University of Pittsburgh – Electric Power Industry Conference 2013

Recent Developments in HVDC and FACTS: Technology Application Case Studies and Implications for North America

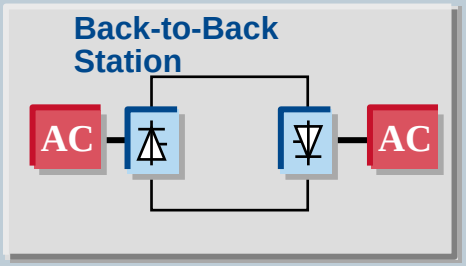
Brian Gemmell, PhD – Director of Sales, Transmission Solutions

HVDC Technology Applications
Continuous Technological Improvements

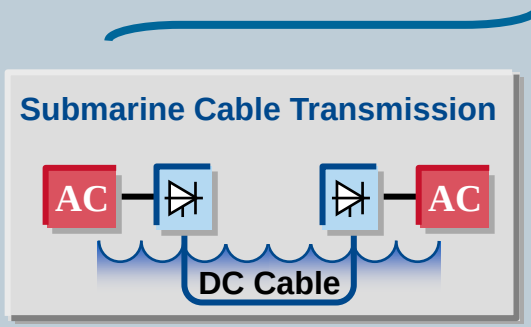
SIEMENS

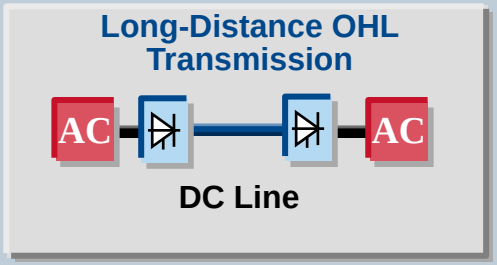
HVDC "Classic"	HVDC "Bulk"	HVDC "VSC"
▪ 500 – 660 kV ▪ up to 4,200 MW	▪ 800 kV for minimal transmission losses ▪ 5,000 – 8,000 MW	▪ VSC: Voltage-Sourced Converter ▪ up to 1,000 MW

B2B – The Short Link



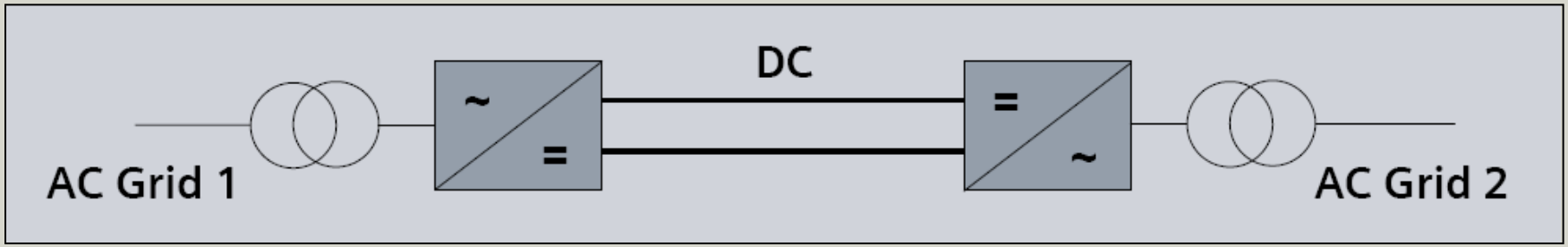
HVDC-LDT – Long-Distance Transmission





For decades, voltage and capacity continuously increased!

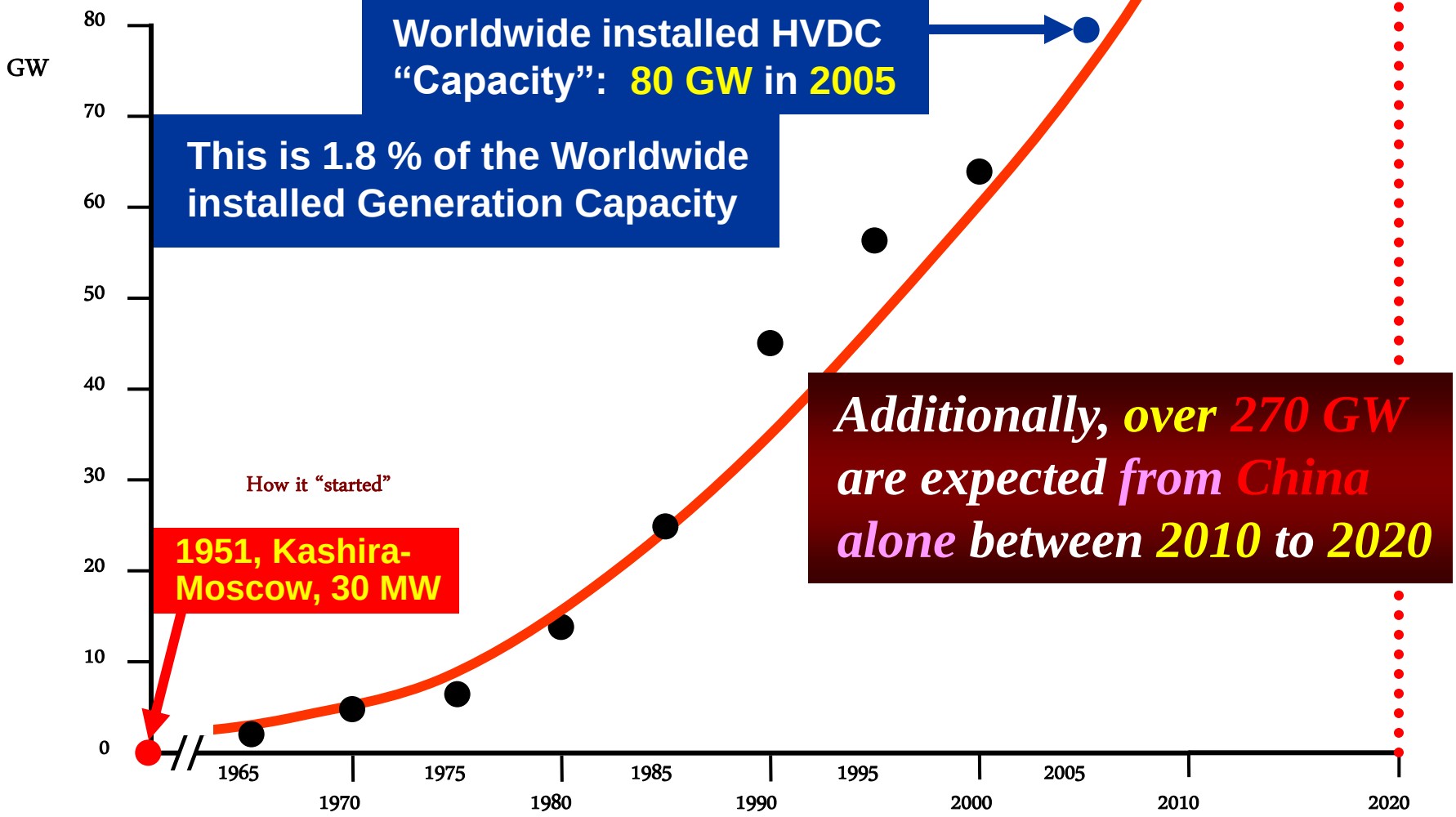
HVDC Technology
Comparison of HVDC Classic & HVDC VSC



HVDC Classic	HVDC VSC
Line-commutated current-sourced Converter	Self-commutated voltage-sourced Converter
Thyristor with turn-on Capability Only	Semiconductor Switches with turn-on and turn-off Capability, e.g. **IGBTs**
	
Harmonic Filters, Conveter Transformers, Large Footprint	No Harmonic Filters, Conventional AC Transformers, Compact Footprint, Black Start & Independent Active/Reactive Power Control

Development of DC Transmission: Worldwide Installed Capacity

Sources: Cigre WG B4-04 2003 - IEEE T&D Committee 2006



China: over 40 HVDCs … with more than 270 GW *

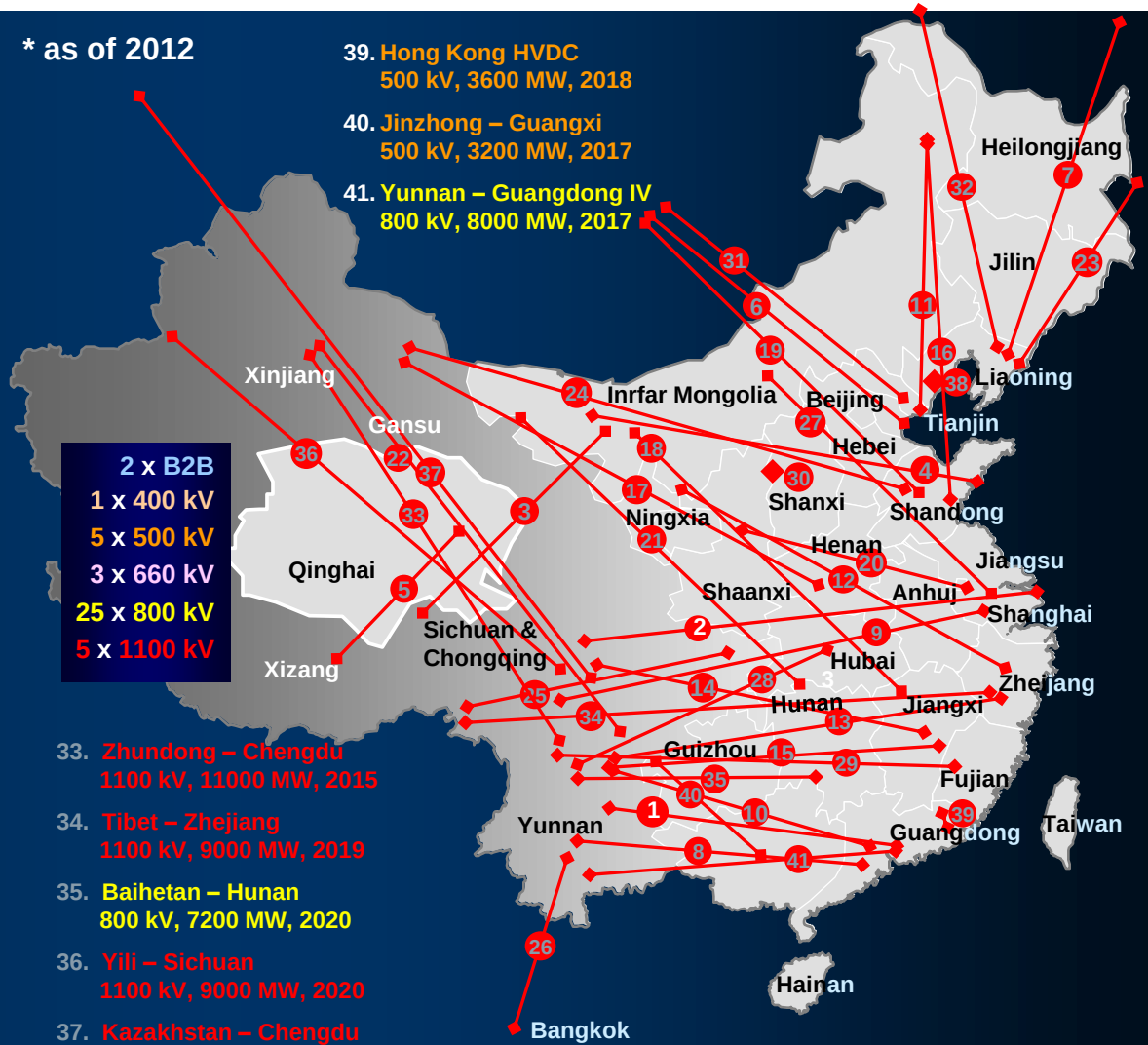
Transmission Capacity are expected between 2010 and 2020

1. Yunnan – Guangdong
   800 kV, 5000 MW, 2009/10
2. Xiangjiaba – Shanghai
   800 kV, 6400 MW, 2010
3. Debao
   500 kV, 3000 MW, 2010
4. Ningdong – Shangdong
   660 kV, 4000 MW, 2010
5. Qinghai – Tibet
   400 kV, 600 MW, 2011
6. Mongolia – Tianjin
   800 kV, 8000 MW, 2018
7. Russia – Liaoning
   660 kV, 4000 MW, 2014
8. Nuozhadu – Guangdong
   800 kV, 5000 MW, 2013
9. Jingping – Sunan
   800 kV, 7200 MW, 2012
10. Xiluodu – Guangdong
    500 kV, 2 x 3200 MW, 2013
11. Humeng – Tangshan
    800 kV, 8000 MW, 2015
12. Ningdong – Zhejiang
    800 kV, 8000 MW, 2016
13. Xiluodu – Zhejiang
    800 kV, 8000 MW, 2014
14. Sichuan – Jiangxi
    800 kV, 8000 MW, 2017
15. Xiluodu – Jiangxi
    800 kV, 8000 MW, 2018
16. Humeng – Shandong
    800 kV, 8000 MW, 2016
17. Hami – Henan
    800 kV, 8000 MW, 2013
18. Mengxi – Jiangxi
    800 kV, 8000 MW, 2016
19. Mongolia – Shandong
    800 kV, 8000 MW, 2016
20. Mengxi – Jiangsu
    800 kV, 8000 MW, 2017
21. Jiuquan – Hunan
    800 kV, 7200 MW, 2017
22. Zhundong – Congqing
    800 kV, 8000 MW, 2016
23. Baoqing – Liaoning
    660 kV, 4000 MW, 2017
24. Hami – Shandong
    800 kV, 7200 MW, 2017
25. Tibet – Chongqing
    800 kV, 7200 MW, 2017
26. Jinghong – Thailand
    500 kV, 3000 MW, 2018
27. Ximeng – Nanjing
    800 kV, 8000 MW, 2018
28. Baihetan – Hubei
    800 kV, 7200 MW, 2018
29. Wudongde – Fujian
    1100 kV, 11000 MW, 2018
30. Northwest – North
    B2B, 1500 MW, 2018
31. Mongolia – Jing-Jin-Tang
    800 kV, 7200 MW, 2019
32. Russia – Liaoning
    800 kV, 7200 MW, 2019

* as of 2012

2 x B2B
1 x 400 kV
5 x 500 kV
3 x 660 kV
25 x 800 kV
5 x 1100 kV

33. Zhundong – Chengdu
    1100 kV, 11000 MW, 2015
34. Tibet – Zhejiang
    1100 kV, 9000 MW, 2019
35. Baihetan – Hunan
    800 kV, 7200 MW, 2020
36. Yili – Sichuan
    1100 kV, 9000 MW, 2020
37. Kazakhstan – Chengdu
    1100 kV, 9000 MW, 2020
38. Northeast – North
    BtB II, 1500 MW, 2013
39. Hong Kong HVDC
    500 kV, 3600 MW, 2018
40. Jinzhong – Guangxi
    500 kV, 3200 MW, 2017
41. Yunnan – Guangdong IV
    800 kV, 8000 MW, 2017



Yunnan-Guangdong – UHV DC Converter

SIEMENS

800 kV DC

HVDC “Classic”
Yunnan-Guangdong Bipole 5,000MW ±800kVdc

Yunnan-Guangdong – 800 kV DC Line

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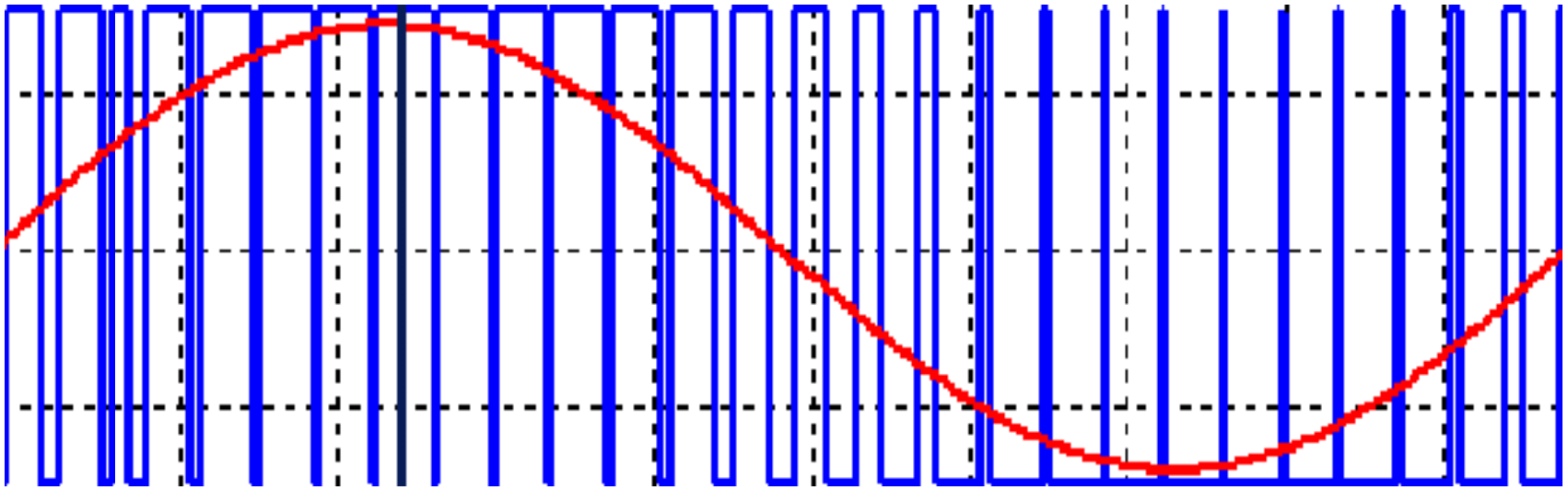
2-Level Voltage-Sourced Converter with Pulse-Width Modulation (PWM)

SIEMENS

The "Old Solution"

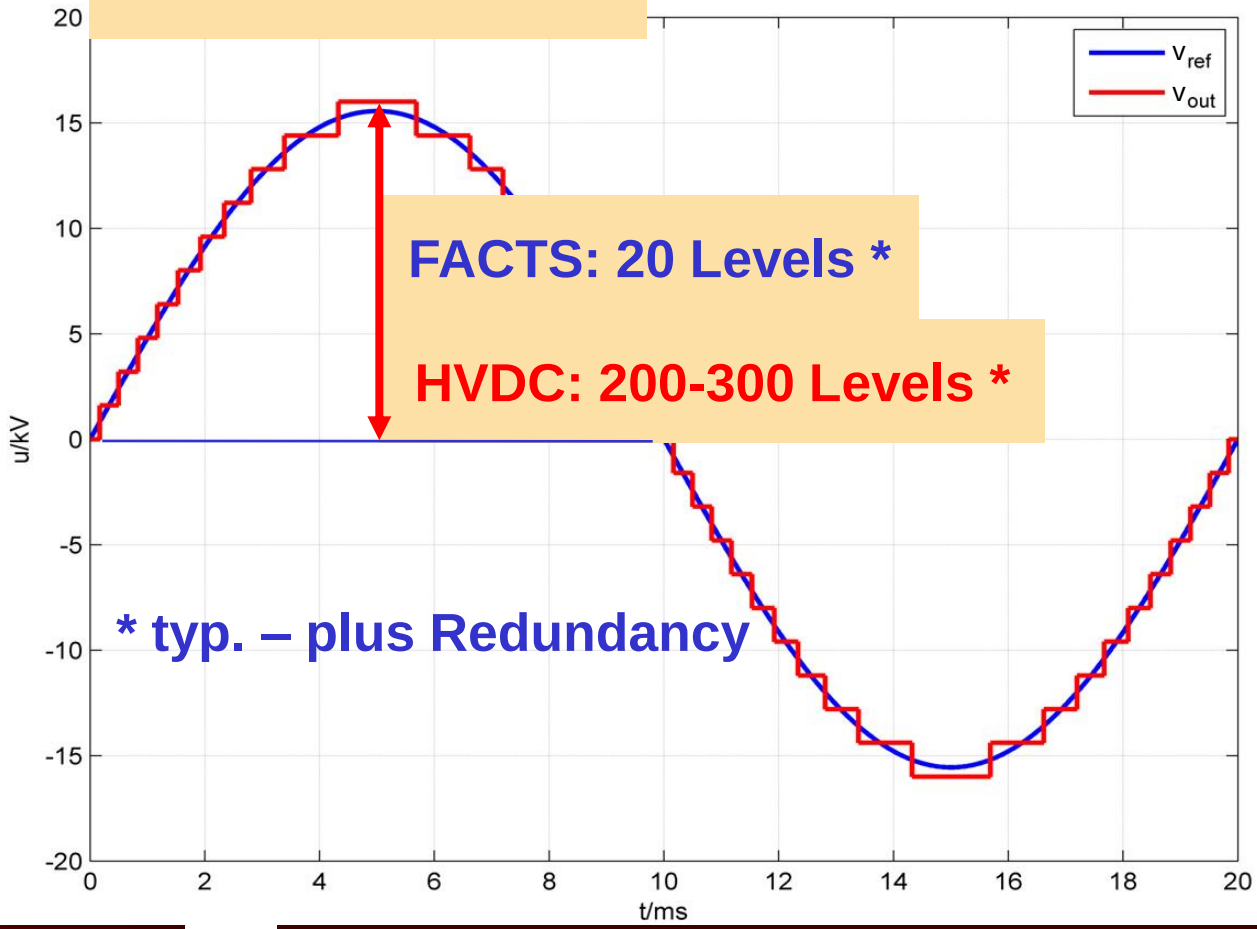


Typically, the Filter Demand of an HV PWM 2-Level Converter is Q_F = 0.2 - 0.3 P_d

Voltage-Sourced Converter with Power Modules: Modular Multilevel Converter – MMC

SIEMENS

The "New Solution"



* SVC PLUS: only HF Filtering

* HVDC PLUS: no AC Filters required

HVDC PLUS with Modular Multilevel Converter – Basic Scheme

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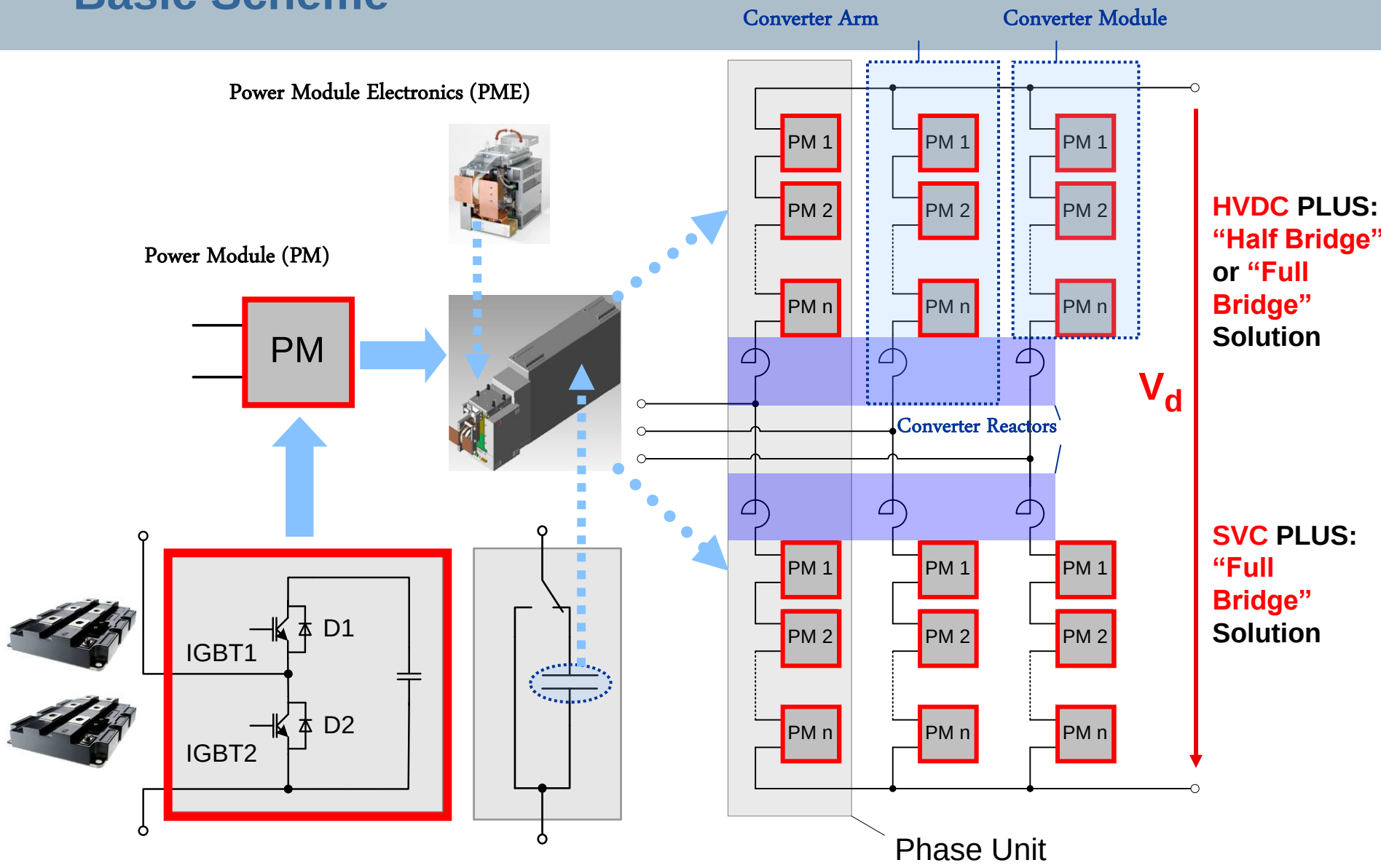
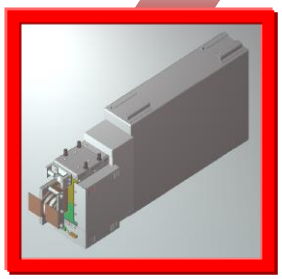
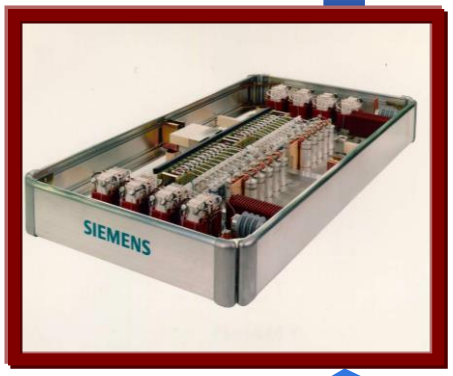
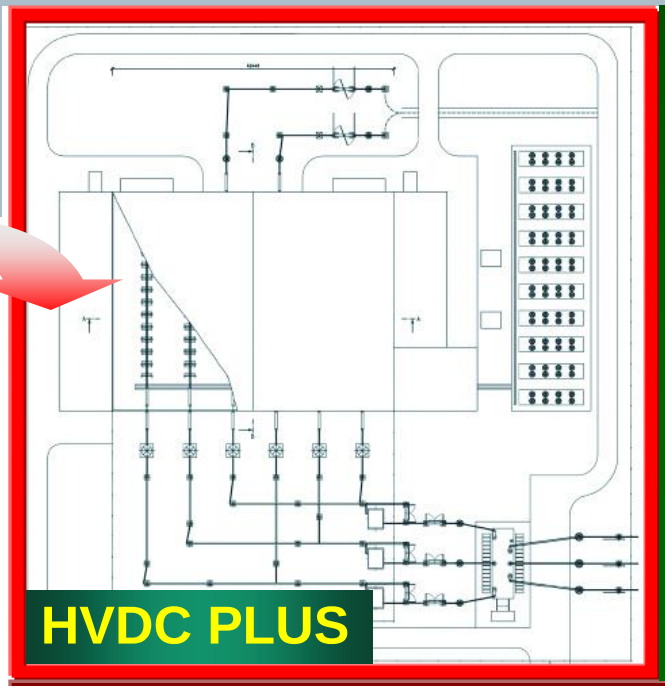


Benefits of HVDC PLUS







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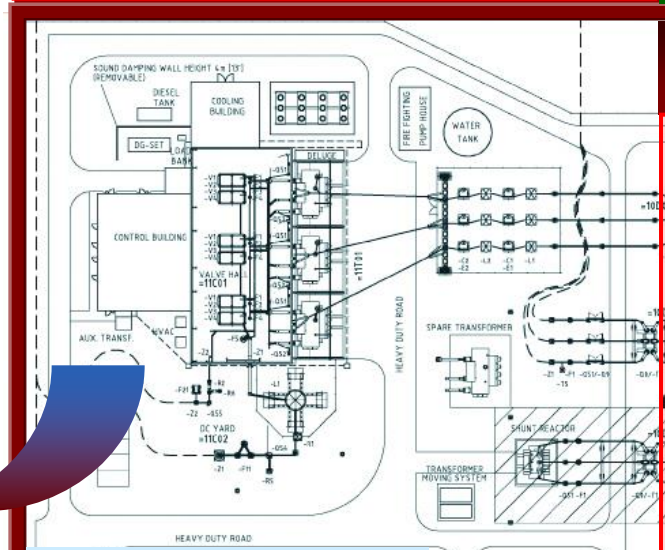
Space Saving

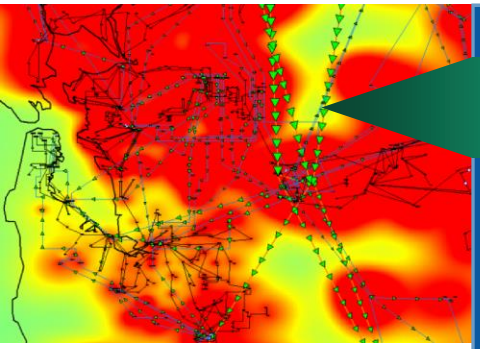


HVDC "Classic"

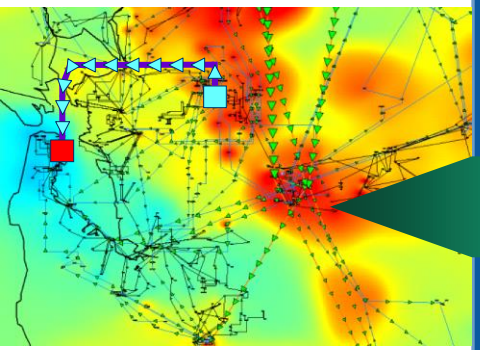
Example 400 MW

Trans Bay Cable Project
Security of Supply for San Francisco Area

SIEMENS

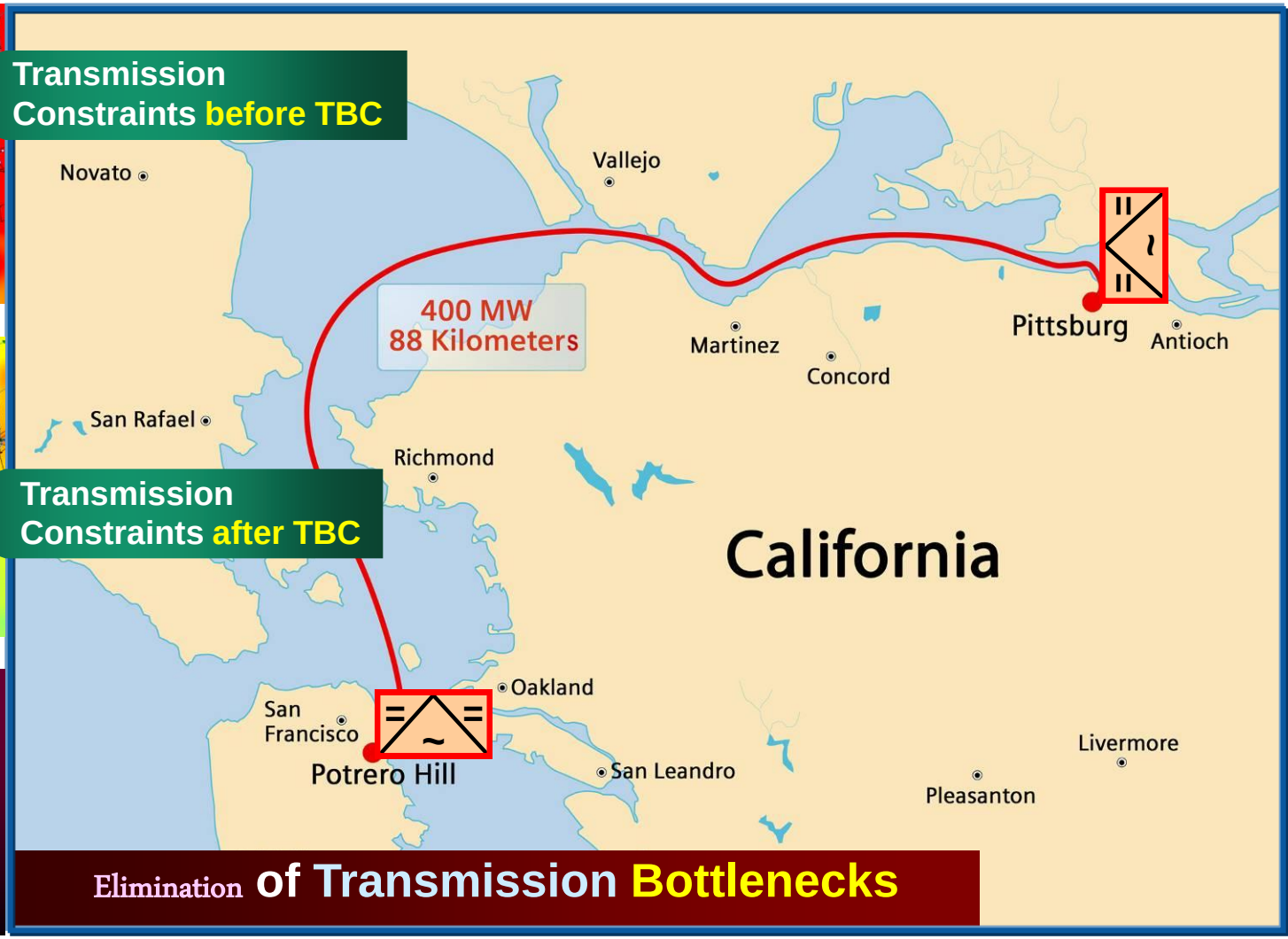


Transmission Constraints before TBC



Transmission Constraints after TBC

- Power Exchange by Sea Cable
- No Increase in Short-Circuit Power



Trans Bay Cable Project

SIEMENS

HVDC PLUS INELFE:
World's first VSC HVDC with 2 x 1,000 MW

SIEMENS

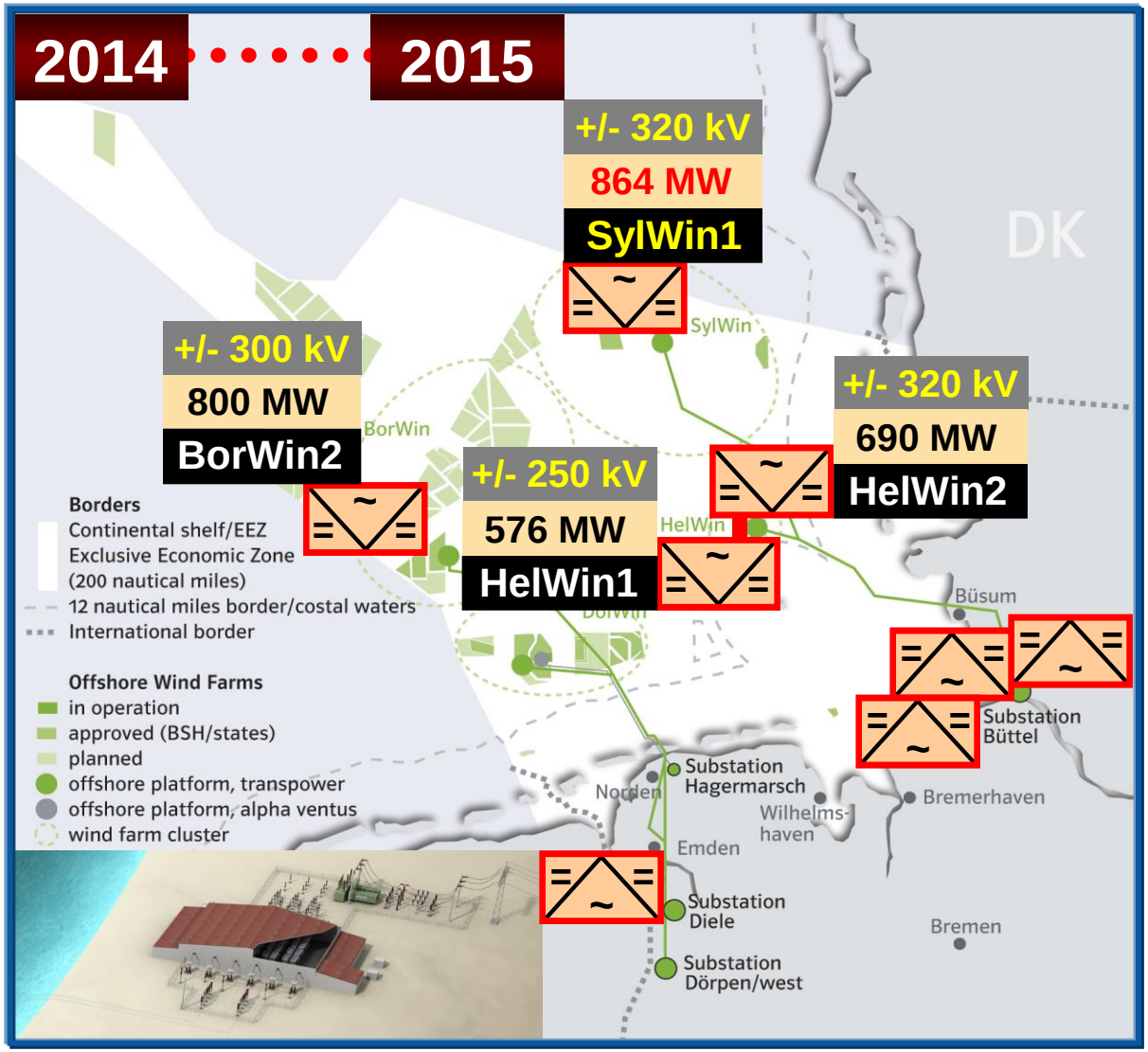
- Power Exchange &
- Increase in Stability
- Sharing of Reserve Capacity
- No Increase in Short-Circuit Power

INELFE

- Customer:
  RTE and REE
- World's 1st VSC HVDC with 2 x 1,000 MW – each @ V_{DC} = +/- 320 kV
  Cable: XLPE, 65 km

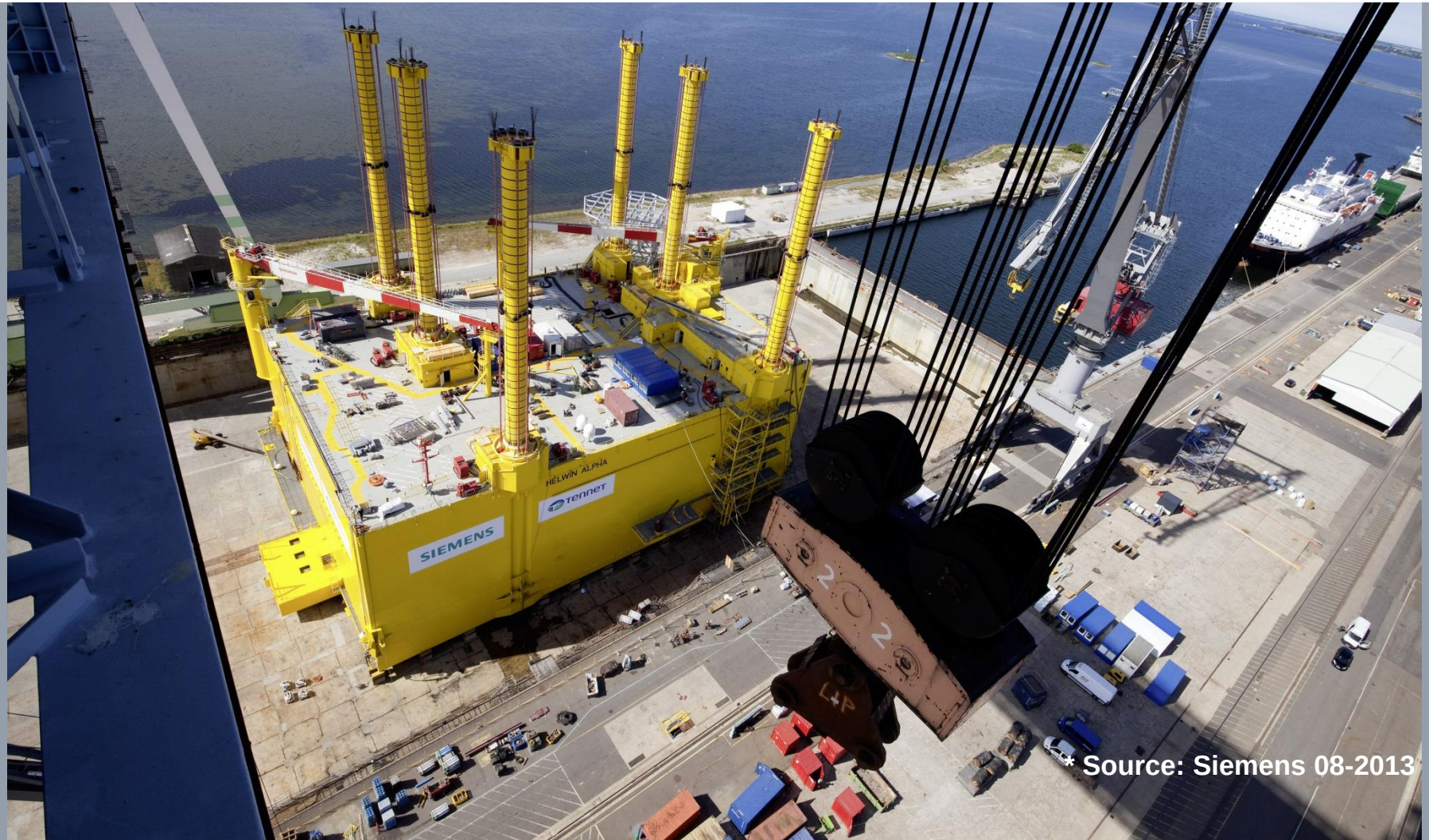
HVDC PLUS
INELFE Converter Station Valve Hall

HVDC PLUS: SylWin1, Germany – World's first Offshore MMC with 864 MW, BorWin2 and HelWin1&2



Platforms with unmatched dimensions:
HelWin1 – from Shipyard to Offshore

Three tugboats were needed to tow the converter platform, weighing 12,000 tons, to its location. After seven days at sea, covering 990 kilometers, HelWin1 finally reached its installation destination



* Source: Siemens 08-2013

HelWin1 – 576 MW

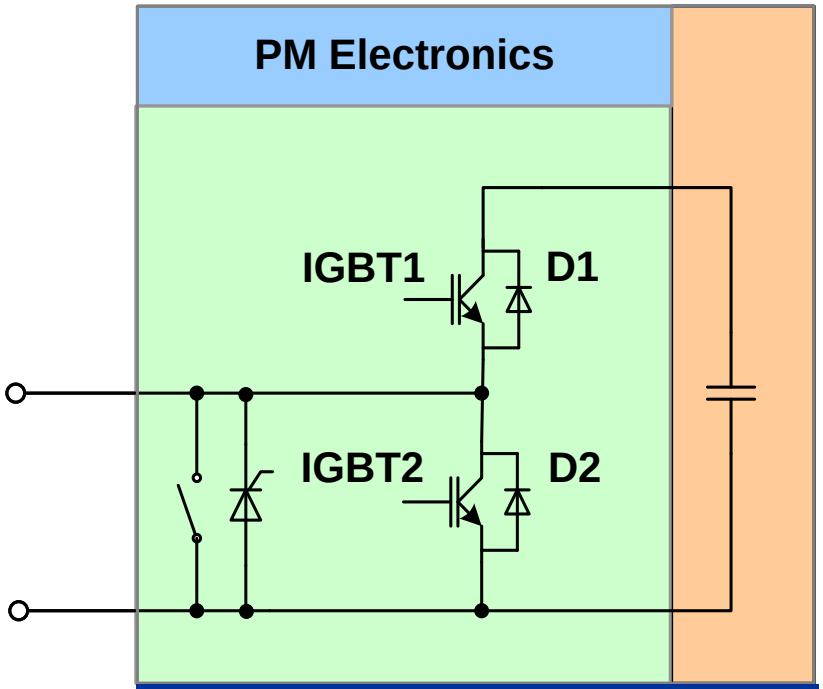
HelWin1 is a floating jack-up platform - the supports are lowered and connected to the supporting structure, and the platform is then raised using a hydraulic jacking system

Source: Siemens 08-2013

Comparison of Half and Full Bridge Power Modules

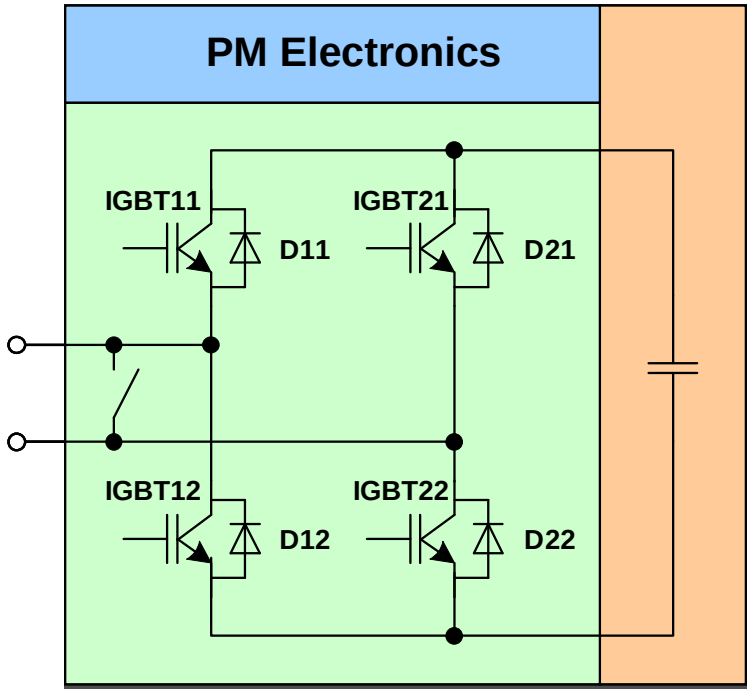
SIEMENS

Half Bridge Power Module*



* The Solution for Cable Transmission w/o OHL

Full Bridge Power Module**



** For Transmission with OHL with or w/o Cable

Success Factors for DC-Line Fault Recovery with VSC – using MMC PLUS Full Bridge proven Technology

SIEMENS

Since 2009 … 81 Full Bridge Converters

and … 14 Half Bridge Converters

} 95 Modular Multilevel Converters with Siemens PLUS Technology

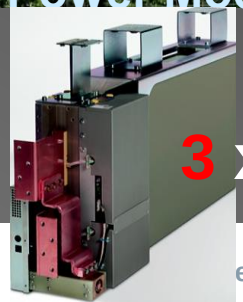
in commercial Application / under Project Execution

Status: 08-2013

52 x SVC PLUS®

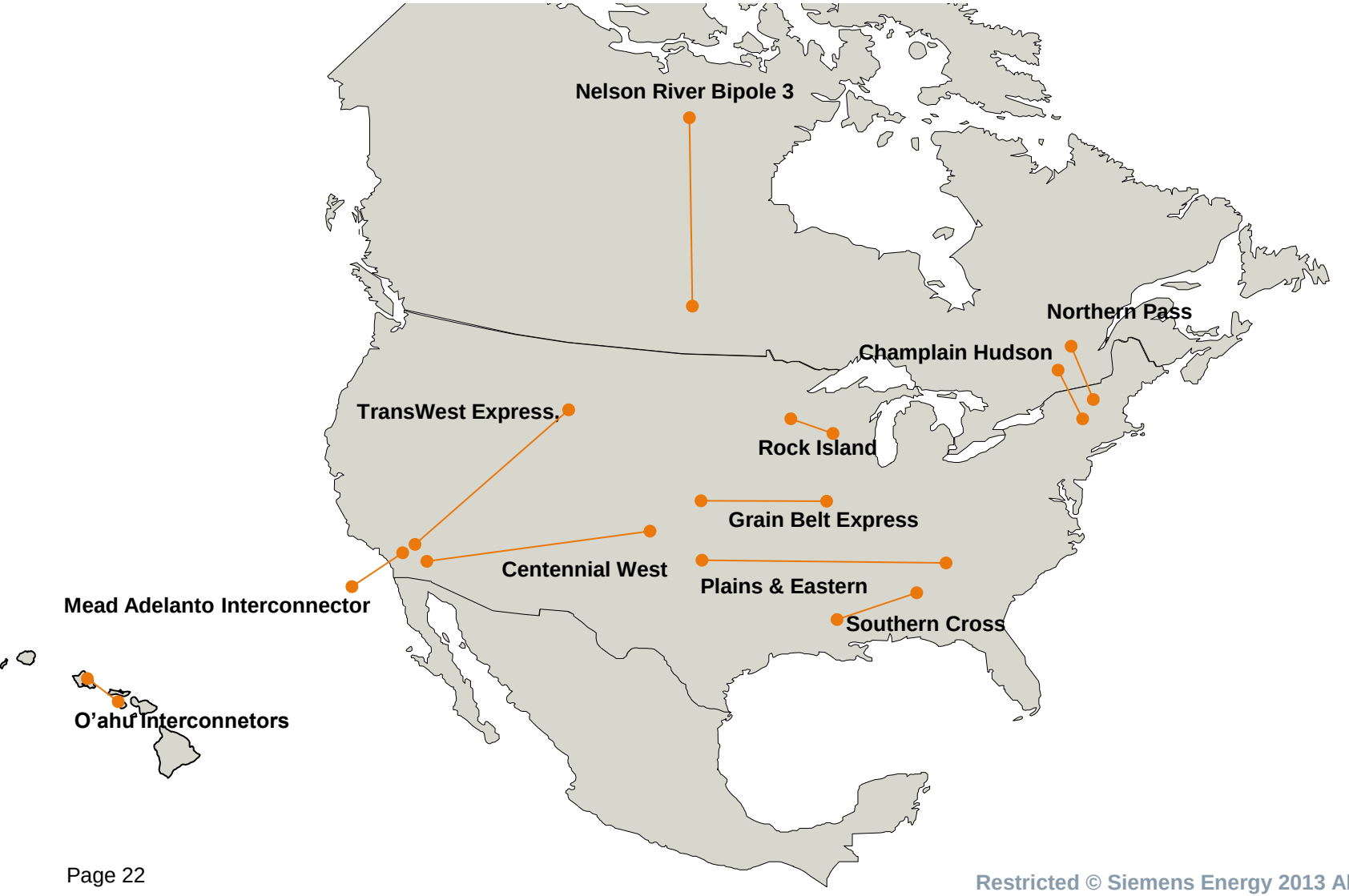
26 x Sitras® SFC plus

… same Power Modules



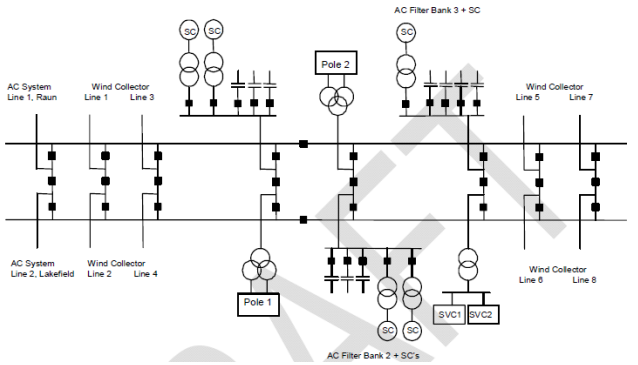
3 x Sitras® SVC plus

North American HVDC Potential Projects for Harnessing Renewables



Large Scale On-Shore Wind Development Main Identified Challenges

- Due to large scale on-shore generation (~3.5 – 4GW), HVDC Classic is the preferred solution
- However, the following issues need to be addressed:
  - Low to very low short circuit ratio at one end (mostly at rectifier side)
  - Lack of inertial support
  - Complex coordination between reactive power controls of HVDC and Wind farm
  - Possible island mode operation with application of synchronous condensers
  - Adequate frequency controls



Thoughts on North American Market for VSC

VSC Technology Benefits

- Superior performance from IGBT compared to thyristors, no harmonic impacts, compact footprint, independent real/reactive power control, black start capabilities, etc

Application Opportunities

- Shunt Compensation
  - STATCOM – Excellent market opportunities, now competing directly with SVC (superior under-voltage and overload capabilities)

- HVDC Transmission
  - Back-to-Back Links – Some Market Opportunities
  - Long Distance Cable Links – Excellent Market Opportunities
  - Long Distance Overhead Links – For power ratings <2,000MW
  - Multi-Terminal Links – Full-Bridge VSC facilitating early deliberation opportunities

Many Thanks for Your Attention

CONTACT:
Dr. Brian Gemmell
Phone: (407) 736-3848
Cell: (407) 280-4153
brian.gemmell@siemens.com