New power semiconductor technology for renewable energy sources application

By

Dejan Schreiber

SEMIKRON

Sevilla

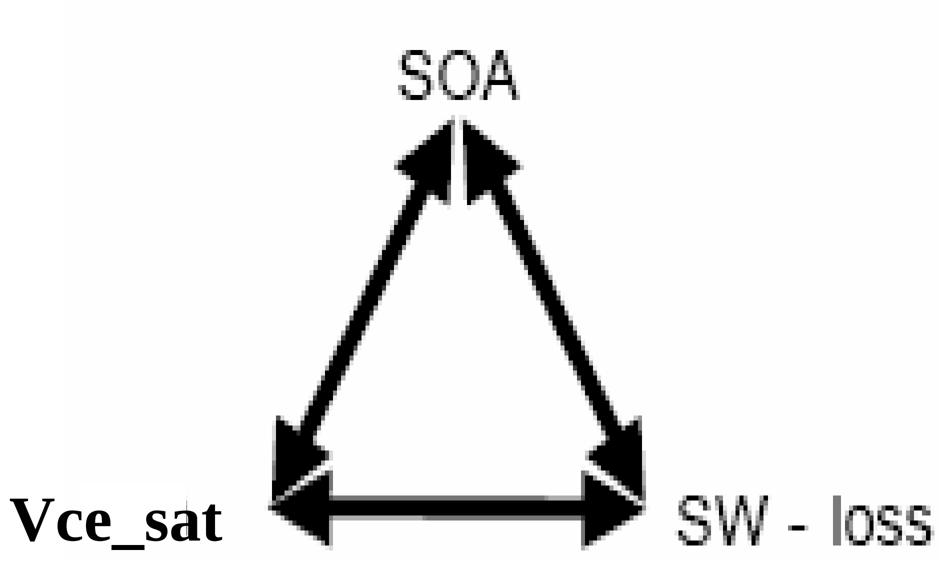
Mai 12. 2005

SEMIKRON
innovation + service

IGBT is the working horse of power electronics

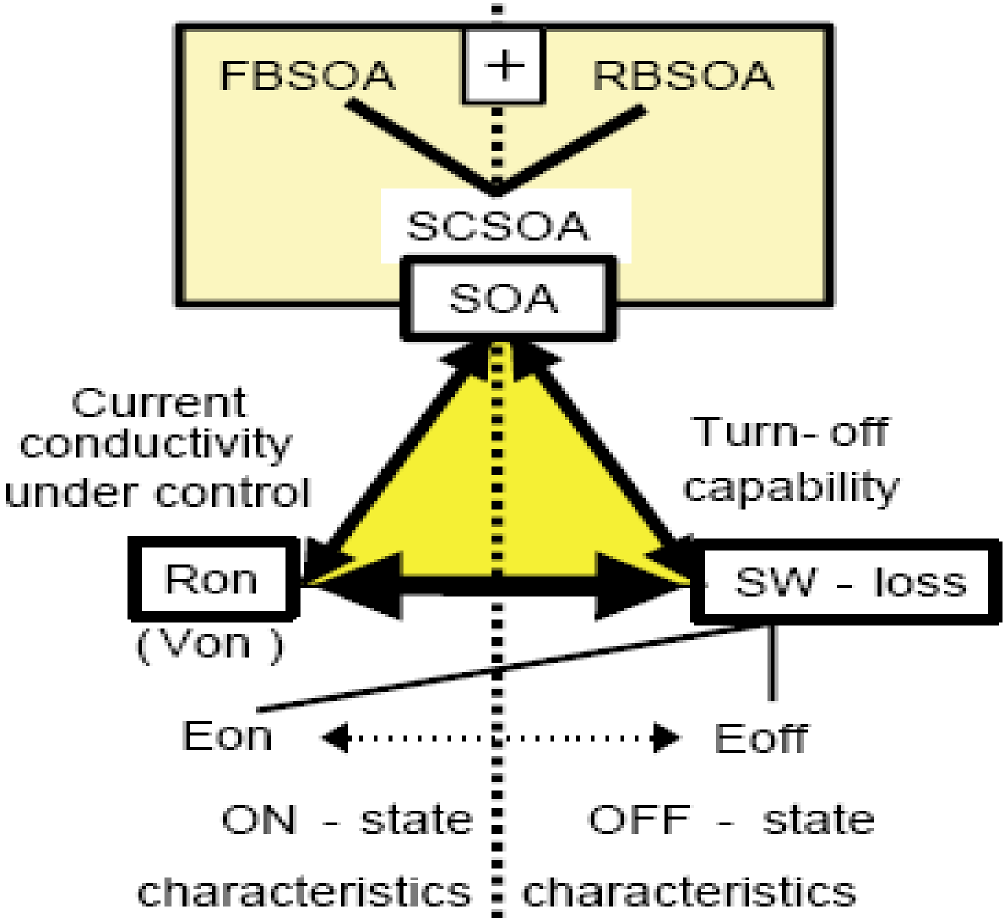
In power semiconductor devices
there is a trade-off between the forward current conducting capabilities (the ON resistance and/or the forward voltage drop) and the turn-off capabilities (the forward-blocking capabilities), where advances in these devices are measured in terms of improvements in this trade-off relationship

- FBSOA - RBSOA
- Vce_sat
- SW - loss
- Turn- off capability
- Current conductivity under control
- OFF – state characteristics
- ON – state characteristics
- SCSOA (Short Circuit SOA)



by Tadaharu Minato and Hideki Takahashi Mitsubishi Electric ADVANCE

IGBT Parameters



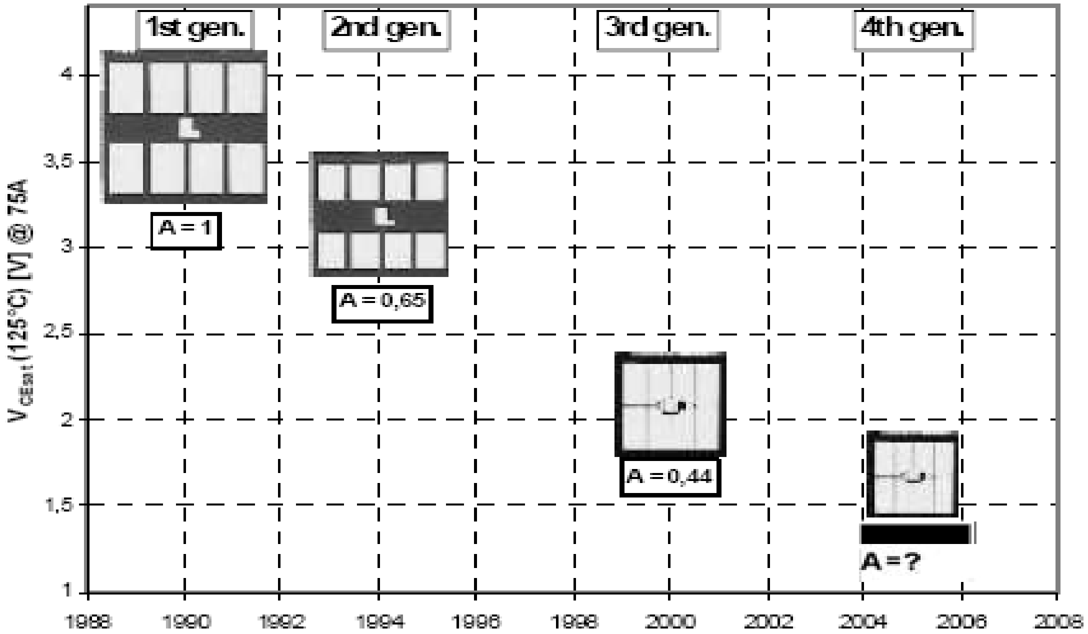
by Tadaharu Minato and Hideki Takahashi Mitsubishi Electric ADVANCE

IGBT Parameters

For traditional 600V, 1200V and 1700V applications in the industrial drives segment an essential demand for short circuit capability of IGBTs exists. Among others this is one reason why the robust

“Non Punch Through” IGBT technology with homogeneous base material dominated the original “Punch Through” concept based on Epitaxial technology. In the last several years a tendency towards a new vertical structure, PT type (thin substrate + buffer layer) called “Trench - Field Stop IGBT3” by Infinion and “Soft Punch Through” IGBT (SPT) by ABB or CSTBT by Mitsubishi.

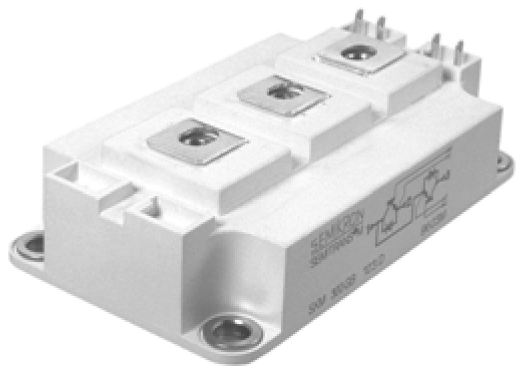
Because of economic reasons there is a strong demand for smaller chips.



65 A/cm^2 80 A/cm^2 120 A/cm^2 ?130 A/cm^2?

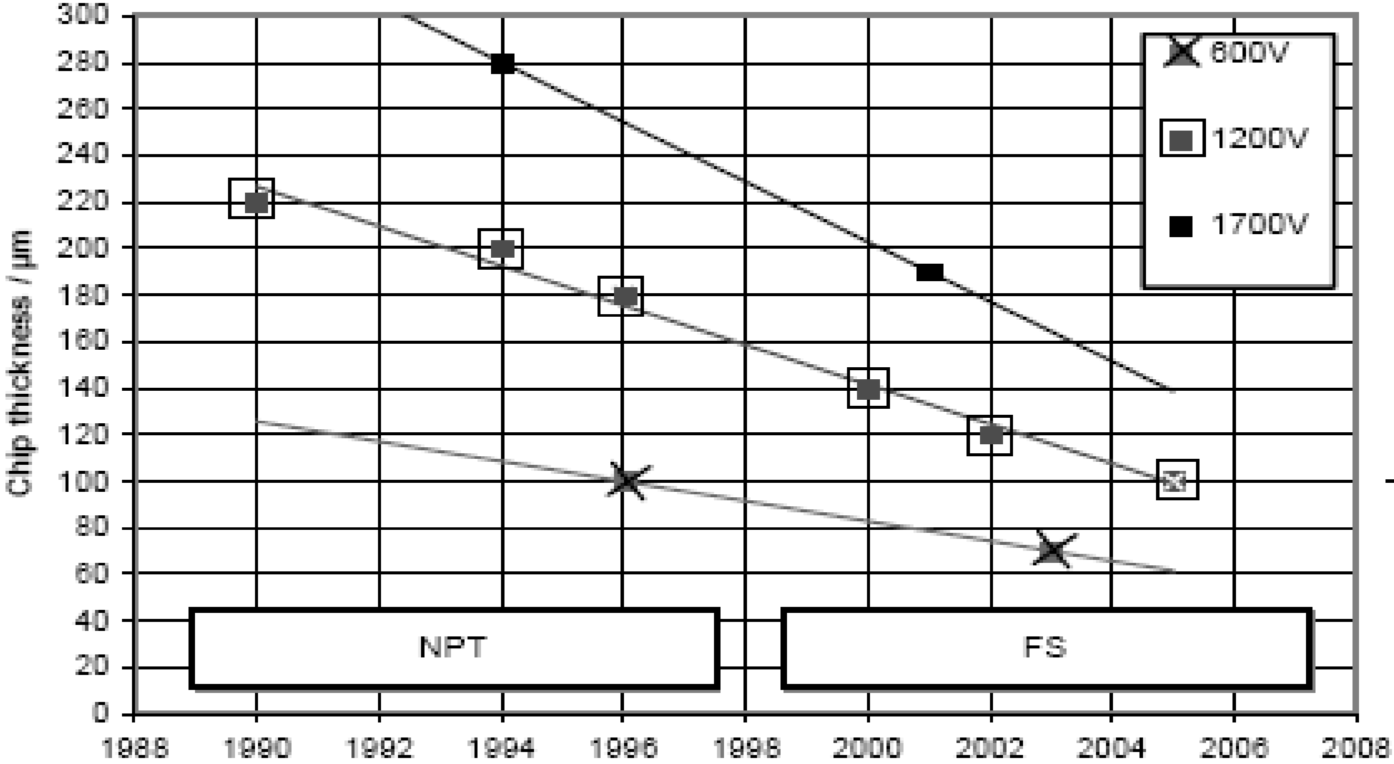
Chip shrink of a 75A/1200V-IGBT Chips

1988: SKM200GB120D
1994: SKM300GB123D
2000: SKM400GB128D
2002: SKM600GB126D



The increase of the IGBT module currents over the last 15 years.

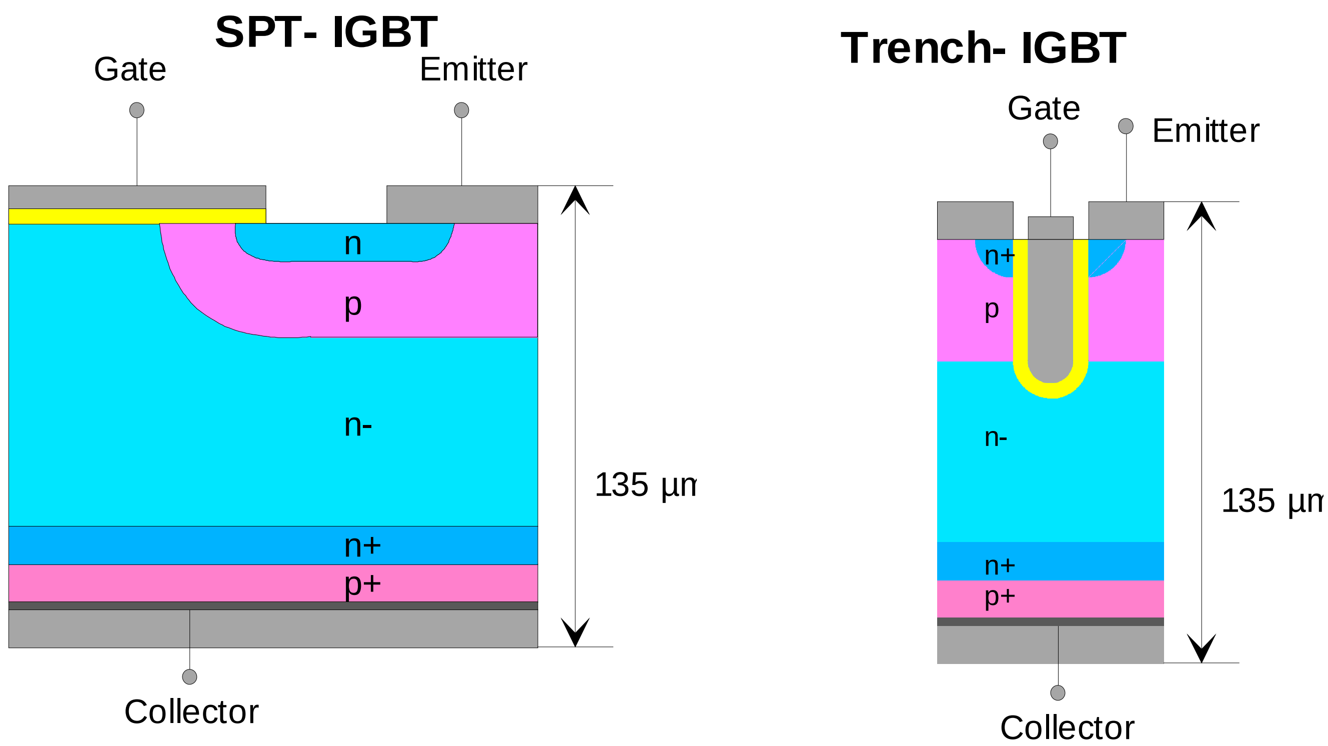
Current density of IGBT Chips



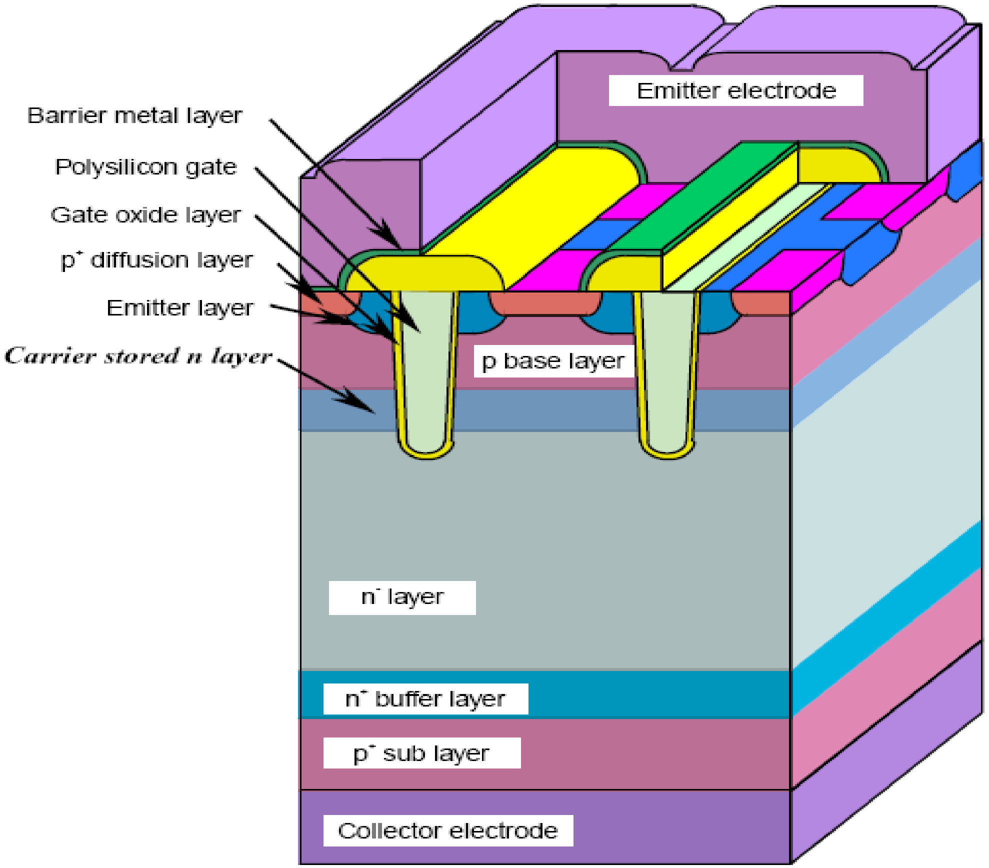
_100µm

Decrease of chip thickness for NPT and SPT (Field-Stop) IGBTs; past and forecast

Thickness of IGBT Chips

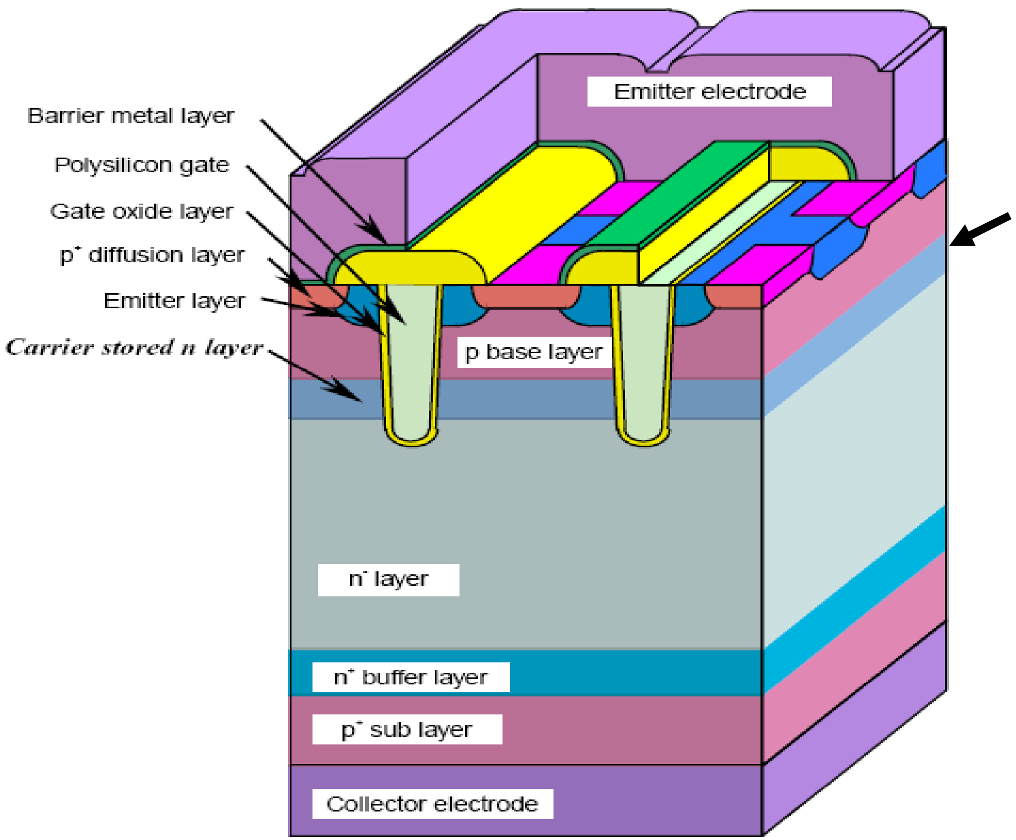


IGBT Structure: SPT and Trench

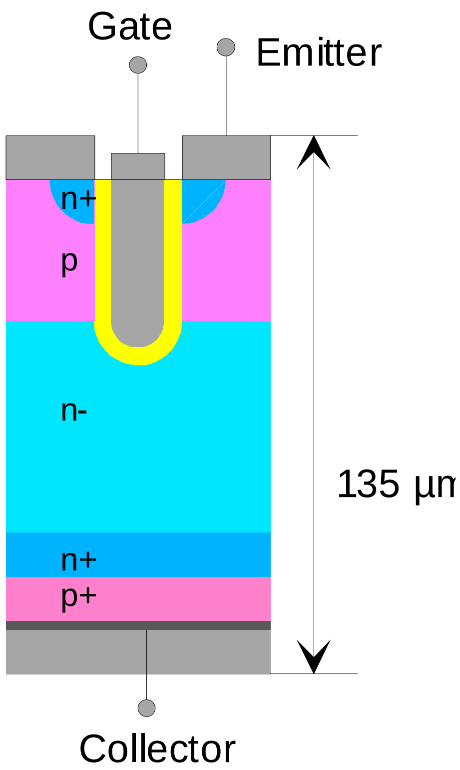


The **C**arrier-**S**tored **T**rench-gate **B**ipolar **T**ransistor (**CSTBT**)

The CSTBT structure



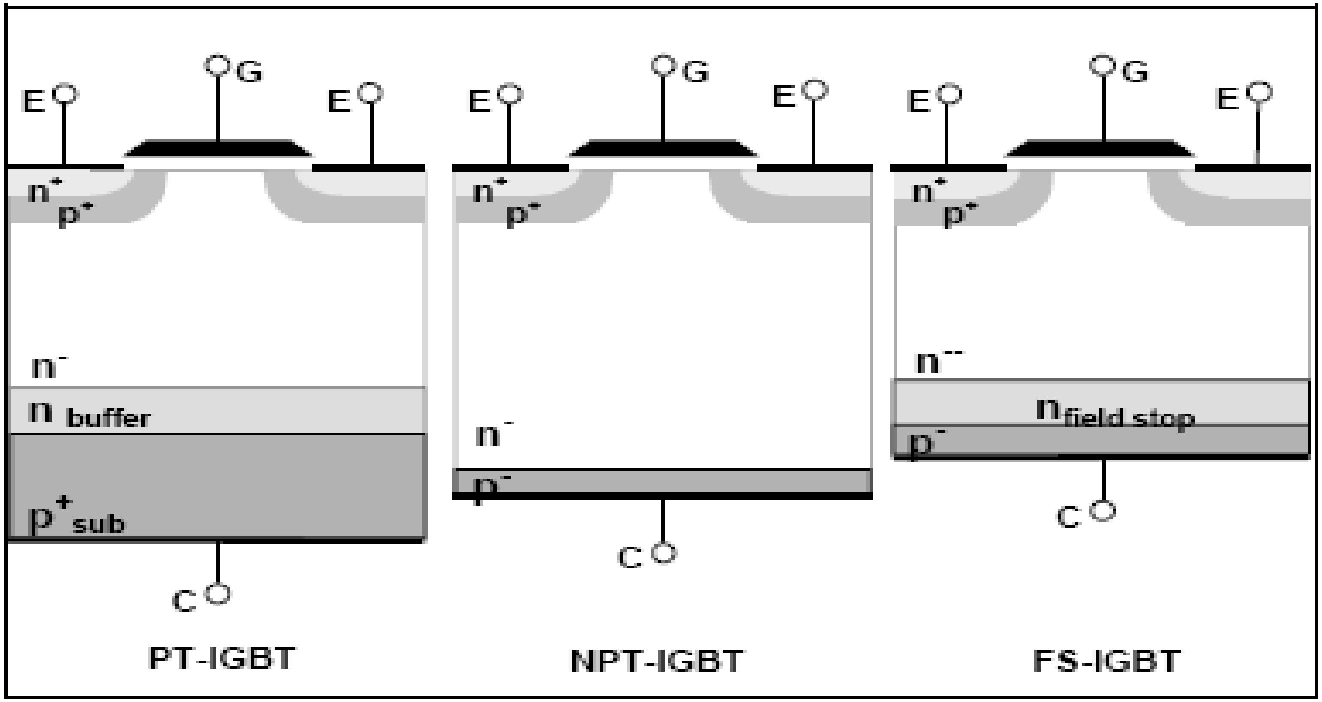
Trench- IGBT



The CSTBT structure

- 1980 IGBT structure patent application
- ('86) **PT-IGBT** 2 layered Epitaxy (n+/n-), planar gate, DMOS (Double Diffused MOS)
- 1988 **NPT-IGBT** n- substrate, thin wafer, planar gate
- (96s) **PT Trench gate**
- (’99s) **Trench Gate field stop IGBT**
- (‘00s) **Soft Punch Through, Planar Gate IGBT, SPT**
- (’01s) **PT-CSTBT** (Carrier Stored Trench IGBT)
- (’05s) **SPT + (PLUS), Soft Punch Through, Pl**anar Gate IGBT, low switching losses**, U**ltra **S**oft
- (late '90s) NPT-IGBT **RB-IGBT** (Reverse Blocking IGBT)
- (’04s) **LPT-IGBT** (LPT-CSTBT) **RC-IGBT** (Reverse Conducting IGBT)

IGBT Technology Trend

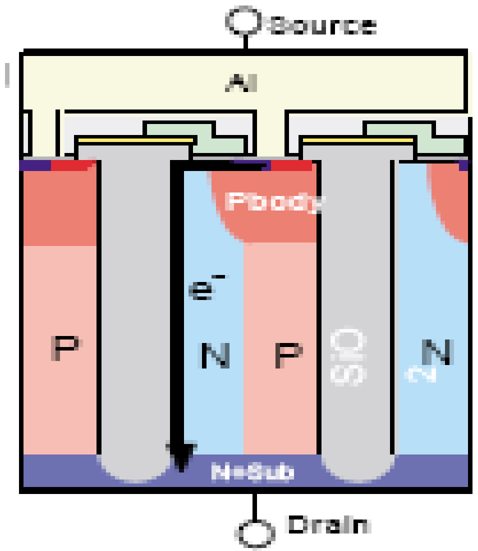


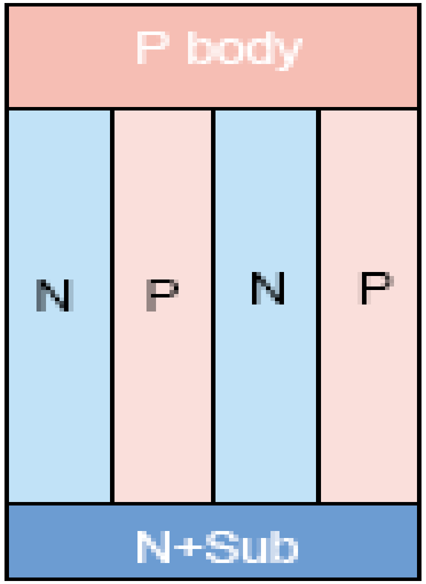
IGBT Chip design

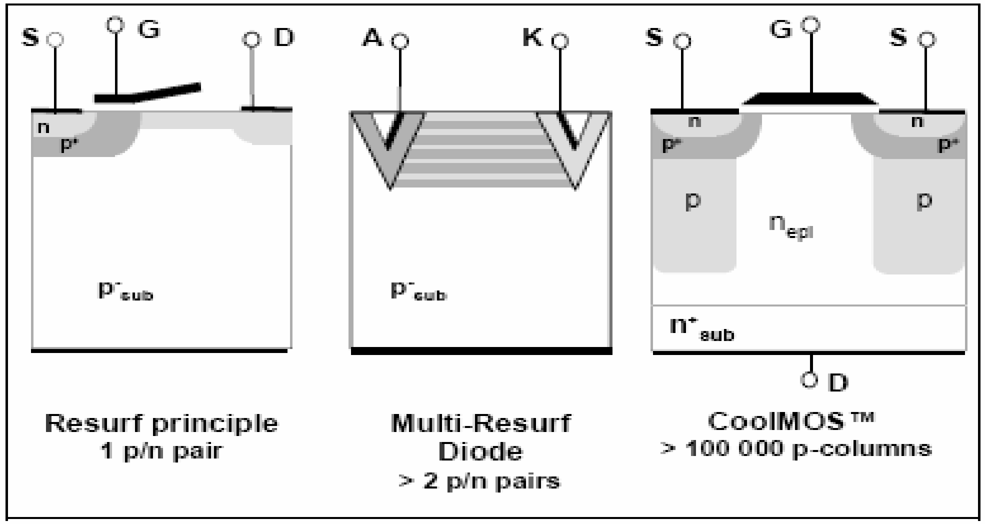
--- Future technology ---

- 2007 Self Clamping IGBT; RB-IGBT; RC-IGBT
- 2009 Super Junction, for >1200V (Like Cool MOS structure, vertical or planar, extreme low Vce_sat)
- 2010 SiC Devices (ex. Junction -FET)

  (SBD : Schottky Barrier Diode known today)







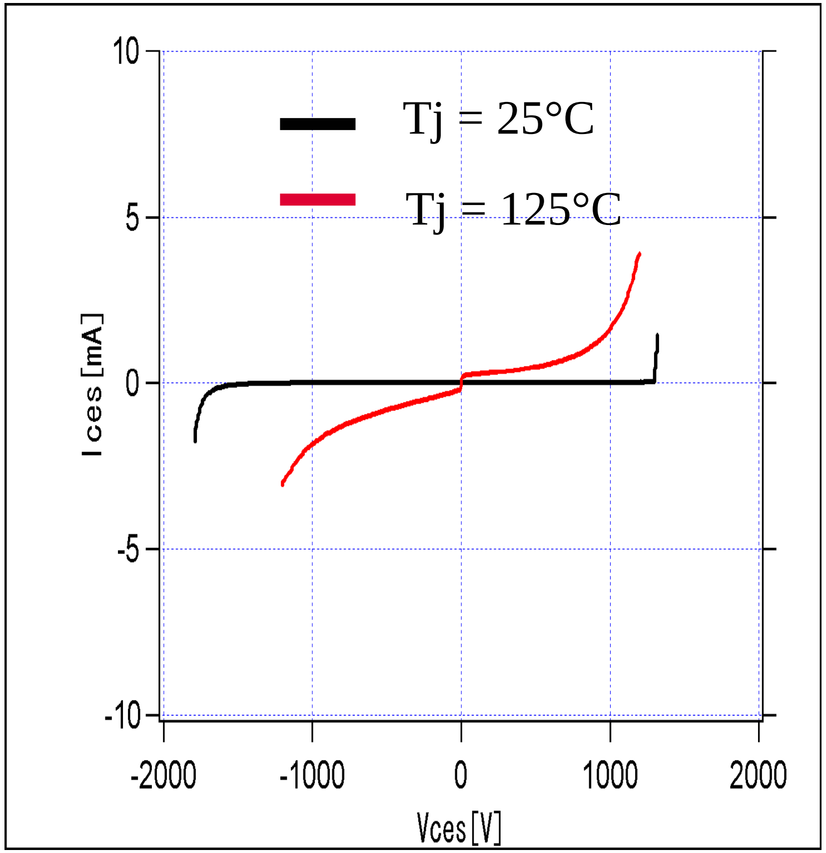
Vertical Structure

Super Junction Technology

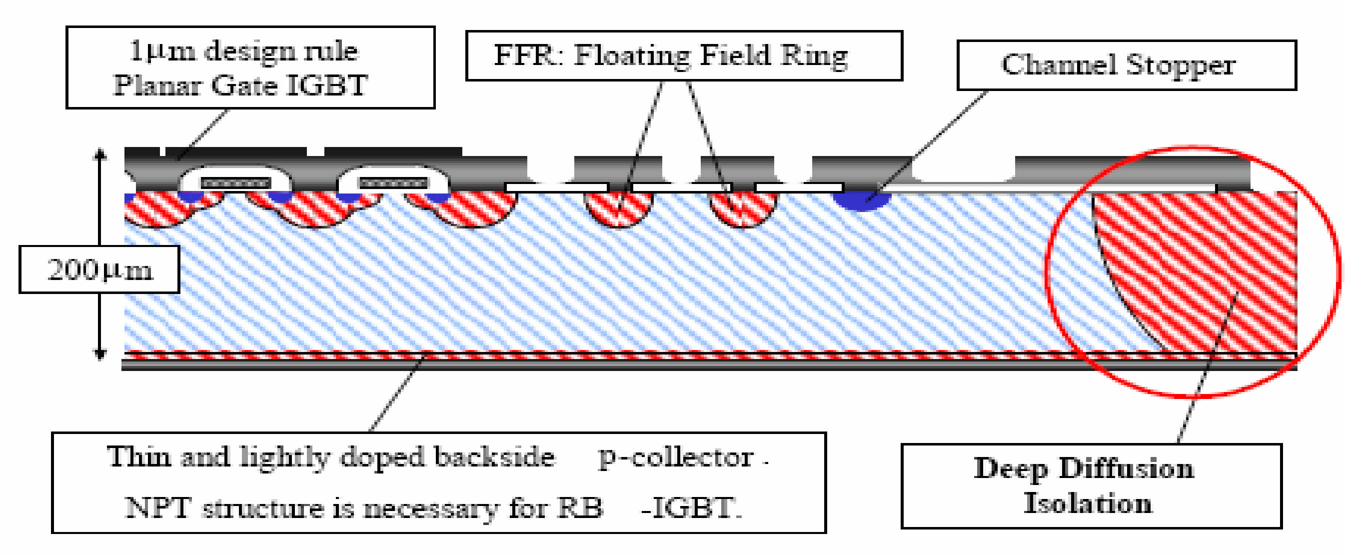
Reverse Blocking IGBT

- The RB-IGBT has a symmetrical blocking voltage characteristic. This means that it can block both forward and reverse voltage in its off state.

  As a result the bidirectional switching element can be simplified because the need for series connected diodes is eliminated.

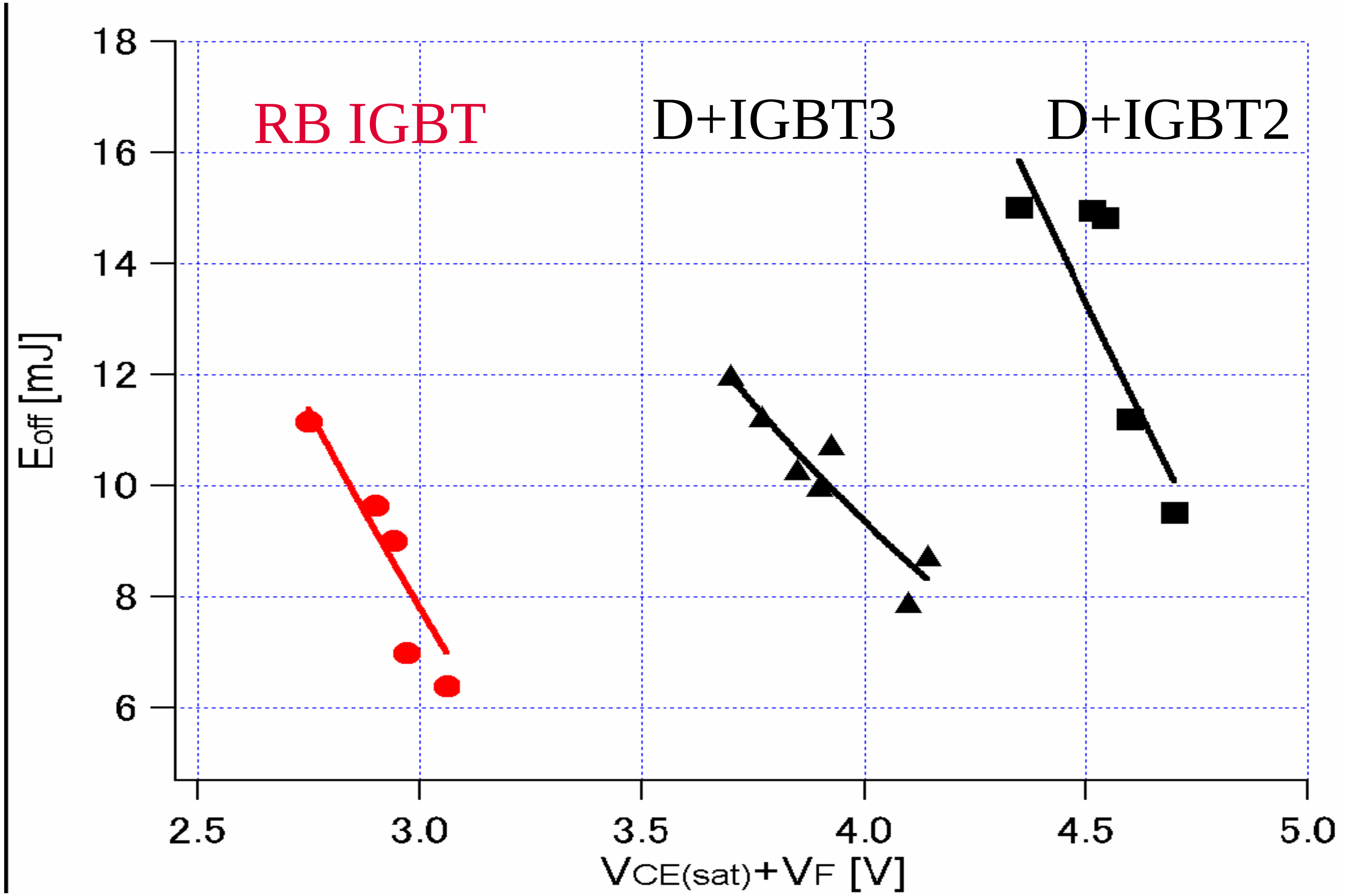


The RB-IGBT is similar to a conventional IGBT except that it has a deep diffusion collector wall surrounding the chip active area. This collector isolation allows the IGBT to block reverse voltage. The isolation is produced using a special process designed to maintain a high breakdown voltage and stable leakage current characteristics at elevated temperatures while minimizing processing time.



RB-IGBT Chip Structure

Eoff versus On-state voltage drop trade-off

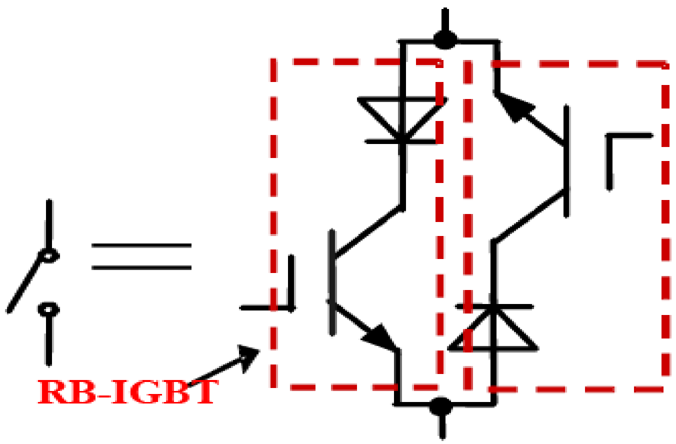


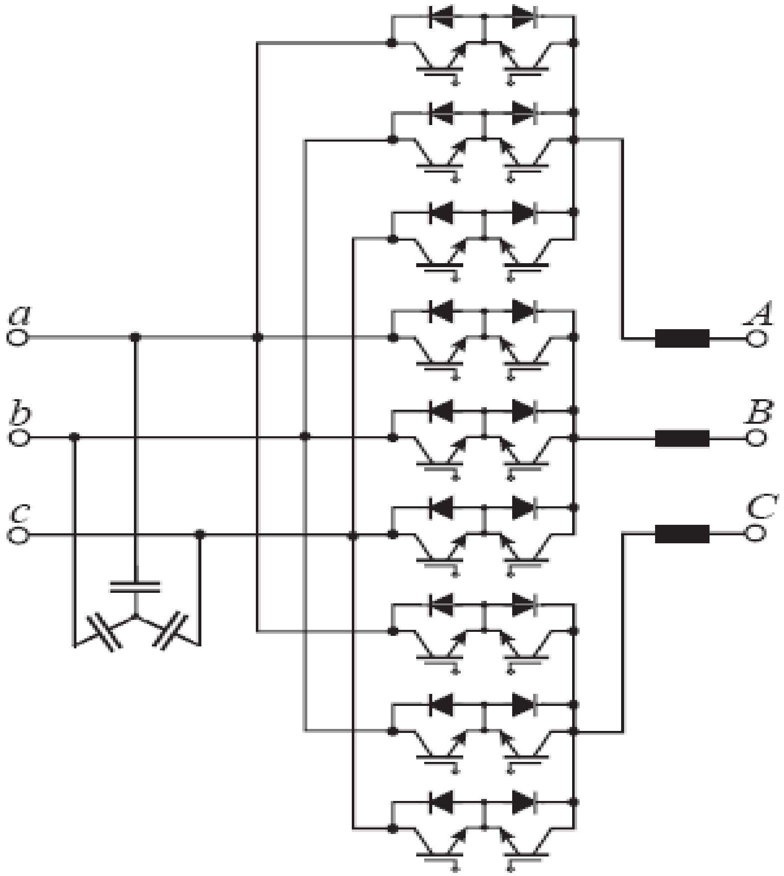
SEMIKRON innovation + service

Almost all semiconductor producers are able to produce RB IGBT. Only, there is no demand for a mass production, no industrial applications for such a product.

Application demands for RB IGBT:

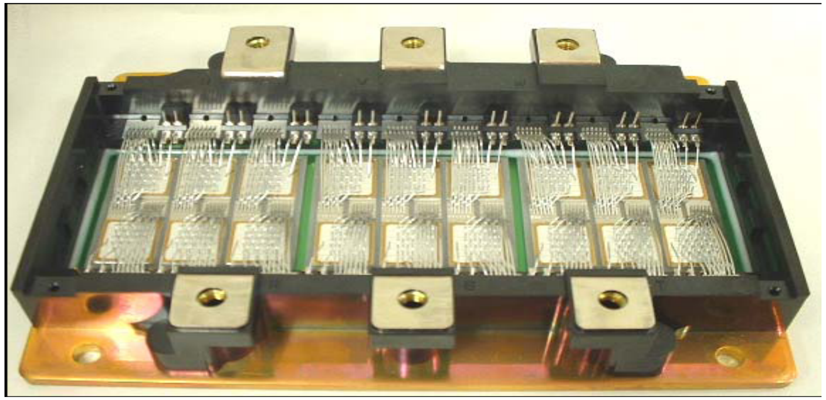
- Matrix Converter
- Current source inverter
- Static switch
- AC Voltage Control

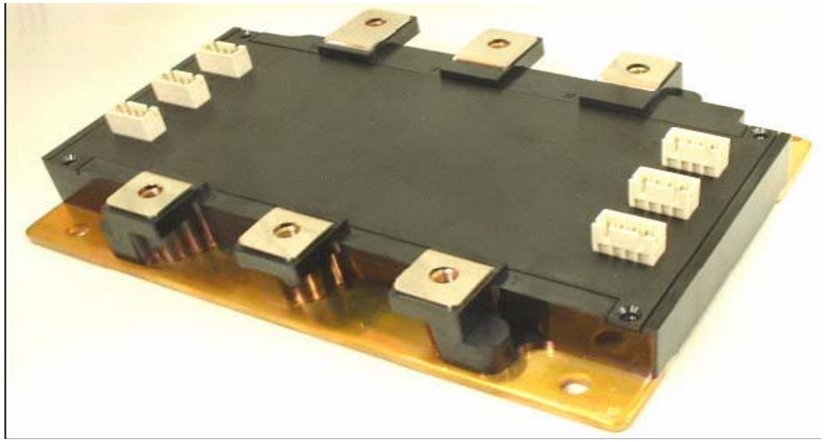




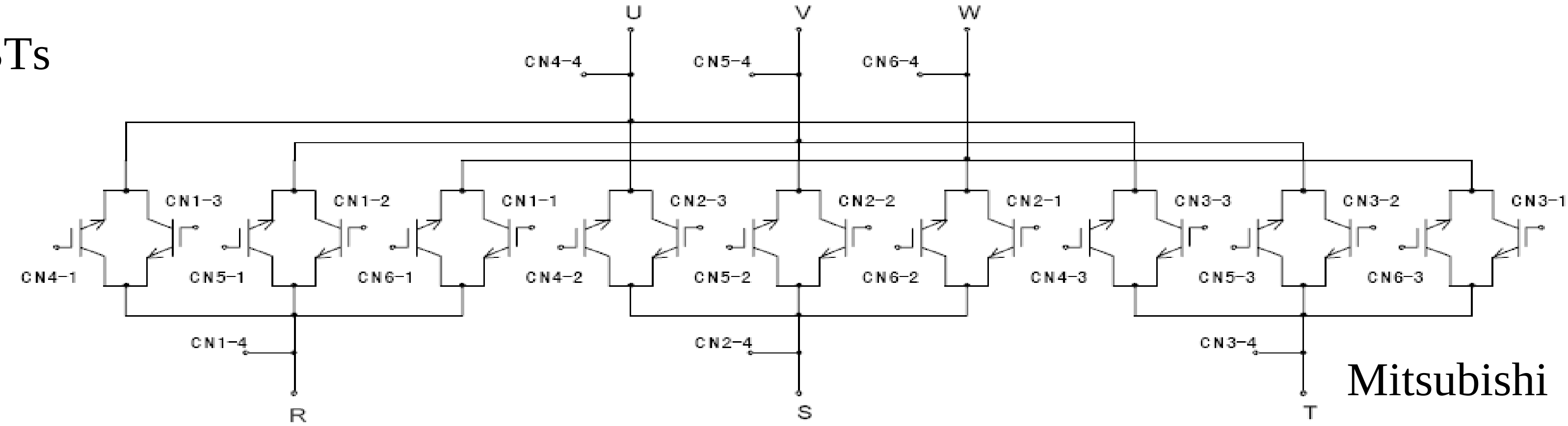
With existing IGBTs and series diodes

Matrix Converter



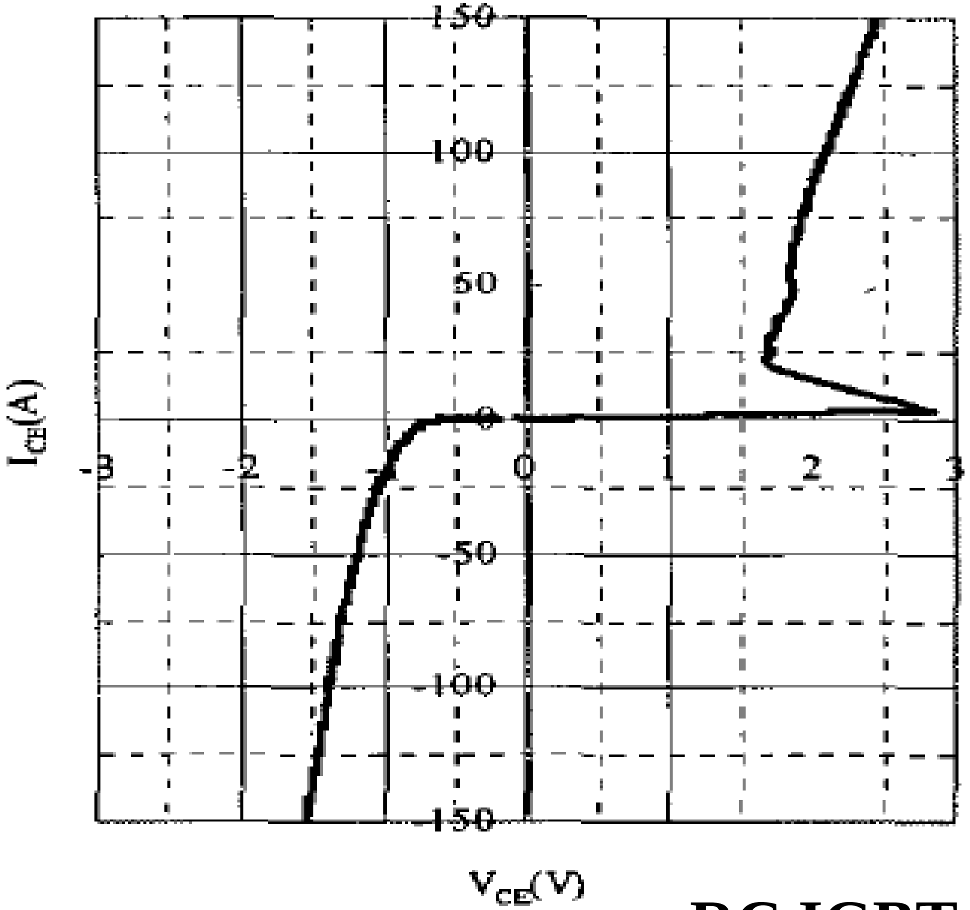


RB IGBTs

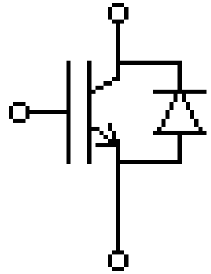


Mitsubishi

Matrix Converter Module Prototype

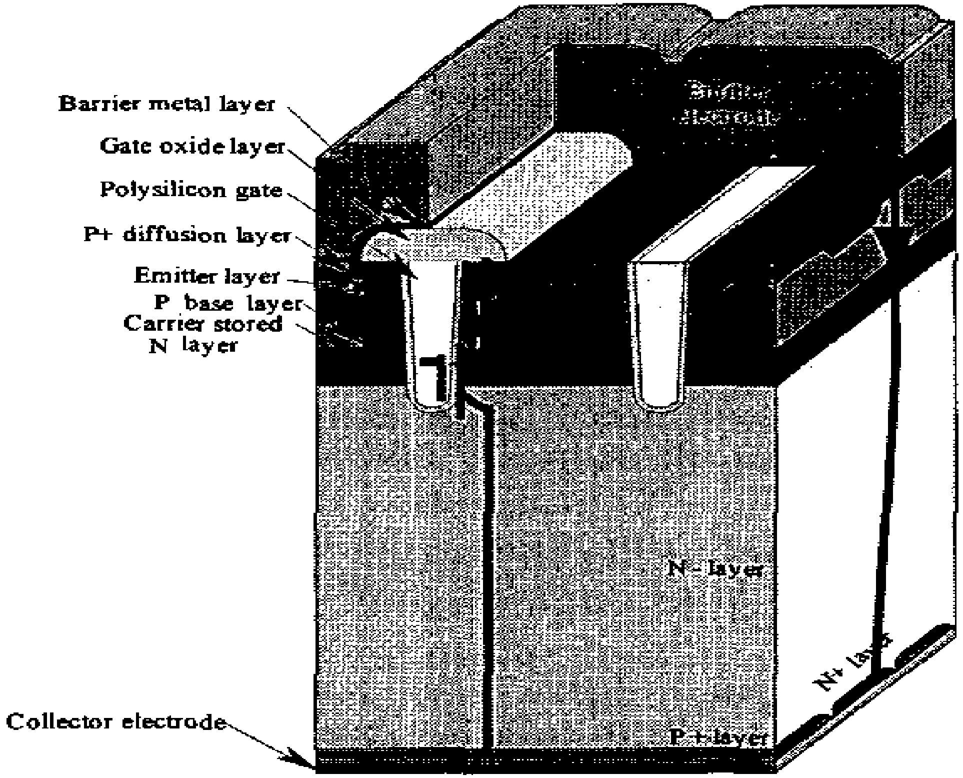


IGBT Chip with built-in FWD



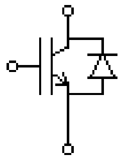
RC IGBT Output Characteristics

Reverse **C**onducting **IGBT**



The strip N-region and strip P-region are independently formed on the wafer backside in the orthogonal-crossing direction to the wafer front side trench-gate stripe direction, instead of forming conventional stacking N-buffer and P-collector layers.

P-region and N-region are formed side by side in the backside structure



IGBT with built-in FWD

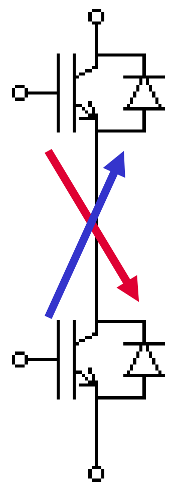
Three dimensional view of RC IGBT structure

RC IGBT Application: voltage source converters

+ Compact construction of IGBT and its FWD
+ Less bonding wires
+ Relatively simple Chip construction
+ Better chips utilization, lower chip rand, (guard rings) structure
- IGBT and diode losses are on the same chip
- IGBT is near to the own FWD, but there is no force current commutations between those two elements

  Top IGBT commutate with bottom diode

  and bottom IGBT commutate with top diode

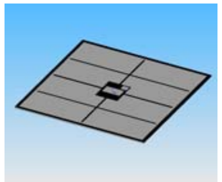


RC IGBT

The term IGBT indicates a unit- cell
structure in an area several microns wide on a silicon chip.

The user, on the other hand, thinks of it as a white (or black) plastic package, on the heatsink, and the final product characteristics, Ic, Vce_sat, Eon&Eoff, Rth_ch, typically SOA, reliability, durability, etc; are also viewed as expressions of the device rather than the performance of the chip itself.

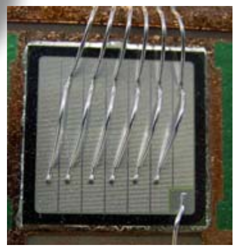
How to make IGBT chip packaging?

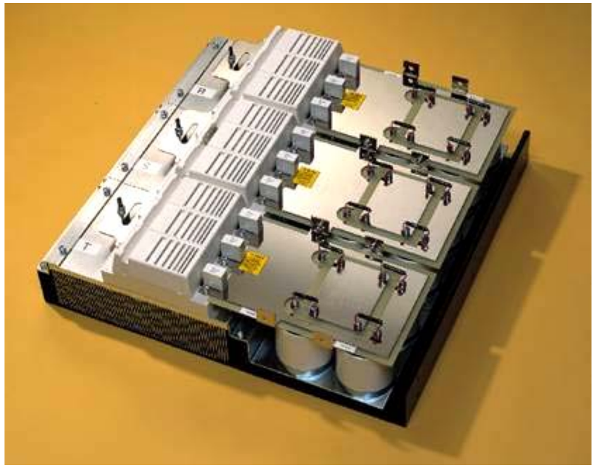


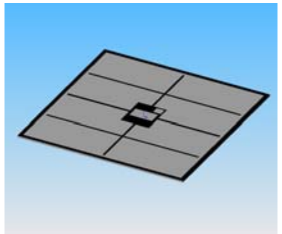
What is an IGBT?

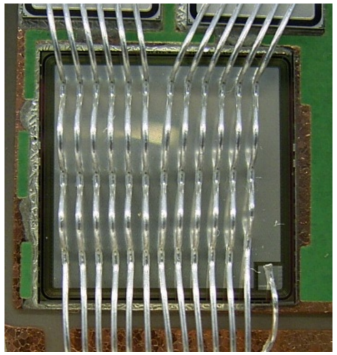
Open questions

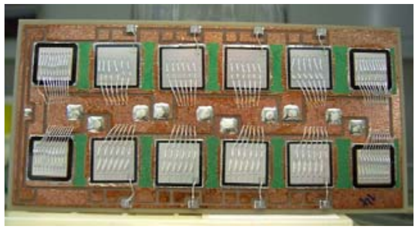
- Silicon Chips produce the losses and have to be placed on the heatsink.
- An isolation between chips and heatsink is needed - ceramic substrate DCB
- Construction with low stray inductances
- High power converters needs a lot of chips in parallel; how to parallelized them
- Applied electrical circuit
- High power needs a high current. Higher voltage needs less current. How to make **M**edium **V**oltage converters
- **MV** silicon
- **MV** windmills
- Wind parks and off-shore applications







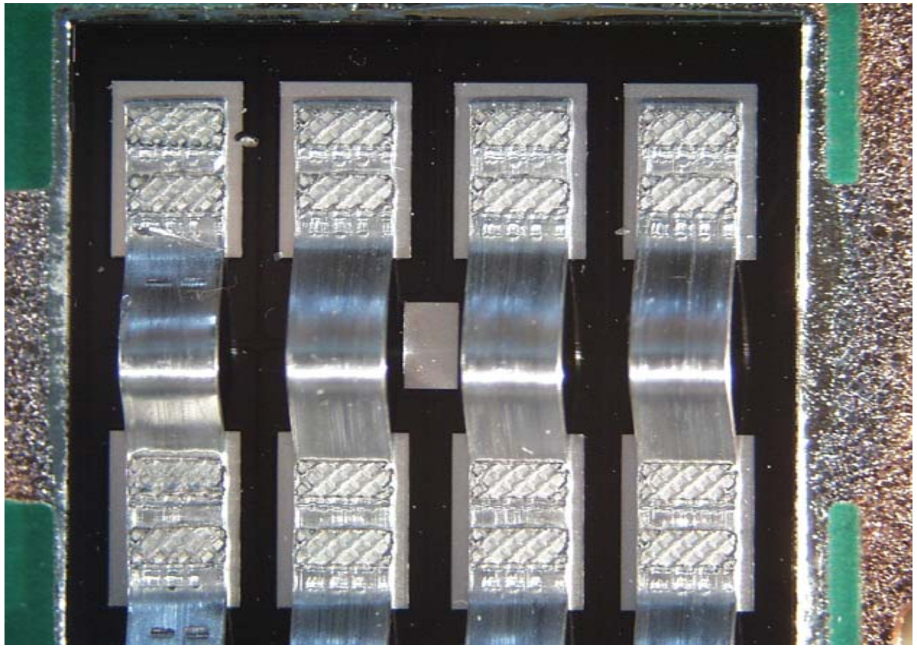




From the wafers to the Windmills

Ribbon Bonds allow 2-4 times higher Current Densities than traditional Bond Wires

300µm 60x8 mil

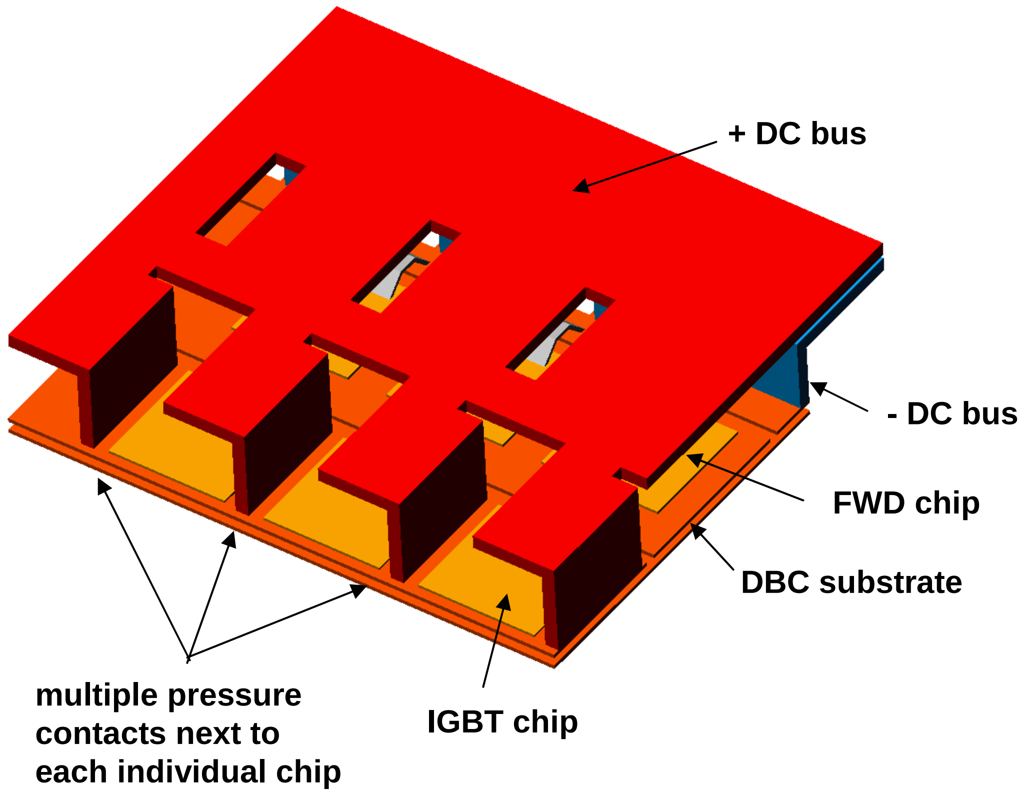


IGBT with Ribbon Bonds

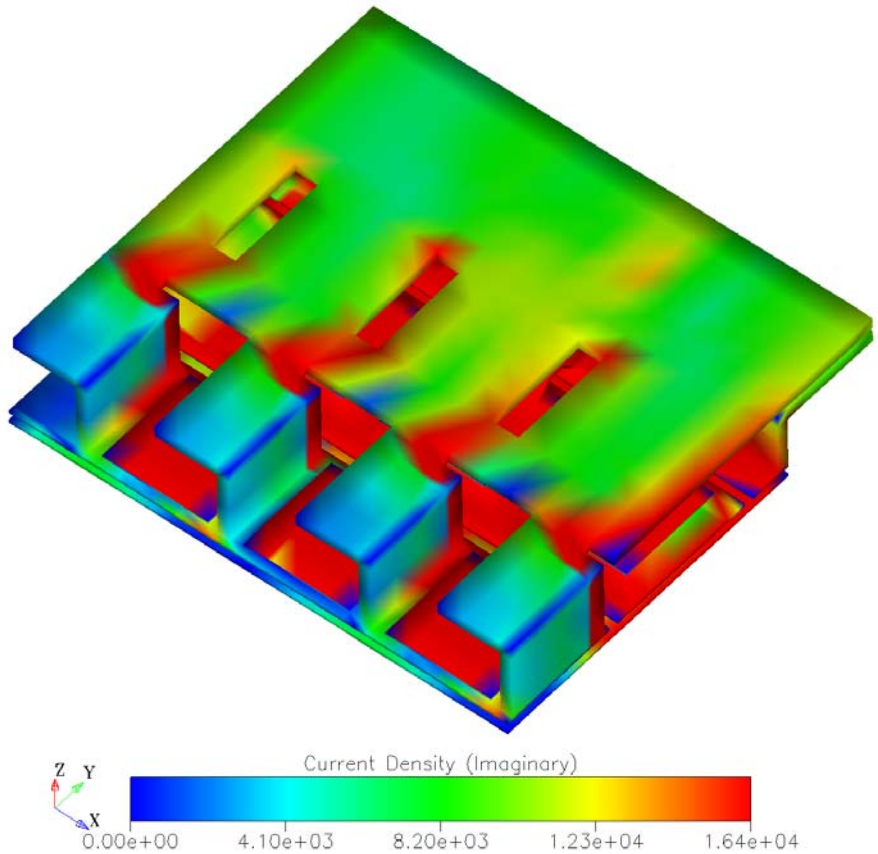
Ribbon Bonding Technology

Low inductance is crucial

- Every switch cycle is creating overvoltage spikes.
- For fast switching transients the parasitic inductance L_σ need to be small $V = L_\sigma \, di/dt$
- Overvoltage spikes are causing EMI problems
- Optimum current sharing of paralleled devices
- No need for additional snubber capacitors

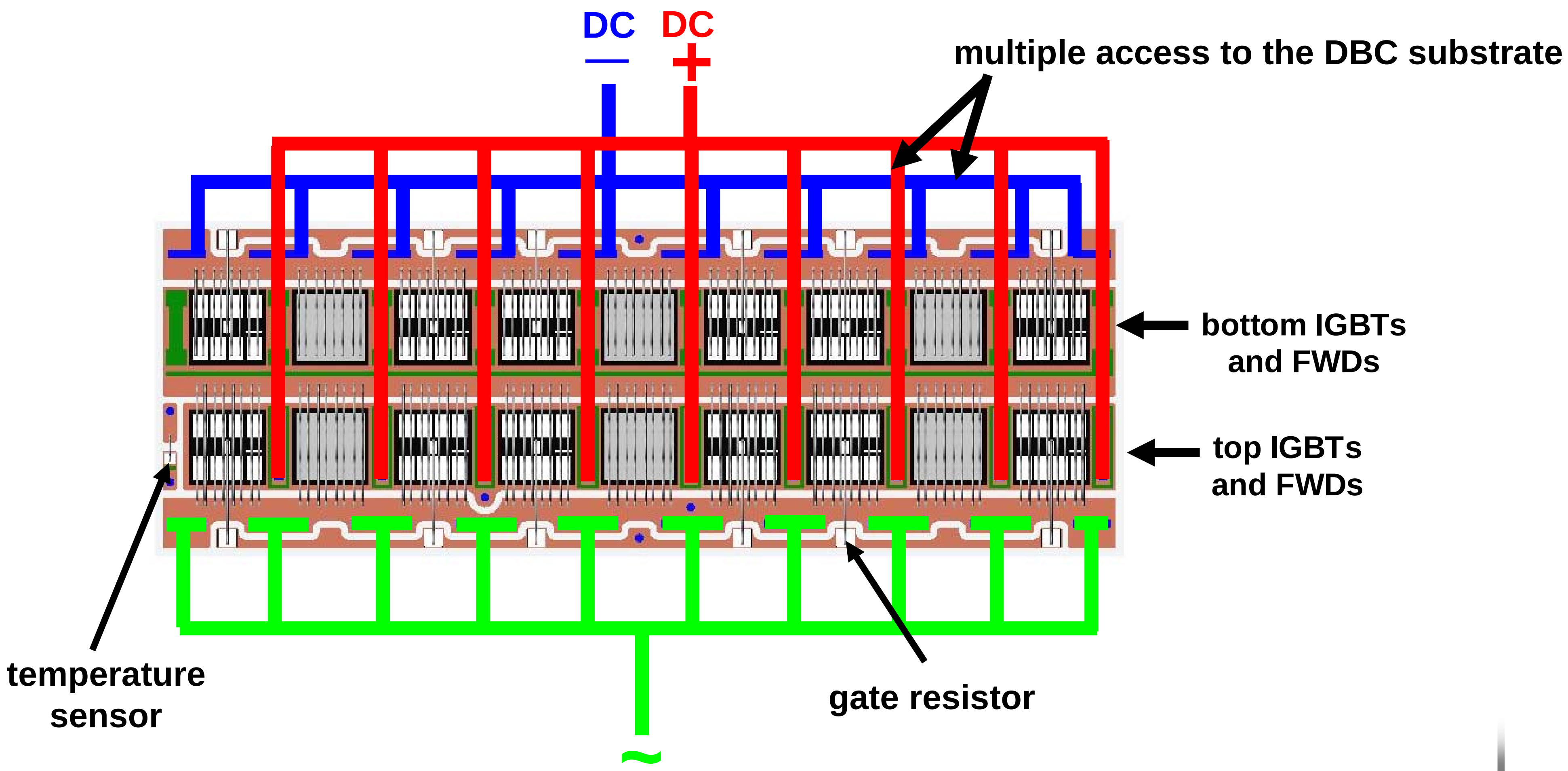


Simplified model for simulating DC link and DBC substrate

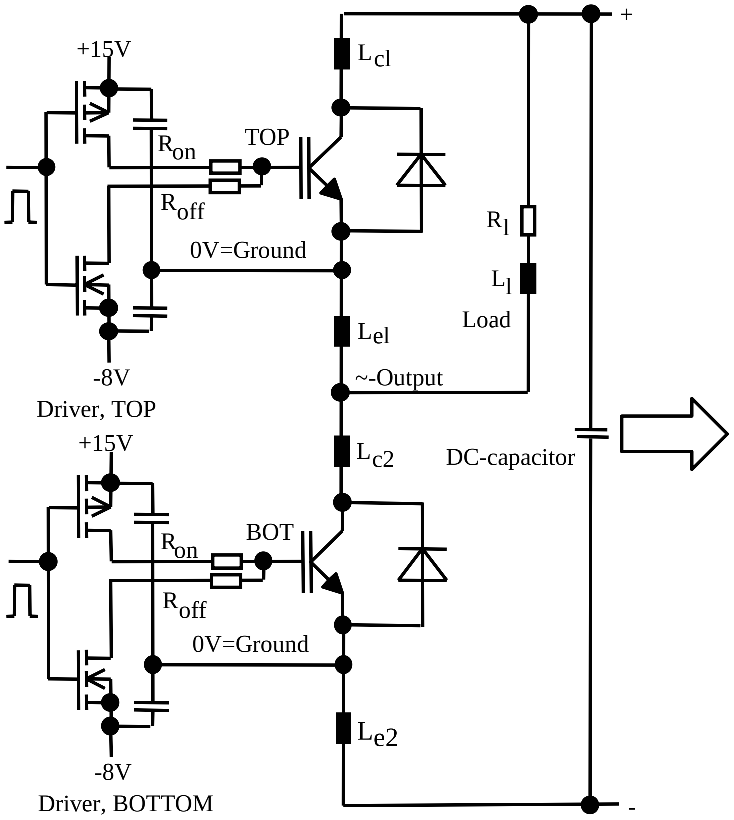


Simulated current density (top IGBTs are turned on)

Simulation of Electromagnetic and Thermal Properties



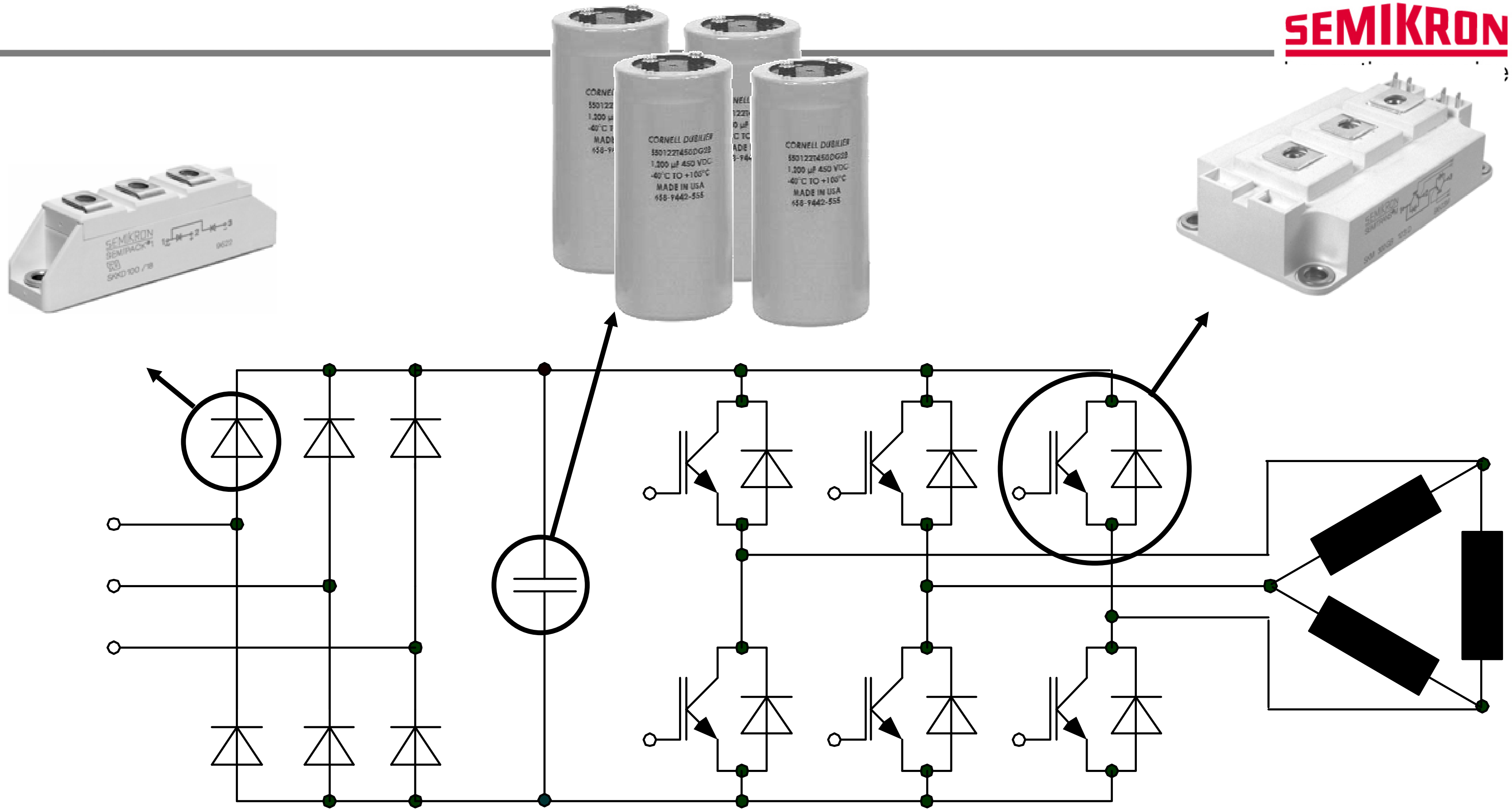
Low Parasitic Inductance of the Construction



Module	L_{CE}
Semitrans 3	20 nH
SKiiP 2	15 nH
SKiiP 3	7.5 nH
HV SKAI	4.0 nH

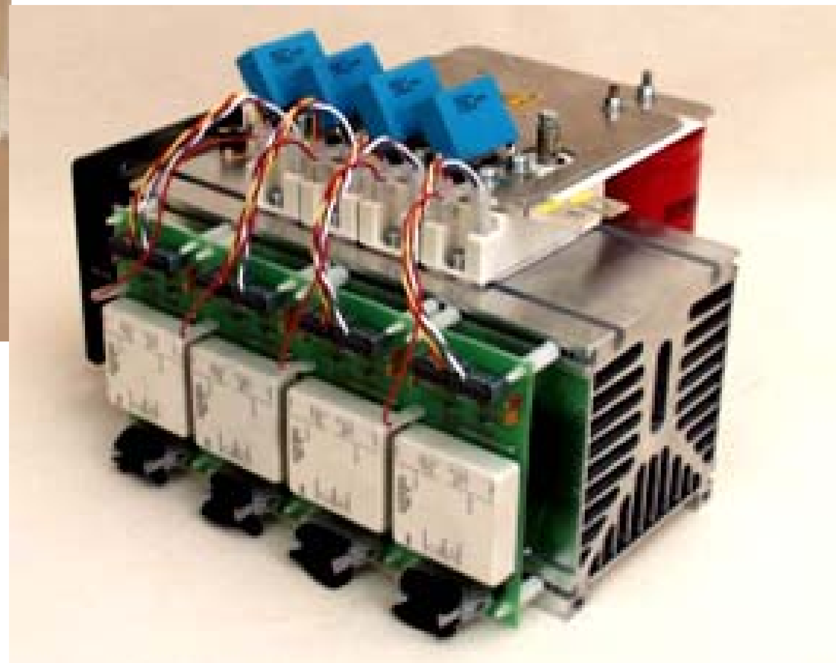
Commutation Inductance L_{CE}

SEMIKRON

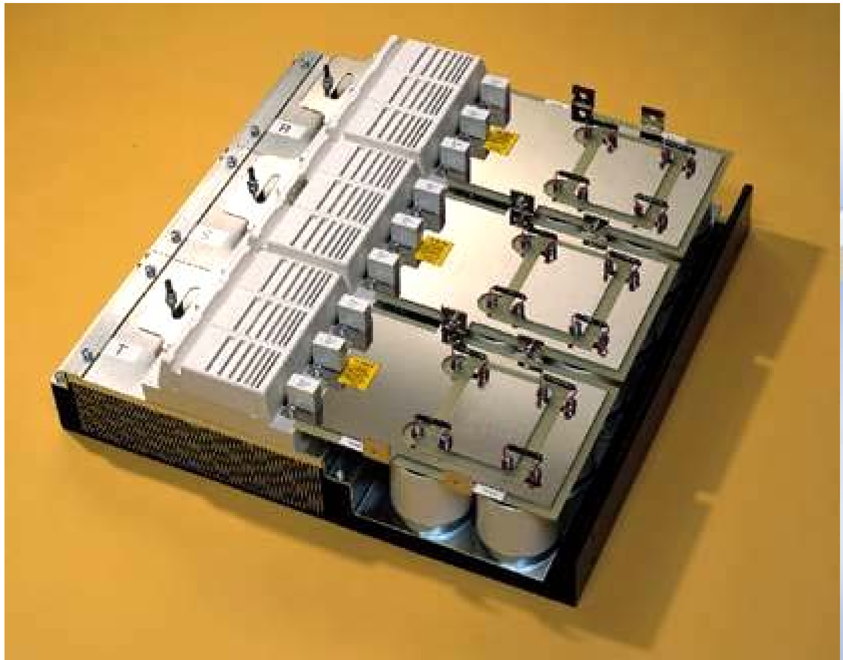


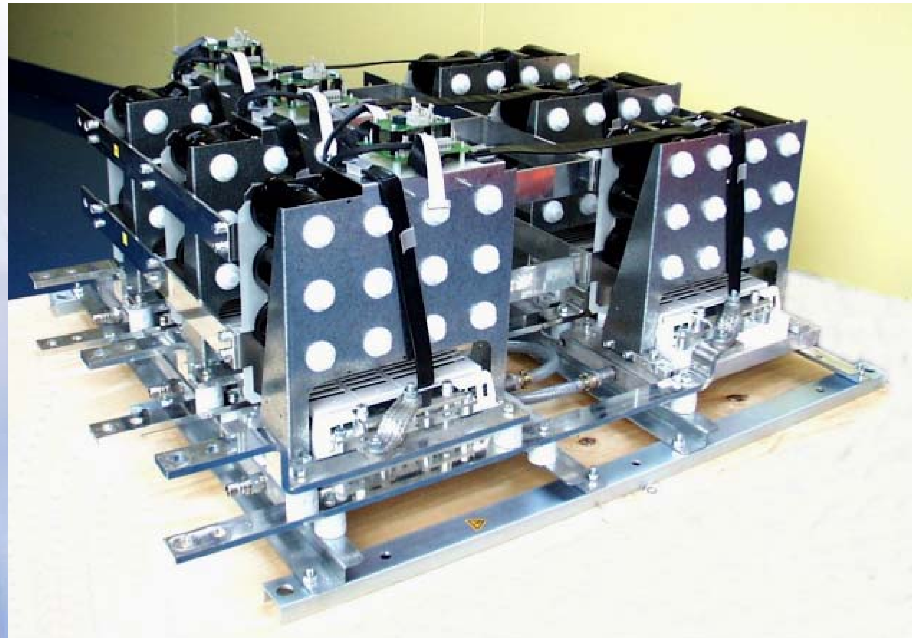
Power Semiconductors, DC Link Capacitors, Cooling, Bus Bars, Sensors, Drivers, Controller, Housing

Drives Solution with Discrete Components



Solutions with Discrete Components

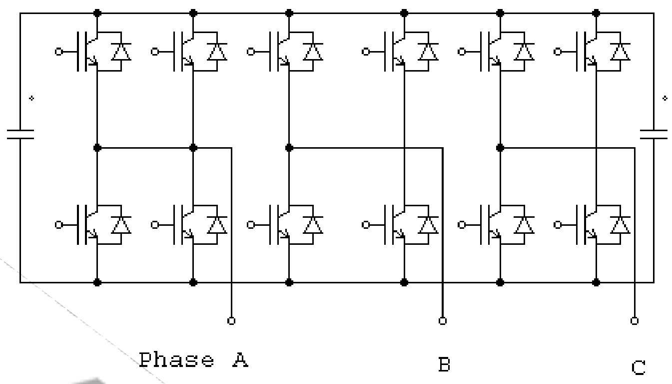




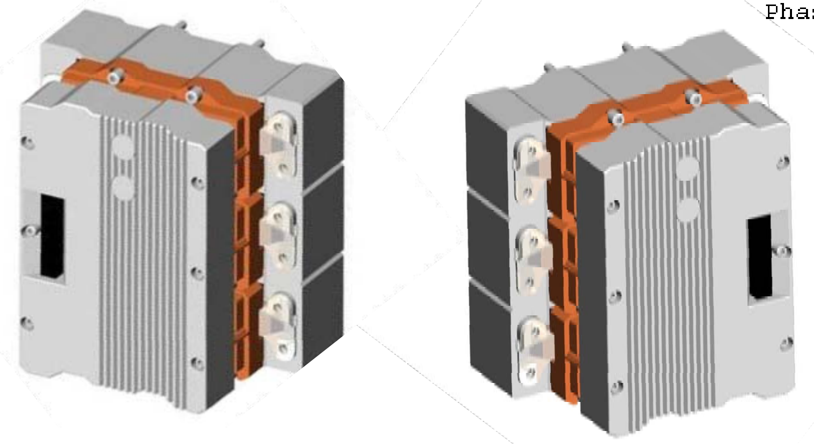
High Power Inverters in SKiiP-Technology

Compact power construction for 690V

Liquid cooling, DC link capacitors, drivers, protection and PWM controller



2 SKiiP513GD172



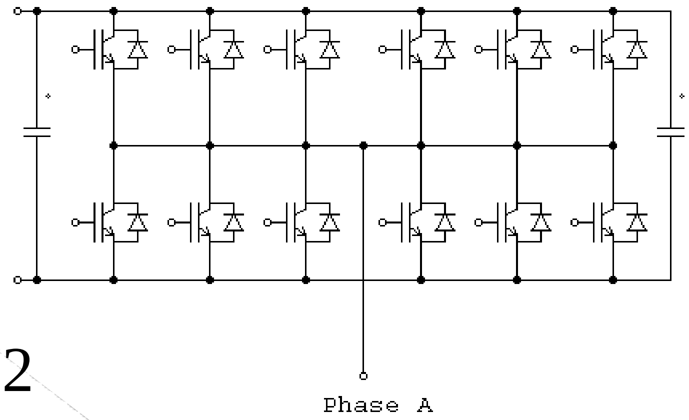
600kVA; Three-Phase Inverter; volume 50 liter, 12kVA / liter

Example with a 600kVA base unit

SEMIKRON
innovation + service

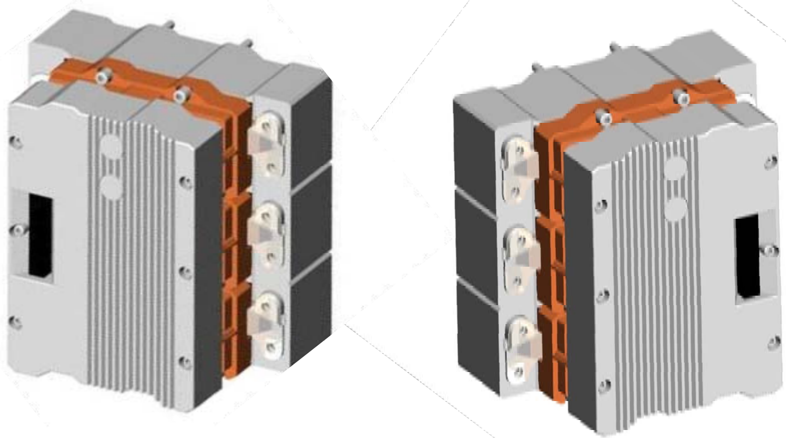
- High Power compact construction for 690V.
- Liquid cooling, DC link capacitors, drivers & protections, PWM controller

3 x



3 x 2//SKiiP1513GB172

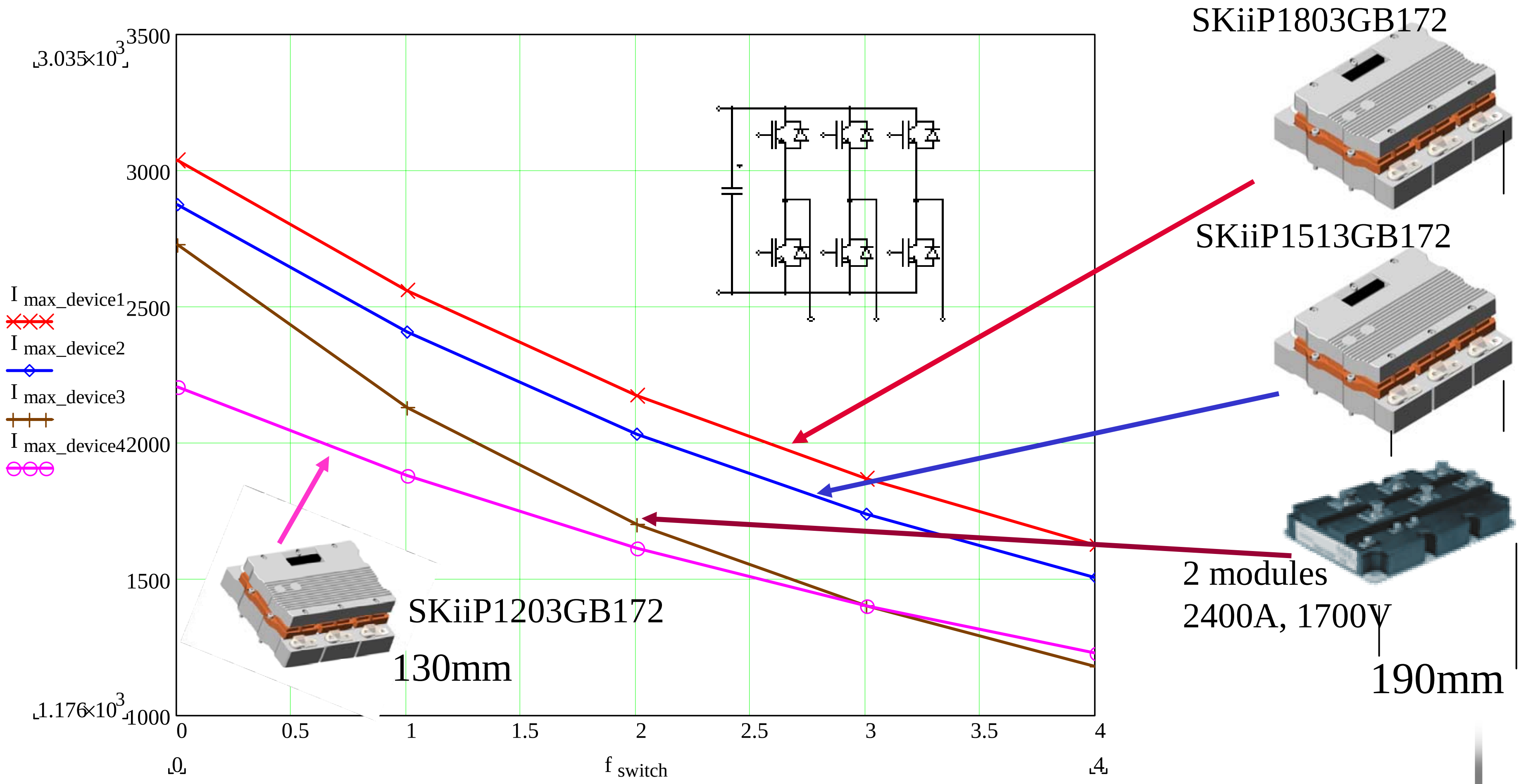
1800kVA



Example with 1800kVA base unit

1700V power semiconductors under same operation conditions

SEMIKRON
innovation + service



Load current vs. switching frequency

Solutions for parallel operation of the IGBT modules

1. One unit for the whole power

   One driver and a lot of IGBT Modules in parallel. Each IGBT Module has its own gate resistors

2. Paralleling of Power STACKs

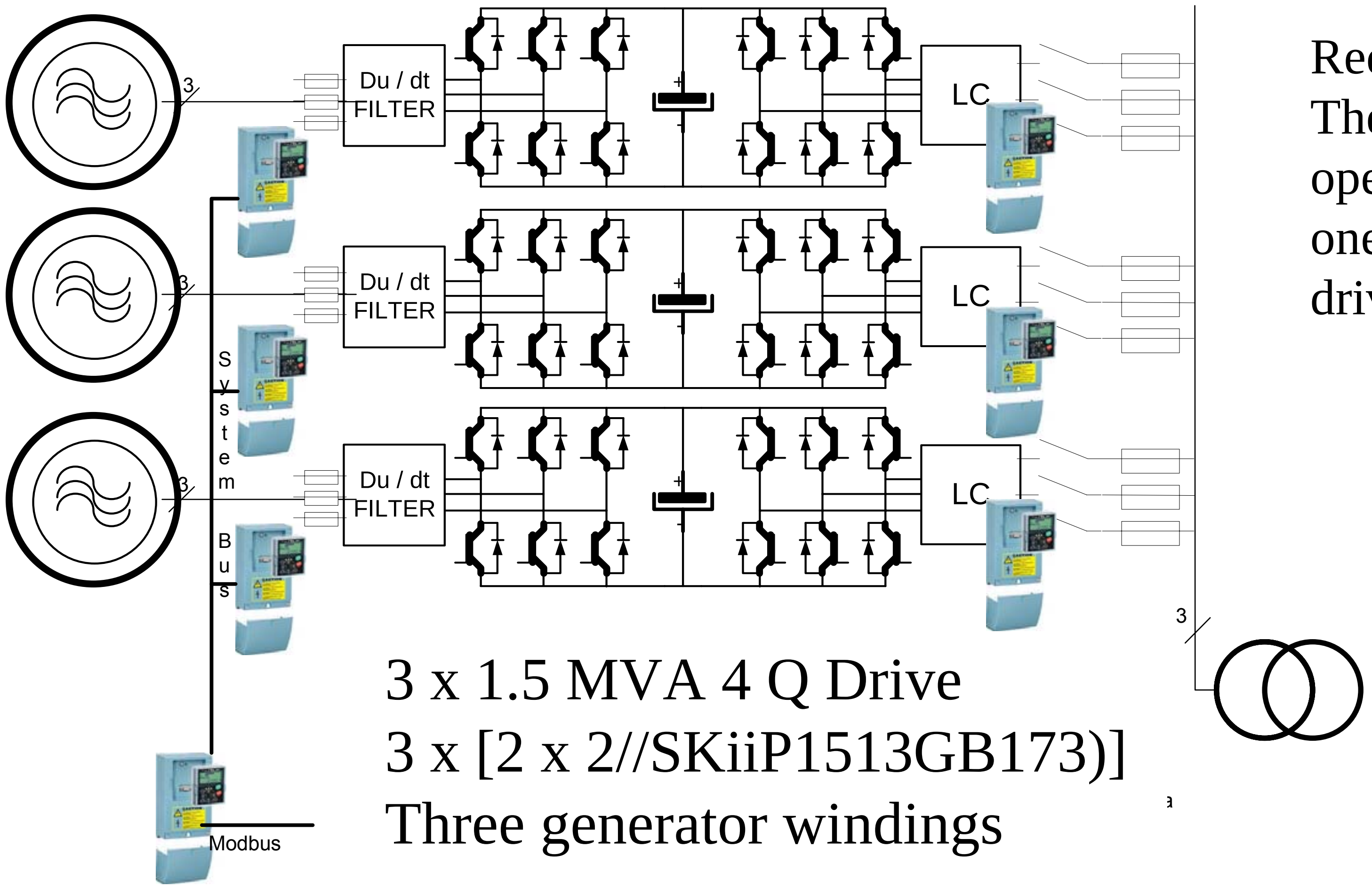
   Two or more gate drivers are driving a group of IGBT modules. One PWM signal is connected in parallel to each driver.

3. Controlled load current sharing of parallelized Power STACKs (Sophisticated PWM control)

4. Galvanic isolation on one side

   (easy paralleling of standard independent basic units)

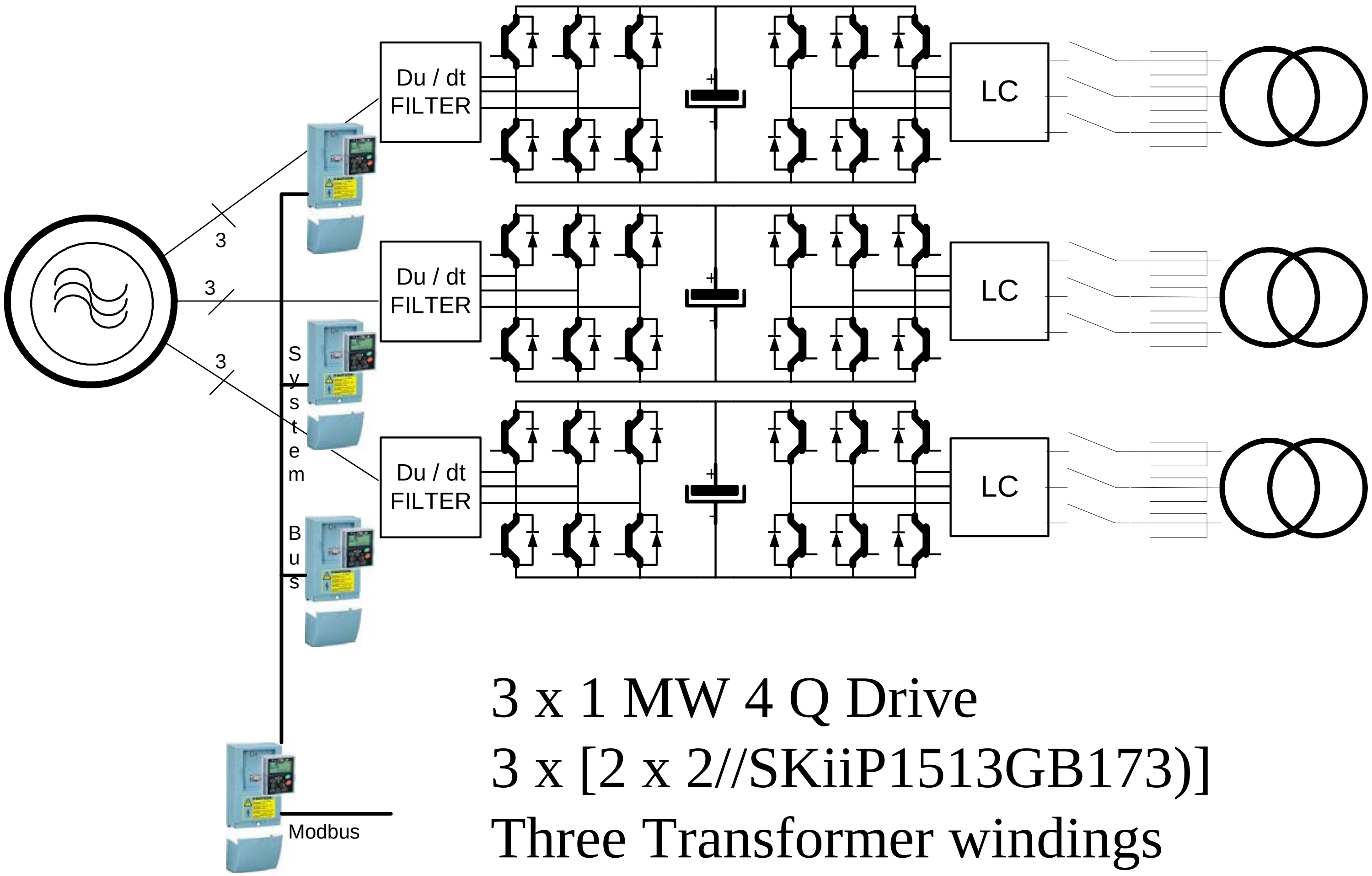
Paralleling of IGBT Modules



Redundancy:
The drive can operate with one or two drives in parallel

3 x 1.5 MVA 4 Q Drive
3 x [2 x 2//SKiiP1513GB173)]
Three generator windings

Three independent 4Q drives in parallel, with separate motor windings



Redundancy:
The drive can operate with one or two drives in parallel

3 x 1 MW 4 Q Drive
3 x [2 x 2//SKiiP1513GB173)]
Three Transformer windings

Three independent 4Q drives in parallel, with separate transformer windings

1.5 MVA, 4 Q drive cabinet

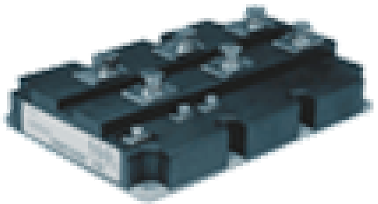
- Medium Voltage Levels:
- 2.3 kV, 3.3 kV, 4.16 kV, 6.3 kV, 11 kV, 13.8 kV…..35kV

- Motor Power Range: 200kW ... 6000 kW .... 11MW……50MW
- Semiconductor Blocking Voltage Range:
- 1.2 kV, 1. 7 kV, 2.5kV, 3.3kV, 4.5 kV , 6.5kV

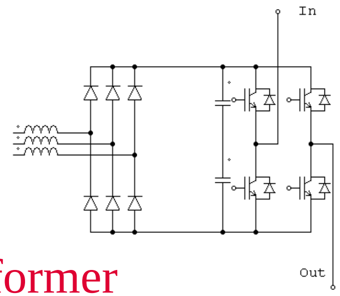
- Line / (Semiconductor Voltage Range):
- 480Vac/ (1200V); 690Vac/(1700V), 1250Vdc/(2500V),
- 1800Vdc / (3.3kV); 2.2kVdc / (4.5kV); 3.3 kVdc/ (6.5kV)

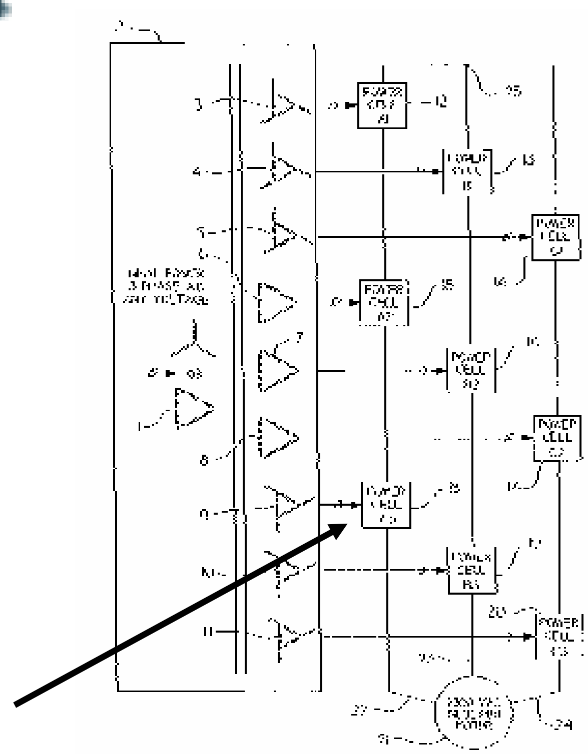
Medium Voltage Values & Semiconductors

- MV voltage source inverter
  - 3.3kV 4.5kV and 6.5 kV IGBT semiconductors, for Three Level Inverter for
    3.3kV, 4.2kV and 6.3kV Medium Voltage lines



  - IGCT based inverters
  - Cell MV construction with low voltage silicon. (1700V)



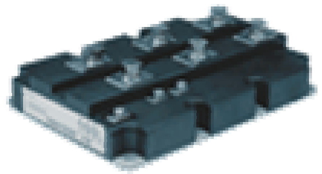


All MV Drive solutions have a full size input transformer

Existing solutions of MV drives

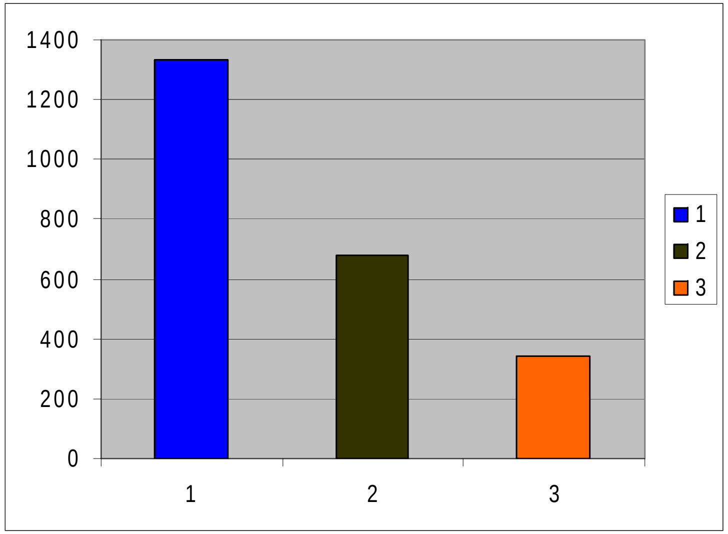
SEMIKRON
innovation + service

Three phase IGBT inverter operation at same cooling conditions and
Fsw= 3.6kHz; cosφ=0.9 and same module size

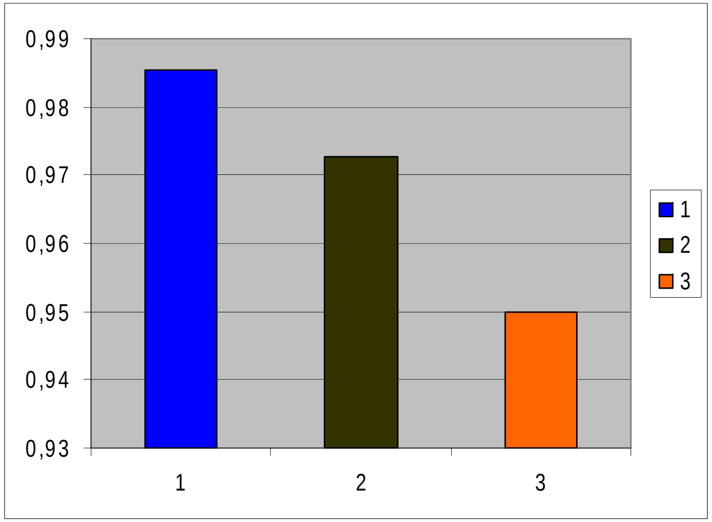


1.7kV, 2400A	3.3kV,1200A	6.5kV,600A
Vdc=1100V	Vdc=1800V	Vdc=3600V
Vac=690V	Vac=1130V	Vac=2260V

Power [kVA]



η

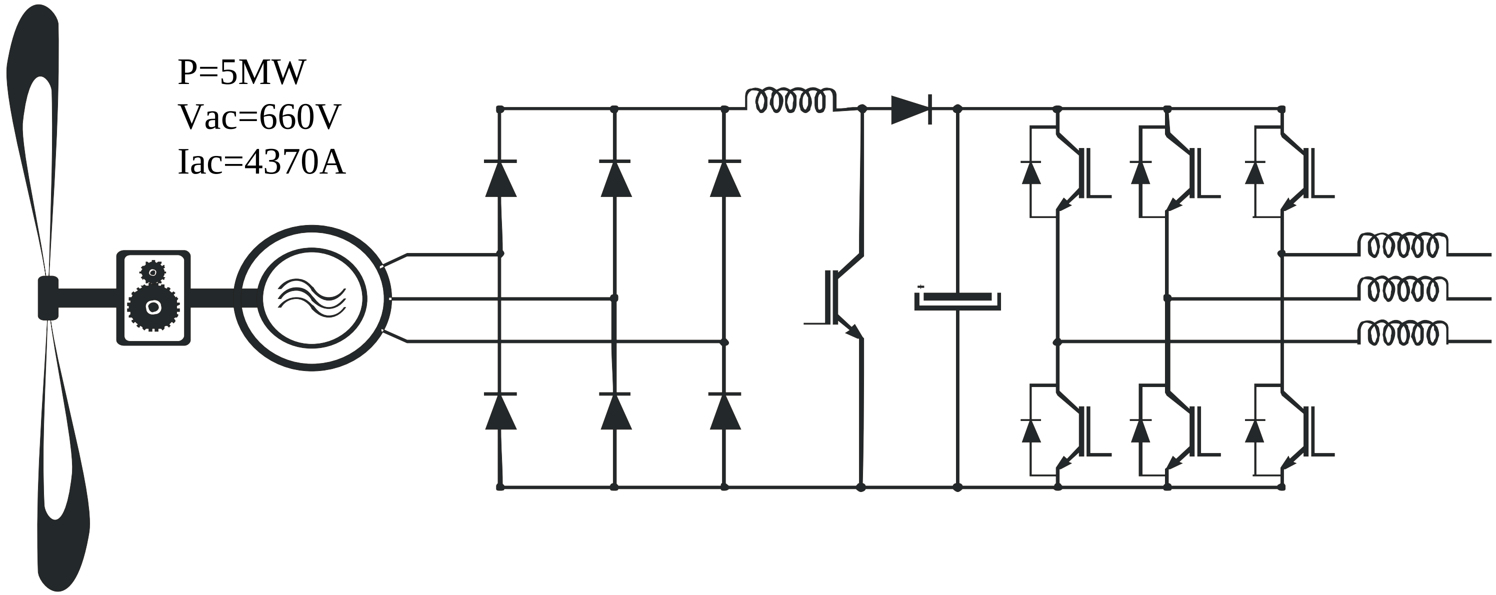


Efficiency comparison of different blocking voltage IGBTs

Windmill designers Goals

- High Power Wind turbine
- Lower losses
- Result: Medium Voltage Motor - Generator
- Variable speed
- High efficiency
- Proven semiconductors
- Clean, sinusoidal line current with simple line transformer
- Good line power factor, and low THD
- Active and Reactive power control
- Modular construction for different voltages, powers for quick assembly
- High reliability
- Lowest costs

Low voltage 5 MW Variable Speed Wind Turbines With Synchronous Motor / Generator



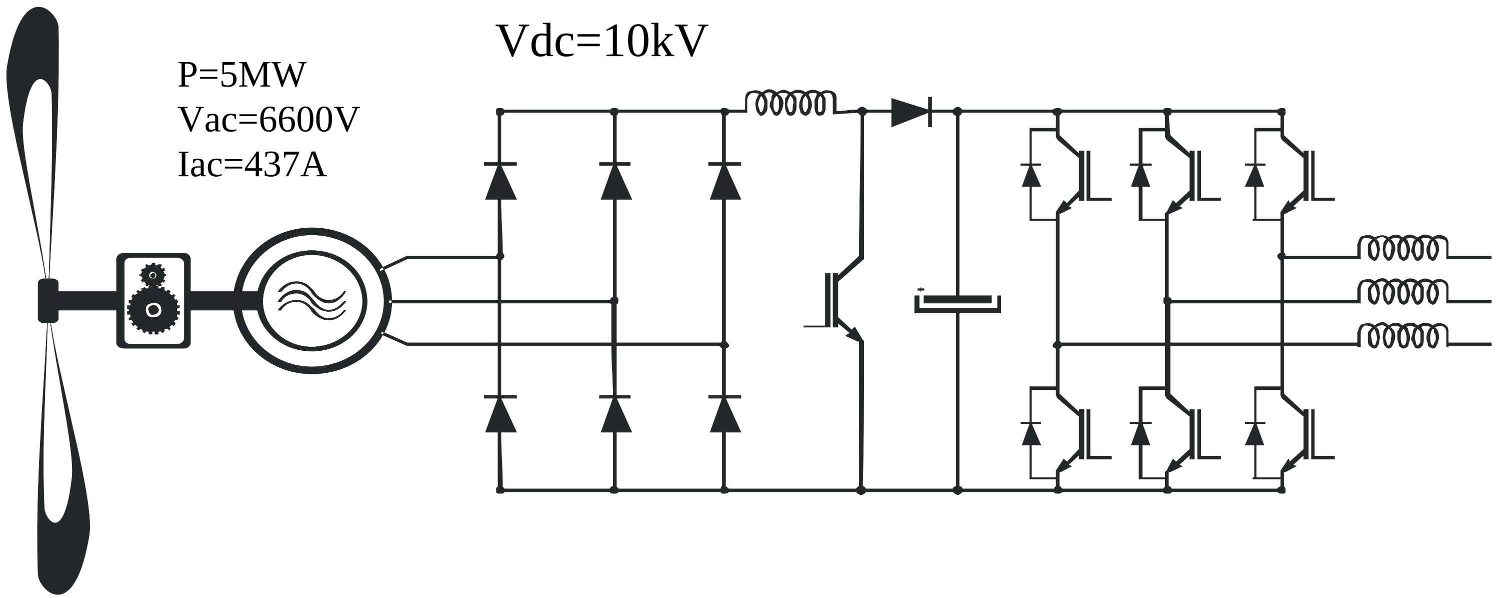
Synchronous motor / generator with the rectifier, boost chopper, and line-side converter for the full generated power

Well known construction with up to 15 units in parallel.
Total number of running units>20.000

Can we make the equivalent MV construction ?

SEMIKRON innovation + service

5 MW Variable Speed Wind Turbines With Synchronous Motor / Generator



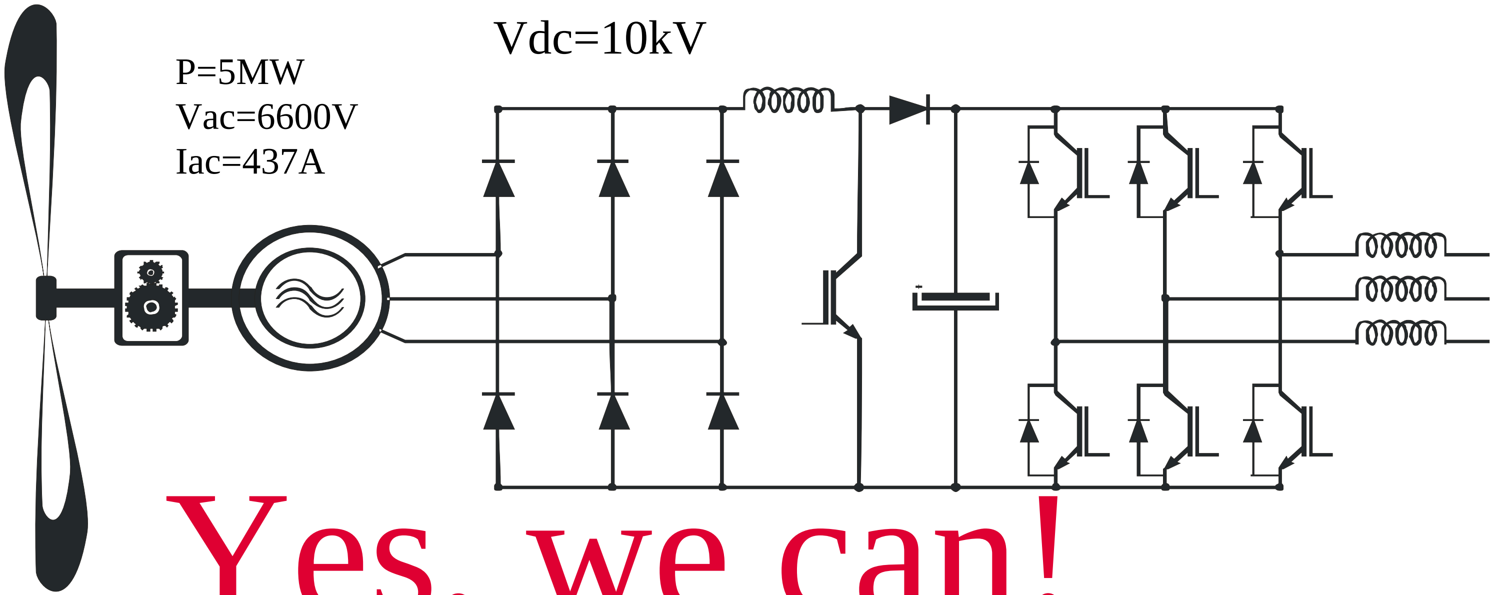
Synchronous motor / generator with the rectifier, boost chopper, and line-side converter for the full generated power

Vdc=10 kV; There is no semiconductors for a such high DC voltage!

Can we make the equivalent MV construction ?

SEMIKRON
innovation + service

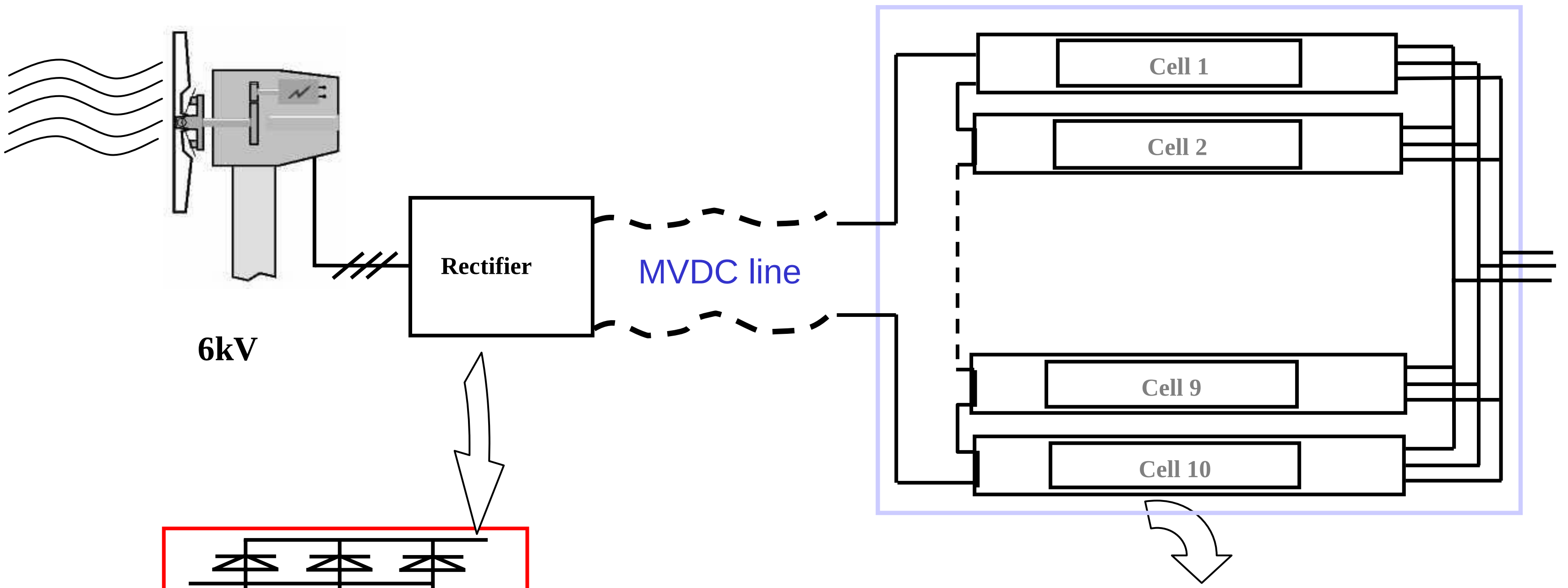
5 MW Variable Speed Wind Turbines
With Synchronous Motor / Generator

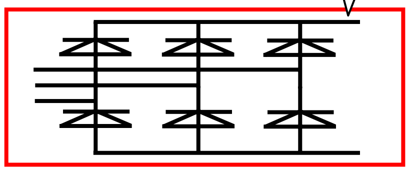


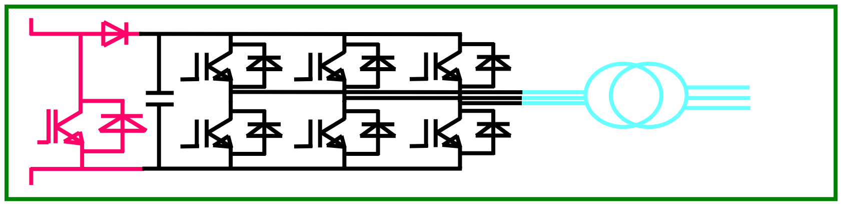
Yes, we can!

Synchronous motor / generator with the rectifier, boost chopper, and line-side converter for the full generated power

Vdc=10 kV; There is no semiconductors for a such high DC voltage!







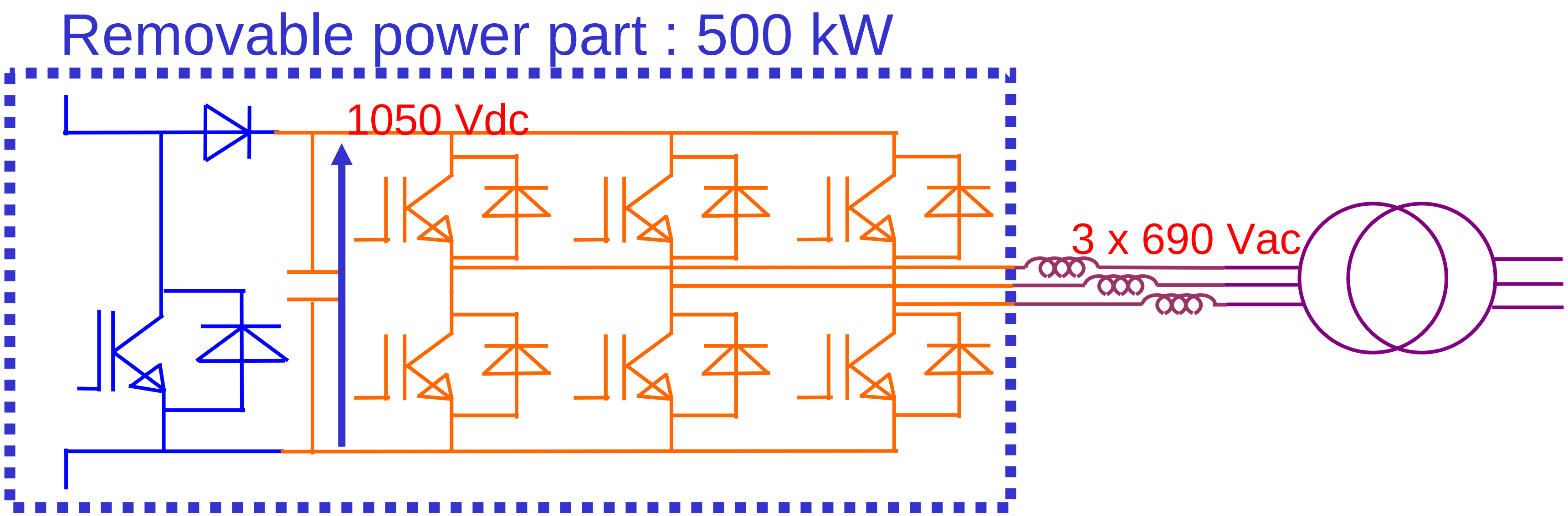
SEMIKRON MV Cell

A power converter that can be placed on the bottom of the tower (less weight in the nacelle),

Medium Voltage Windmill on Cell Principle

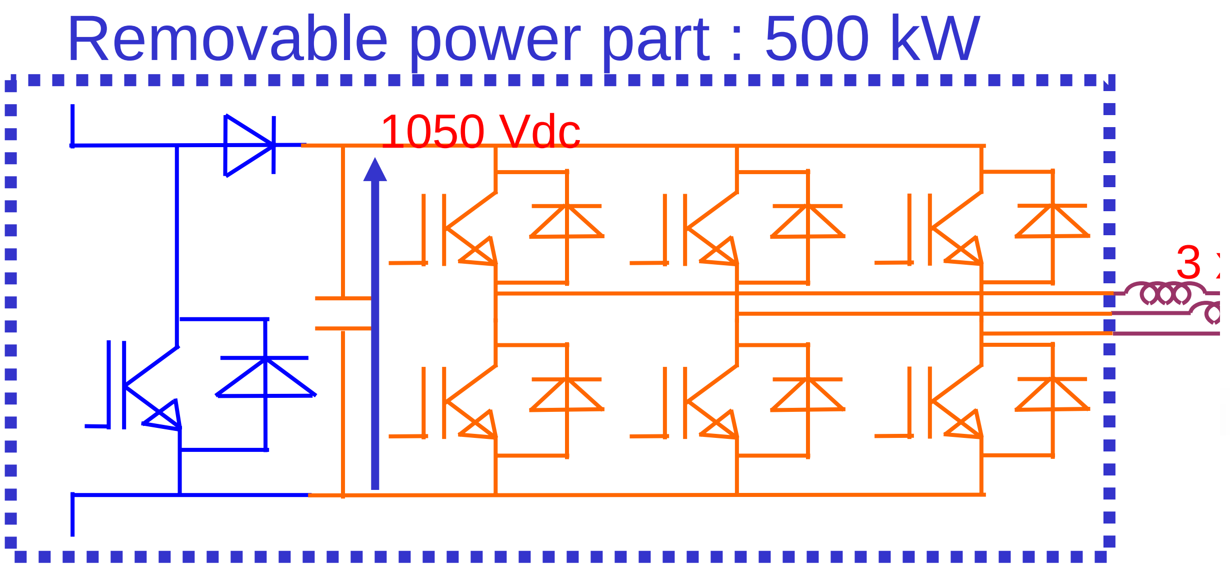
SEMIKRON
innovation + service

Only LOW VOLTAGE SEMICONDUCTORS

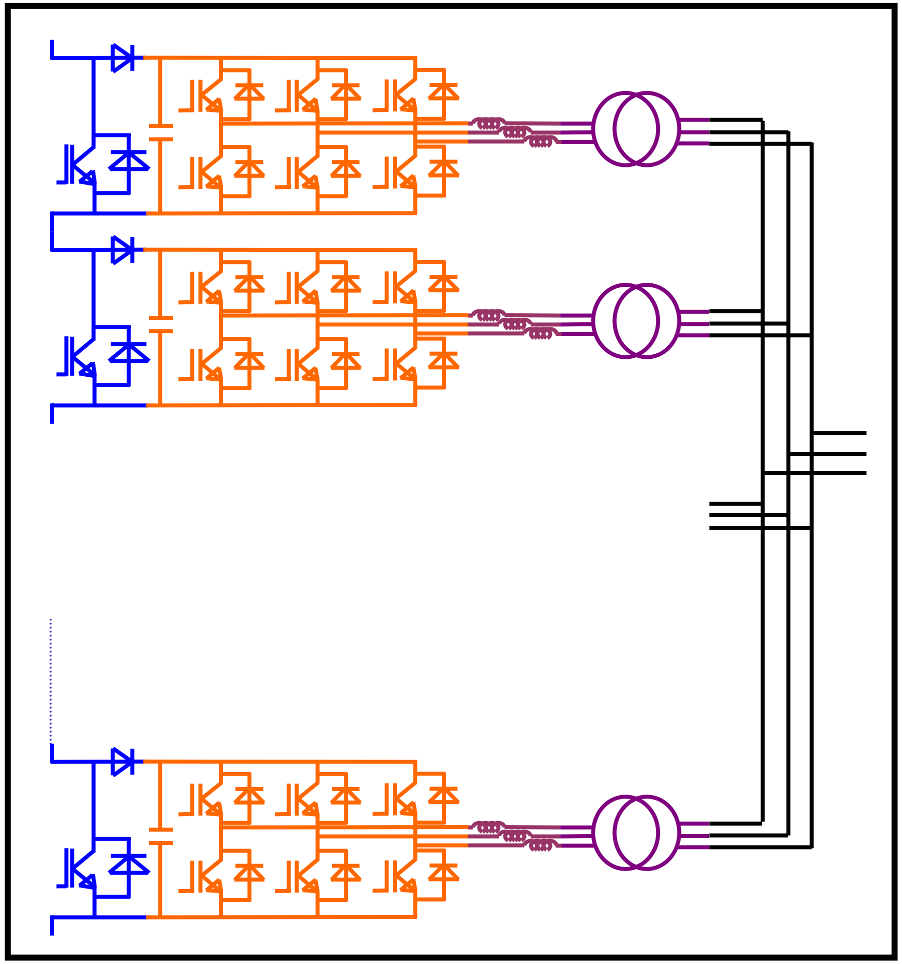


Basic 600 kVA, 500kW cell

Only LOW VOLTAGE SEMICONDUCTORS



Basic 600 kVA, 500kW cell

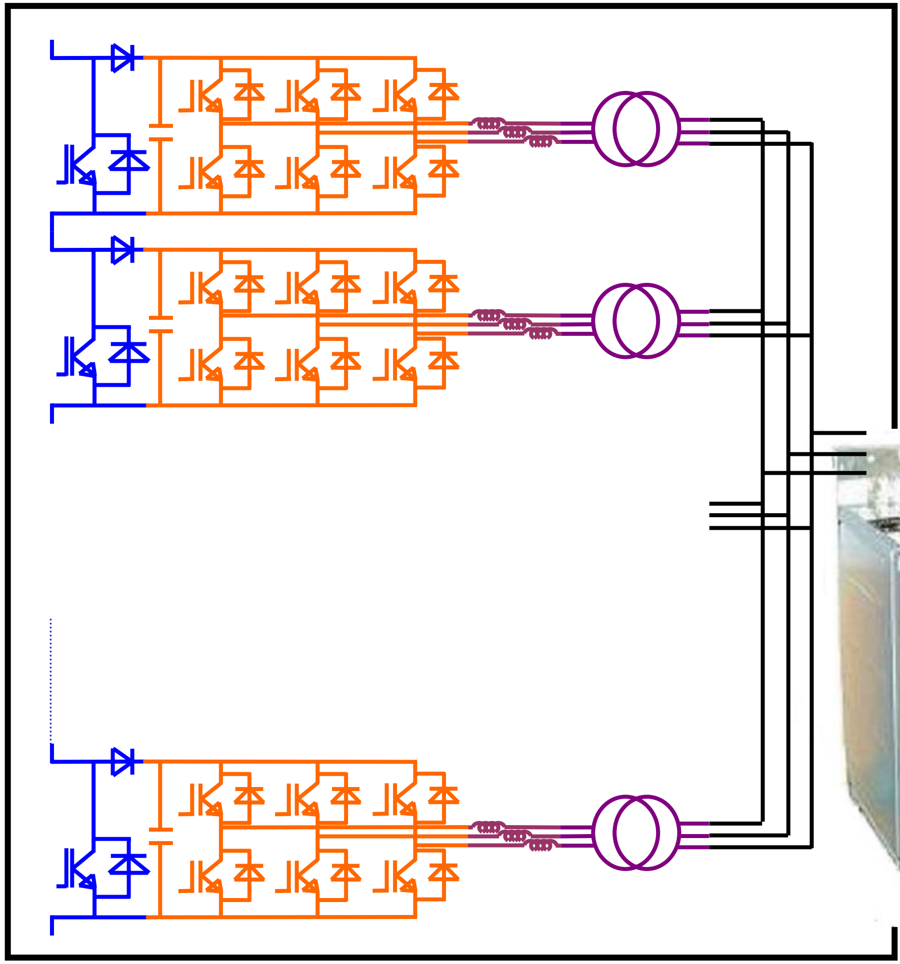


MODULARITY

-Series connections of Cells for different voltages

-Parallel connections in one Cell for various power ranges

Complete inverter construction



MODULARITY
-Series connections of Cells
 for different voltages
-Parallel connections in one Cell
 for various power ranges

Complete inverter construction

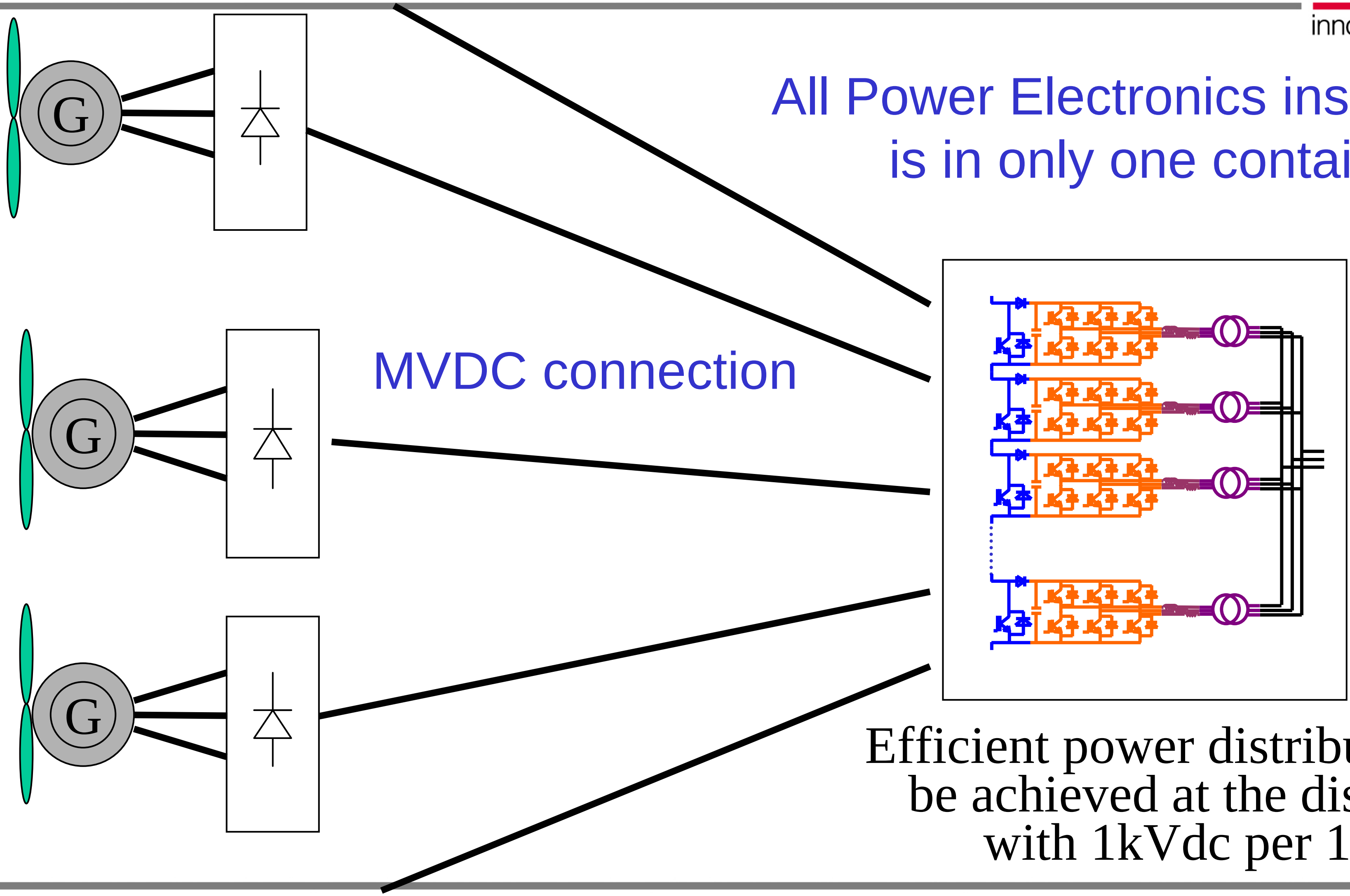
SEMIKRON
innovation + service

Features

- Generator DC voltage range from 0V to Vdc_{max}
- DC voltage per cell 1000V(1700V silicon)
- Vdc Max per Cell 1200V
- Number of Cells = Vdc_{max}/Vcell(+1)
- Cell Power: $Pgen_{max}$/Number of Cells
- Redundancy of the system (+1)
- Cell switched-on time varies from 0% to 100%
- Switched-off Cell can produce full reactive power
- High efficiency at lower power
- Line side ripple frequency=Ncell*Fsw_{cell}
- Simple line side transformer

SEMIKRON
innovation + service

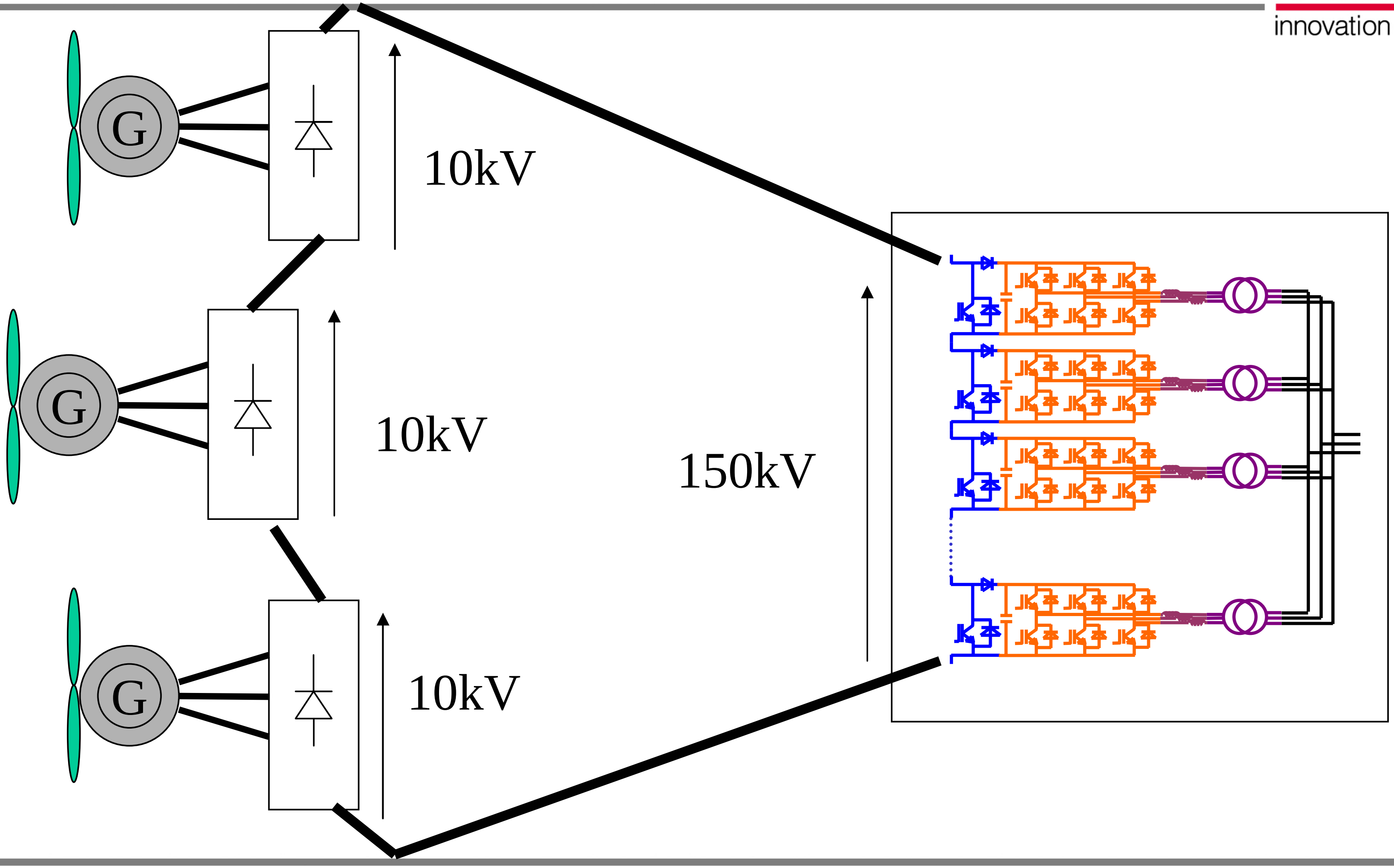
All Power Electronics installation
is in only one container



Efficient power distribution can
be achieved at the distances
with 1kVdc per 1km

Wind park concept

Connecting several windmills in series for DC voltages of 100kV or more; the power converter is on the shore, and the windmills are connected with a single cable



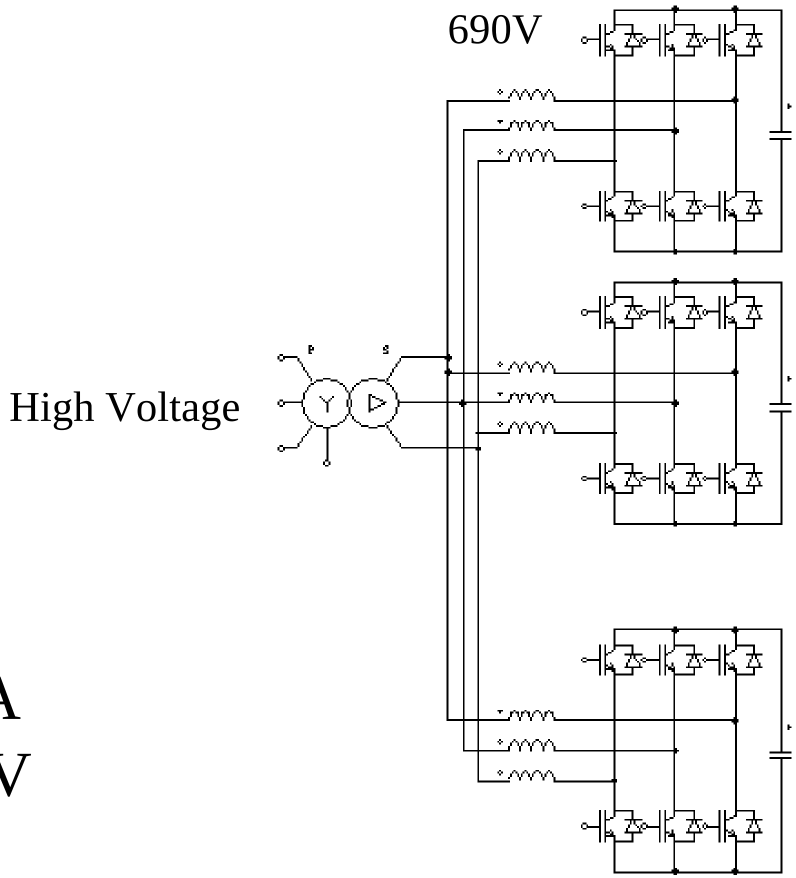
Series connection of several windmills

STATCOM Static Compensator:
- allows both leading or lagging power factor; voltage stabilization and load balancing

Active Filter and STATCOM

for unlimited power range

2 MVA
& 690V



Energy Management