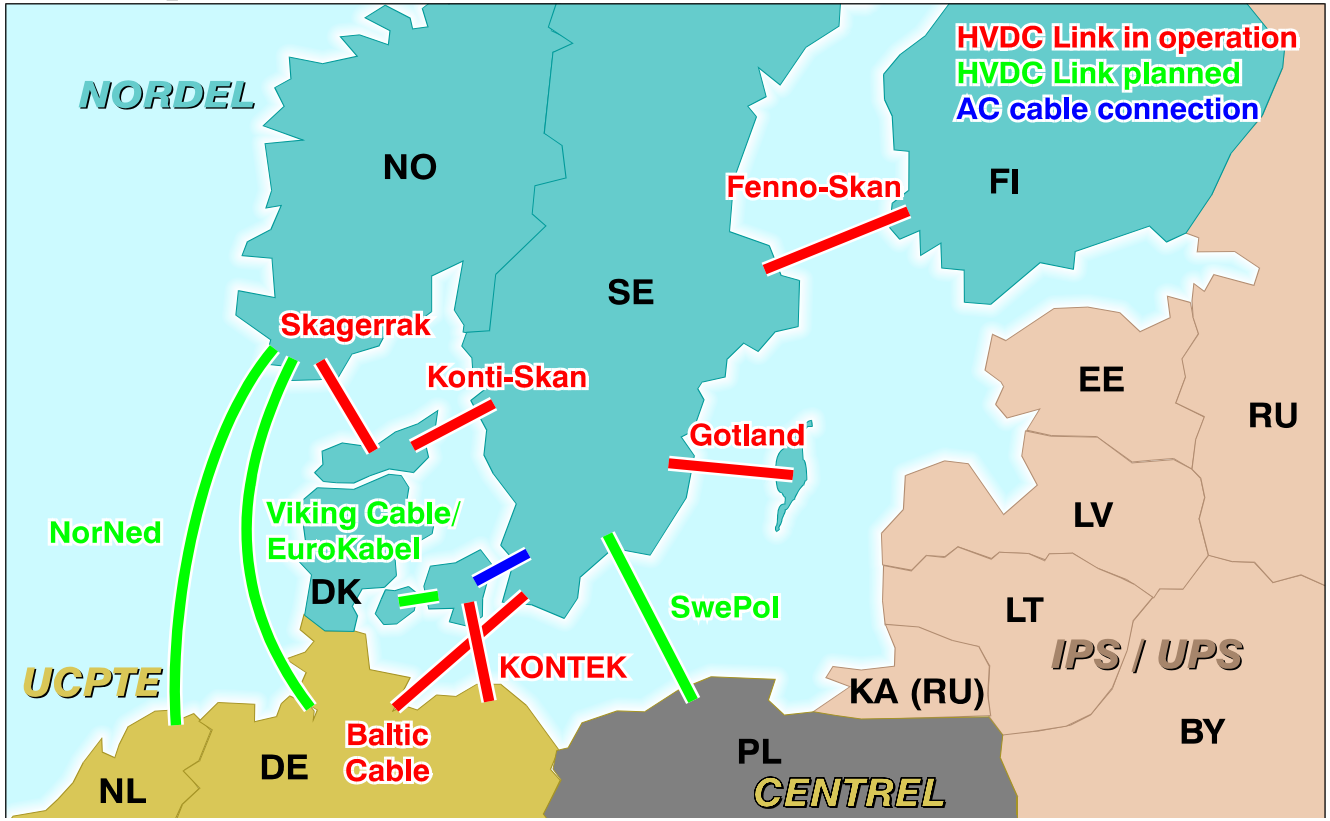


Dynamic Results

- a – without Power Modulation
- b – with Power Modulation of HVDC Control
- c – further Improvements with Pingguo TCSC/FSC

NORDEL - UCTE Interconnections (Studies for new HVDC Links)

Topics and Highlights of the Interconnection Studies



NORDEL

- 90 generators
- 220 nodes
- 320 transmission lines
- 80 transformers

8/11 HVDC links

UCPTE/CENTREL

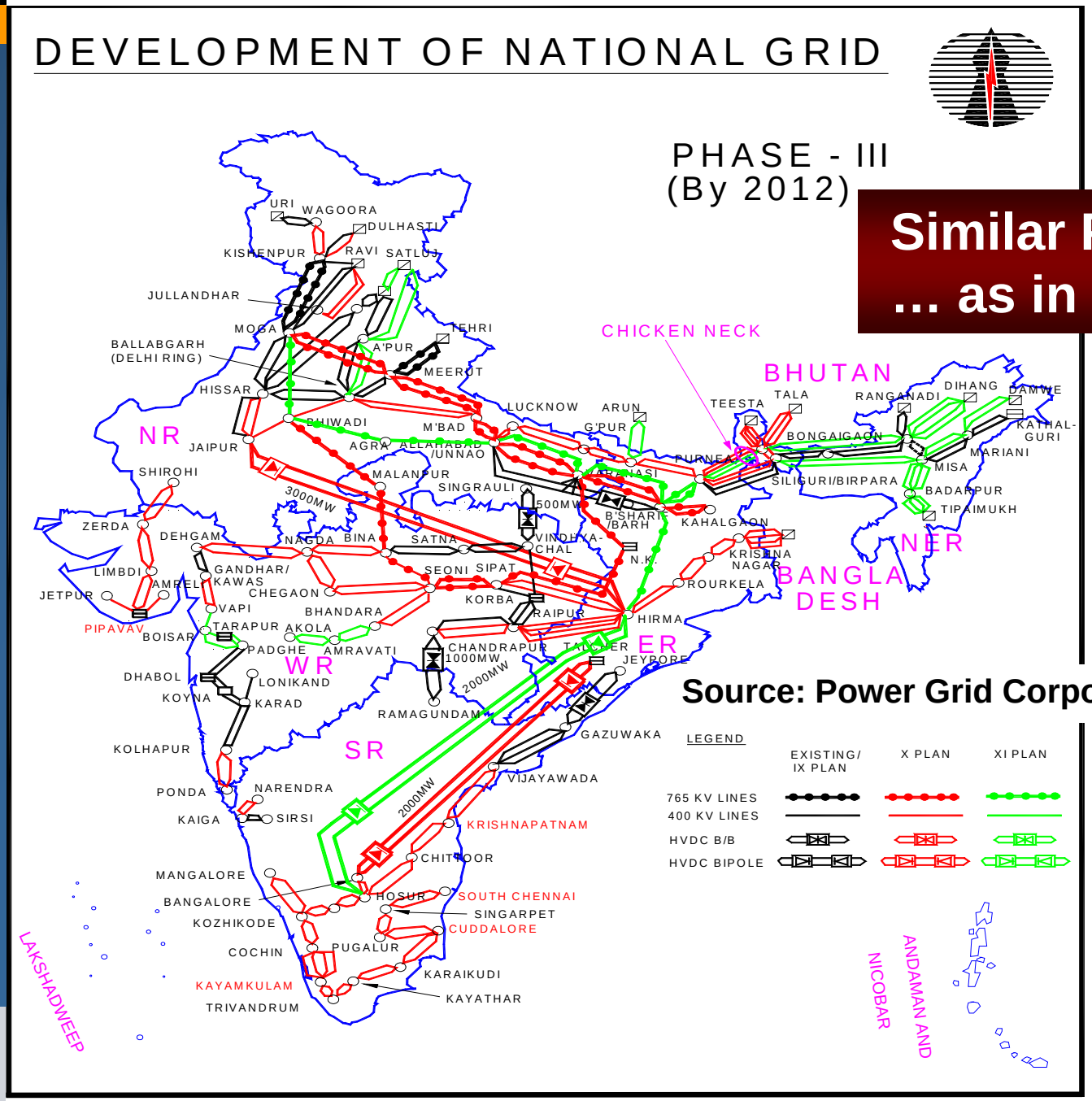
- 400 generators
- 1900 nodes
- 3200 transmission lines
- 940 transformers

High Voltage

Grid Extension in India - Hybrid AC plus DC

Prospects in China and India:

"Smart" and Strong Grids



Similar Perspectives … as in China

Source: Power Grid Corporation of India, 2003

High Voltage

India: East-South HVDC Interconnector

2003

DC Station Kolar – close to Bangalore

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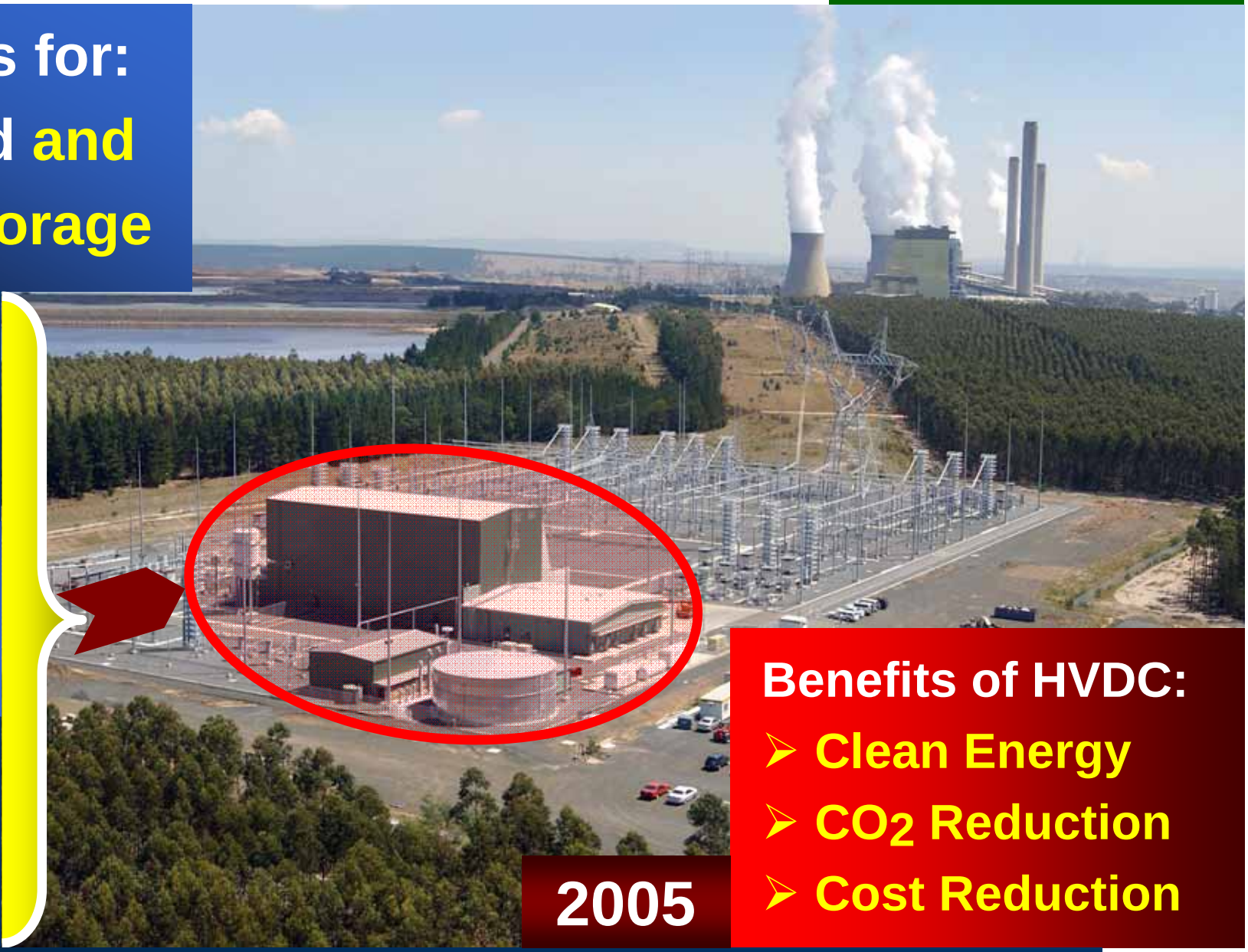
Basslink HVDC: remote Infeed of Green Energy

Hydro Plants for:

- Base Load and
- Energy Storage

Plus Wind Power



Benefits of HVDC:

- Clean Energy
- CO_2 Reduction
- Cost Reduction

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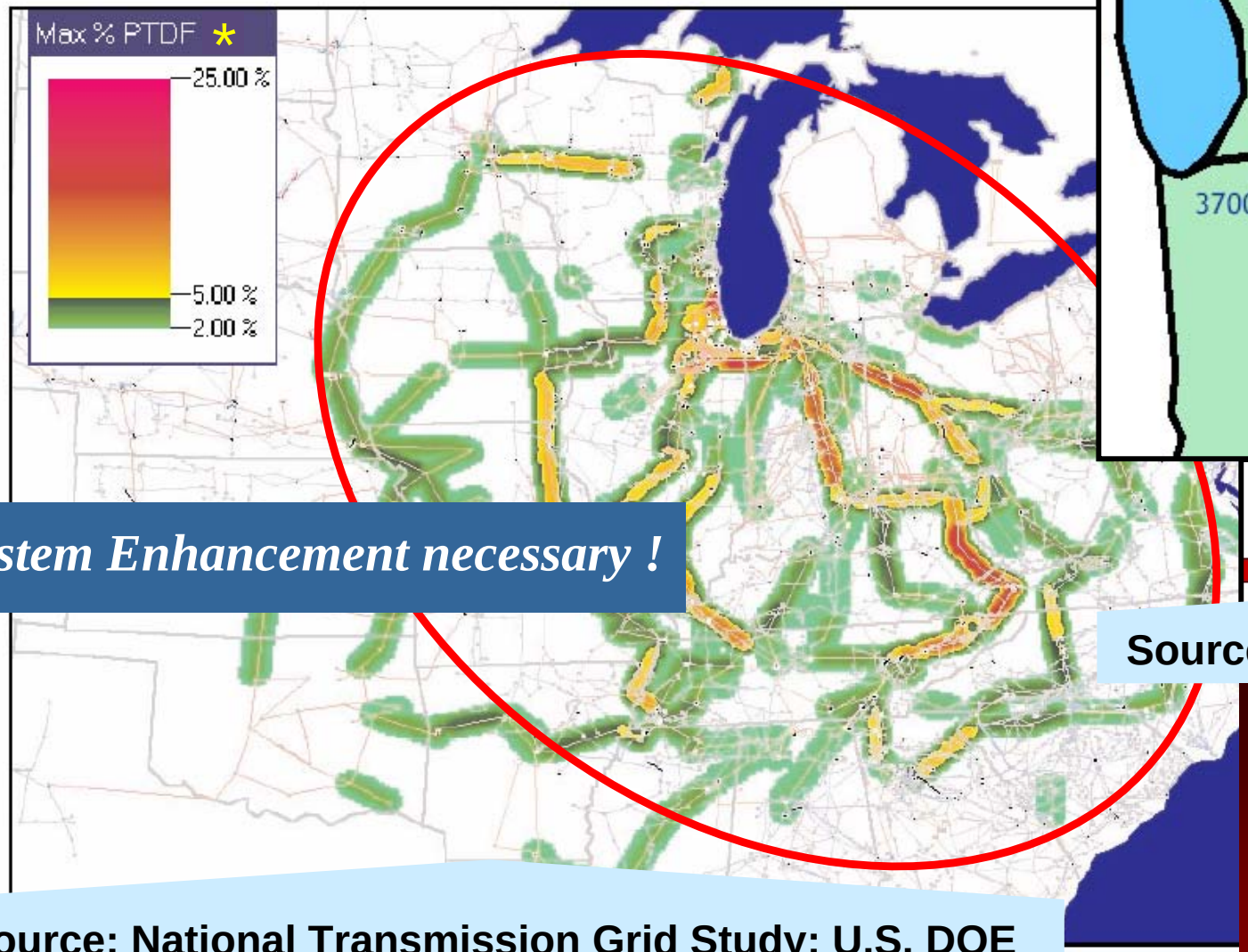
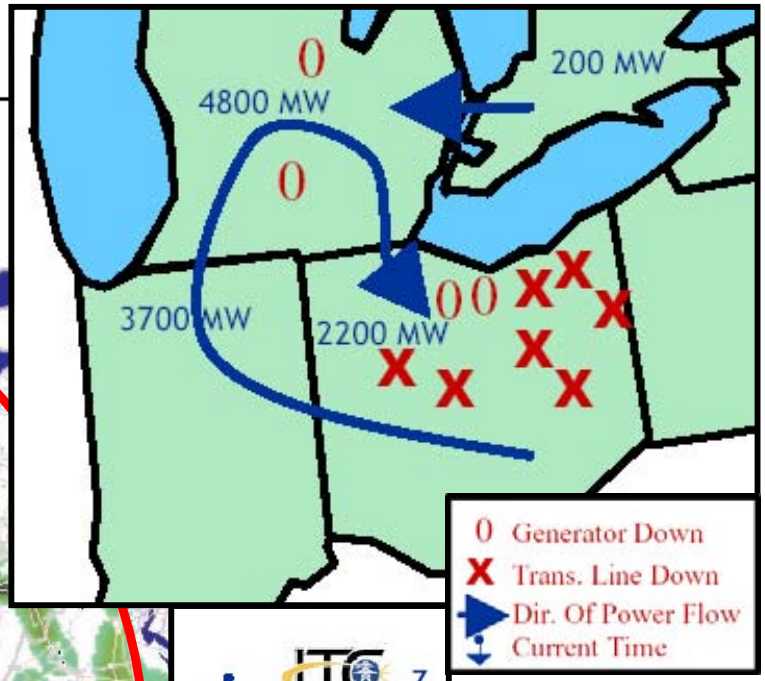
Covering Base and Peak-Load Demands

Initial Conditions in the US Blackout Area: Congestion, Overloads and Loop Flows

Figure 3: Loop Flow of Power Transfer from Wisconsin to TVA





System Enhancement necessary !

Source: ITC 8/2003 – "Blackout"

Source: National Transmission Grid Study; U.S. DOE 5/2002 – "Preview"

Problems only in the synchronous interconnected Systems

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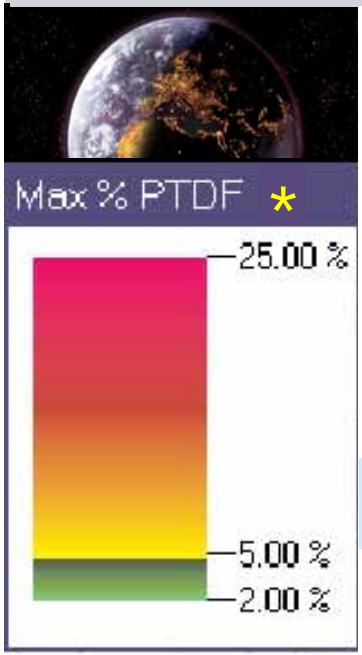
* PTDF = Power Transfer Distribution Factor

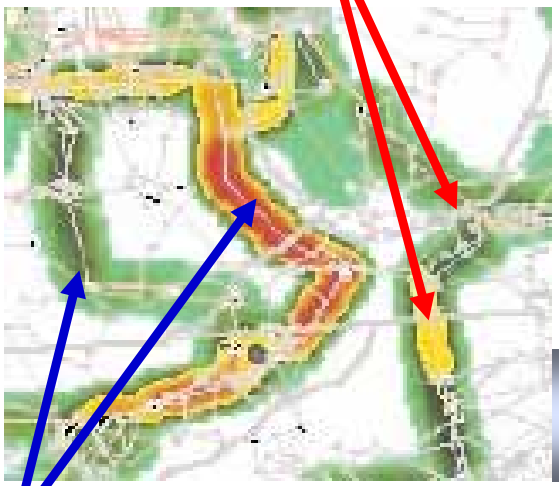


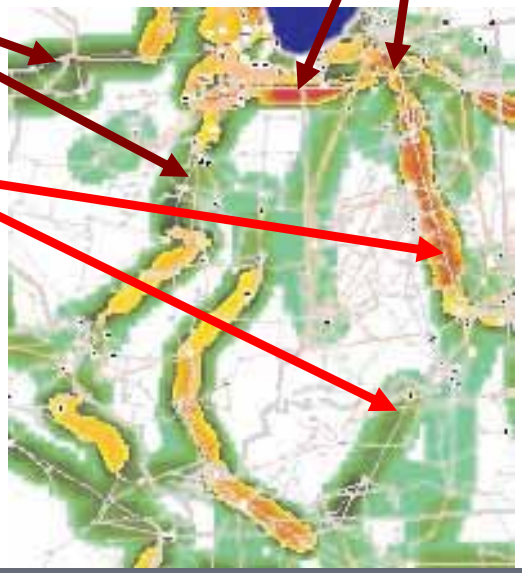
Elimination of Bottlenecks in Transmission - Prevention of Overloads and Outages

Short-Circuit Current Limitation for Connection of new Power Plants

SVC & HVDC for Prevention of Voltage Collapse

Load Management by HVDC





The FACTS & HVDC "Application Guide"

Load Displacement by Series Compensation

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* PTDF = Power Transfer Distribution Factor

500 kV TCSC Serra da Mesa, Furnas/Brazil – Essential for Transmission

- Current Control
- Impedance Control
- Power Oscillation Damping (POD)
- Mitigation of SSR (Option)

- Up to 500 POD Operations per Day for saving the System Stability
- A System Outage of 24 hrs would cost 840,000 US$ *

* 25 US$/MWh x 1400 MW x 24 hrs

1999

Benefits:

- o Increase of Transmission Capacity
- o Improvement of System Stability

> + 60 °C

up to 85 °

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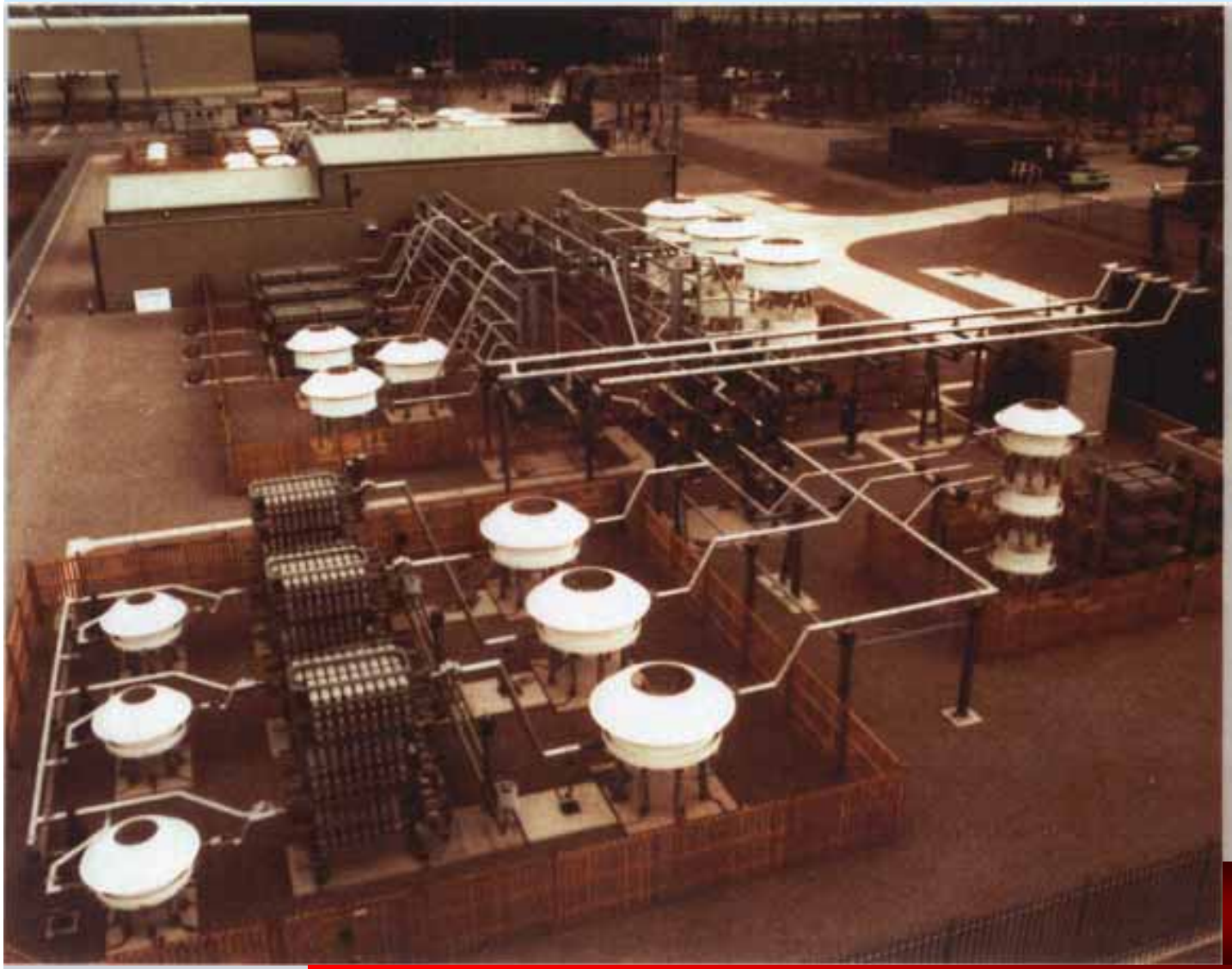
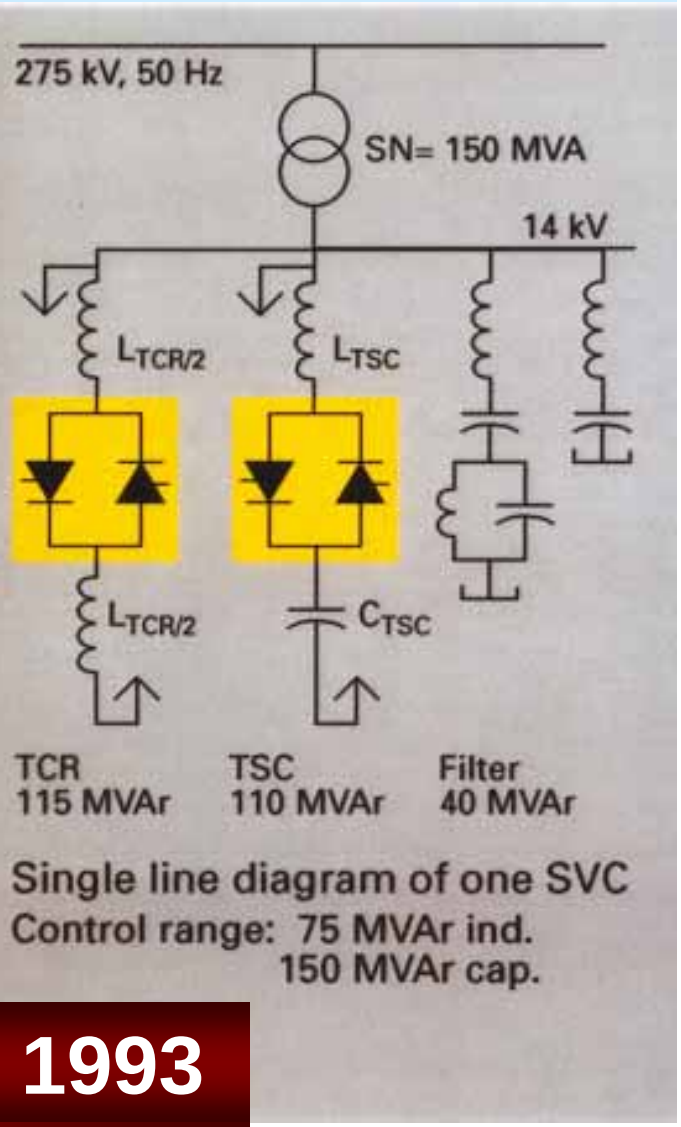
Europe: UK goes ahead with FACTS - 27 SVCs

Example **Harker** Substation - 2 parallel SVCs



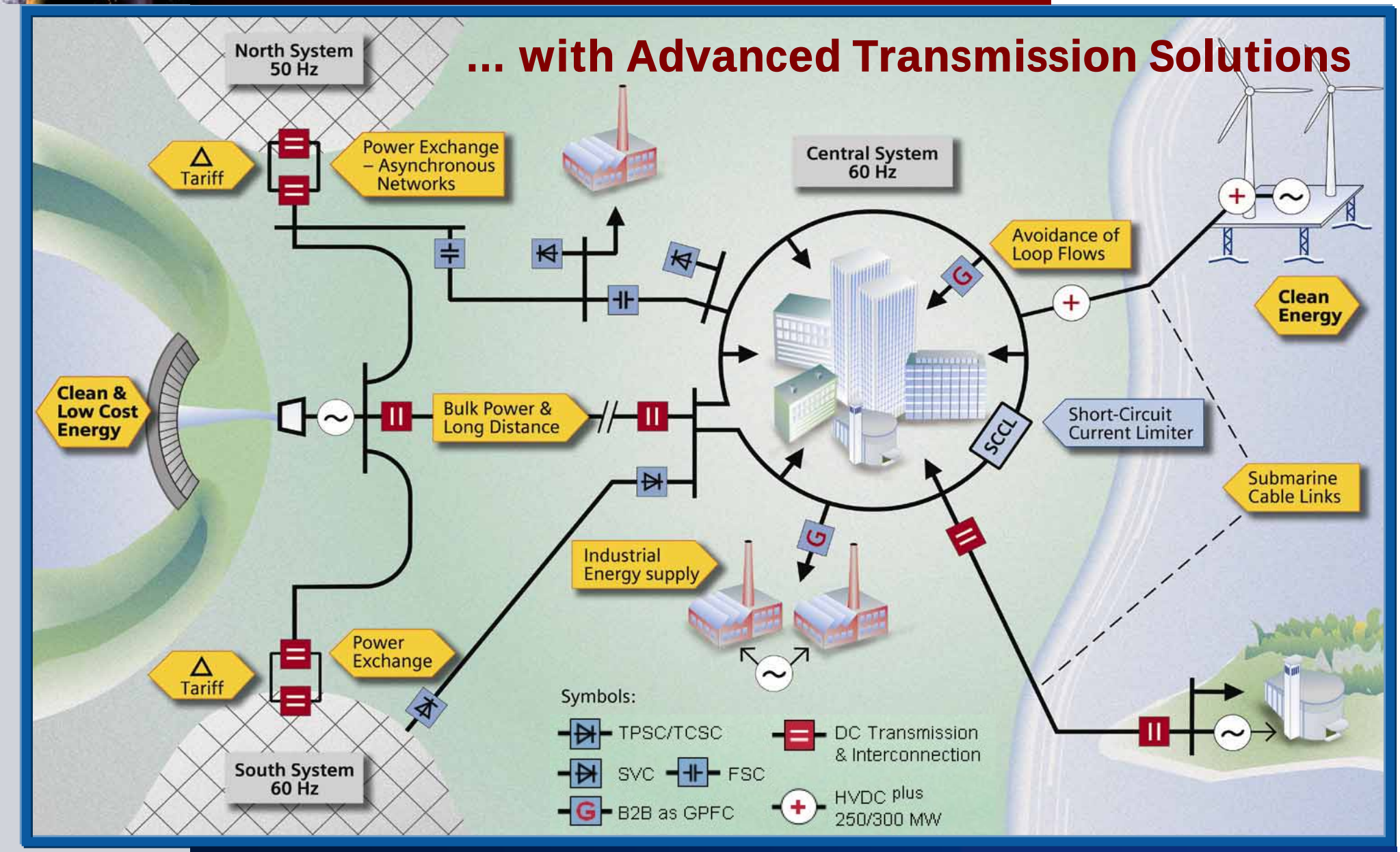


Single line diagram of one SVC
Control range: 75 MVAr ind.
150 MVAr cap.

1993

Deregulation caused Transmission Problems

Power System Expansion ...



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From Congestion, Bottlenecks and Blackout towards a "Smart Gird"