Towards Realization of a Highly Controllable Transmission System – HVDC Light®

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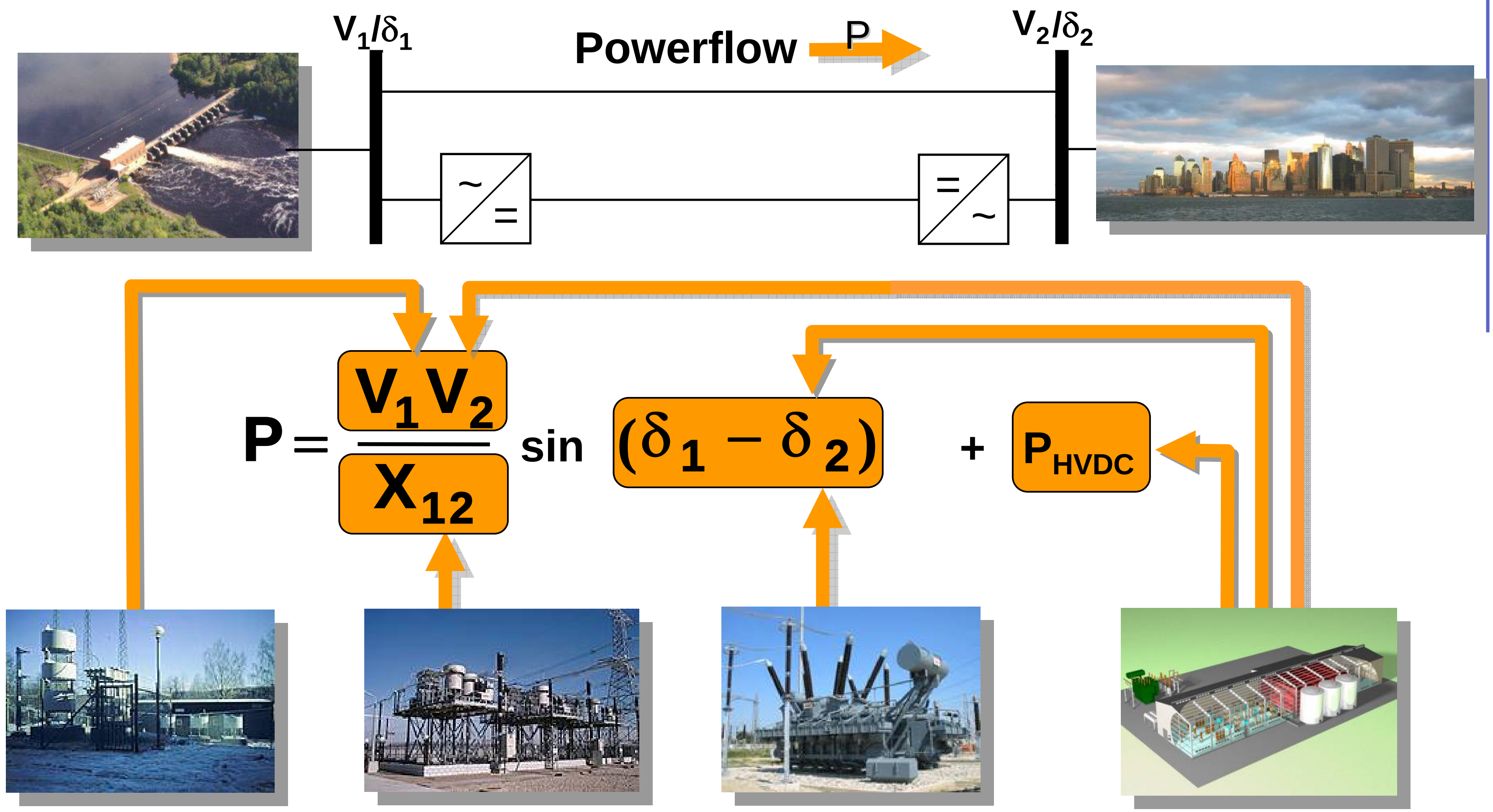
ABB Corporate Research

Outline

- Background
- HVDC Classic versus HVDC Light
- Benefits and Applications HVDC Light
- Power System Control with HVDC Light
- Extensions to Power System Control

Ways to Control a Corridor's Powerflow



$$P = \frac{V_1 V_2}{X_{12}} \sin(\delta_1 - \delta_2) + P_{HVDC}$$

SVC Classic and Light

SC and TCSC

Phase Shifting Transformers

HVDC Classic and Light

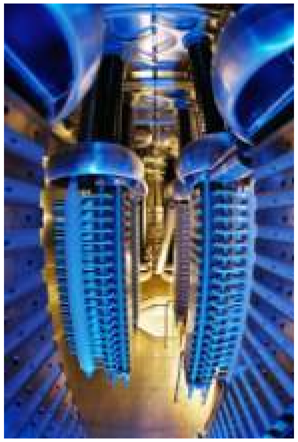
HVDC Development

Mercury Arc

Thyristor
Gen 1

Thyristor
Gen 2

Transistor
(IGBT)



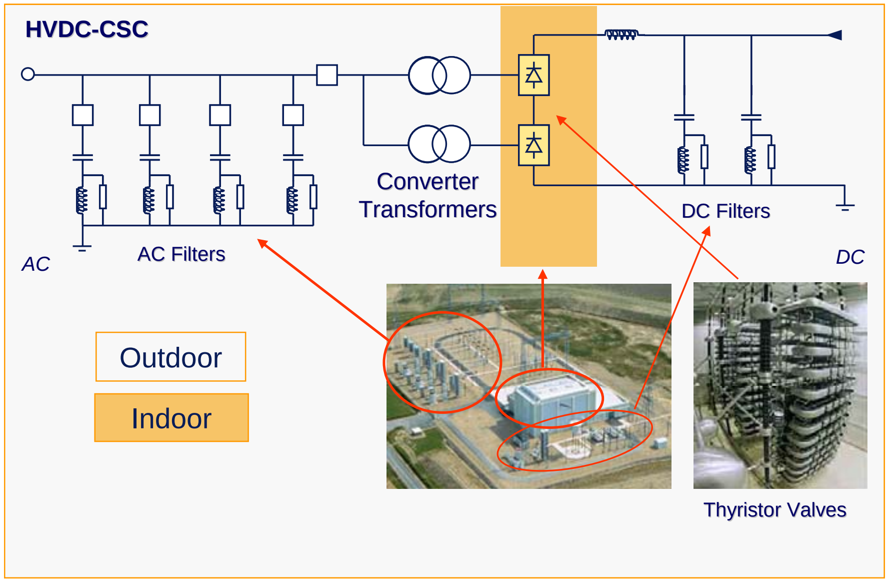
HVDC Light

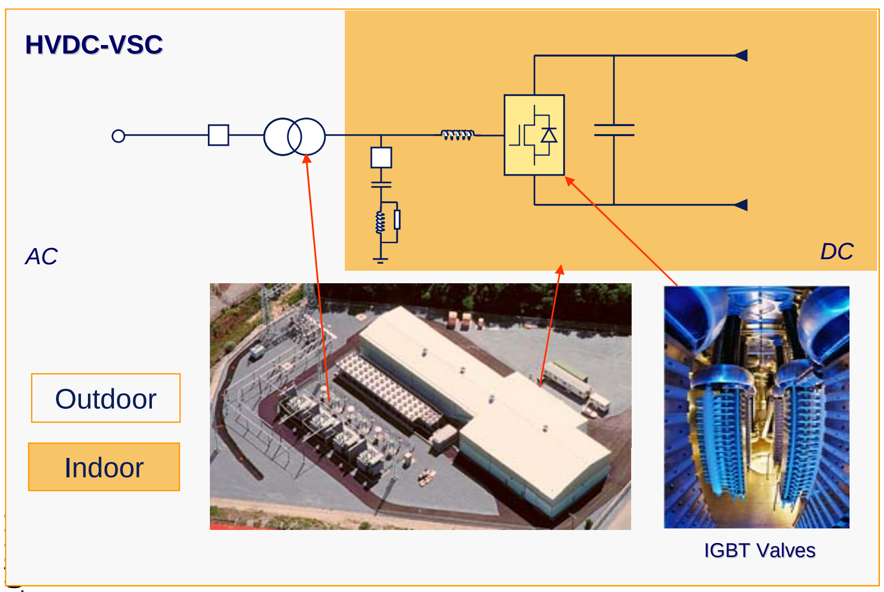
Year

1954 1970 1980 2000

HVDC Classic

Core HVDC Technologies





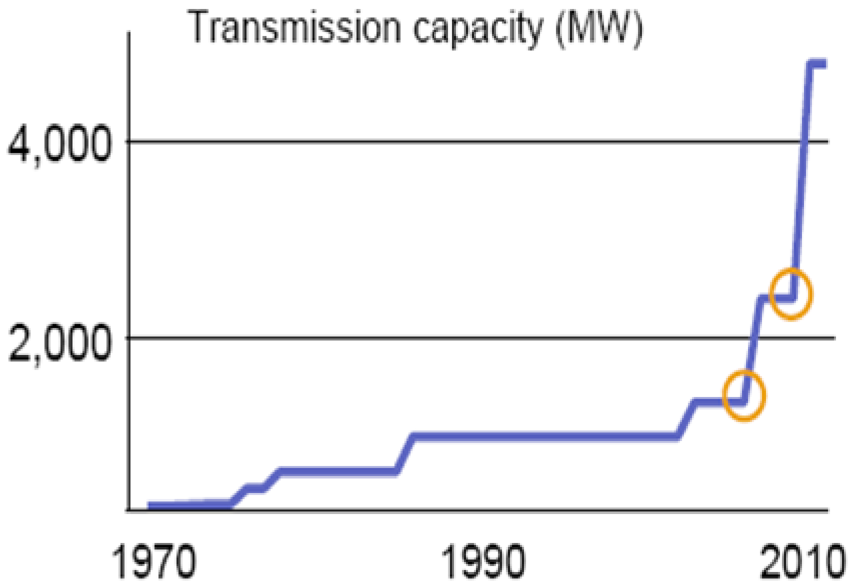
HVDC Classic

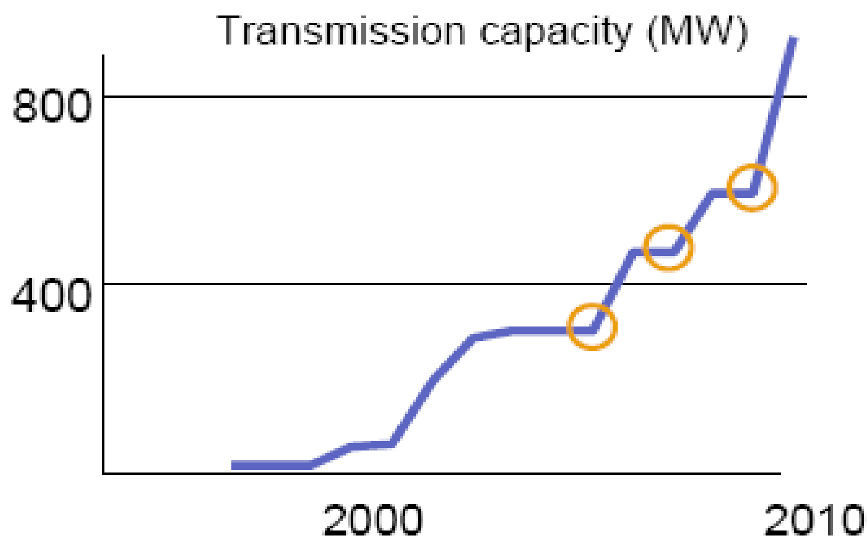
- Current source converters
- Line-commutated thyristor valves
- Additional switched reactive power control
- Current Projects: Xiangjiaba – Shanghai, ±800 kV, 6400MW, 2000km

HVDC Light

- Voltage sourced converters
- Self-commutated IGBT valves
- Use Pulse Width Modulation to realize desired power injections
- Integrated continuous reactive power control
- Black start capability
- Current Projects: Borkum 2, E.ON Netz, ±150kV, 400MW

Core HVDC Technologies





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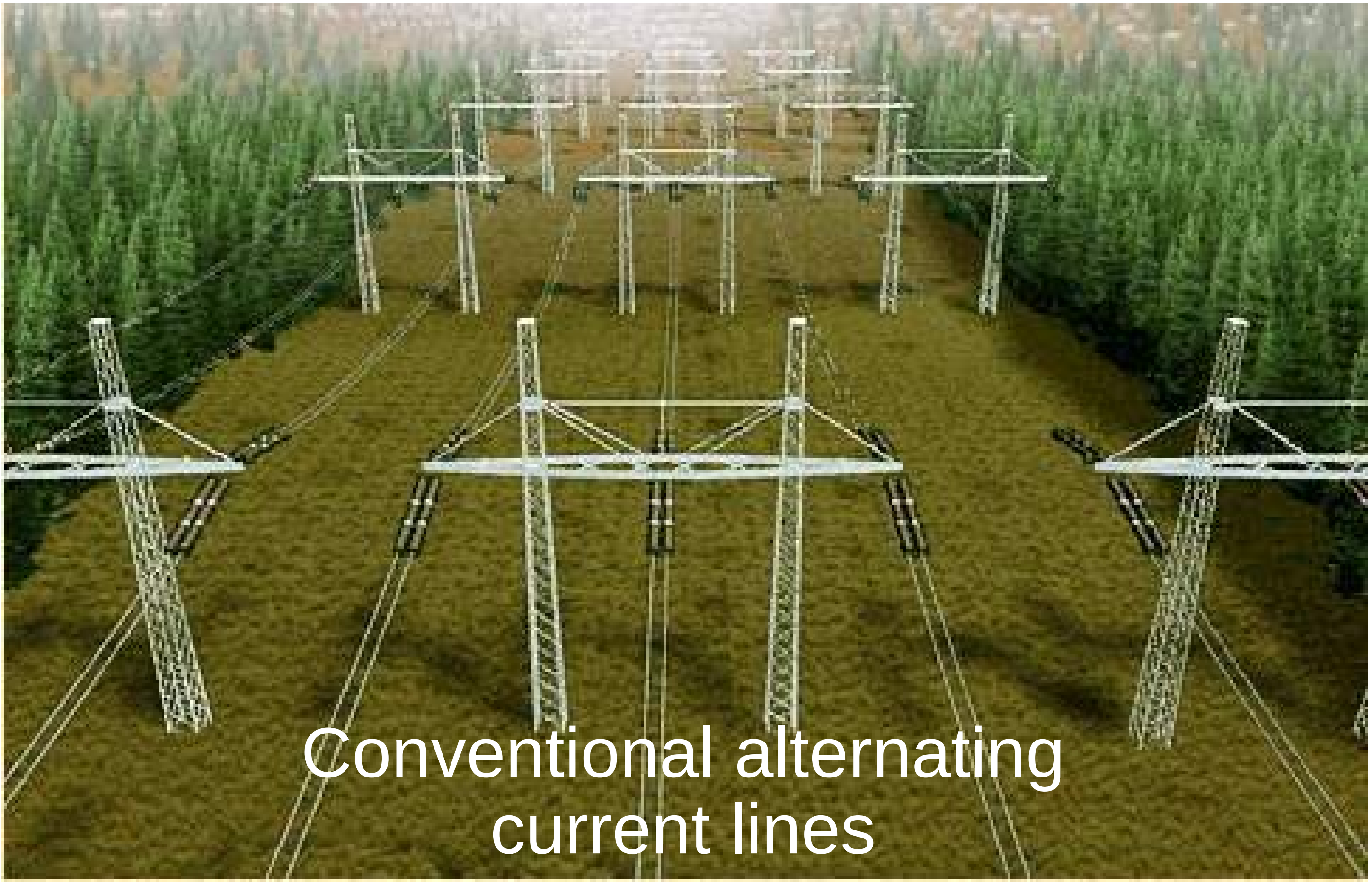
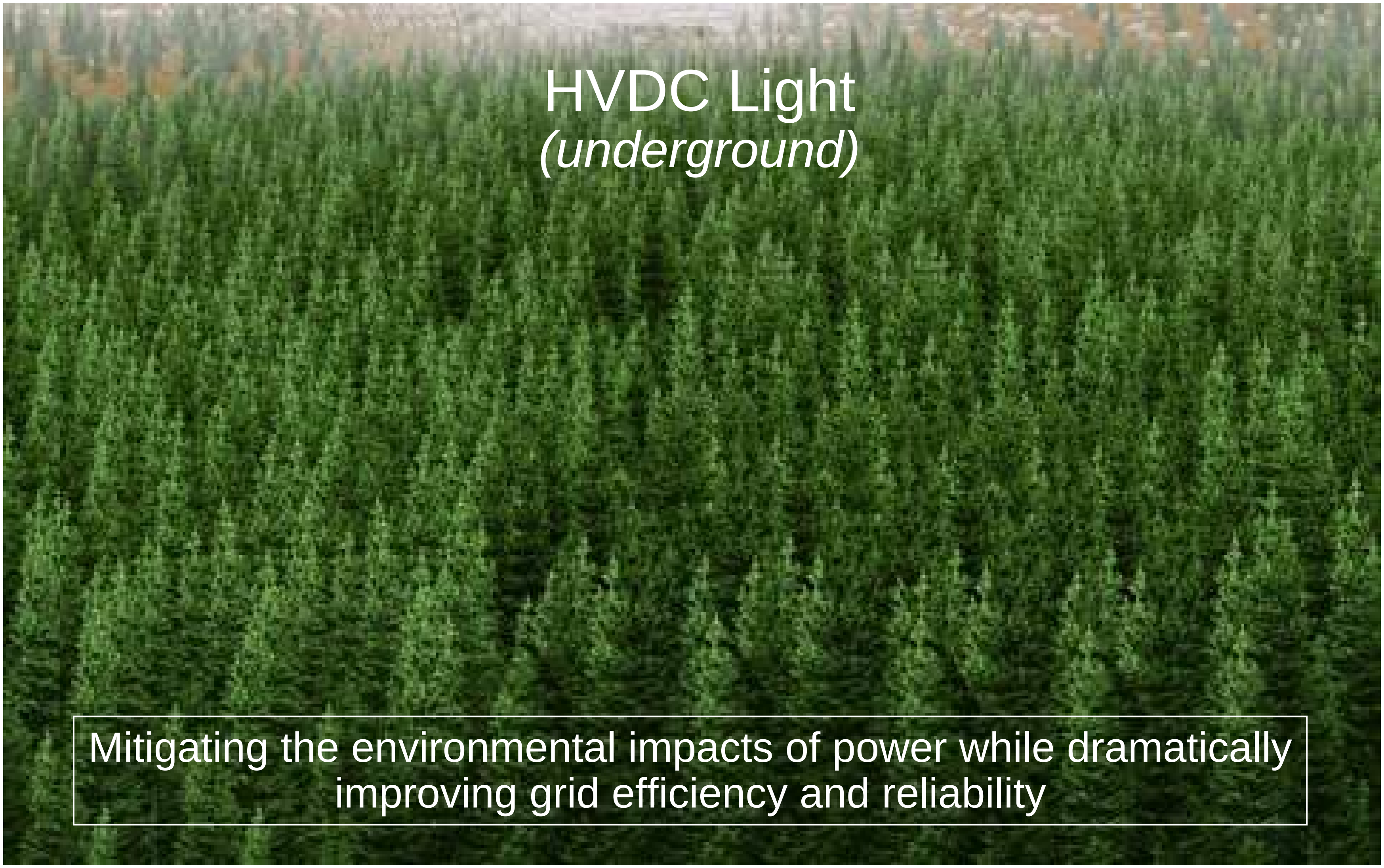
Bulk Power Transmission

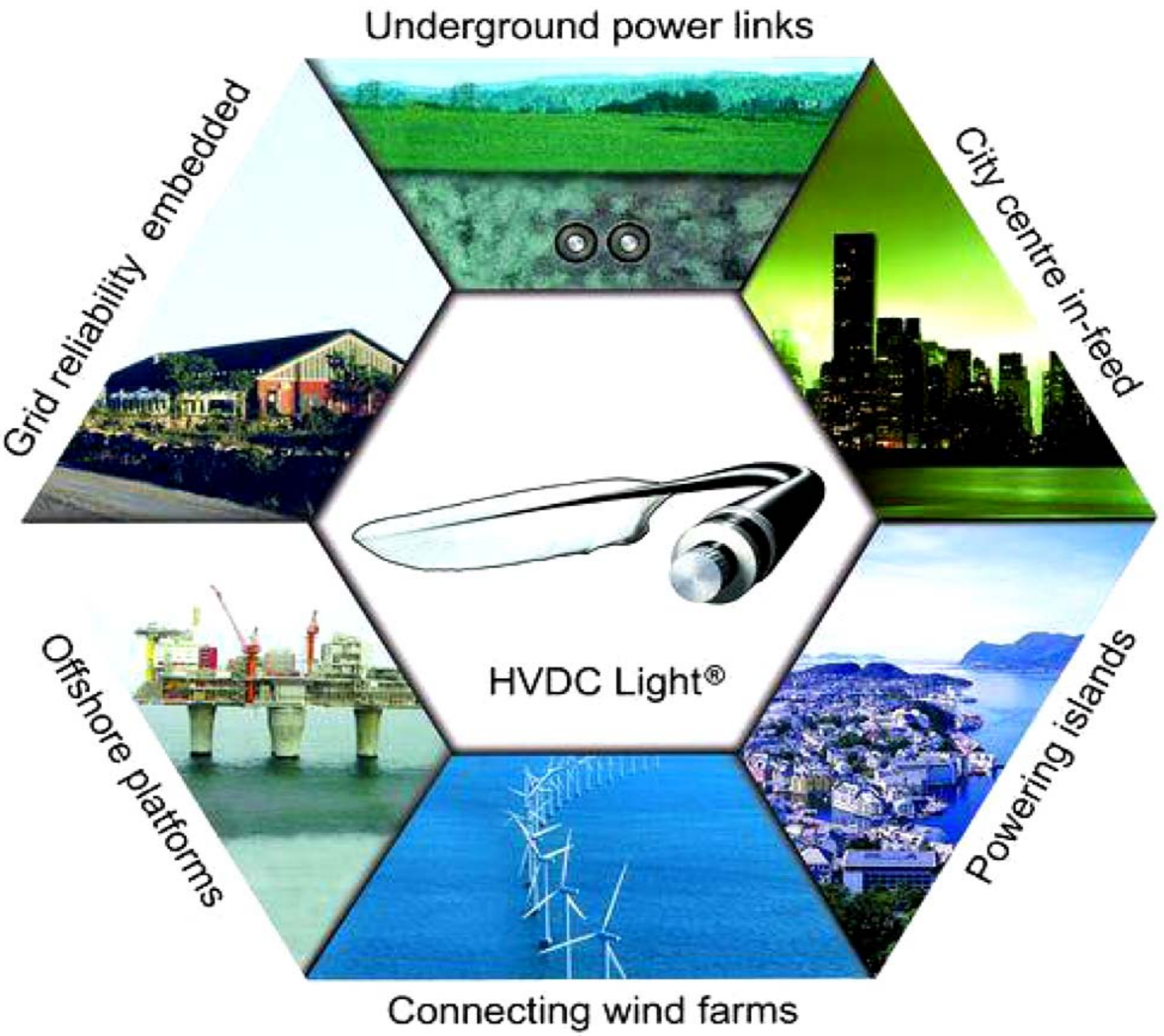


Bulk Power Transmission

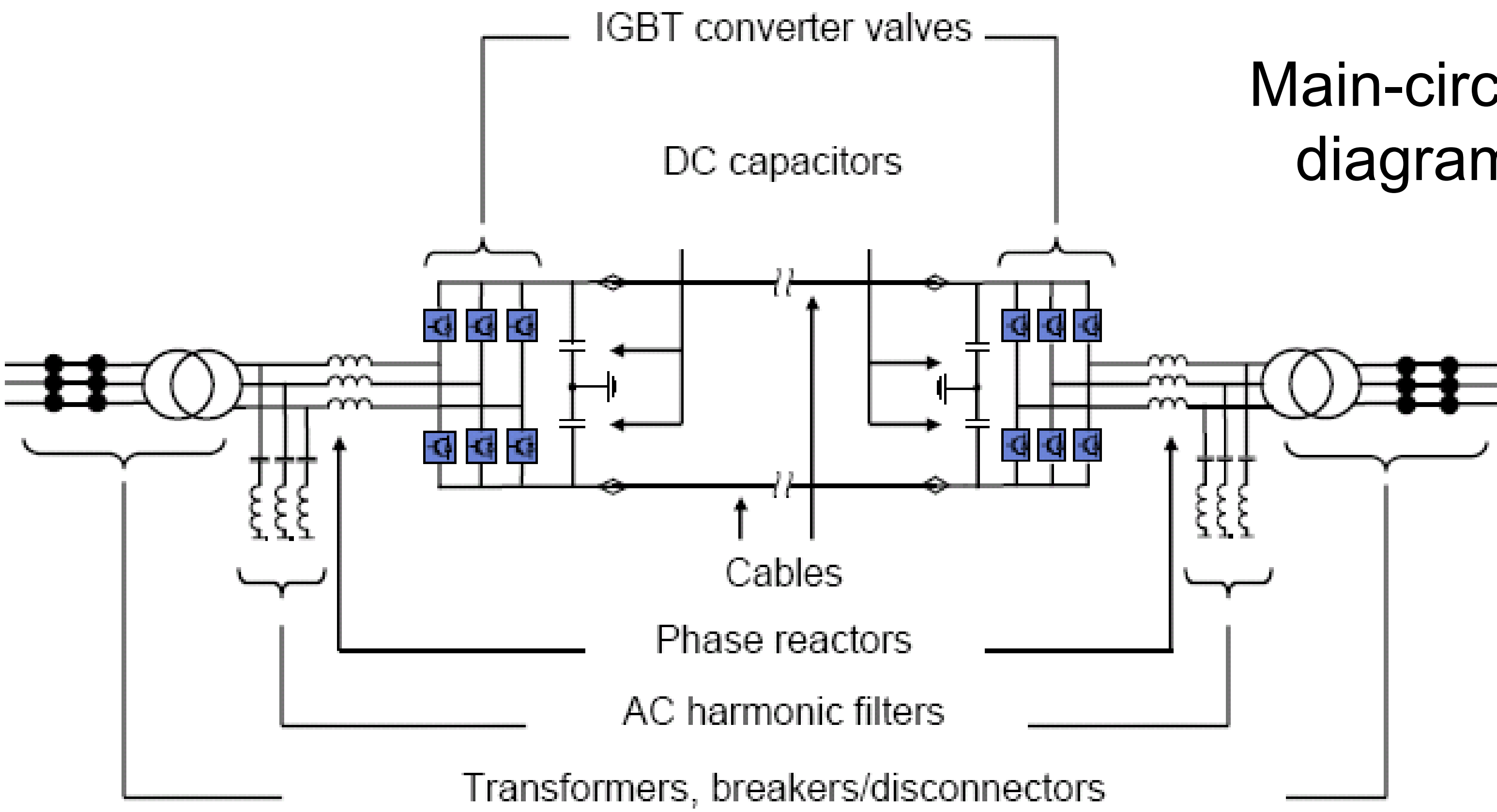
Bulk Power Transmission



HVDC Light – Sample Existing Applications



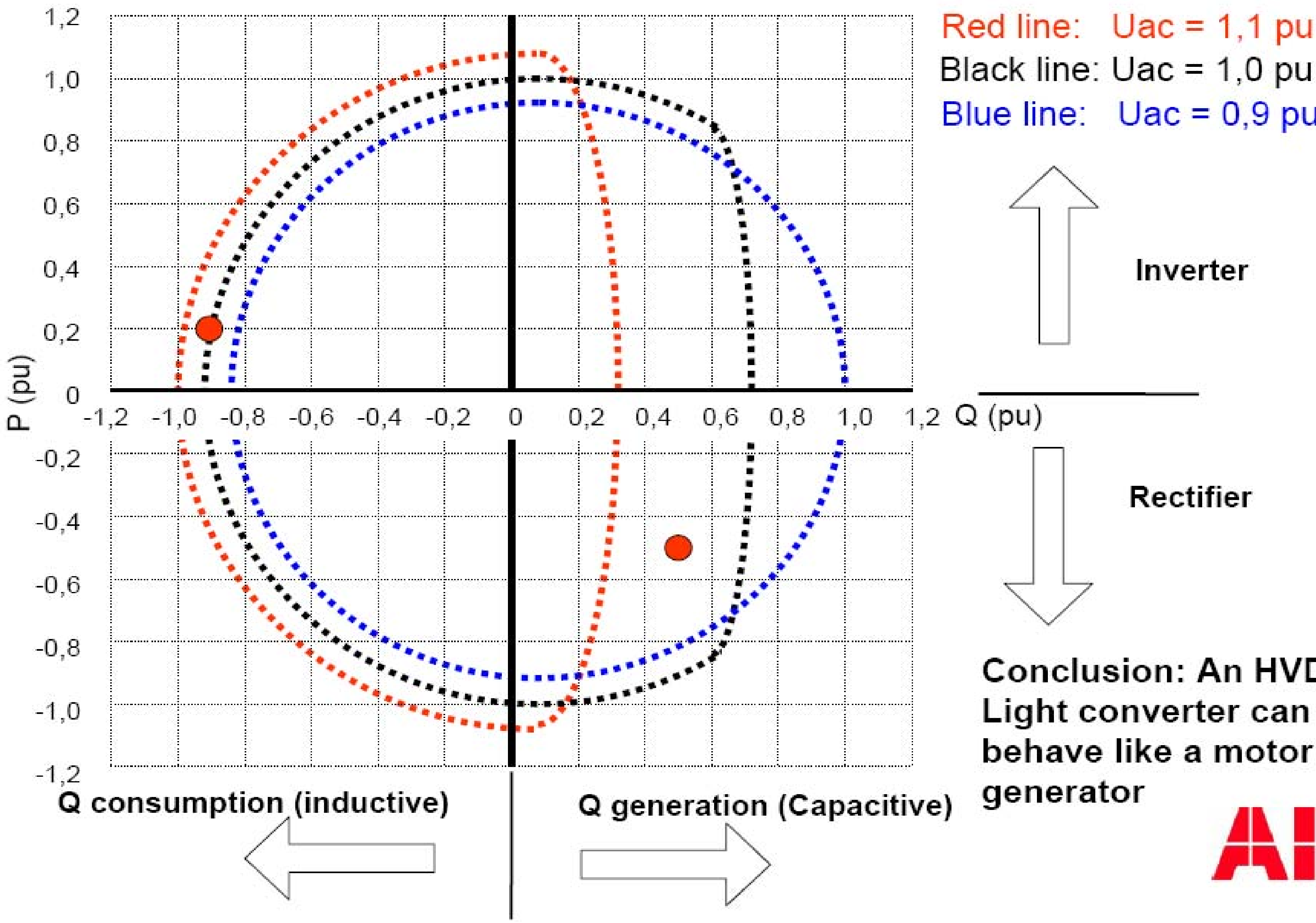
HVDC Light – Building Blocks



Main-circuit diagram

HVDC Light – HVDC Transmission based on Voltage Source Converters (HVDC-VSC)

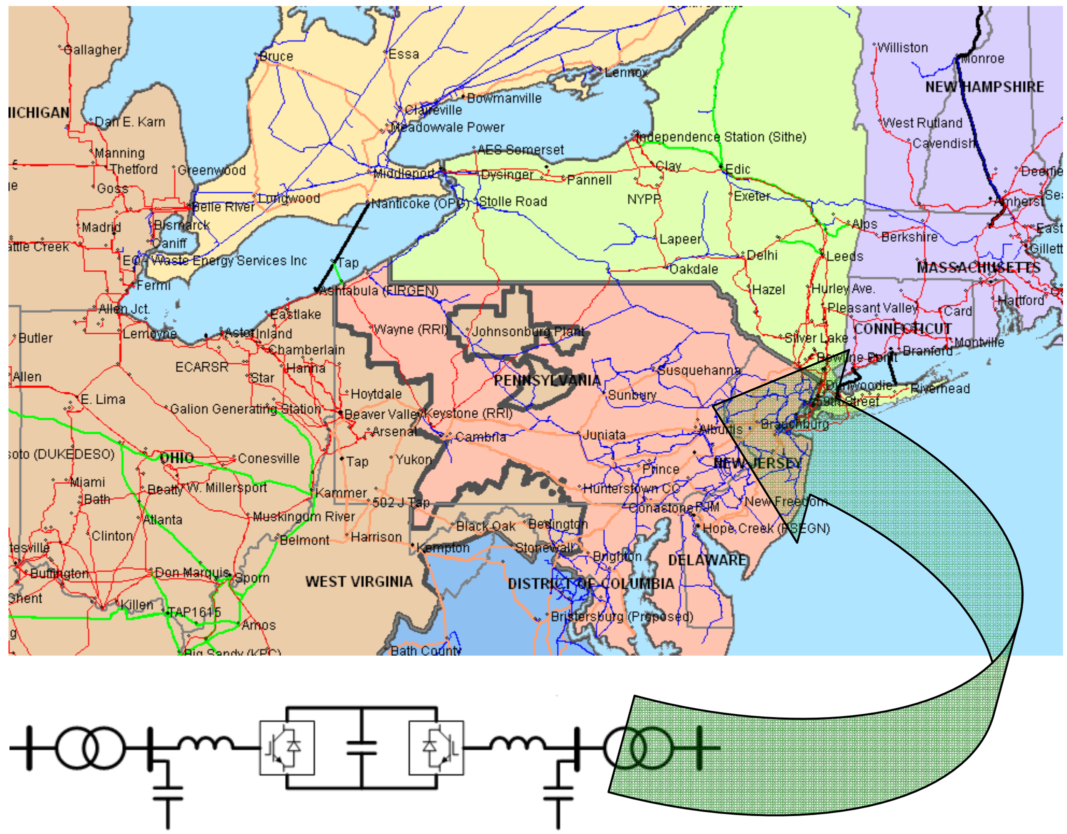
Active and Reactive Power Capability



Conclusion: An HVDC Light converter can behave like a motor or a generator

Smart Transmission Grid with Embedded HVDC Light

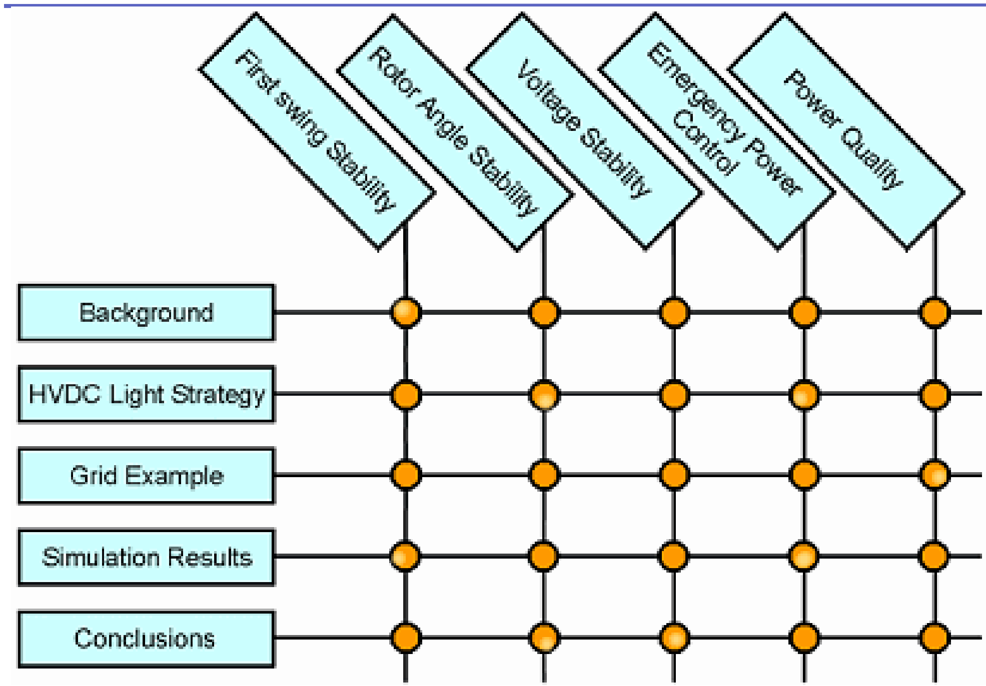
- Full power flow controllability
- Fast response to disturbance
- Feasible multiterminal configurations
- Intelligent control functions using local and/or remote signals

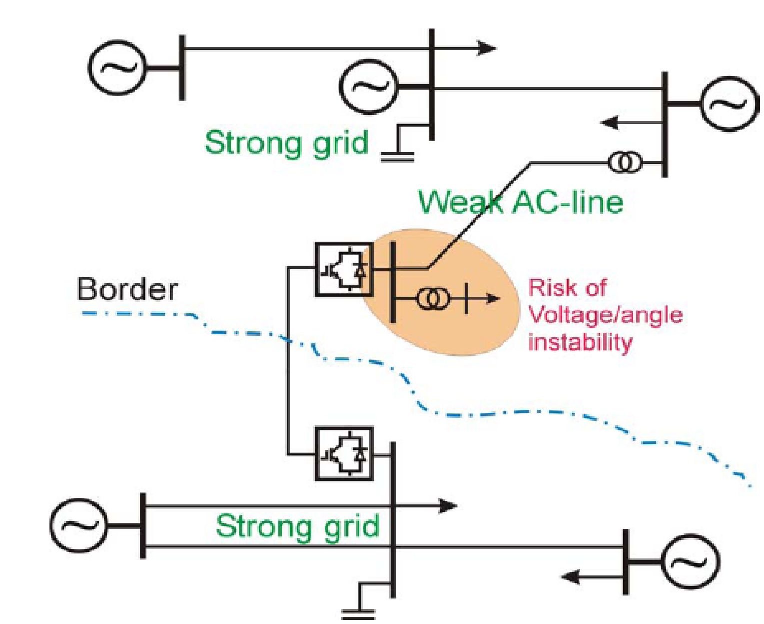


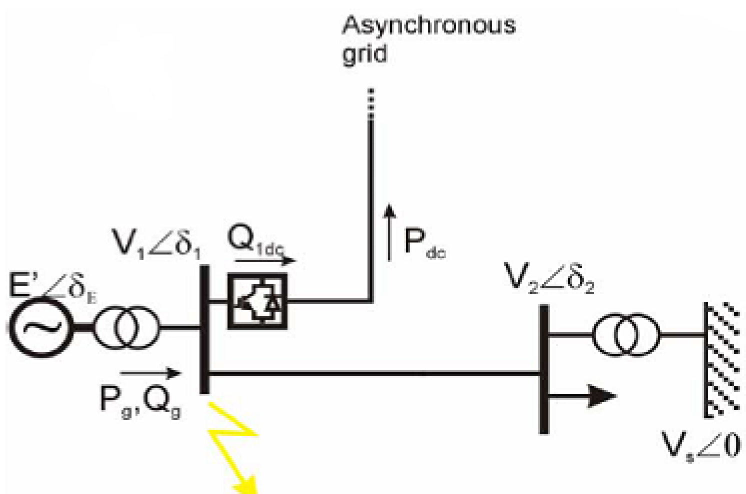
Embedding HVDC Light in AC networks opens up new possibilities to improve:

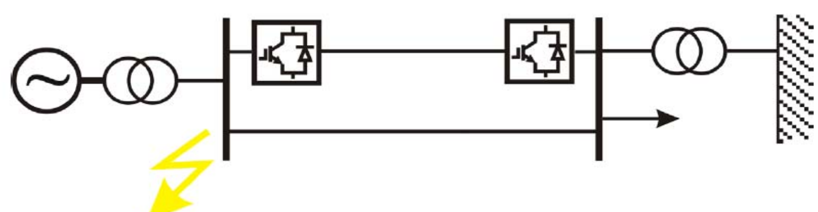
- grid reliability,
- delivery efficiency,
- controllability

HVDC Light Tutorial





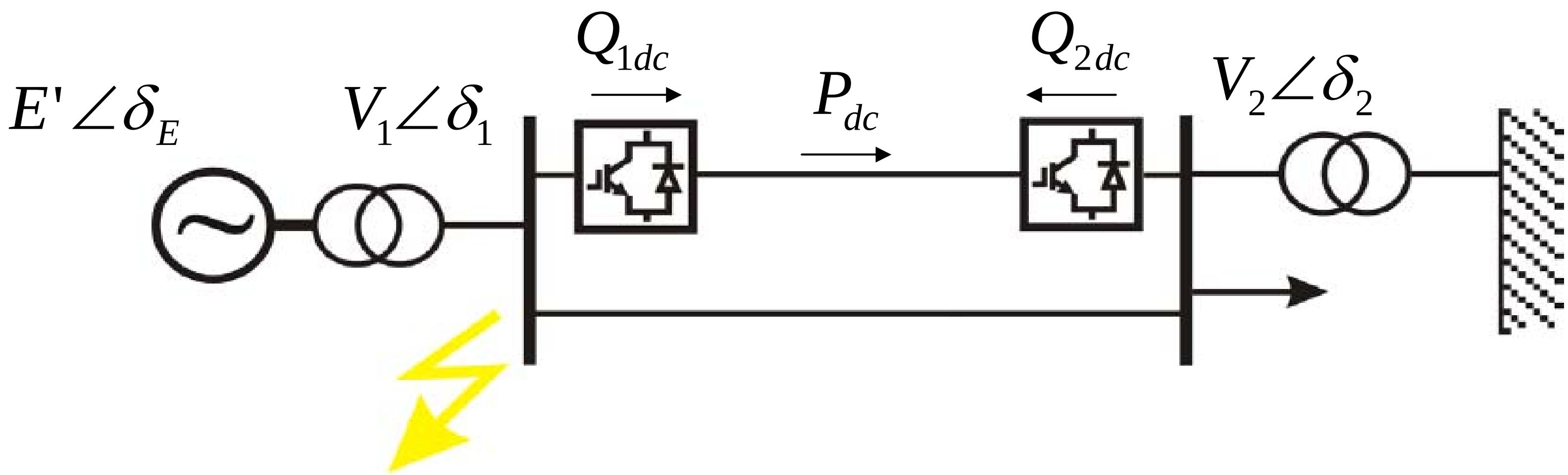




http://www.abb.com/cawp/GAD02181/C1256D71001E0037C1256D08002E7282.aspx#

Damping Control Example for SMIB

- HVDC Light capacity is 10% of the AC flow capacity
- Control Strategies:
  - Active Power Modulation (Q=0) – acting as HVDC Classic
  - Reactive Power Modulation (P=0) – acting as SVC
  - Active and Reactive (mixed) Power Modulation



Example created by Stefan Thorburn ABB-SECRC

Control Strategies Available

- **Reactive control only (P=0)**

$$Q_{1dc} = -I_{conv} \cdot V_1 \cdot sign\left(\frac{d\delta_E}{dt}\right) \qquad Q_{2dc} = I_{conv} \cdot V_2 \cdot sign\left(\frac{d\delta_E}{dt}\right)$$

- **Active control only (Q=0)**

$$P_{dc} = I_{conv} \cdot \min(V_1, V_2) \cdot sign\left(\frac{d\delta_E}{dt}\right)$$

- **Active and reactive control**

$$P_{dc} = I_{conv} \cdot \min(V_1, V_2) \cdot \cos(\delta_1 - \delta_2) \cdot sign\left(\frac{d\delta_E}{dt}\right)$$

$$Q_{1dc} = -I_{conv} \cdot V_1 \cdot \sin(\delta_1 - \delta_2) \cdot sign\left(\frac{d\delta_E}{dt}\right)$$

$$Q_{2dc} = I_{conv} \cdot V_2 \cdot \sin(\delta_1 - \delta_2) \cdot sign\left(\frac{d\delta_E}{dt}\right)$$

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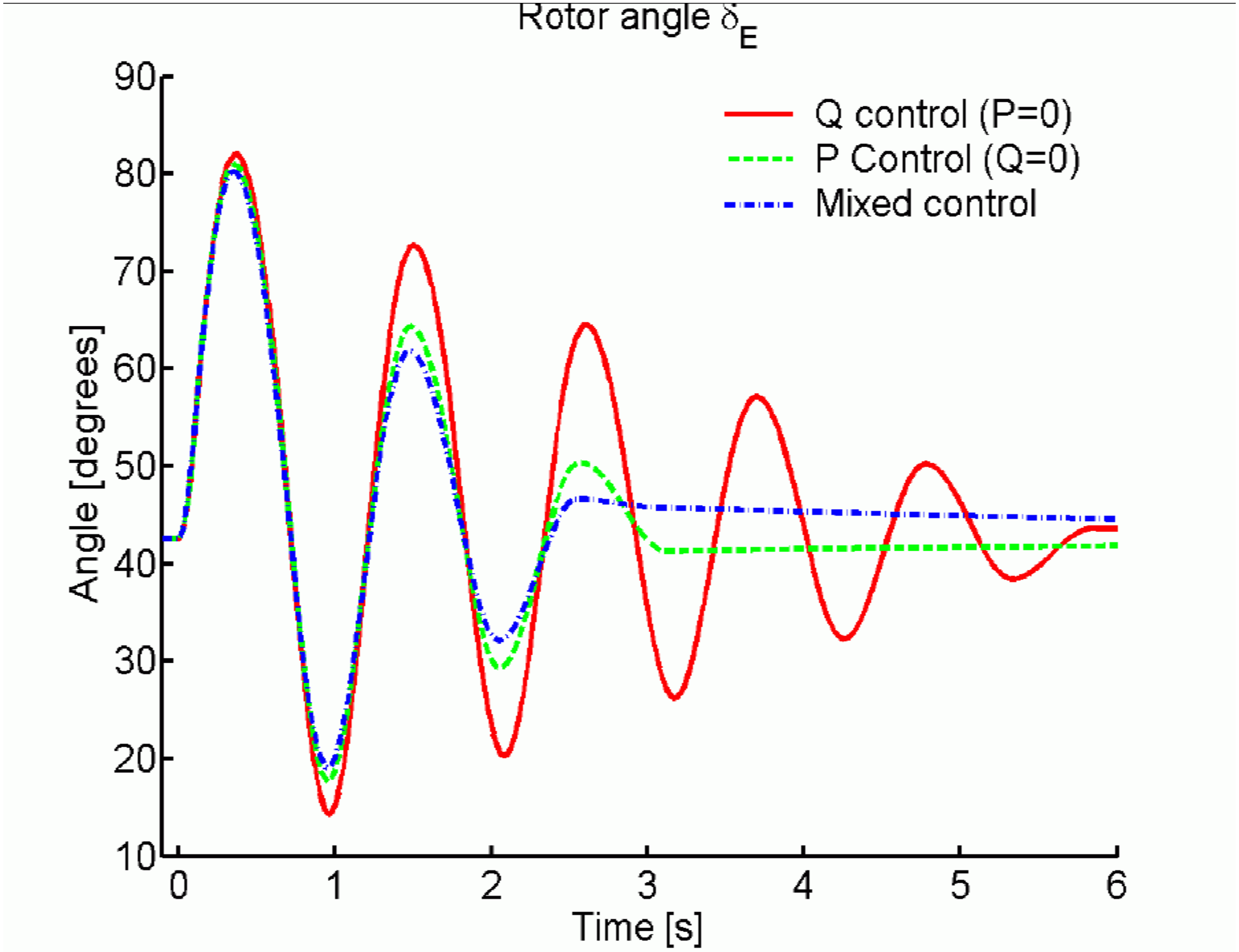
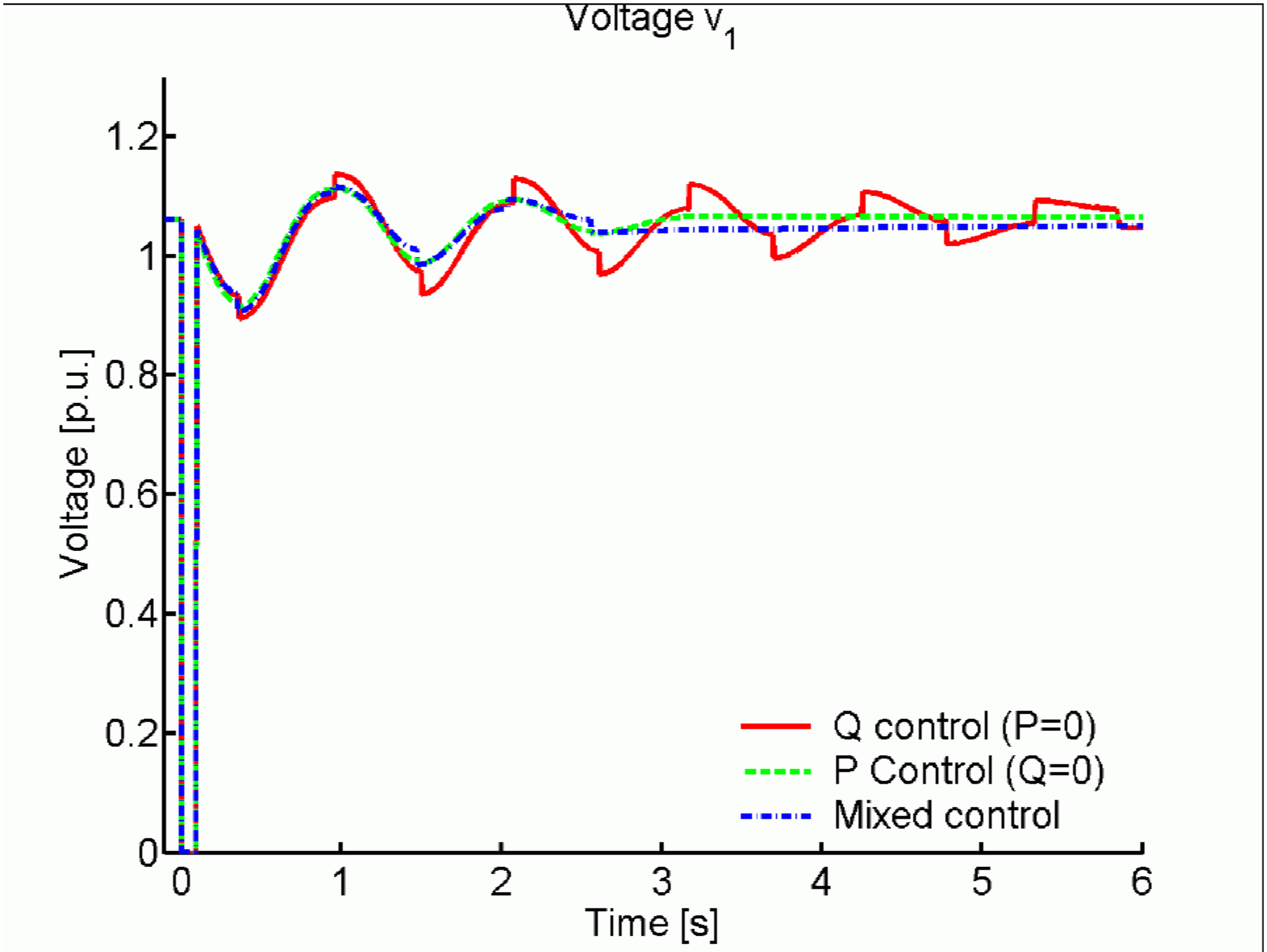
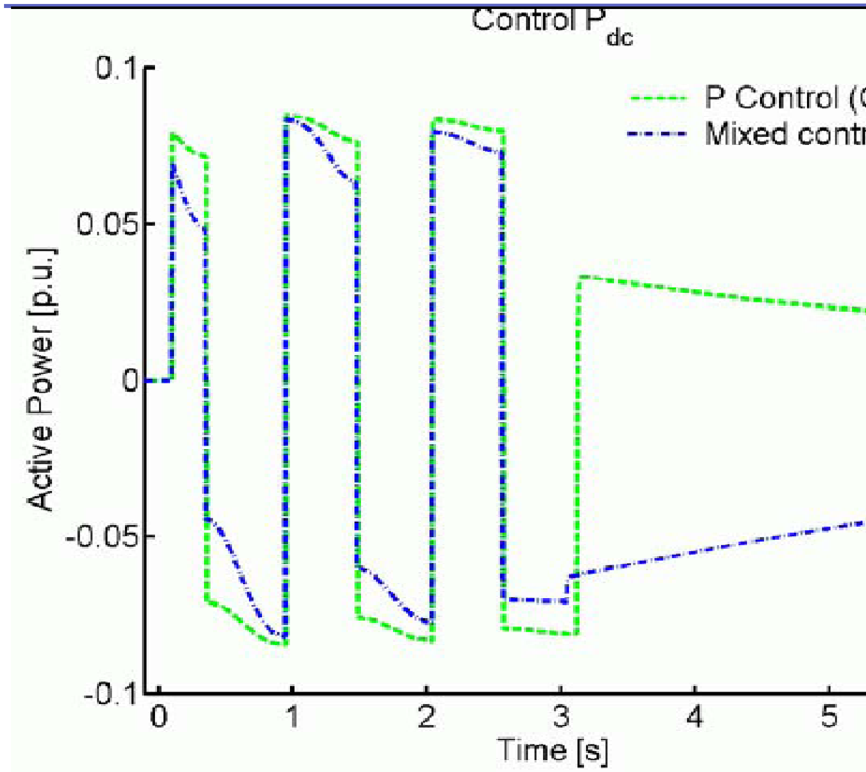
Machine Angle Response



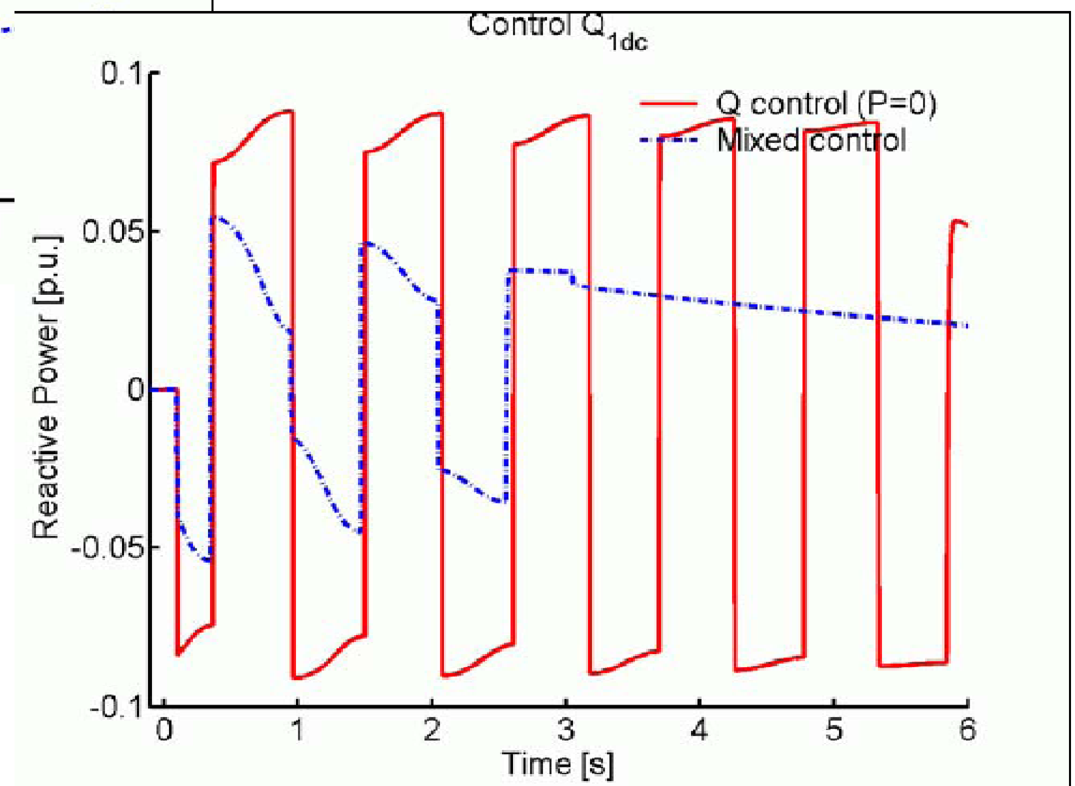
Sending End AC Voltage Magnitude



Control Effort



P_{dc}



Q_{1dc}

Extensions to Power System Control

- Control of Combined AC/DC systems:
  - S. Chan and M. Athans, “Small-Signal Control of Multiterminal DC/AC Large-scale Power Systems,” MIT 1981
  - J. Zaborsky and M. Ilic, “Exploring the Potentials of an All DC Bulk Power System,” IREP 2001
  - H. Clark, A-A. Edris, et al., “Softening the Blow of Disturbances,” IEEE Power and Energy Magazine 2008

- Voltage Source Converter (VSC)-based series and shunt devices are <u>fast</u> and <u>powerful</u> actuators

- With advances in real-time situational awareness (e.g., WAMS and PMUs) coupled with VSC-based actuators, system-wide control of power system dynamics becomes more attainable

- Work needed on the application and extension of modern control theory, in order to manage multiple dynamic phenomena

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