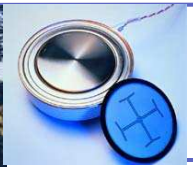
Teaching First Course
in Power Systems

NSF Sponsored
Workshop

Increasing Role of HVDC & FACTS

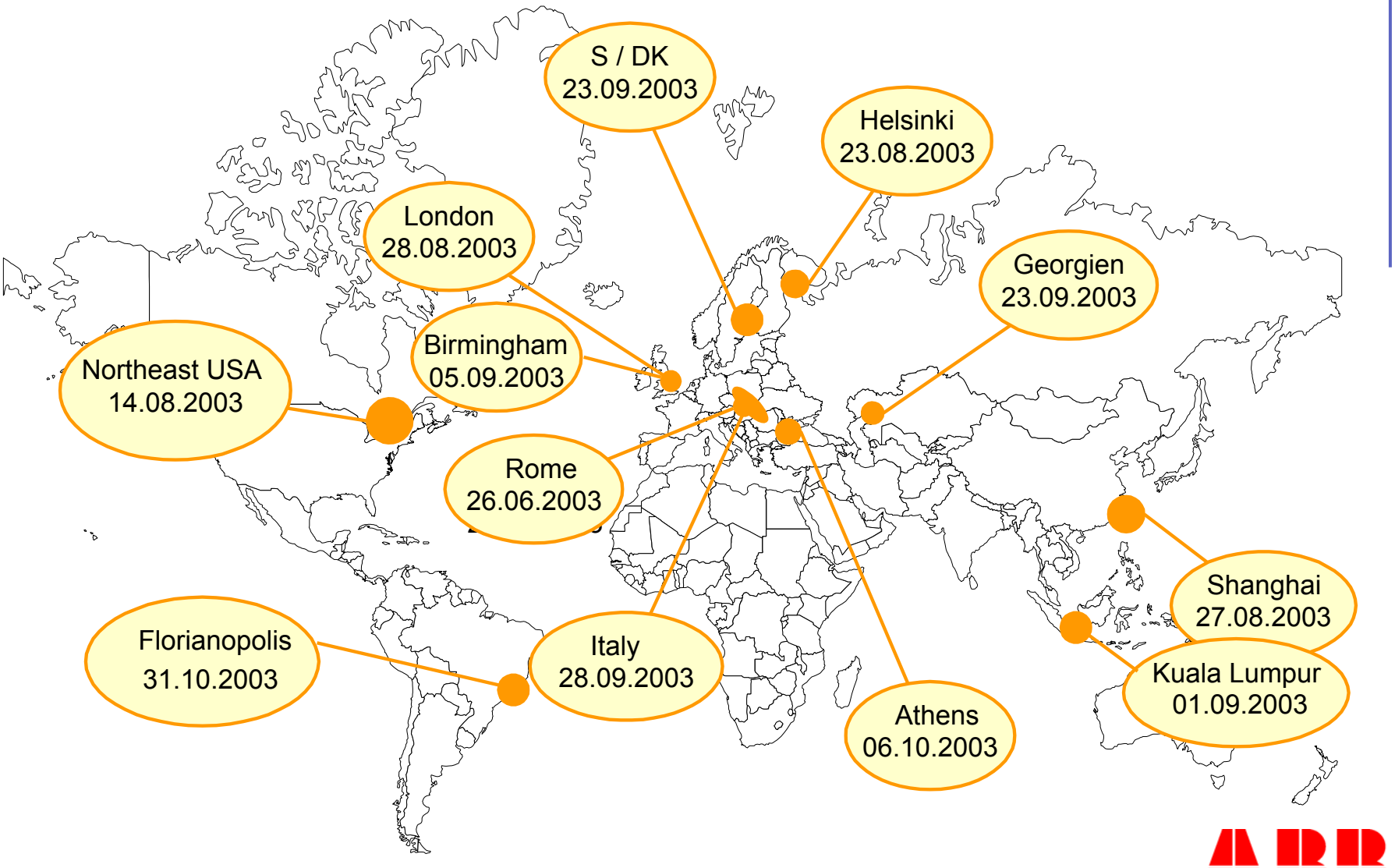


Michael Bahrman, P.E.
ABB Grid Systems

Topics

- Power Industry Challenges
  - Economically Meeting Market Needs
  - Reliability
  - Timely Permitting
  - Education
- Role of HVDC & FACTS
- Technology Overview
  - FACTS – SVC, STATCOM, TCSC
  - HVDC – Conventional, Capacitor Commutated, VSC Based
  - Monitoring
- Application Example
- Development
- Industry View of Educational Requirements

2003 - The Year of Blackouts



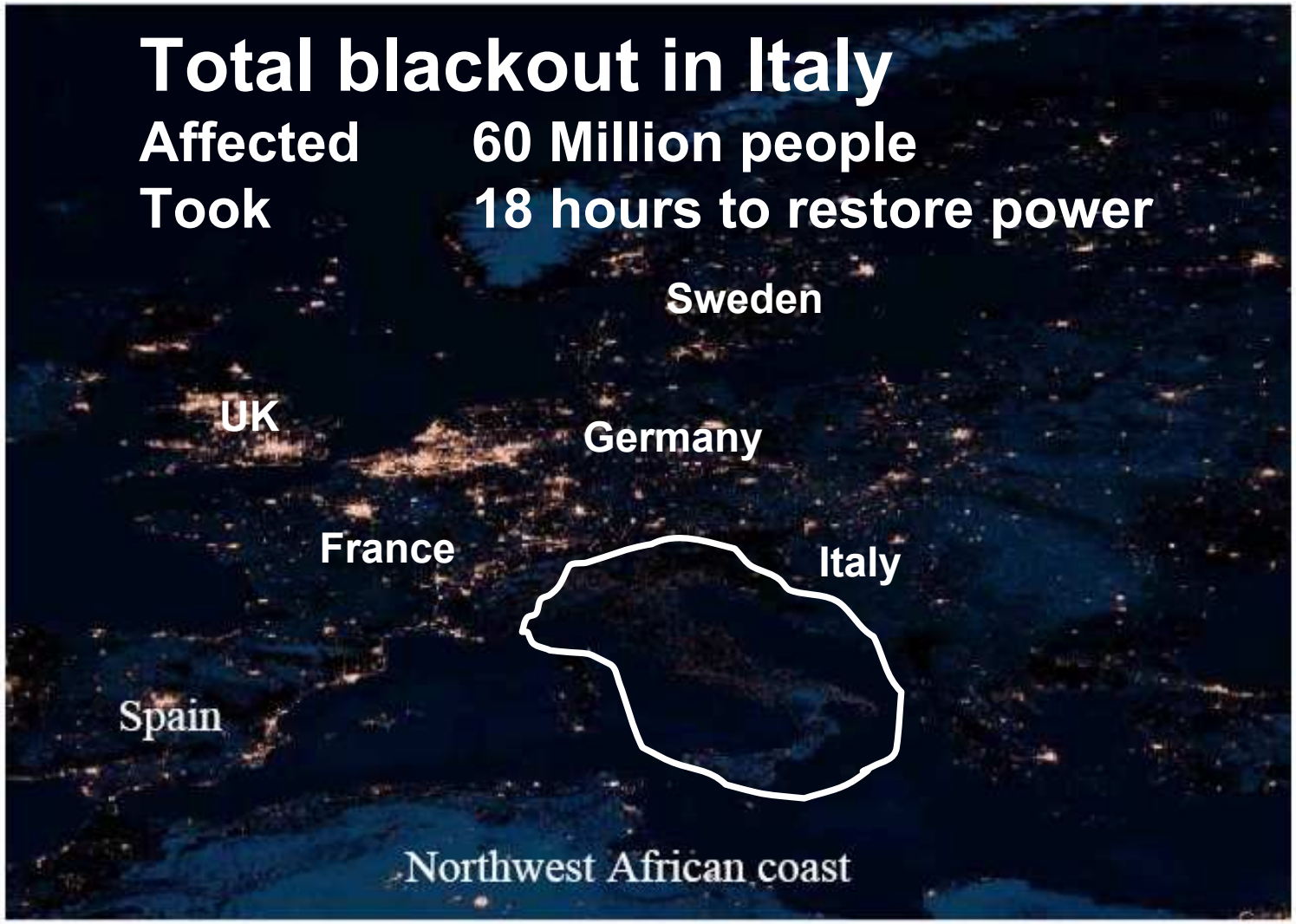
European View after 8/2003 US Blackout

Before the Italian blackout, in August 2003

The head of GRTN, Italian Independent System Operator, assured Italians that their nation would not suffer the kind of massive blackout North America did.

“The risk in Italy is tiny, Italy's network is more modern than the U.S. one, and European nations have tighter protocols on assistance and interconnections with other countries' power supplies.”

Europe, 03:28 September 28 2003



Revised European View

The head of GRTN, Italian Independent System Operator

"Our system is **more secure than the American one, but it's also more vulnerable"**

What Is the Cost of a Transmission Line?

Transmission & Distribution World

Minnesota, Wisconsin Grid Project Approved by Wisconsin Public Service Commission

Public Service Commission of Wisconsin; Minnesota Power, Inc.

Online Exclusive, Dec 16 2003

The Public Service Commission of Wisconsin yesterday determined that the increased costs for the construction of the already-approved Arrowhead-Weston transmission line are reasonable and the project should continue.

On Oct. 30, 2001, the commission authorized Wisconsin Public Service Corporation, Minnesota Power and the American Transmission Company to construct a 210-mile, 345 kV transmission line linking the Arrowhead substation near Duluth, Minnesota with the Weston substation near Wausau.

The commission re-opened the case in December 2002 to look at the revised cost estimates of the proposed project that went from US$165 million to $420 million. The increased costs are due in part to estimated costs for farm disease mitigation, substation improvements, increased costs for building materials and higher prices for land acquisition.

ABB

Why Underground? - Power Line Protest, CT

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Tower of Power

People Power Fighting Power mainlining

by Paul Bass - February 5, 2004

To stand below the 80-foot tower of steel known as the "lattice" is to feel power. Not your own power; you're a mere ant in the shadow of a skeletal giant, a robotic *uber*-insect. To stand there and gaze skyward at the outstretched arms holding disc-shaped conductors is to feel a 115-kilovolt electrical current hurtling through suburban New Haven County toward the DVD-, central air-, Jacuzzi-, laptop-humming homesteads of Fairfield County's Gold Coast.

An army of such towers dots the brushy landscape off Rimmon Road in Woodbridge, by the grounds next to Congregation B'nai Jacob synagogue. One lattice tower hovers above the complex's basketball court, playground, parking lot, day-care center and K-8 Ezra Academy religious day school. Parents have driven past these towers each morning for years with little, if any, thought about them. Nowadays, though, those towers loom as large in their fears as they do in the sky.

Like counterparts in dozens of white-collar suburbs throughout southern Connecticut, these parents have joined others in their town to fight a plan to replace those towers with new metal poles. The poles would bear high-voltage lines carrying three times as much electricity through the air--and past the children. The parents fear that electro-magnetic fields, or EMFs, radiated by the new overhead lines would put their children at risk of cancer. They're fighting to get the state to force the power companies to reroute the lines underground instead.

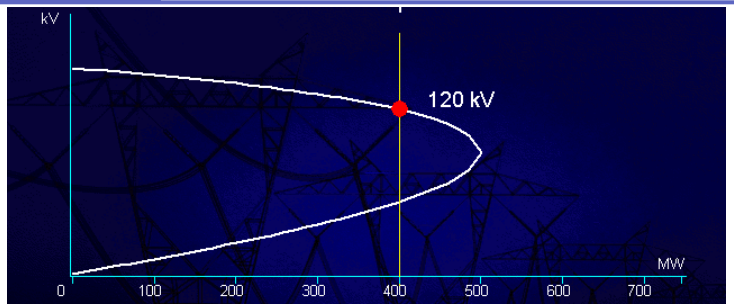
Reiter: I do not want to see a mother mourning the death of a child because we did not act.

Also see cover art

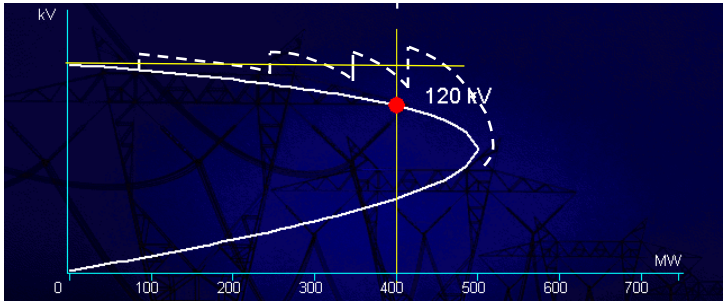
JYM MORGAN PHOTO

Woodbridges Reiter: I do not want to see a mother mourning the death of a child because we did not act.

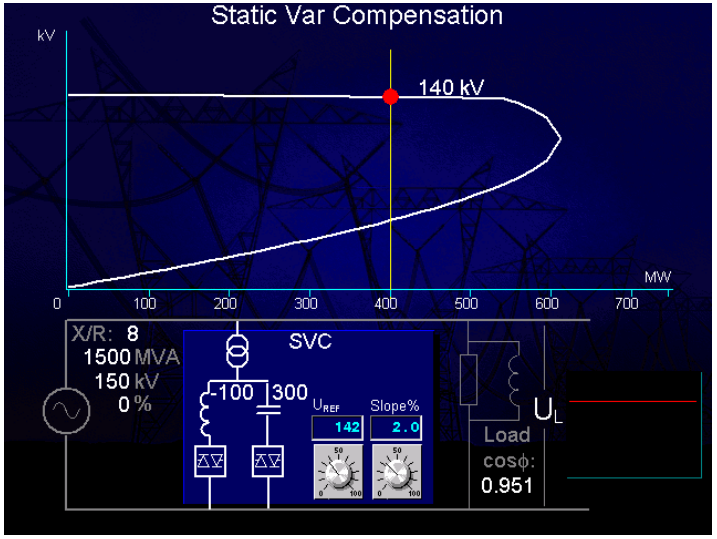
Increased Transfer with Voltage Support



n-1 Contingency – 1500 MVA Short Circuit Level



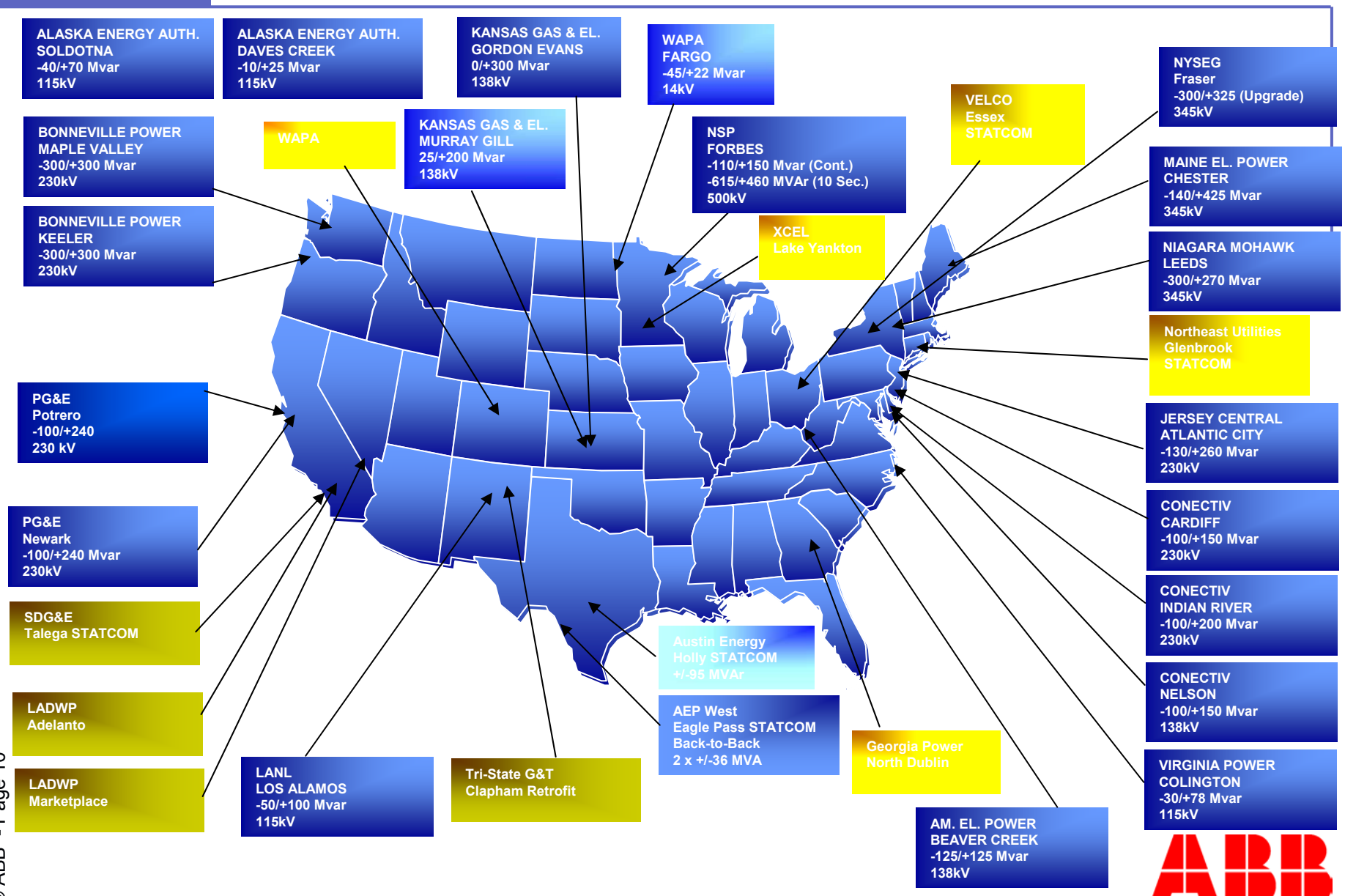
n-1 Contingency – 1500 MVA Short Circuit Level



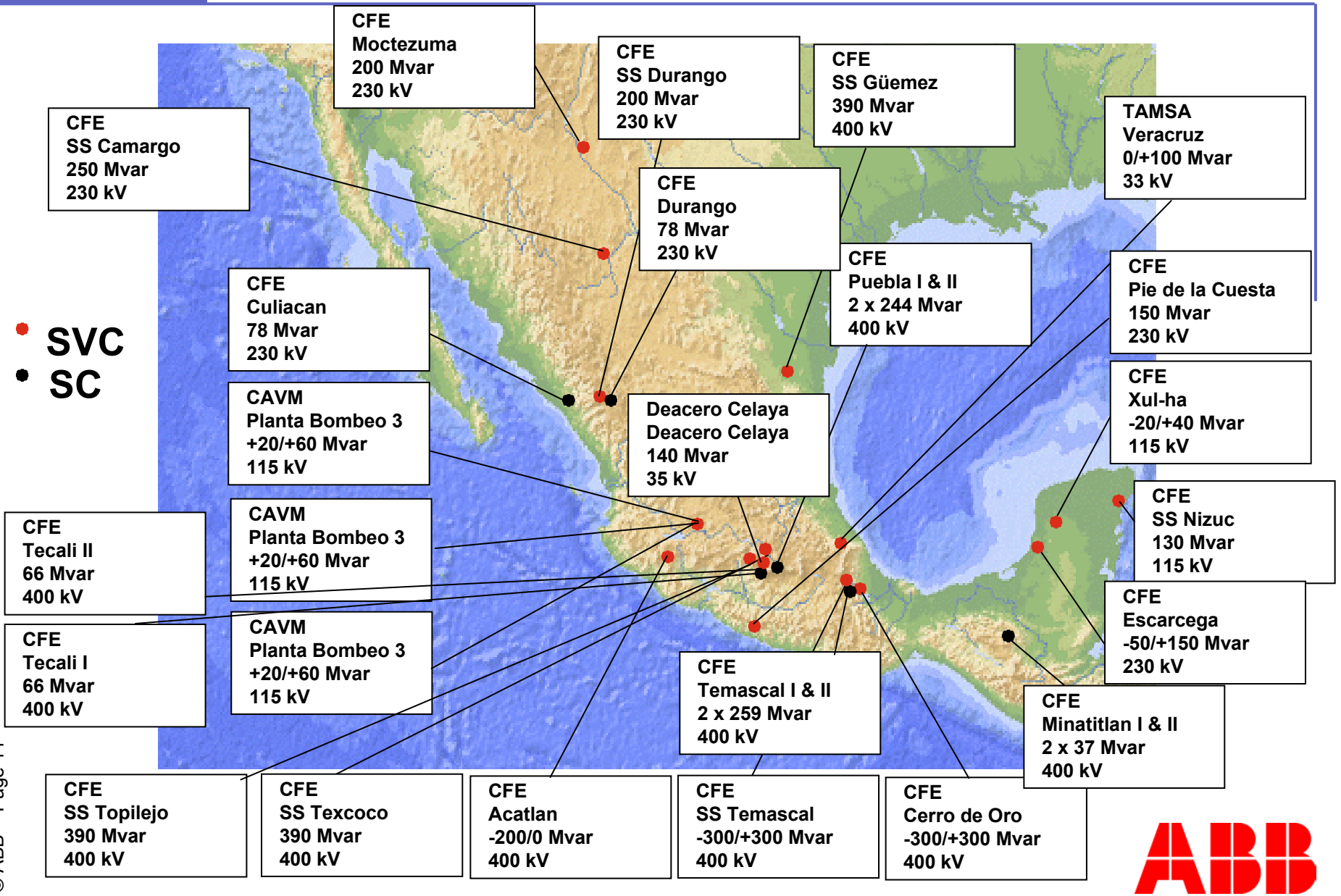
- Maximum power flow depends on network and voltage support
- Steady state voltage via slow devices, e.g., switched capacitors, tap changers
- Dynamic reactive power reserve required for contingencies
- Improved post-contingency voltage profile due to SVC or STATCOM dynamic reactive support

ROLE OF FACTS

Role of FACTS – SVC & STATCOM



Role of FACTS in Mexico



Dynamic Voltage Support – SVC/ STATCOM

SVC – AC Control of Reactors & Capacitors

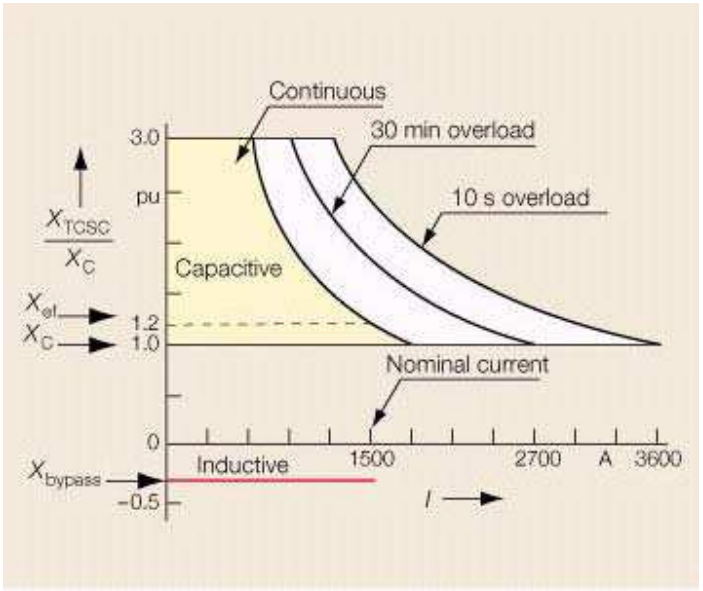
STATCOM – Synthesize AC from DC

- Maximum power flow depends on network and voltage support
- Steady state voltage via slow devices, e.g., switched capacitors, tap changers
- Dynamic reactive power reserve required for contingencies
- Dynamic voltage support requires fast action, e.g., generators, SVC[1)] or STATCOM[2)] - *all VARS are not the same*

1) Static Var Compensator
2) Static Compensator (ABB SVC Light)

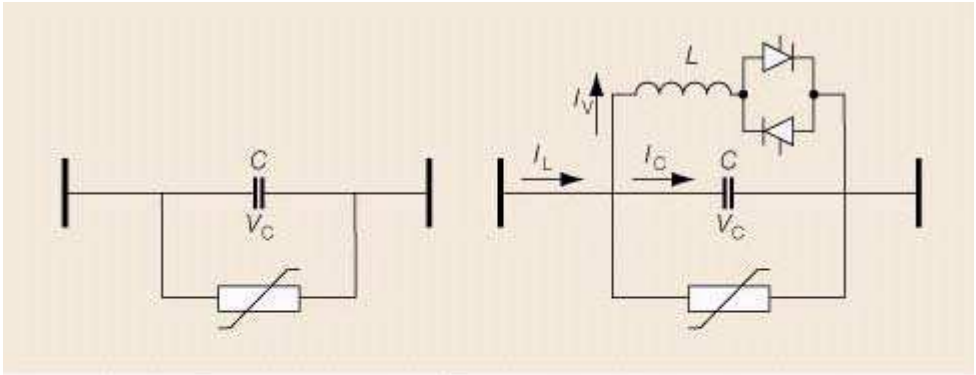
Thyristor Controlled Series Compensation

- **Series compensation can be boosted, oscillation damped and SSR mitigated by thryristor control, e.g. TCSC**



Impedance-current characteristic of the TCSC installed in the Imperatriz substation of Brazil's North-South Interconnection.

I	*Line current*
X_{TCSC}	*TCSC reactance*
X_{ef}	*Nominal boost level*
X_C	*Unity boost level*
X_{bypass}	*Boost level at TCSC bypass*



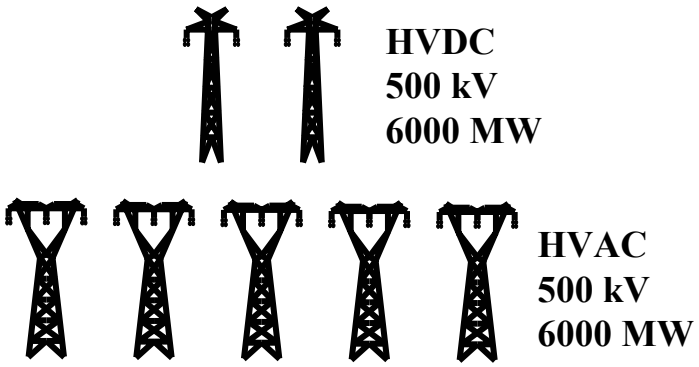
Two typical series compensation schemes with a fixed series capacitor and TCSC

C	*Series capacitor*	I_V	*Valve current*
L	*Parallel inductor*	I_L	*Line current*
I_C	*Capacitor current*	V_C	*Capacitor voltage*

View of the Imperatriz TCSC

DC Transmission Characteristics

China: Three Gorges,



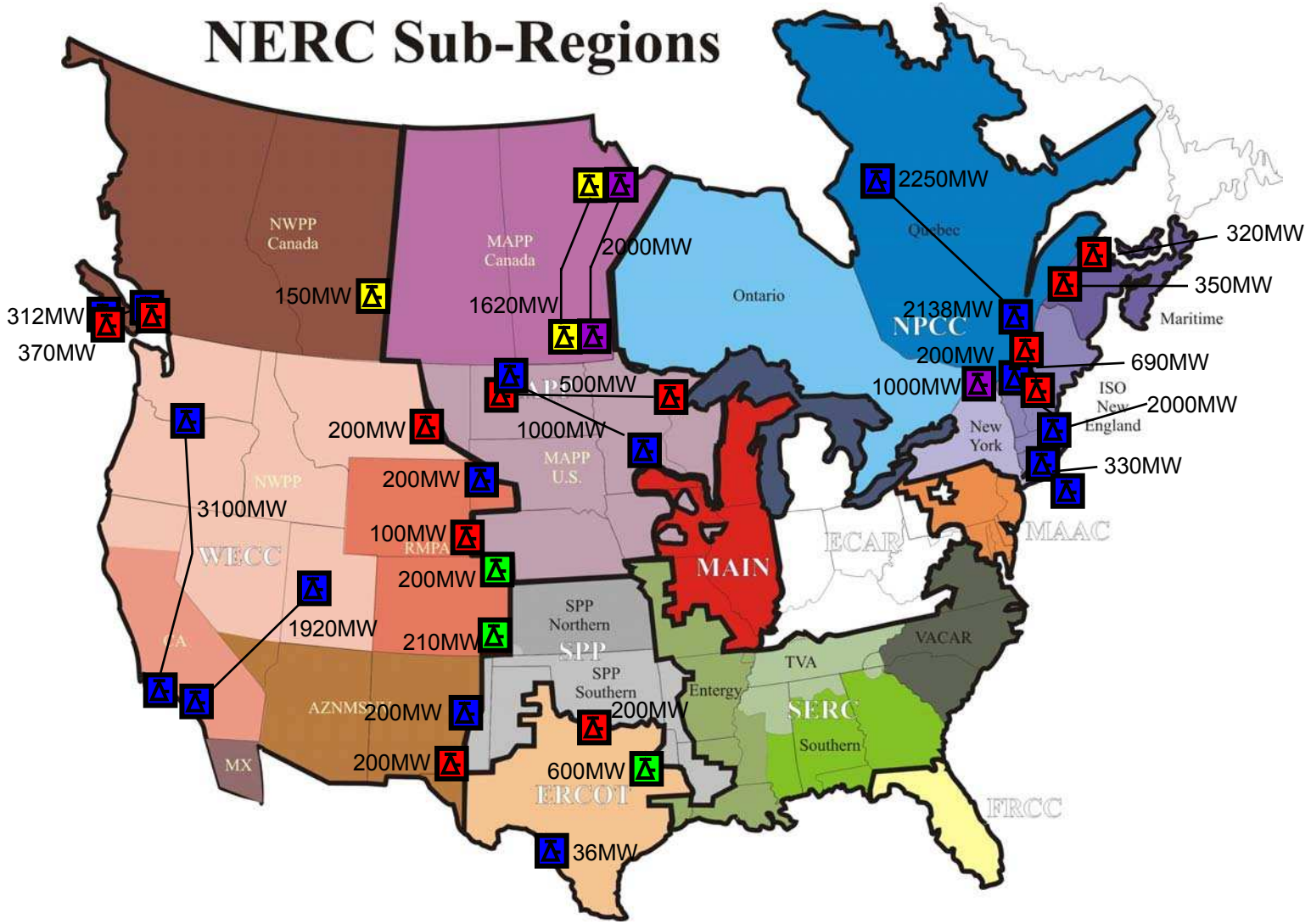
- Controllable - power injected where needed
- Bypass congested circuits – no inadvertent flow
- Higher power, fewer lines, no intermediate S/S needed
- Two circuits on less expensive line
- No stability distance limitation
- Reactive power demand limited to terminals
- Narrower ROW
- Lower losses
- No limit to underground cable length
- Asynchronous

Why Did the Blackout Not Reach Quebec?

The province of Québec, although considered a part of the Eastern Interconnection, is connected to the rest of the Eastern Interconnection only by DC ties. In this instance, the DC ties acted as buffers between portions of the Eastern Interconnection; transient disturbances propagate through them less readily. Therefore, the electricity system in Québec was not affected by the outage, except for a small portion of the province's load that is directly connected to Ontario by AC transmission lines.

Source: U.S Canada Power Systems Outage Task Force, April 2004

HVDC Projects in North America



HVDC Transmission Technologies

HVDC Classic

- Power control
- Terminals demand reactive power
- Reactive power balance by shunt bank switching
- Minimum system short circuit capacity of twice rated power

HVDC Classic with series capacitor (CCC)

- Power control
- Weak systems, long cables
- Reactive power from series capacitor
- Minimum system short circuit capacity of rated power

VSC Based Transmission - HVDC Light®

- Real and Reactive Power control
- Dynamic Voltage Regulation
- Modular and Expandable
- Black Start Capability
- No Short Circuit Restriction

The Conventional HVDC Converter Station

Converter station

Transmission line or cable

Smoothing reactor

Converter

AC bus

DC filter

Shunt capacitors or other reactive equipment

AC filters

Telecommunication

Control system

Power Ratings:

100 - 3300 MW

The CCC* Converter Station

*Capacitively-commutated converter station

Transmission
Line, Cable or Back-Back

Smoothing
reactor

Converter

AC bus

Weaker Systems
Back-to-Back
100 - 600 MW

DC filter

Commutation
capacitors

Contune AC filters

Telecommunication

Control
system

The HVDC Light Station

Strong or Weak Systems
Dynamic Voltage Control
Underground Transmission
Up to ±150kV, 530MW

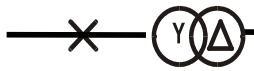
Converter station

Voltage Source(d) Converter - VSC

Phase Reactor

Transmission Cable

AC bus



AC filters

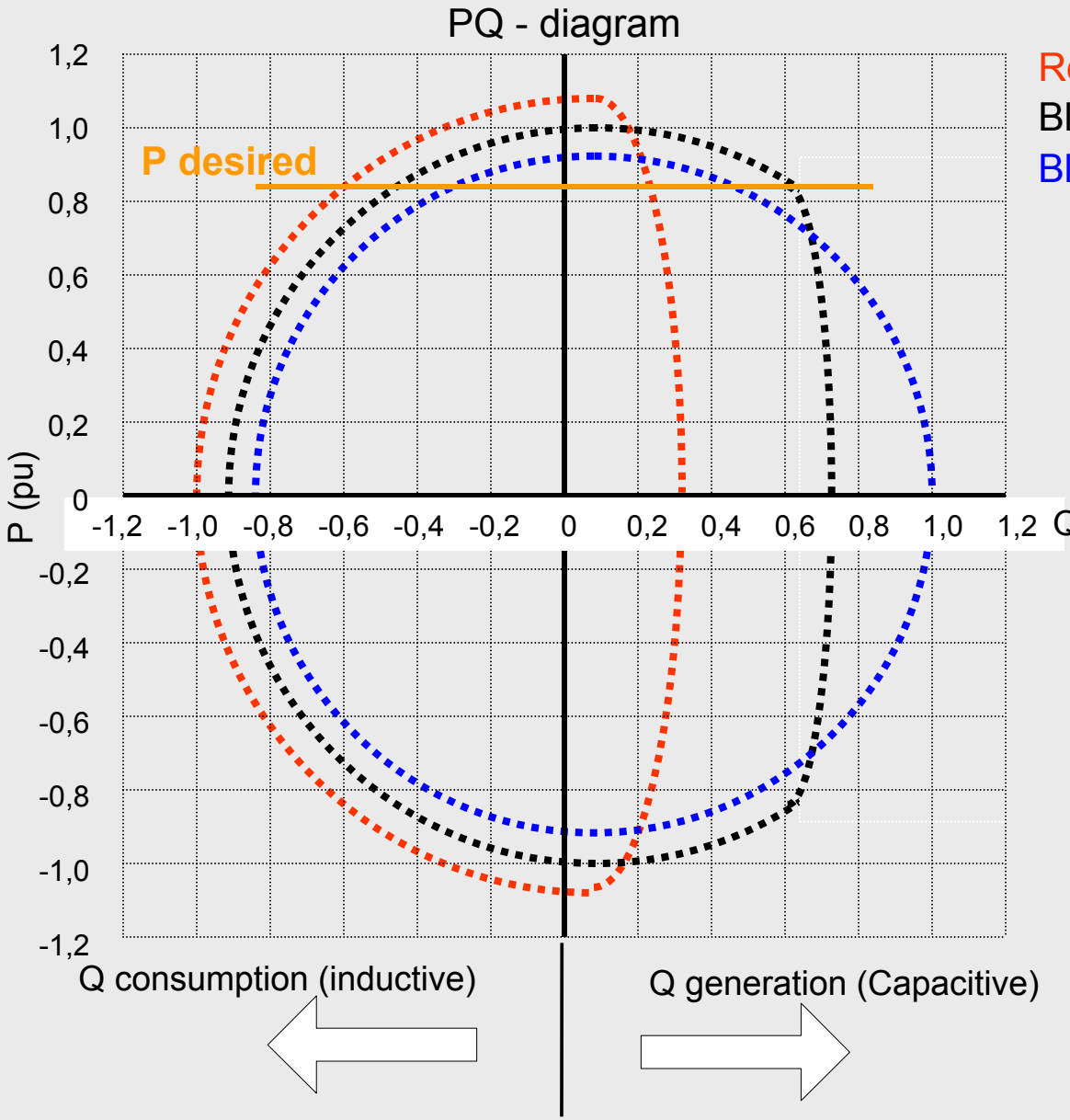
DC Capacitor

Control system

Dry DC Capacitor

IGBT Valves

HVDC Light, P-Q Diagram



Red line: Uac = 1,1 pu

Black line: Uac = 1,0 pu

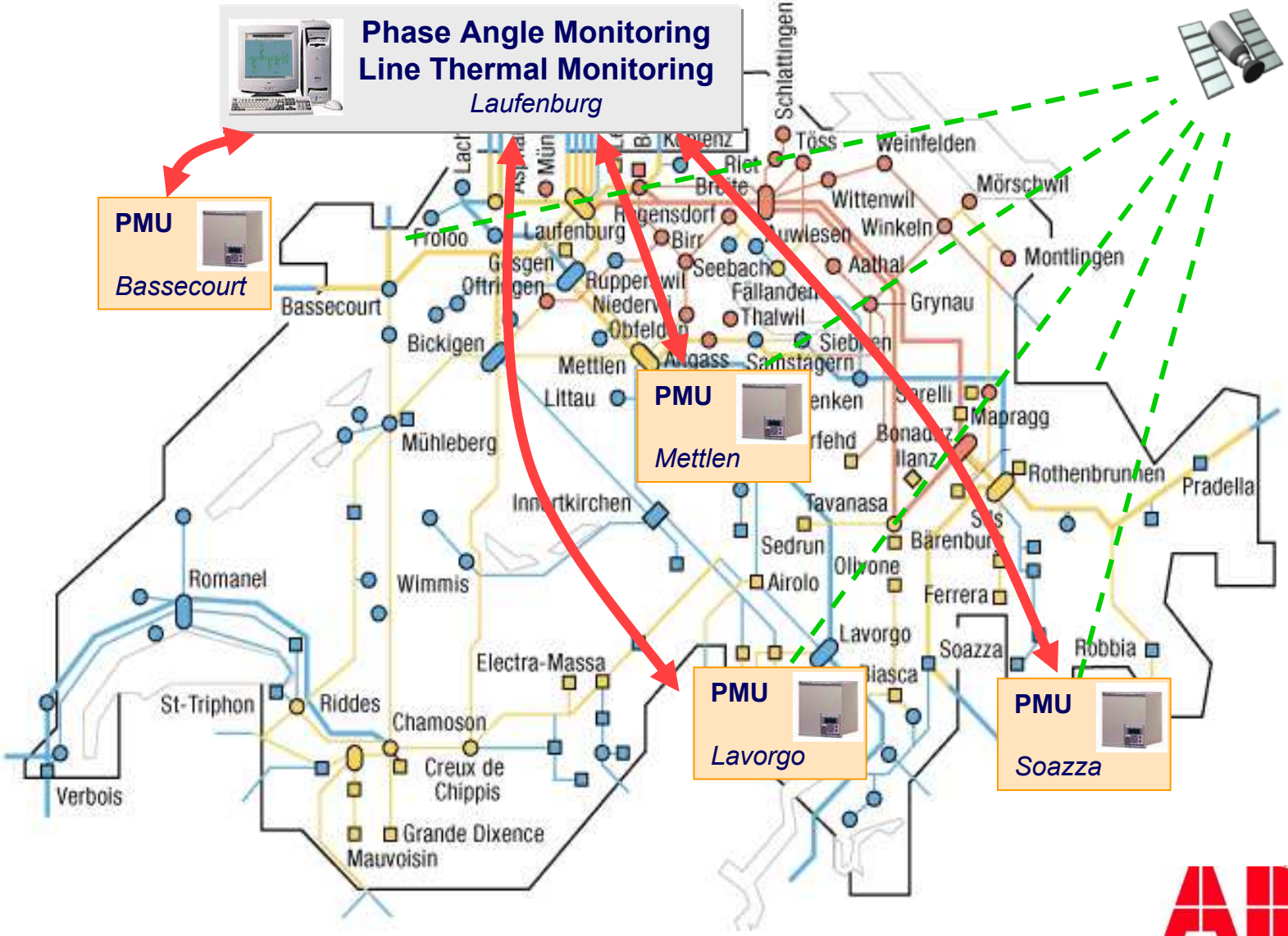
Blue line: Uac = 0,9 pu

Rectifier

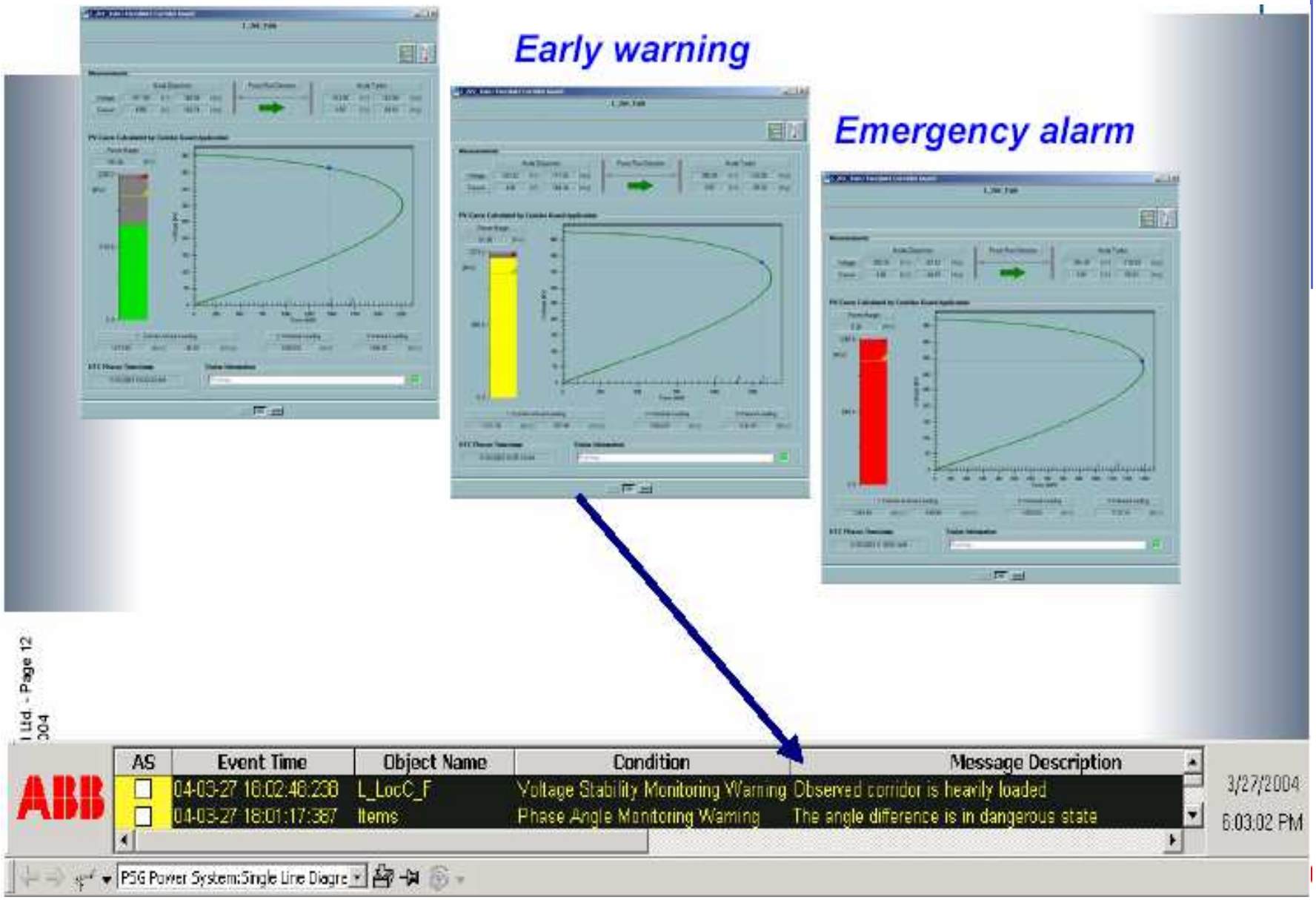
Inverter

Conclusion: HVDC Light™ converter acts like virtual generator or motor.

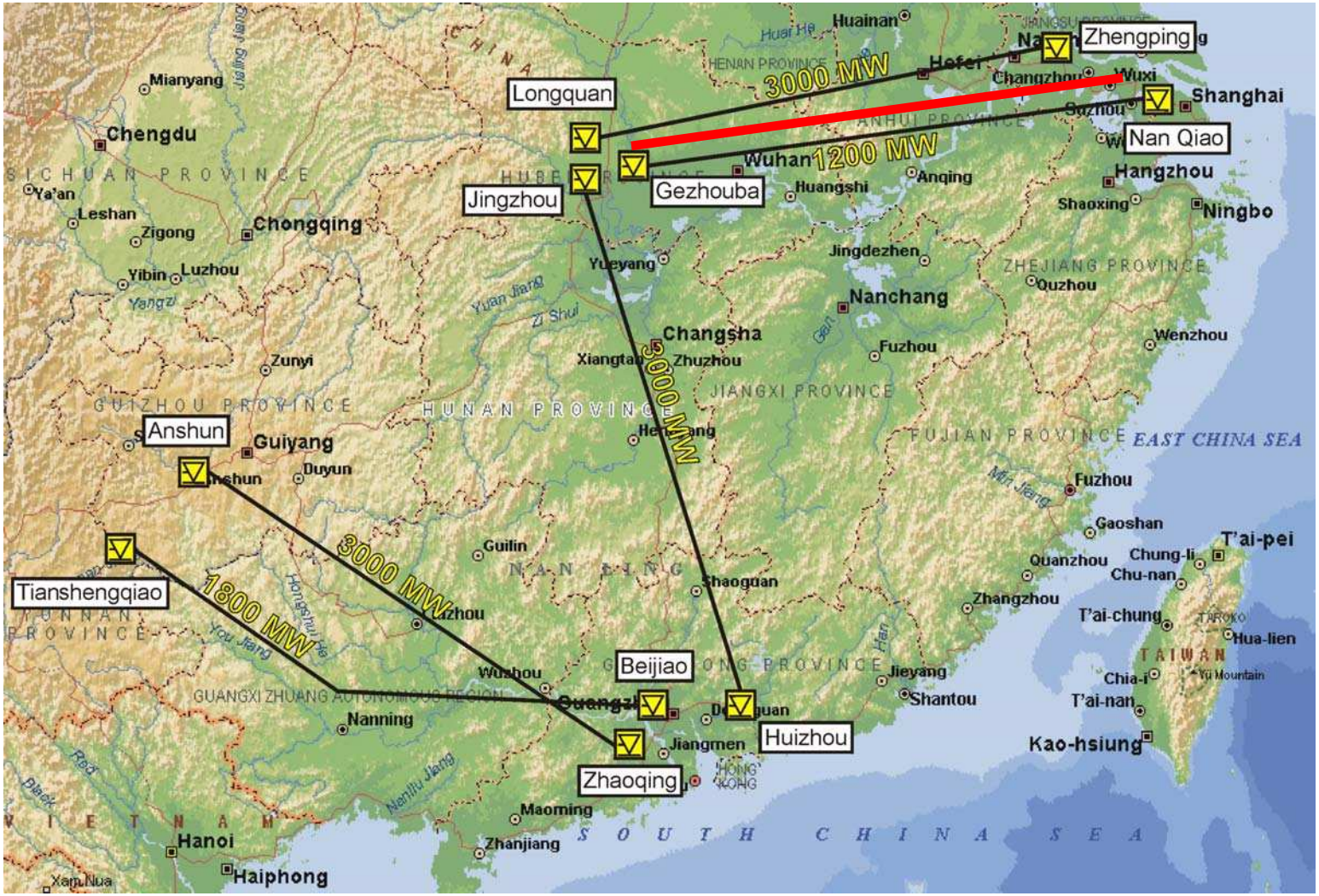
First Wide Area Monitoring in UCTE



Example: Voltage Stability Indication

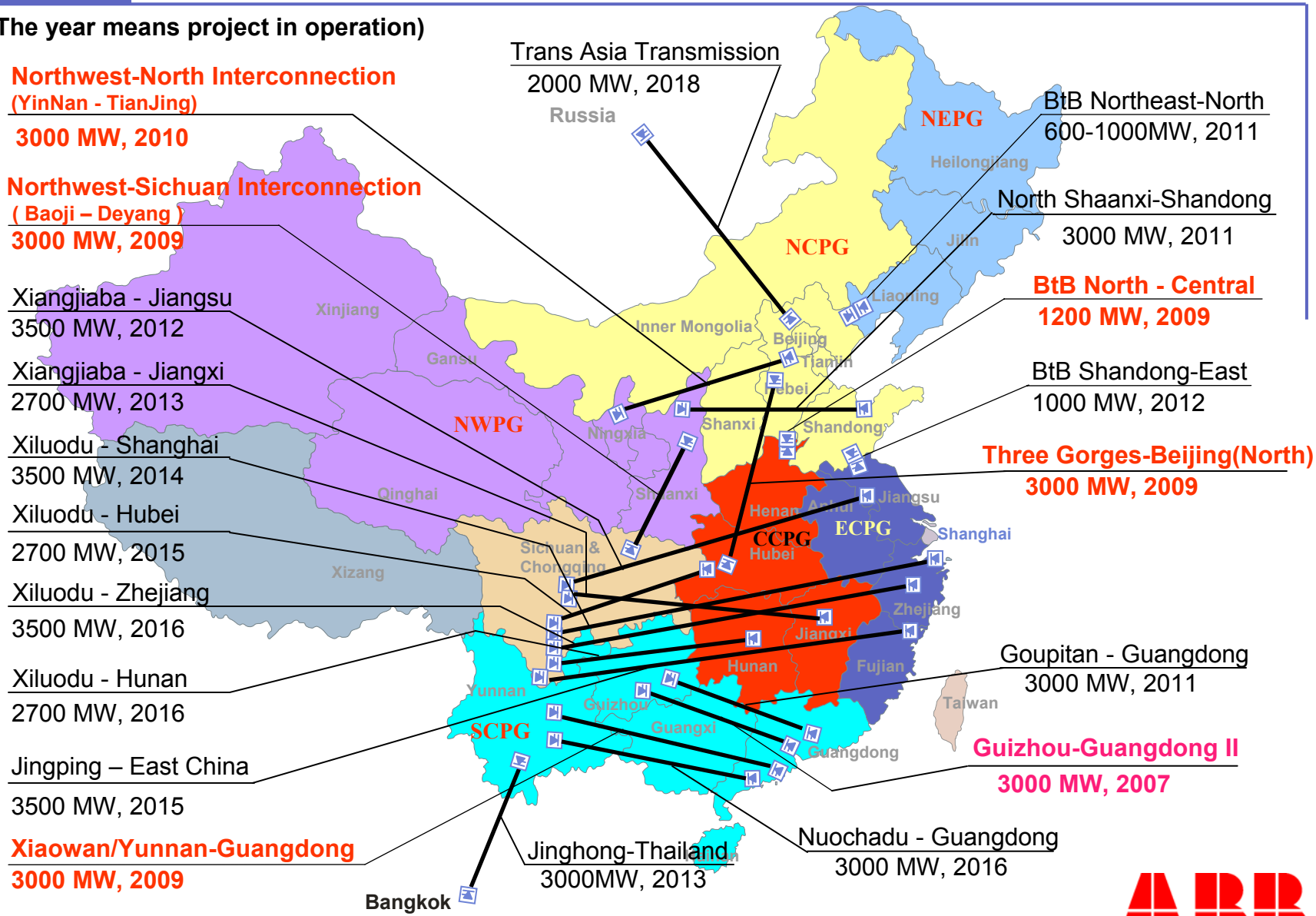


HVDC Links in China



Future HVDC Projects in China

(The year means project in operation)



Development of HVDC Valves

Performance

First generation Mercury Arc Valve

First generation Thyristor Valve

Second generation Thyristor Valve

HVDC Light IGBT Valve

Year

1954 1970 1980 2000

Maturation of HVDC & SVC Light®


1) 3MW,±10kV


2) 50MW,±80 kV


3) 7MW,±10kV


4) 3x 60MW,±80kV


5) 330MW,±150kV


6) 200MW, ±150kV


7) 2x40MW,±60kV

1994 1996 1998 2000 2002 2004 2006

Start Light Development

1) Hellsjön Demo Proj

2) Gotland Light

3) Tjæreborg

4) Directlink

5) Cross Sound

6) Murraylink

7) Troll A

8) Estlink

f) Holly

e) Avesta Polarit

d) Evron

c) Moselstahlwerk

b) Eagle Pass

a) Hagfors

Common VSC Development

1st Generation

2nd Generation

2nd Generation

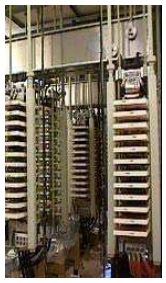
1st Generation

HVDC Light®

ABB IGBT

SVC Light®

FUJI IGBT




a) 0-44 MVAR


b) 2x36 MVAR

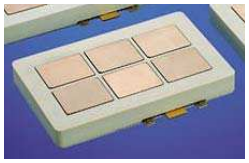

e) 0-164 MVAR

HVDC Light Development

- **HVDC Light**

➔ 350 MW, cost reduction of >20%

➔ up to 1000 MW for Interconnections, Back-to-Back, Offshore and SVC

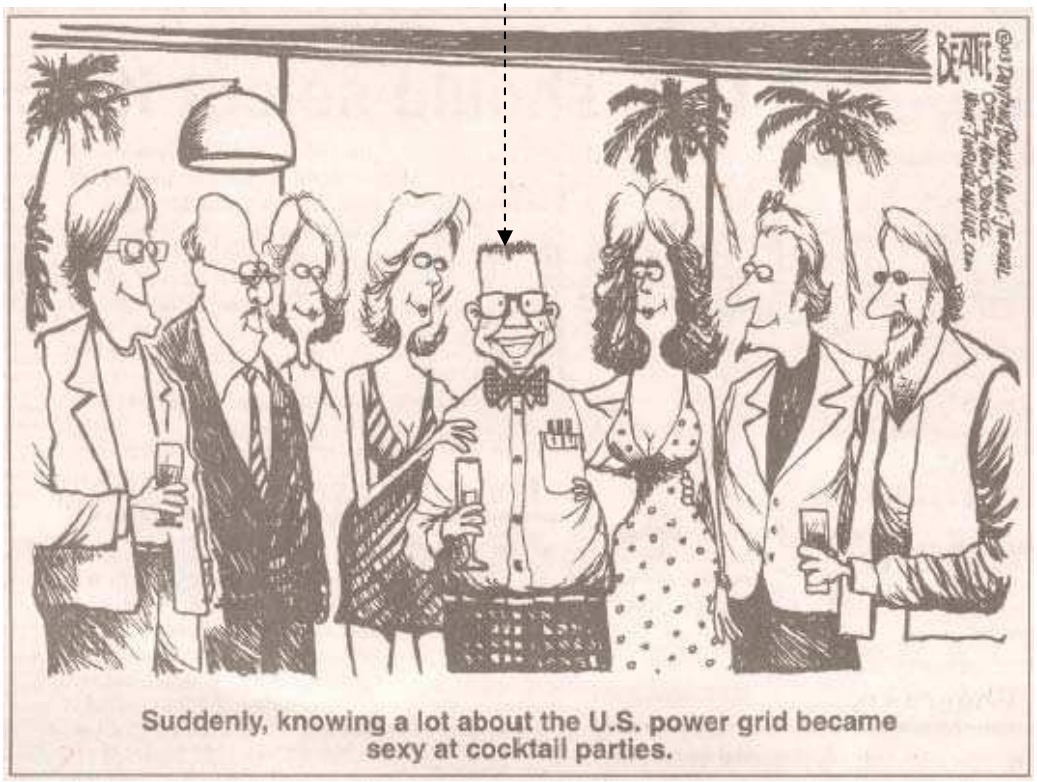

DC Voltage	500 A	1000 A	1500 A
+/- 80 kV	95 MVA	190 MVA	285 MVA
+-150 kV	178 MVA	356 MVA	535 MVA
+/- 300 kV	356 MVA	713 MVA	1070 MVA

2004

12/2005

Industry Need for Power System Education

- Electric Machinery
- Power Electronics
- Power System Analysis
- High Voltage Equipment
- Tele-communication
- Economics Regulatory Public Policy
- Control & Protection
- Insulation Coordination
- Technical Writing Speaking



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