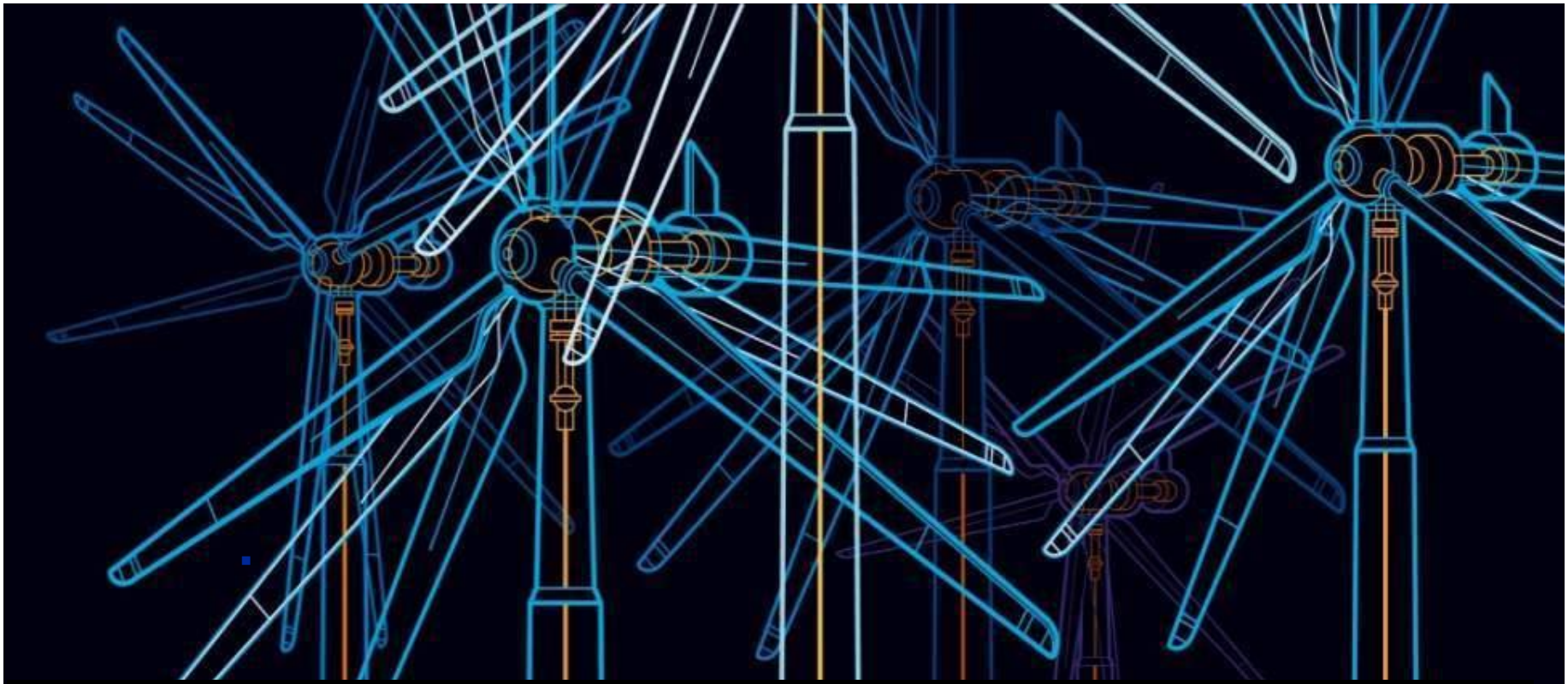
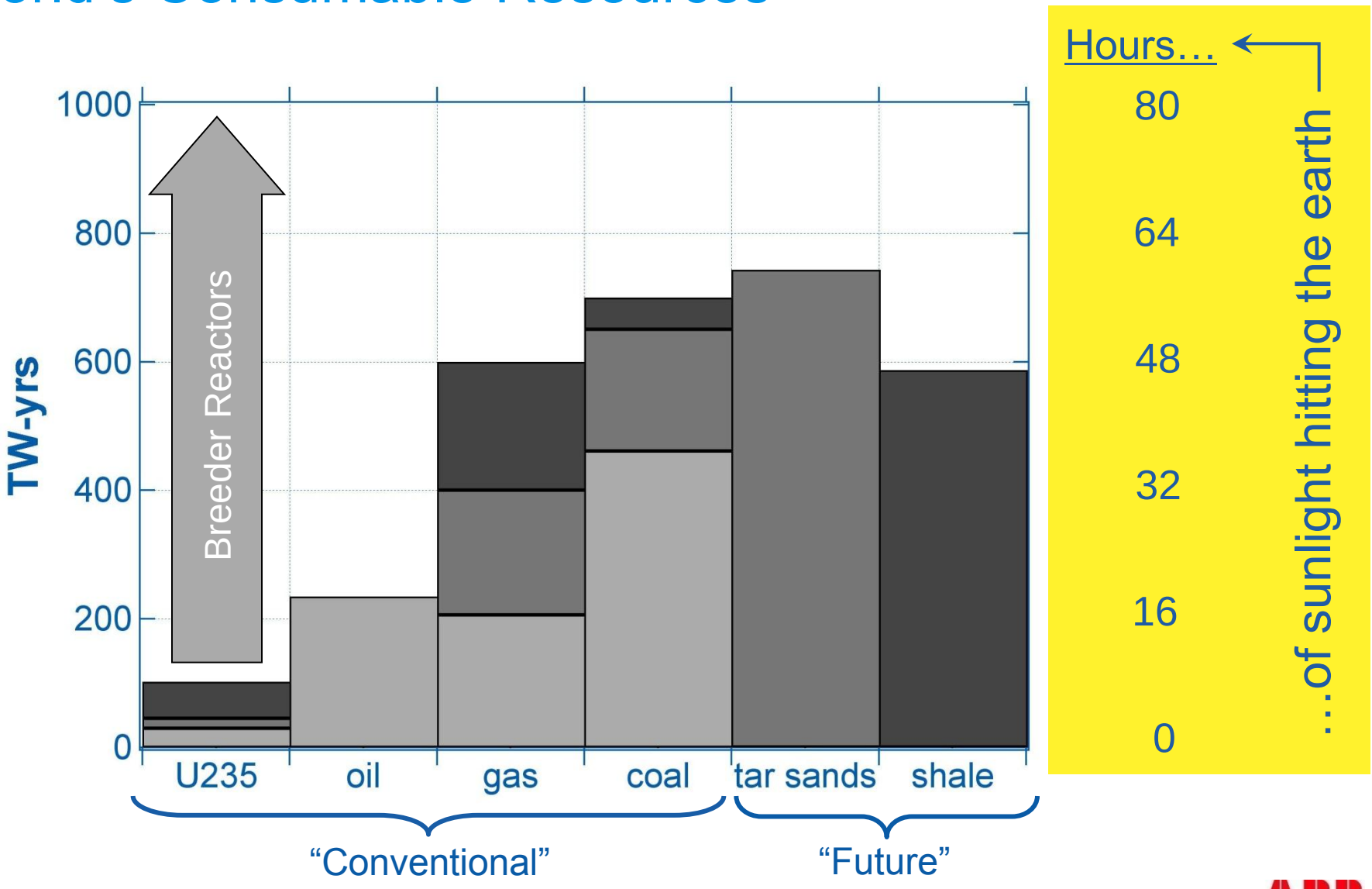


Peter K. Steimer, Corporate Research Fellow, Power Electronics, ABB Switzerland Ltd, 15.09.2014

# High power electronics innovation

# Introduction
## World's Consumable Resources



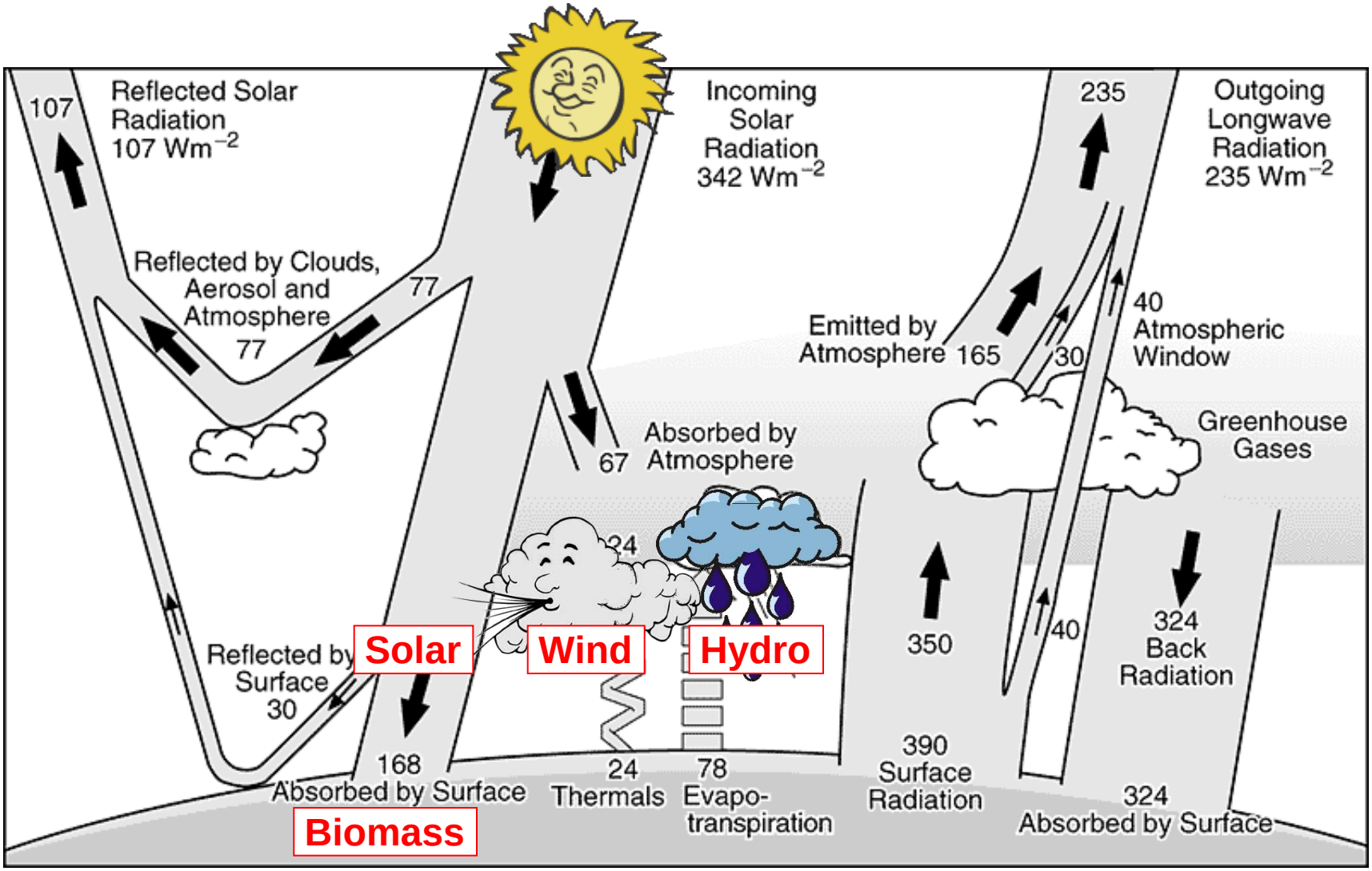




References: [1] Electricity in 2030: PV's Role, Brent P. Nelson, IEEE Energy 2030, Atlanta 2008

# Introduction

## The most important Renewables – driven by the Sun




References: [2] Earth's Annual Global Mean Energy Budget, JT Kiehl and KE Trenberth, Bulletin of the American Meteorological Society, Vol 78, No. 2, February 1997

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# Electrical Energy Systems
## Energy efficiency and 20% new Renewables

$CO_2$ emissions [3]: - $^2/_3$ of the electrical power based on fossil fuels
- transportation is second largest contributor

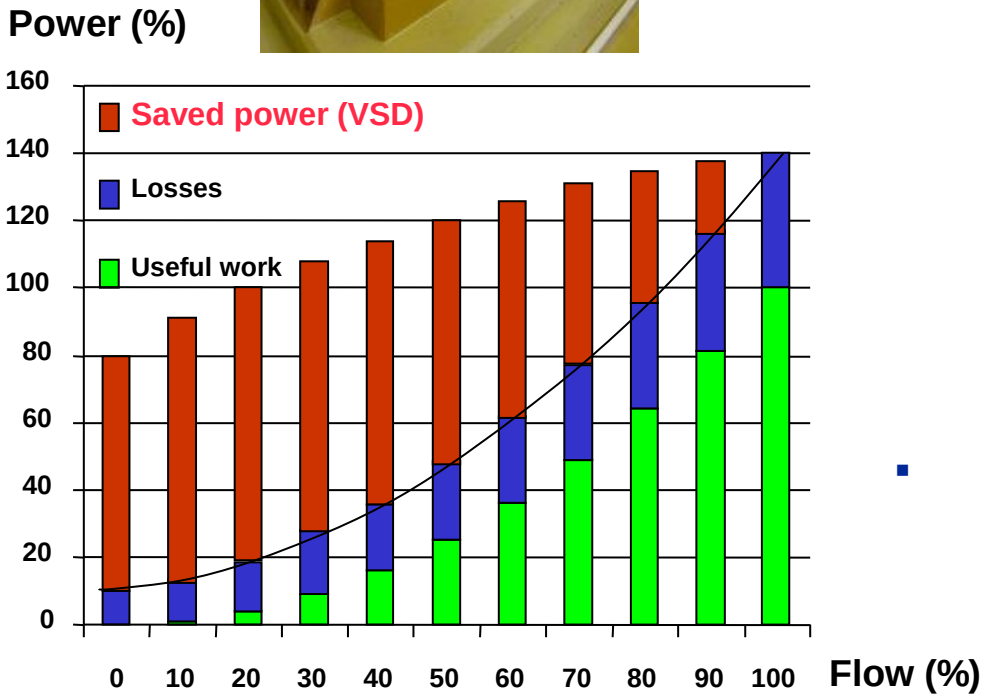
- #0: Transition to gas: 2 to 3 times lower emmissions than coal

- #1: Energy efficiency from primary energy to end user
  1. High effciency combined cycle plants (up to 60% efficient)
  2. Use of waste heat in bulk power generation (up to 85% efficient)
  3. Variable speed drives for pump, fan and compressor applications
  4. More electric transportation for scooters, cars, buses, trains, ships

- #2: New Renewables (Wind, Solar) will contribute 20% in 2030
  1. up to 12% contribution of Wind (2013: 2.5%, CAGR = 10%) [4]
  2. up to 7% contribution of Solar (2013: 0.4%, CAGR =15%) [5]

References: [3] World Energy Outlook 2012 (International Energy Agency)
[4] Global Wind Energy Forecast 2012-2025 (IHS Emerging energy reserach)
[5] Projections on solar power, 2013 (IHS Emerging energy reserach)

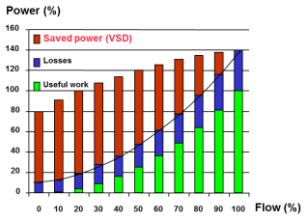
# # 1: Energy Efficency
## Pump and fan applications




- 60 - 65% of industrial electrical energy is consumed by motors
- Substantial energy saving by variable speed drives in pump and fan applications [5]
  - 30 to 40% energy saving, when running below nominal flow
  - Applies to 30% of all industrial pump and fan applications
- Globally appr. 1900 TWh of annual energy saving potential

References: [6] Impact of Motor Drives on Energy Efficiency, P. Barbosa, P. Wikstroem, M. Kauhanen, PCIM 07

# # 1: Energy Efficency
## Energy saving priorities




| #1: ENERGY EFFICIENCY | Potential / year |
|---|---|
| ▪ Power generation (installed base) | |
| ▪ Use of waste heat | 3000 TWh |
| ▪ Transportation (installed base) | |
| ▪ Hybrid, 30% savings (equivalent to) | 3000 TWh |
| ▪ Industry (installed base) | |
| ▪ VSD for pump and fans | 1900 TWh |

| #2: NEW RENEWABLES | Potential / year |
|---|---|
| New Windpower installations | |
| ▪ New installations in 2009 – 2020 | 2000 TWh |

References: [7] Enabled by High Power Electronics - Energy efficiency, Renewables and Smart Grids, P. K. Steimer, ECCE Asia (IPEC) 2010

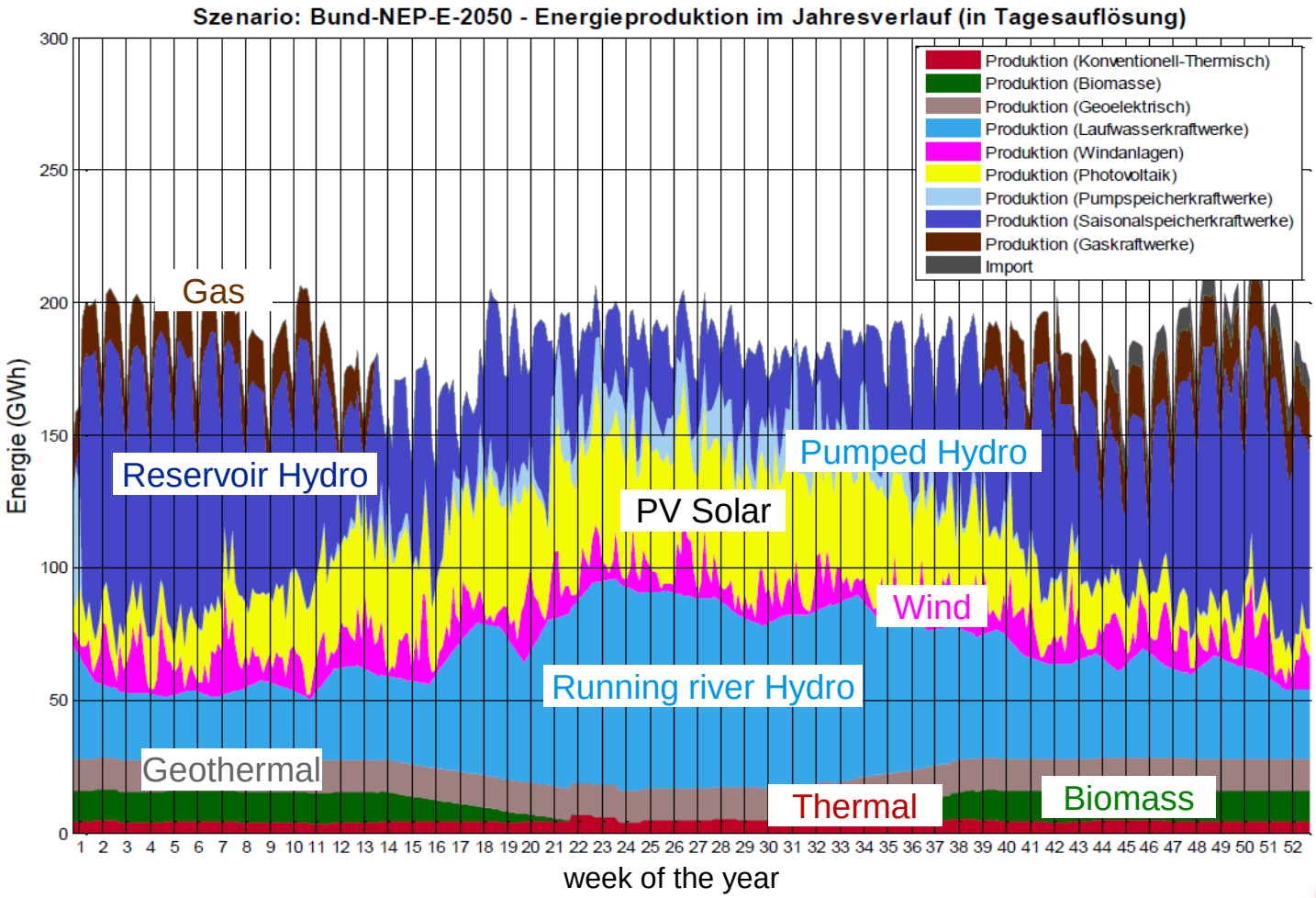
# #2 New Renewables
## 90% Renewables in Switzerland in 2050

PV: 11 GW

Wind: 2.85 GW

PHP: 5 GW
200 GWh

- Electrical energy systems with 90% renewable power generation




References: [8] SCS Energiemodell für die Schweiz, 2013 (Supercomputing Systems)

# #2 New Renewables
## Future high penetration of renewables

Combine best of old and new electrical energy systems :

1. Fossil fuel Power plants
   - Combined cycle and gas power plants with more power ramping
2. Extension of grid infrastructure
   - Transmit greater power over greater distances (DC, UHV)
   - Voltage stability in distribution grids (V-control, battery storage, DC )
3. Hydro power plants
   - Pumped hydro as low cost storage option (4 to 8 hours typical)
4. New renewables
   - Wind prefered due to highest energy return on invested energy
   - PV Solar prefered due to simple application incl. storage option
   - CSP attractive due to molten salt thermal storage option

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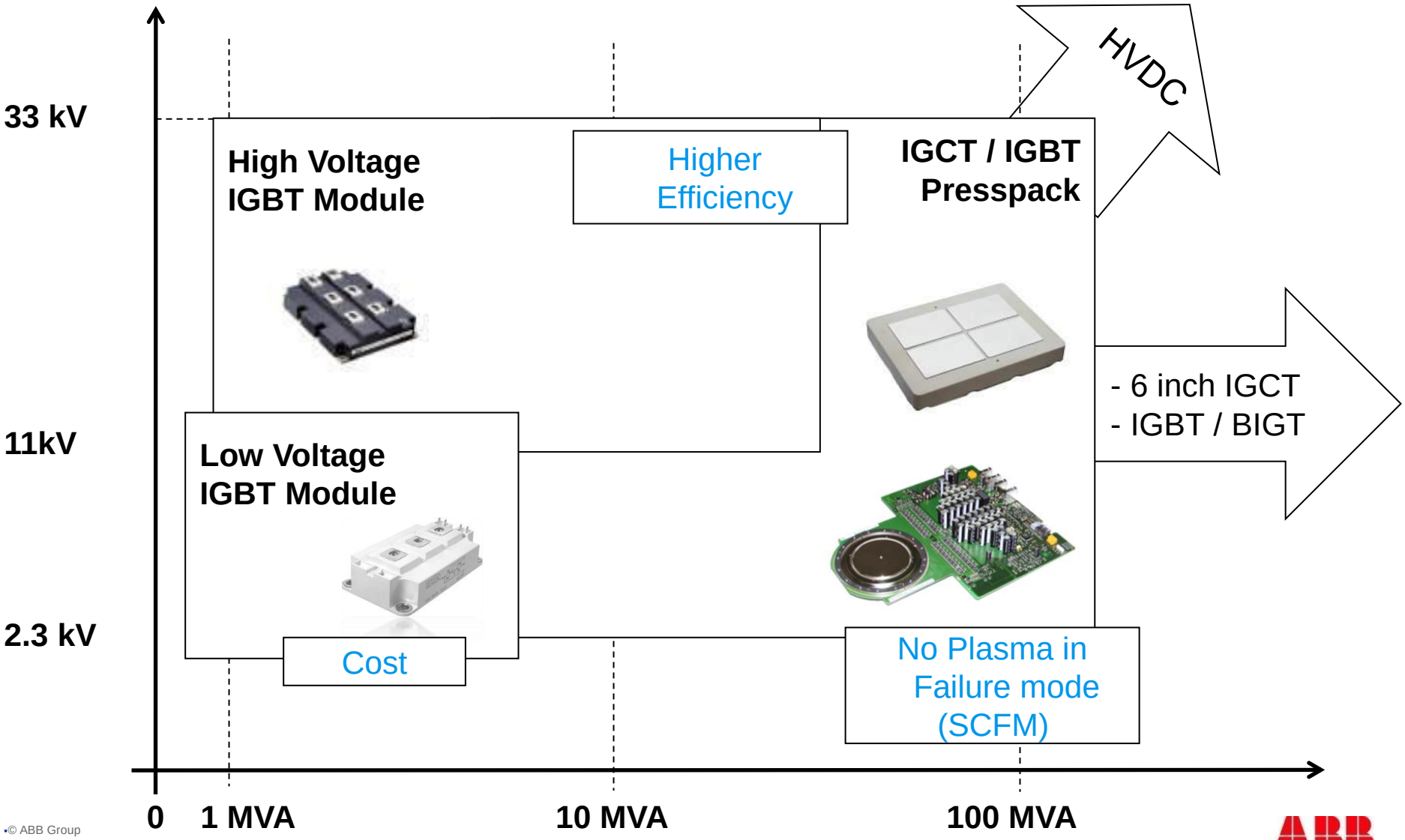
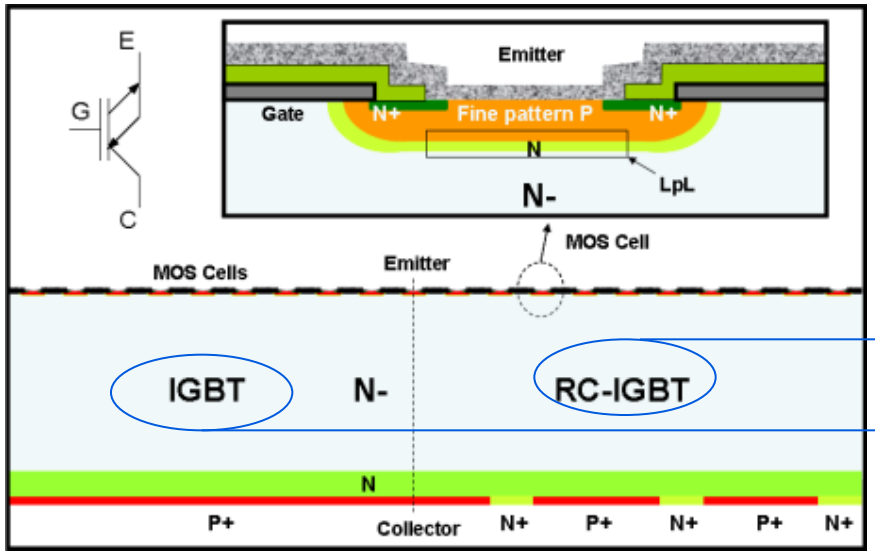
# Power Semiconductors
## Medium Voltage Converters



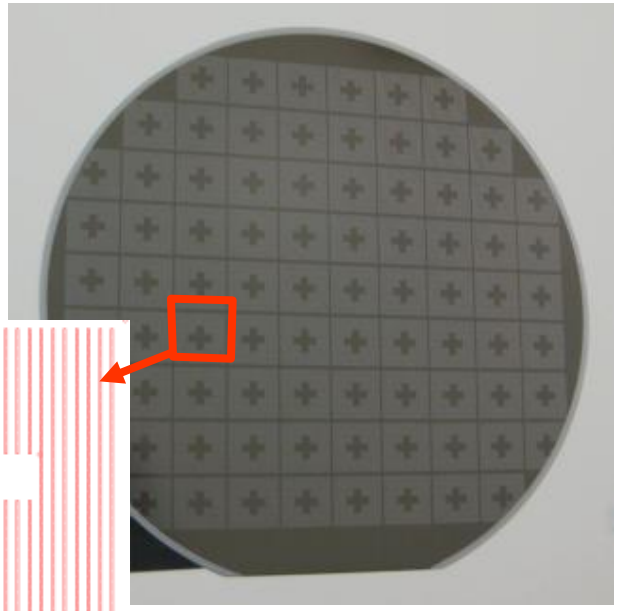

SCFM: Short-circuit failure mode

# Power Semiconductors
## Bi-mode IGBT technology (BIGT)

- Integrates an IGBT & diode in one structure
  => Reverse Conducting (RC) IGBT




**BIGT Wafer Backside**

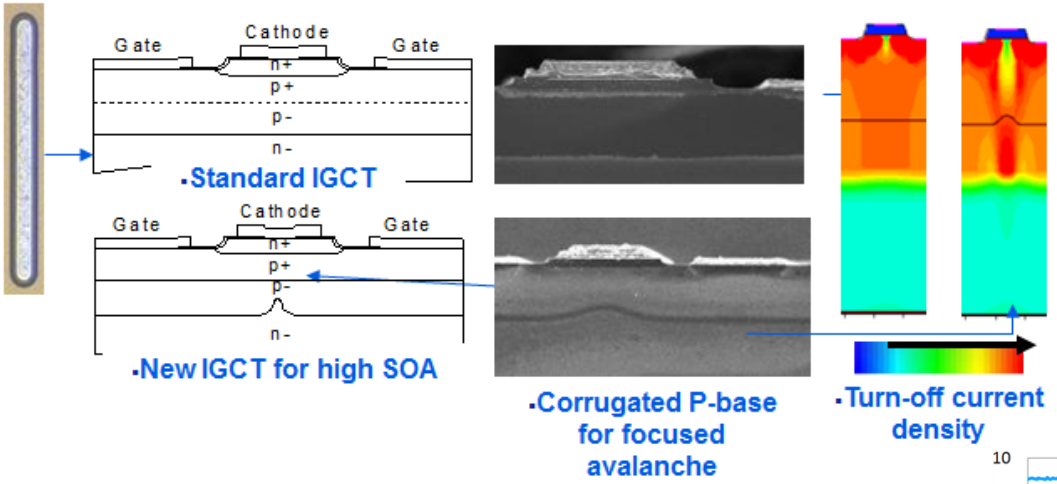


- Lower Losses due to larger Area for IGBT and diode
  - both use whole silicon area

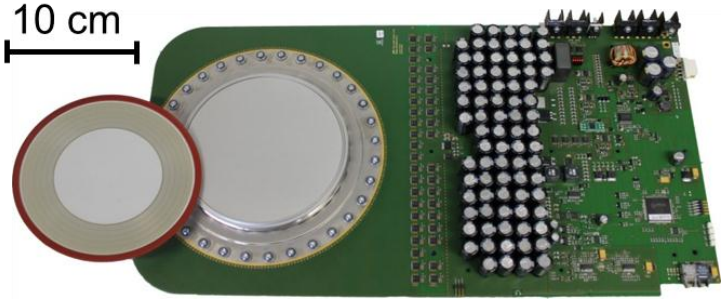
References: [9] M. Rahimo, et al., "The Bi-mode Insulated Gate Transistor (BiGT) - A Potential Technology for Higher Power Applications", ISPSD 2009

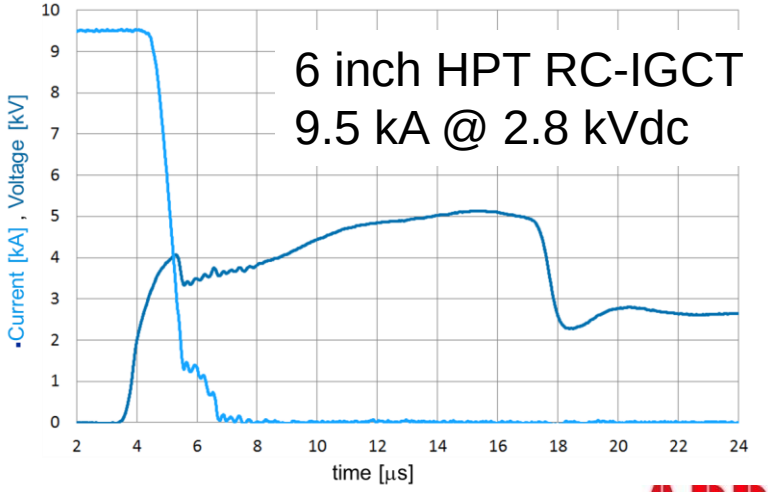
# Power Semiconductors
## High performance IGCT technology (HPT)

- High Safe Operating Area (SOA) due to corrugated base junction profile




- Combined with RC technology



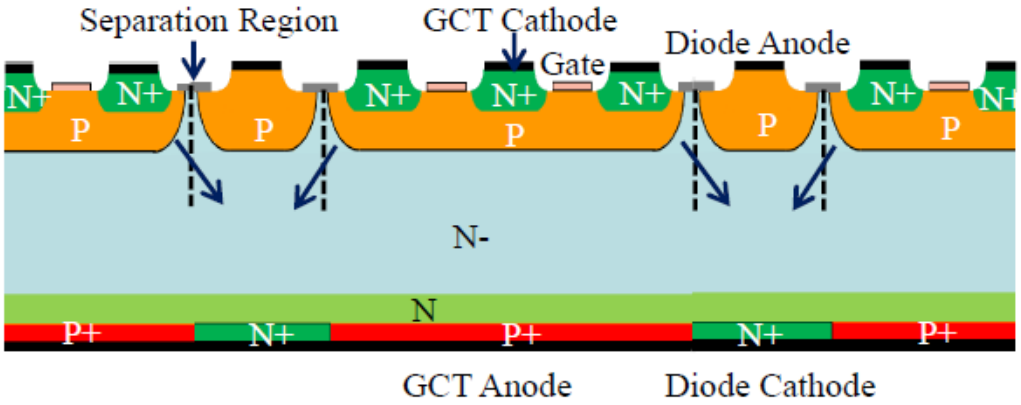



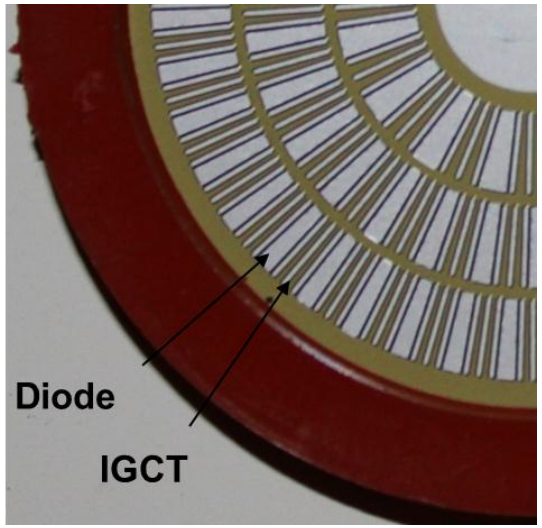



References: [10] The 150 mm RC-IGCT: a Device for the Highest Power Requirements, T. Wikström M. Arnold, T. Stiasny, C. Waltisberg, H. Ravener, M. Rahimo, IEEE ISPSD 2014

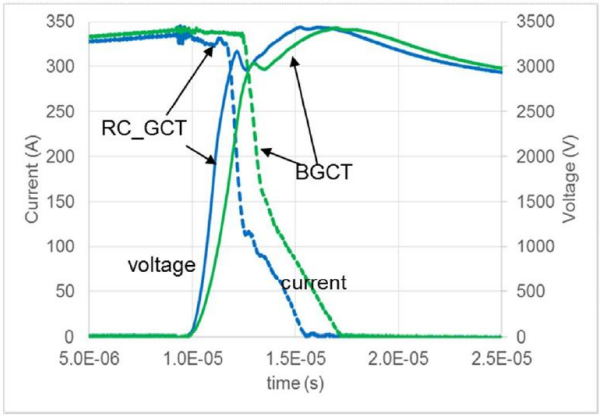
# Power Semiconductors
## Bi-mode IGCT technology (BGCT)

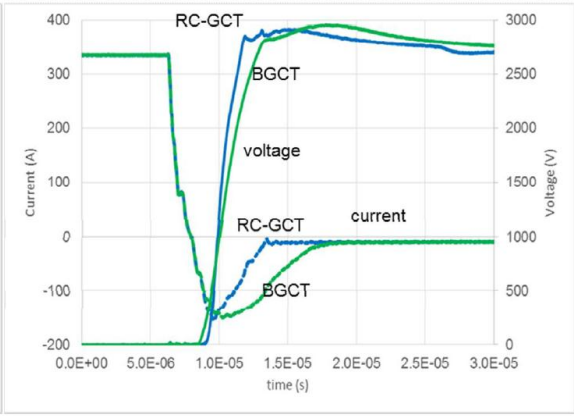
- Integrates IGBT & diode in one structure
  => Reverse Conducting (RC) IGCT




- Lower losses
- Low leakage currents



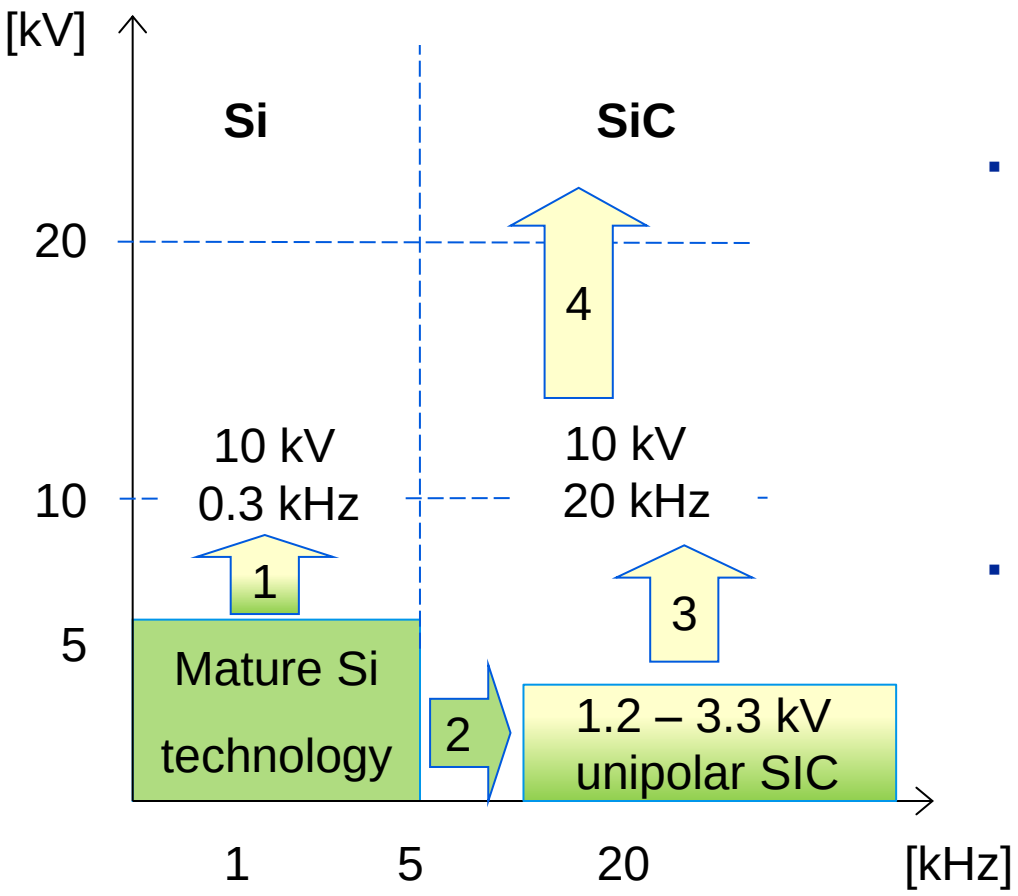







References: [11] The Concept of Bi-mode Gate Commutated Thyristor, U. Vemulapati, M Bellini, M. Arnold, M. Rahimo and T. Stiasny, IEEE ISPSD 2012

# Power Semiconductors
## Future trends for high power semiconductors




- Silicon devices up to 10 kV
  1. BIGT and BGCT as new high power device options
- Wide band gap material devices
  2. Unipolar 1.2 kV / 1.7 kV devices
  3. Extension to 10 kV unipolar SIC devices, up to 20 kHz
  4. Later bipolar SiC
- Packaging
  1. Higher temperature and
  2. Higher voltage packaging

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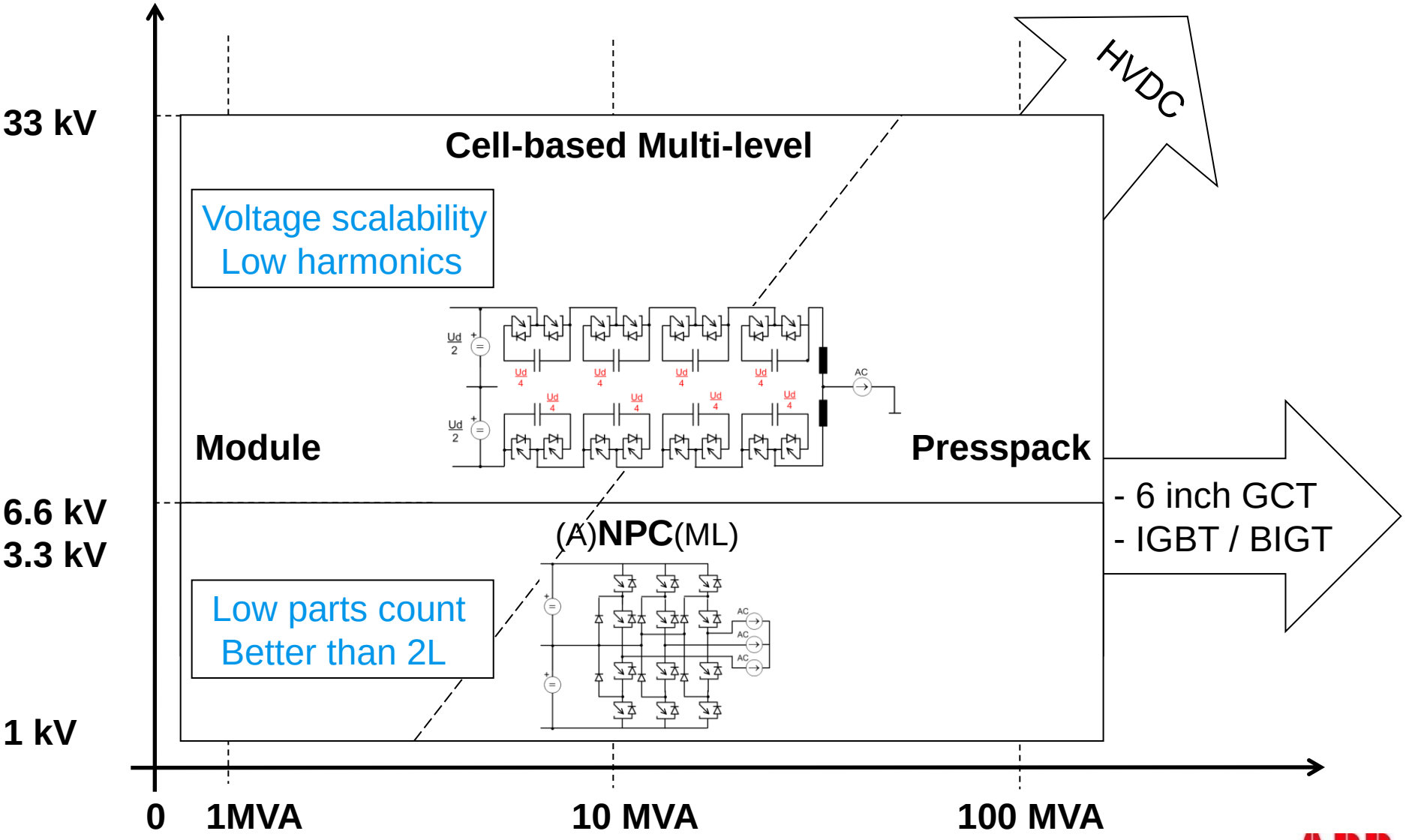
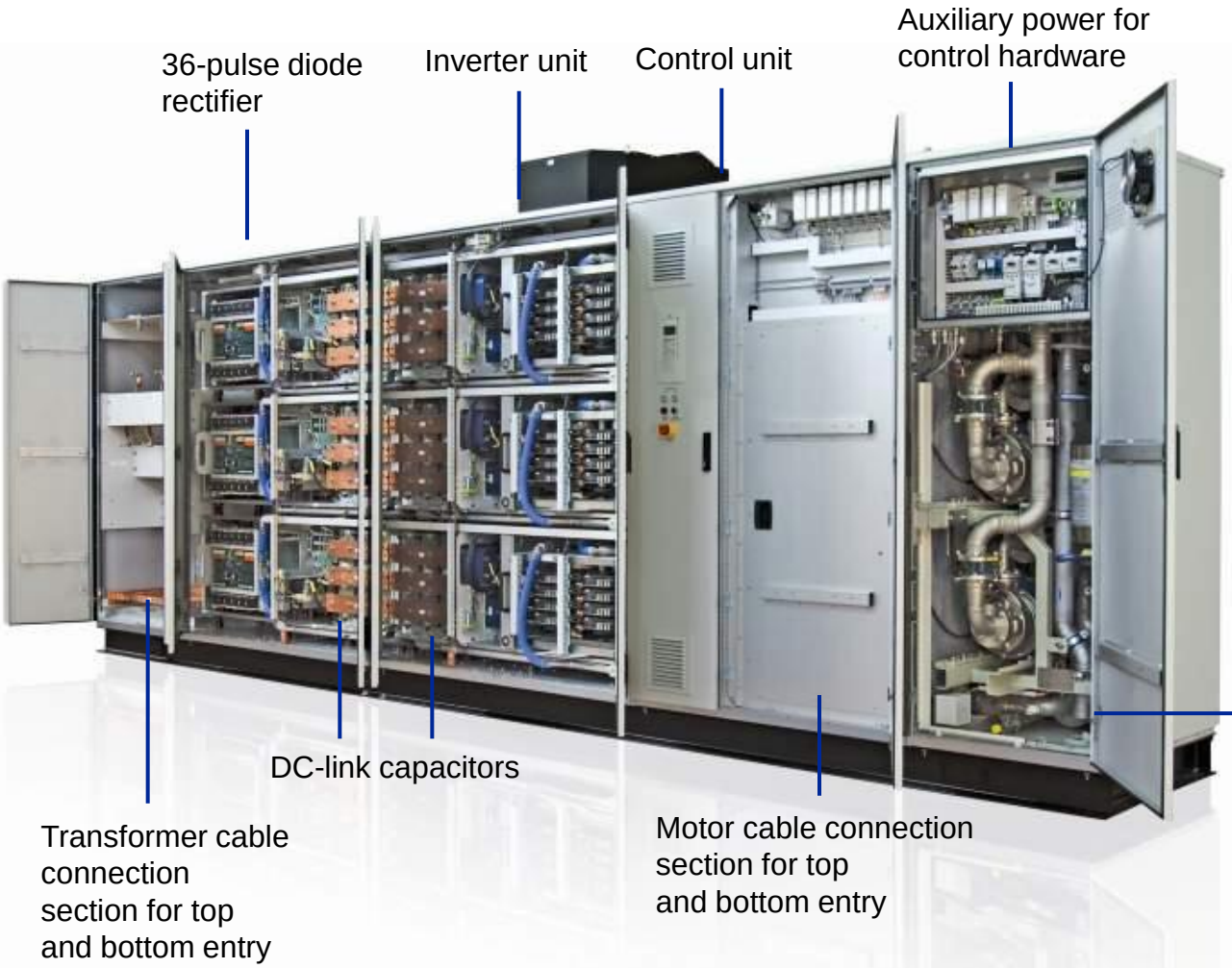
# High power electronics applications
## Topologies



# #1 Efficiency: MV Drives
## Cell-based Multi Level Converter

MV drive: 5-level converter based on supplied NPC RCIGCT cells

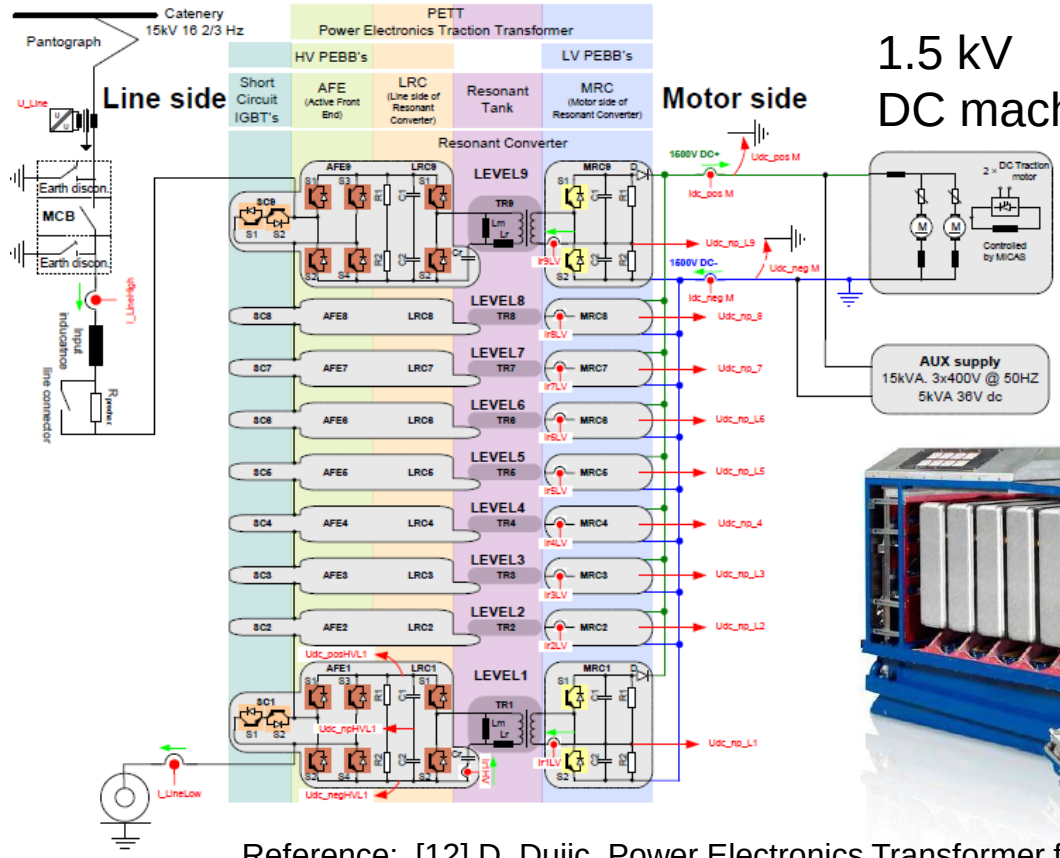



Vollbrücke mit zwei RCIGCT NPC Phasen-bausteine

# #1 Efficiency: Transportation
## Power Electronics Transformer

- Power Electronics Transformer: 8+1 MMC cells for 15 kV, LLC resonant DC/DC, MF Xfrms at 1.8 kHz

15kV, 17 Hz



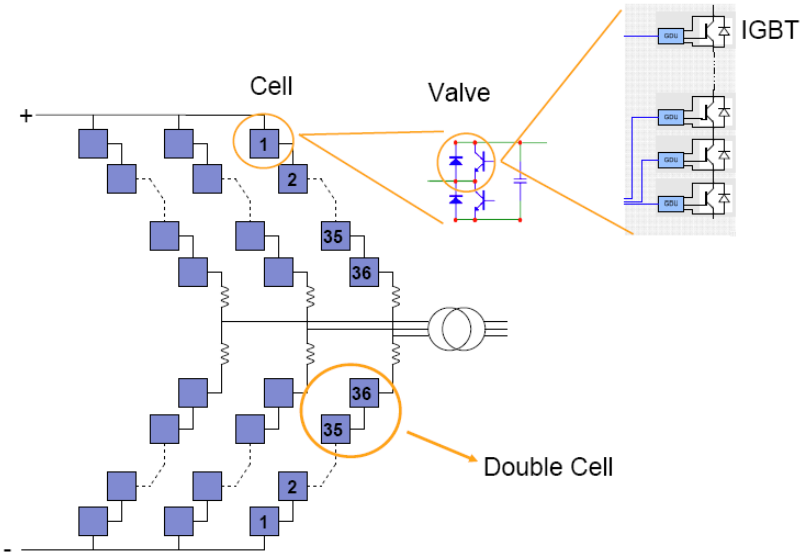

1.5 kV
DC machine

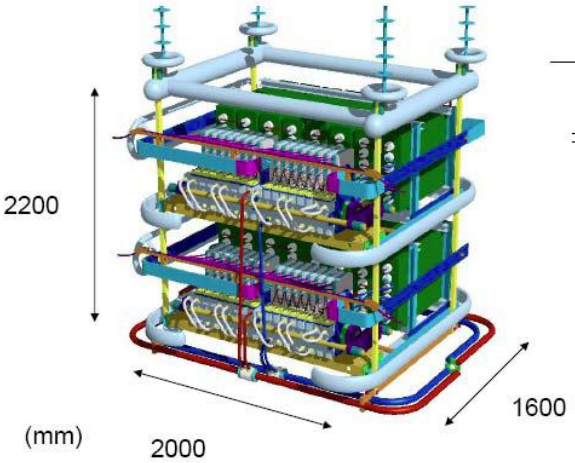

10’000 km of operation

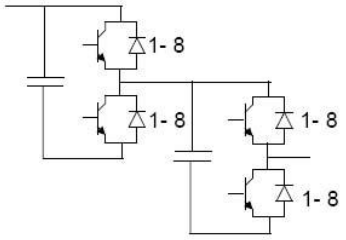
PE transformer

Reference: [12] D. Dujic, Power Electronics Transformer for on-board applications – an overview, Industrial session on HV and high power, APEC 2013

# #2 New Renewables
## HVDC connection for Offshore Windpower



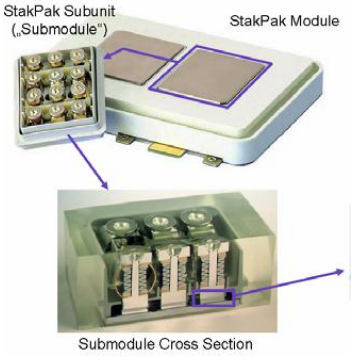




Mass 3000 kg

DolWin 1 (MMC transmission system based on Presspack IGBT technology)

| | | |
|---|---|---|
| Commissioning year: | | 2013 |
| Power rating: | | 800 MW |
| No. of poles: | | 2 |
| DC voltage: | | ±320 kV |
| Length of DC lines: | sea | 75 km |
| | land | 90 km |

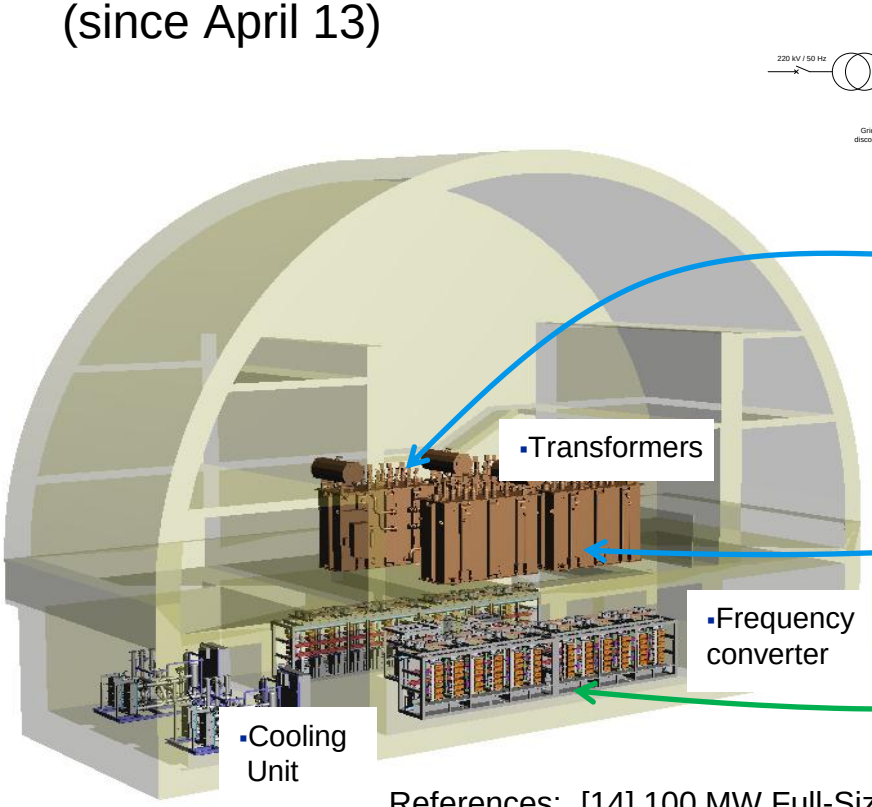


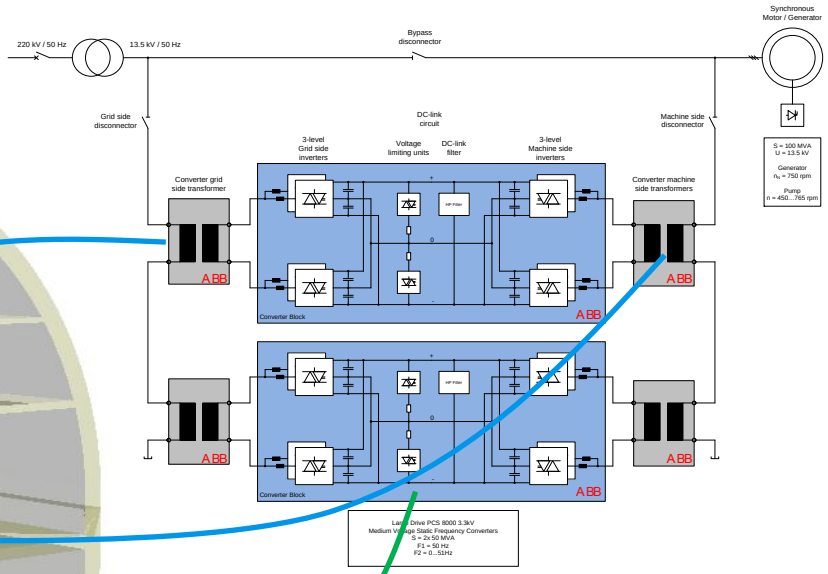

Reference: [13] B. Jacobson, P. Karlsson, G. Asplund, L. Harnefors, T. Jonsson: VSC-HVDC Transmission with Cascaded Two-Level Converters,Cigré session 2010, paper B4-110

# Variable speed Pumped Hydro

# #2 New Renewables
## Variable speed Pumped Hydro

- The converter-fed synchronous machine (CFSM) is the future variable speed solution (replacing complex DFIM)
- First retrofit reference rated at 100 MVA in commerical operation (since April 13)




References: [14] 100 MW Full-Size Converter in the Grimsel 2 Pumped Storage Plant, Hans Schlunegger, Andreas Thöni, Hydro 2013 conference, Innsbruck

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# High Power Electronics Innovation
## Conclusions

Electrical power system

1. Optimum co-existance of the old AND new electrical energy system needed to mitigate the very costly $CO_2$ impact

Power Semiconductors

1. Silicon based IGBT, IGCT, BIGT and BGCT are todays choices
2. SiC based devices to grow with selected volume applications

Applications

1. Energy effciency is #1 to minimize our $CO_2$ footprint (short-term)
   - Strong driver for drives applications and electrical transportation
2. New Renewables are #2 to miminize our $CO_2$ footprint (long-term)
   - Strong driver for multiple power electronics applications

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for a better world™