Makan Chen, E. Tsyplokov, R. Schnell, P. Hong, H. Wang, S. Klaka, ABB, November, 2016

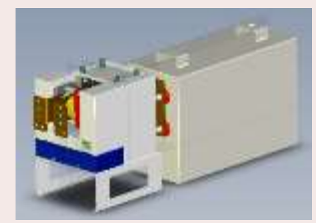
Power Devices for GW VSC-HVDC Application
Development trend and status with StakPak

Power and productivity for a better world™

Power Device Trend for VSC-HVDC Application

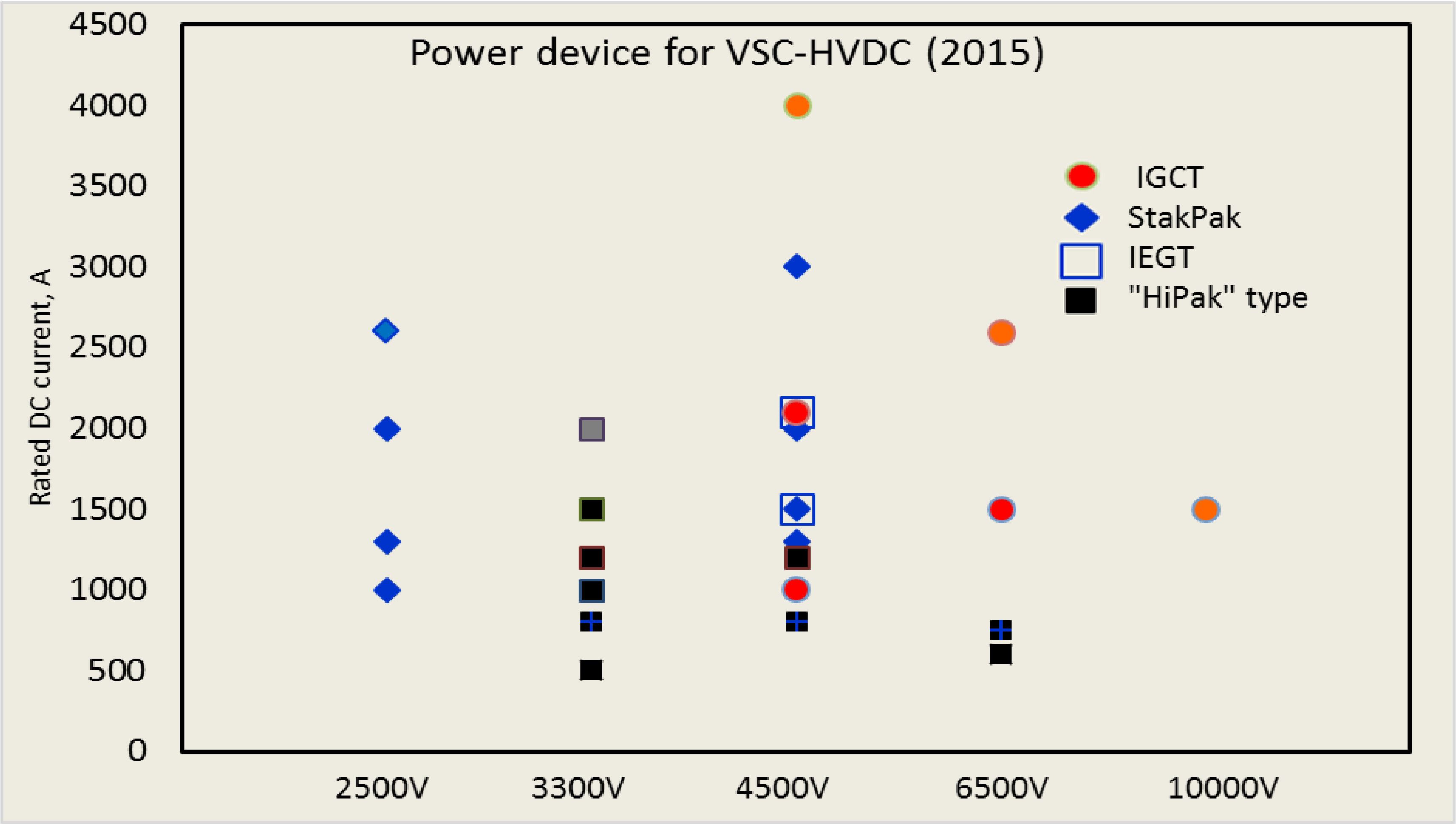
- Brief Overview
- Power device development guideline
- StakPak: Design & Benefit
- IGCT: Potential Benefit
- Future Trend
- Summary

Overview of VSC-HVDC (simplified)
System vs device

Name	HVDC Light	HVDC Plus	HVDC MaxSine	HVDC Flex
OEM Rating Ref	ABB 1000 MW 16 links	Siemens 1000 MW 3 links	Alstom 25 MW Demo(+2)	CN OEMs 1000 MW 2+2…
Stack				
Device				 
Device	rating: 500-2100 A, 2500-4500 V			

→ Transimmitted power up, device rating challenged

Overview of Power Semiconductors for VSC-HVDC
Typically 3300 & 4500V, potential 3000A+



Basic Characteristic of power device
3300V & 4500V, 1200- 2000A

	StakPak	HiPak	HiPak	IEGT	IGCT
	4500V,2000A	5SNA 1200G450300	5SNA 1500E330305	ST2100GXH22A + diode	"5SHY 80Y4500"
VCES, V	4500	4500	3300	4500	4500
Ic / $0.5I_{TGQM}$, A	2000	1200	1500	2100	4000
Max turn-off I, A	4000	2400	3000	5500	8000
I_{FSM}	16-32 kA	9 kA	13.5 kA	-	48 kA
V_{CEsat} / V_F ,125C, V	3.33	3.53	2.68	4.7	3.38
Total switch losses/pulse, J	*24.44*	*13.08*	*7.2*	*25*	*31.3*
Conduction losses (3ms-pulse), J	*20.0*	*12.7*	*12.0*	*29.6*	*40.6*
Total losse (3ms pulse), J	44.4	25.8	19.2	54.6	71.9
Total losses (3300V →100%), J	127%	123%	100%	*149%?*	103%
R_{th} (Junction to case), K/kW	4.5	9.5	8.5	5.25	8.5
Chip tech	SPT+	SPT+/trench	SPT+/trench	IEGT	GCT
Integrated GU?	No	No	No	No	Yes
SC current limiting	Yes	Yes	Yes	Yes	No
Case rupture (explosion rating)	Yes	No	No	Yes	Yes
SCFM	Yes	No	No	Yes/No	Yes

- Losses increases with Vce square!

Power Device: System needs and device options
Pushing physical limit of semiconductors

System needs	Device options
High reliability & availability	Incorporate feedback, controllability
Higher current	BiGT, Enhanced trench, bigger, IGCT, Tvj
Higher voltage	4500V, 6500V (but losses)
Higher surge current	BiGT, more diode, IGCT
Lower losses	Enhanced trench, technology curve
Higher energy density	BiGT, Enhanced Trench, chip size, IGCT
Case rupture (explosion rating)	PressPack/StakPak,
Design simplicity & modularity	Modular type device
Series connection (DC-Breaker…)	PressPack device

Reliability consideration -1
Reliability is key to uninterrupted operation

- Robust chip design: large/high SOA and controllability
- Robust module design: low parts count & standardization
- Manufacturing: quality designed in, economy of scale, TQM
- Gate driver: must be matched for safe operation
- Application: low Ls, safety margin for worst conditions
- Vdc: design with 100 FIT (FIT rate exponential to Vdc)…
- Field feedback: essential for matured application

Guideline to Device Current and Voltage Trade-off: voltage vs losses, current vs di/dt

Voltage class: less series connection but total losses up

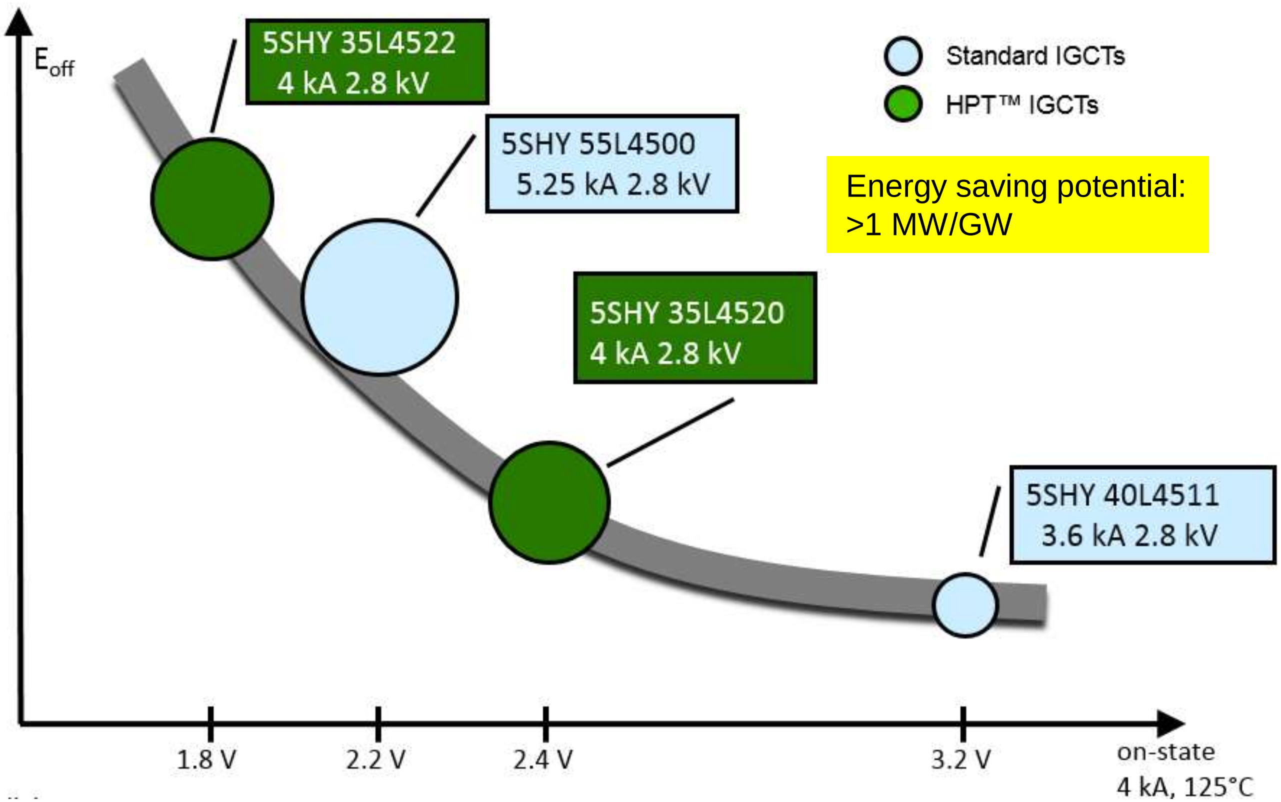
- 7.5kV in IGBT, 10kV in IGCT demonstrated (junction termination challenge)
- Nominal Vce-sat up with Vce, switching losses up with V^2 (3300V → 6500V)
- → 6500V feasible but 4500V optimal (price of passive component up with Vce)

Current

- Current density (A/cm2): new generation, e.g. enhanced trench
- Rth: improved cooling increase current capability, e.g. Presspack
- Bigger module: more chips in parallel limited by current sharing (asymmetric Ls),
- Over-voltage: caused by di/dt*Ls (unless Ls proportionally reduced)
- → 4000 A limit?

IFSM: higher diode ratio e.g. StakPak & BiGT

IGCT product range –loss optimization
Moving along technology curve for optimized application



- Low on-state voltage, for breakers: 5SHY 35L4522.
- Low frequency: 5SHY 55L4500.
- Medium frequency: 5SHY 35L4520
- Low switching losses: 5SHY 40L4511 (proton-irradiated)

Assembly Tolerant & Fail-Safe Operation
Efficient assembly & safe operation

Converter cell design and assembly

- Assembly: construction tolerance should not impact on fragile chip
- Modularity: facilitate whole power range with same device platform
- Series connection: PressPack favoured
- Maintenance: fast & easy access for replacement, low part counts

Fail-safe operation

- SCFM: device should fail into stable shorted state & last till breaker activated
- Case rupture (explosion rating): remain mechanically intact during fault, contain damage

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StakPak 5SNA 2000K451300 –Design
VCE = 4500 V, IC = 2000 A

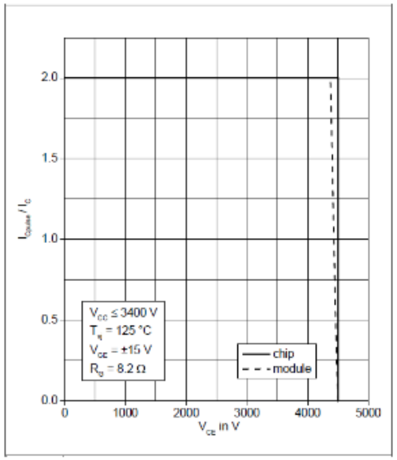
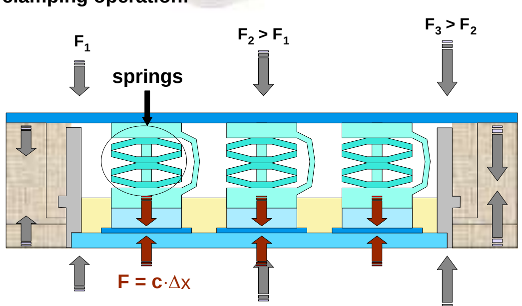


Fig. 11 Turn-off safe operating area (RBSOA)

clamping operation:



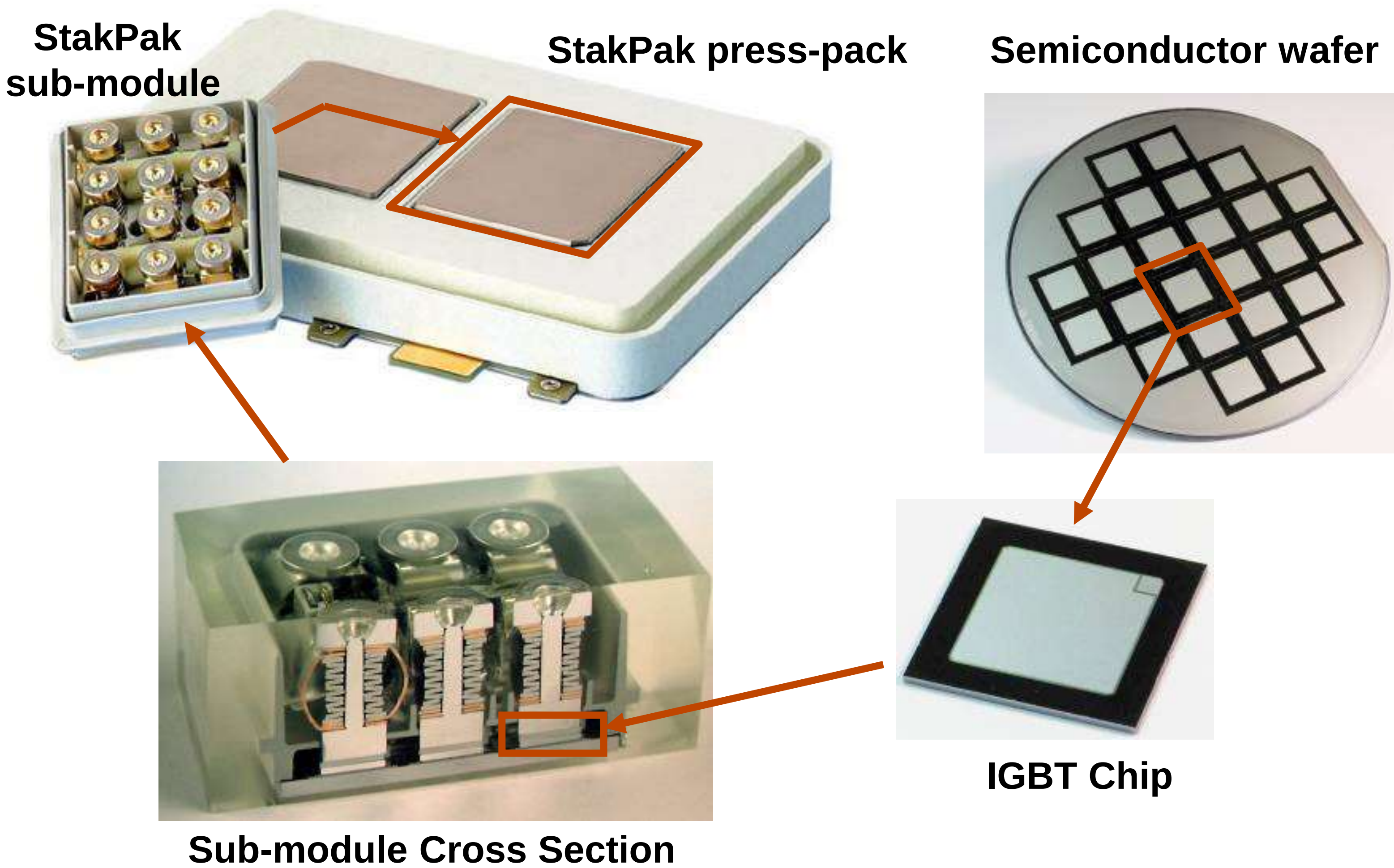
SPT+ technology:

- low-loss, rugged SPT+, large SOA
- High controlability
- Smooth switching SPT+ chip-set for good EMC

Press-pack module design

- High tolerance to uneven mounting pressure
- Explosion resistant package
- Direct bonding to Mo-basedplate → low Rth
- SCFM Fail-safe →for series connection

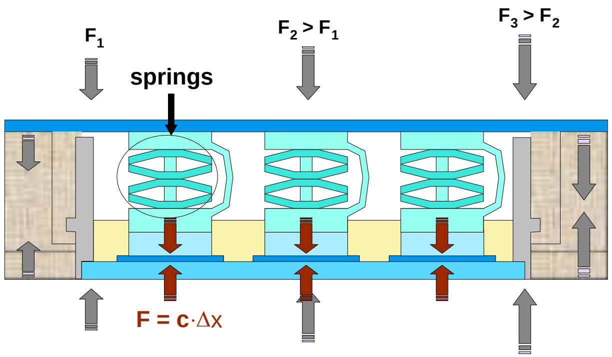
StakPakTM –ABB Proprietary IGBT module technology



StakPak Innovative Clamping
Easy and Controlled Clamping

Internal construction of the sub-module reveals the unique ABB design: Press-Pin with Spring contacts for each Chip position

clamping operation:



- Independent suspension for each chip with individual spring-contact
- Contact force for the chip is defined by the spring and not influenced by un-even mounting force
- Surplus external force is absorbed by the rugged module frame
- Tolerant against inhomogeneous mounting force – the choice for large stacks
- Fm = 60-75 kN

StakPak -Gate drive

- Standard gate IGBT driver can be used
- RG-on = 1.8 Ohm, RG-off = 8.2 Ohm, CGE = 330 nF
- Active clamp available
- Standard gate driver interface
- Gate driver with small jitter needed for series connection

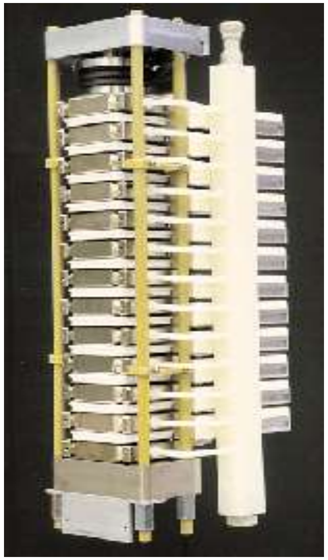
IGBT StakPak –Modular Design

***n* standard submodules**

+

Glass fibre reinforced frame

=



StakPak Stack

Possible current ratings

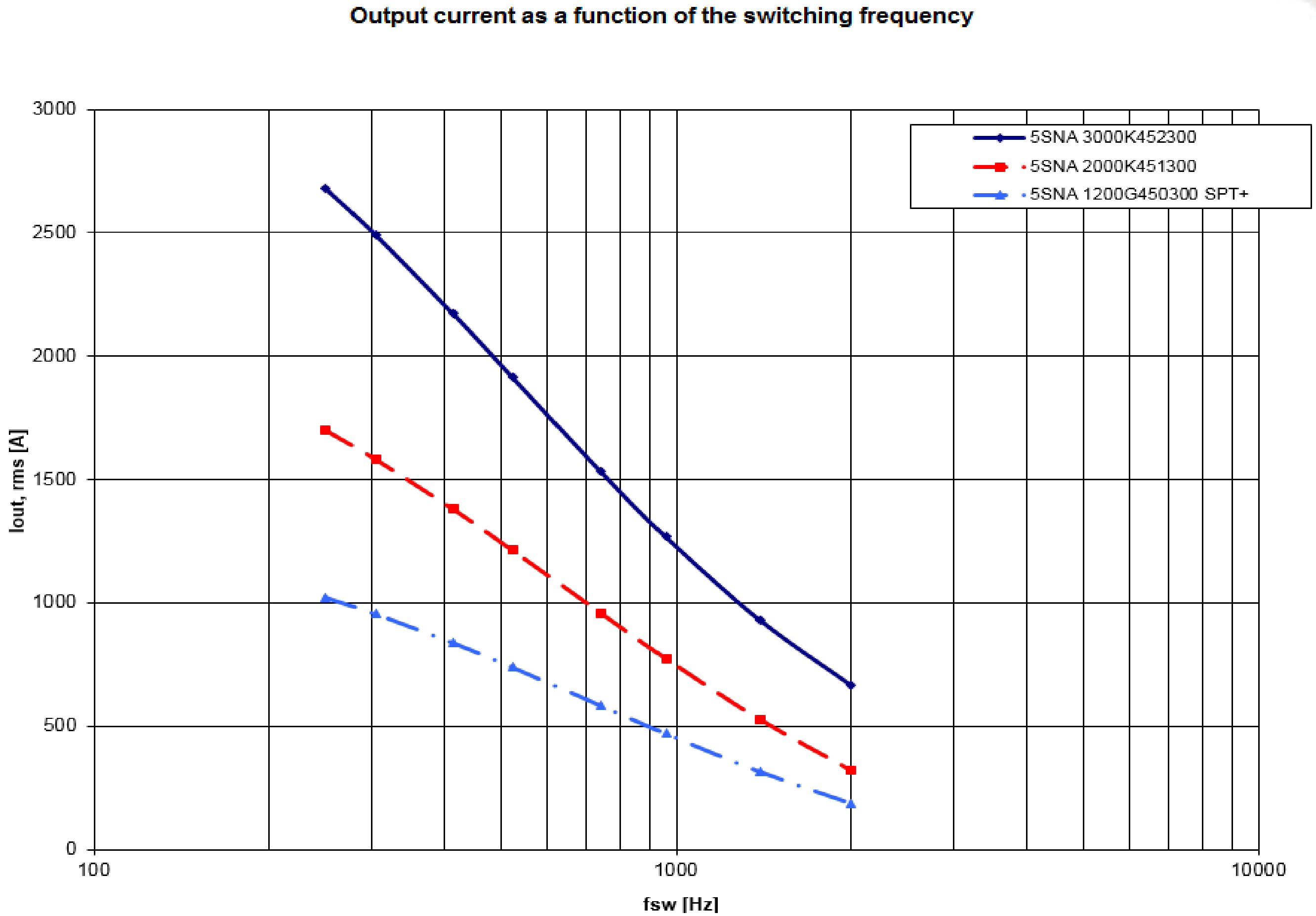
700A – 3000A

StakPak line-up
Product Matrix

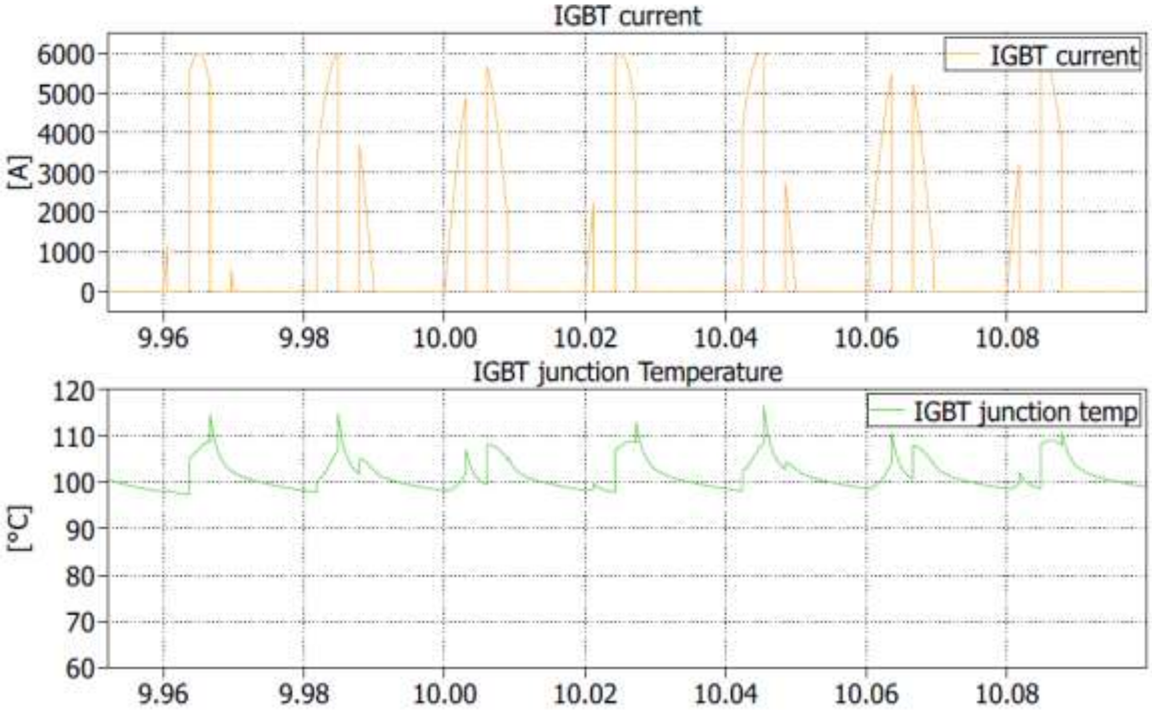
Part Number	Voltage V_{CEs} [V]	Current I_C [A]	IGBT / Diode current ratio	Submodules [n]	SCFM rated
5SNA 3000K452300*	4500	***3000***	1:1	6	no
5SNA 2000K452300*	4500	2000	1:1	4	no
5SNA 2000K451300	4500	2000	1:1	4	yes
5SNA 2000K450300	4500	2000	1:2	6	yes
5SNA 1300K450300	4500	1300	1:2	4	yes
5SNR 20H2501	*2500*	*2000*	1:1	*6*	yes
5SNR 13H2501	*2500*	*1300*	1:1	*4*	yes
5SNR 10H2501	*2500*	*1000*	1:1	*3*	Yes

- The standard 1:1 IGBT to Diode current ratio suits most applications
- For special applications which require high diode performance, ABB offers a 1:2 IGBT to Diode current ratio

Phase current simulation (2 level) (250Hz, RMS) 3000K452300 (4500V / 3000A, Tj100° C)



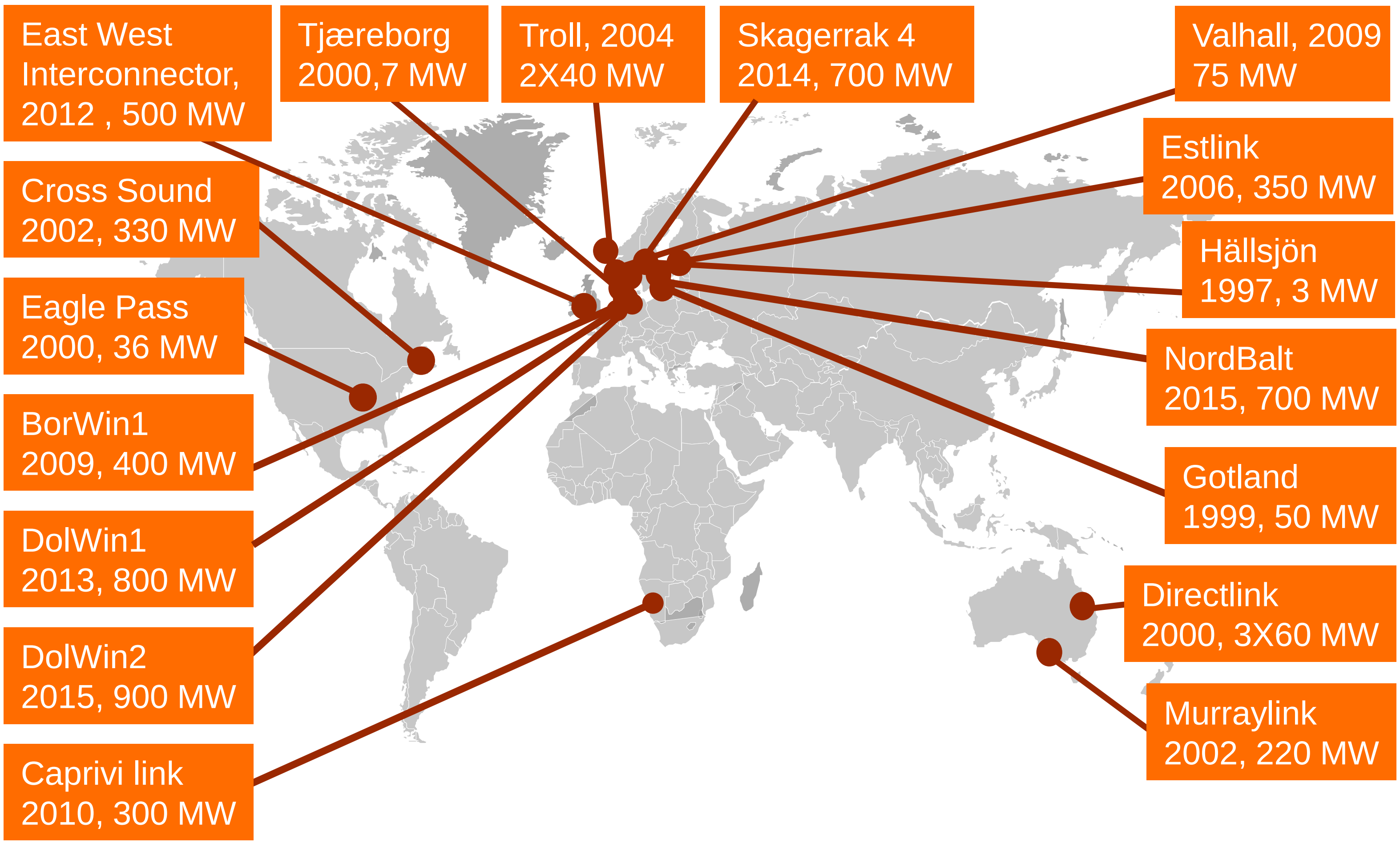
StakPak 5SNA 3000K452300 (4500V, 3000A)



50 Hz 6000A transient over-current: dT=10° C per switch, dT =10° C for 3 ms (150Hz), dT =-10° C for 3 ms off

→ turn-off of 6000A (2Ic) transient over-current realistic if designed Tj =100C

Project references
HVDC Light technology



Awarded 1200 MW HVDC Light Project by Scottish Hydro Electric

Example: Same IGBT Chip Technology for HVDC «Light» Off-Shore Windpark DolWin in the North See

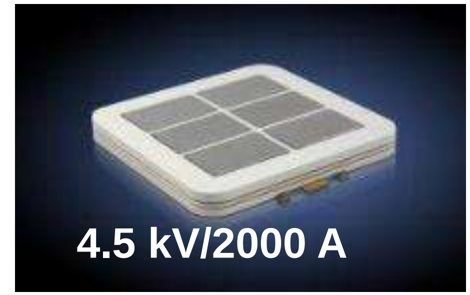
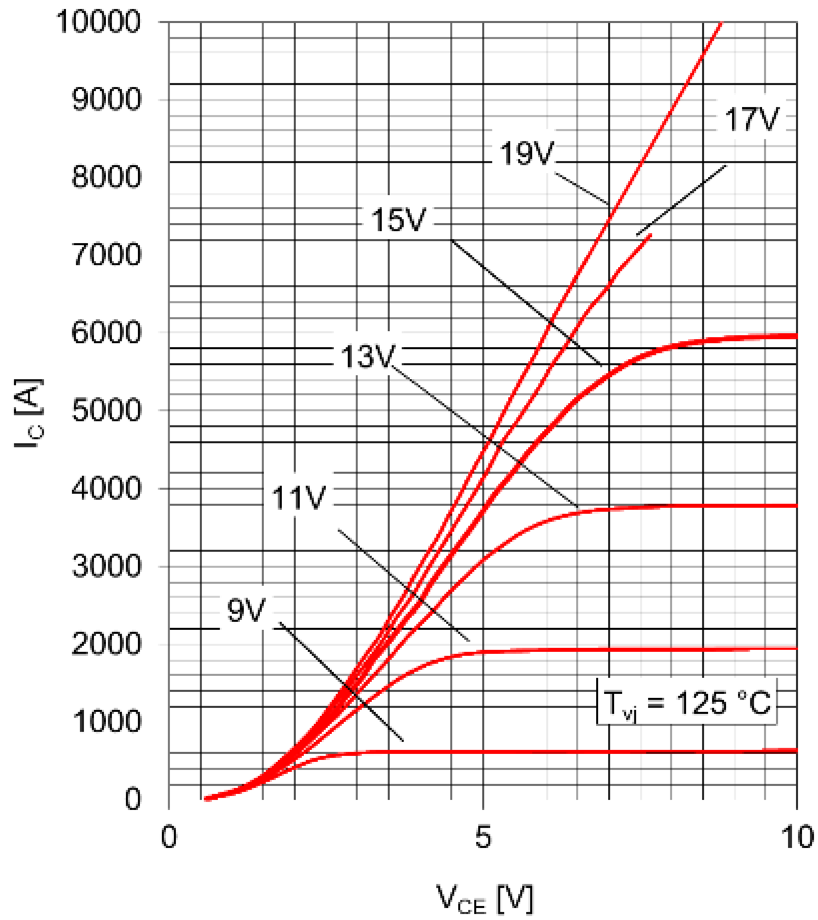
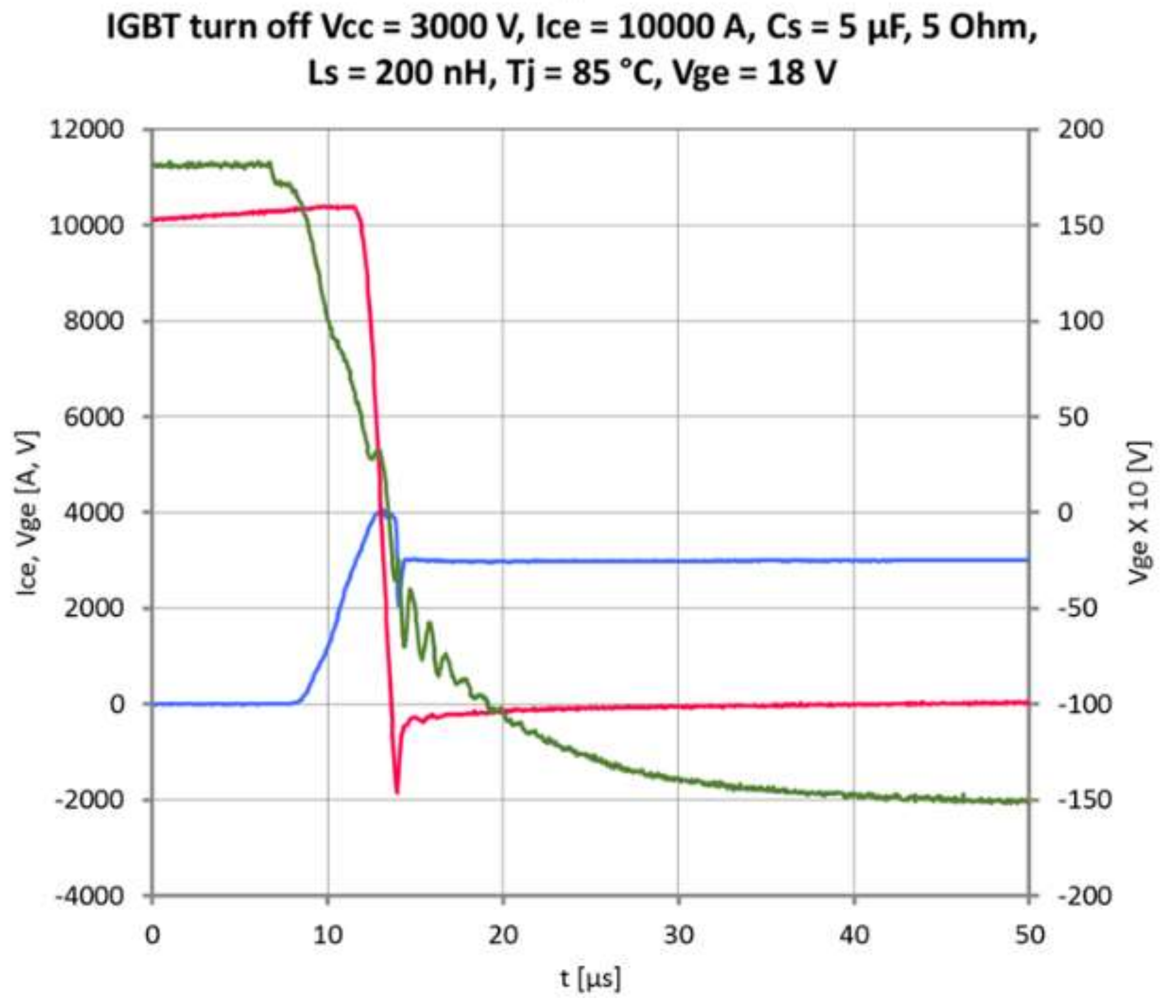


ABB IGBT StakPak operating in more than 10 HVDC Light projects worldwide

IV Characteristic of StakPak
10 kA reached w/o desaturation -5SNA 2000K450300

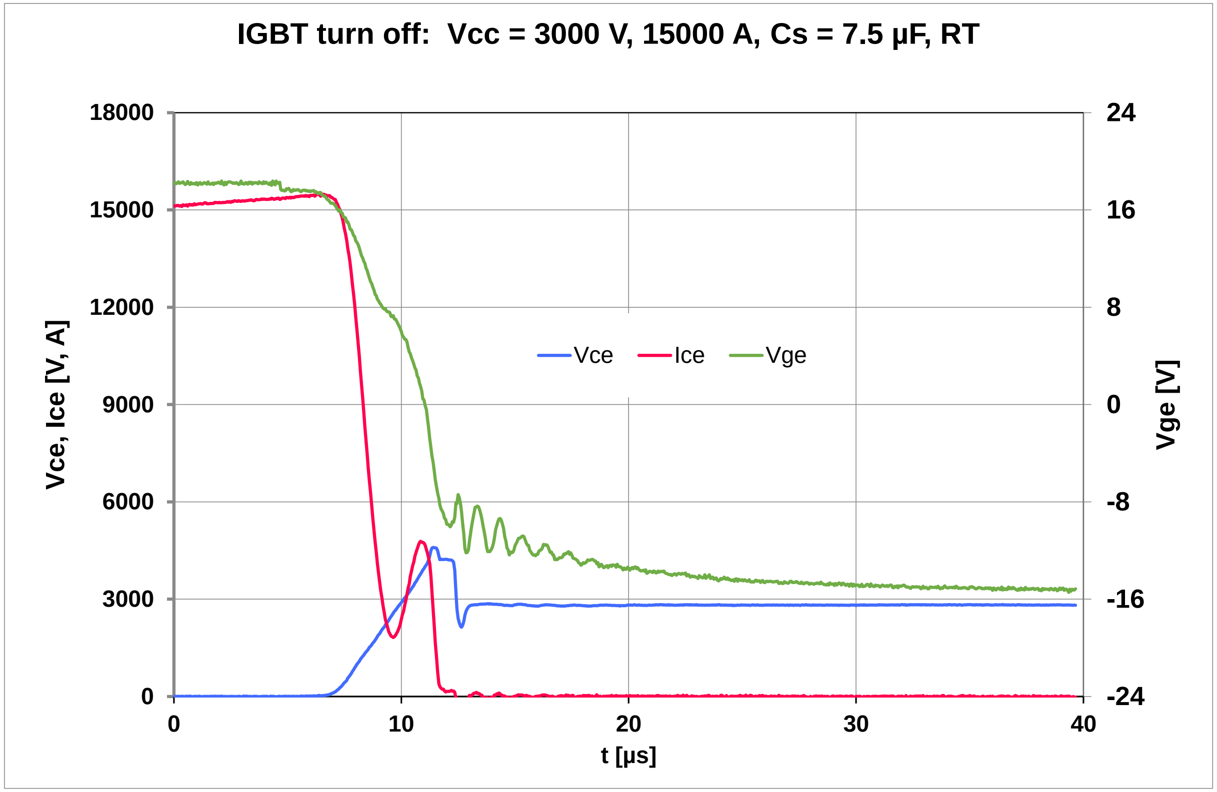


Turning off behavior of StakPak
Safe 10 kA turn-off with snubber -5SNA 2000K451300

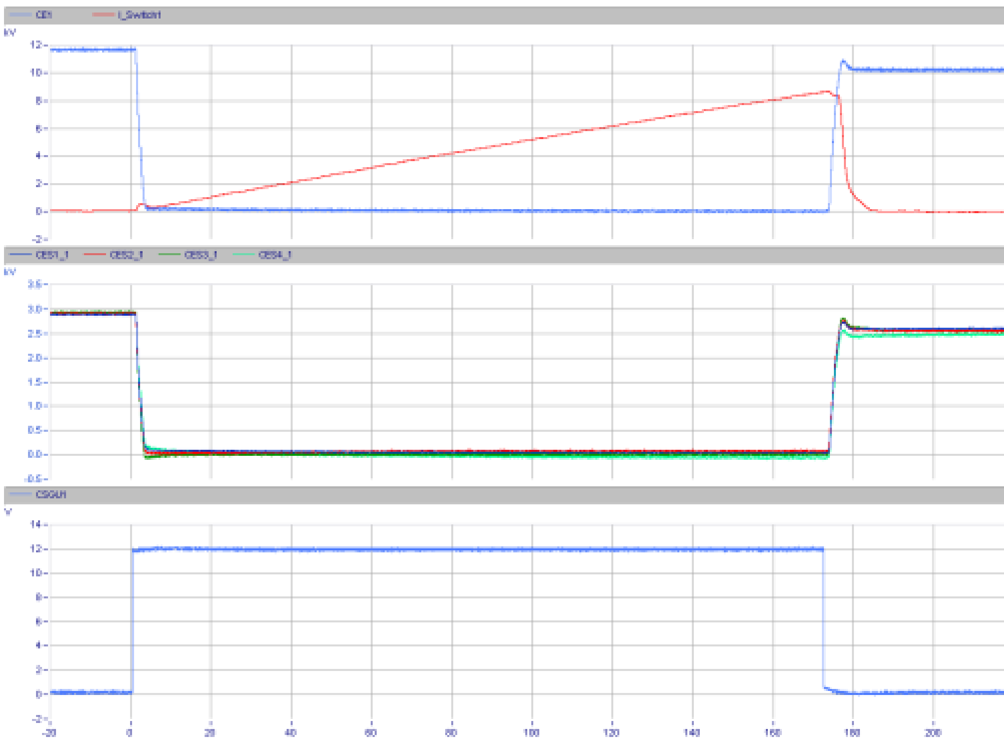


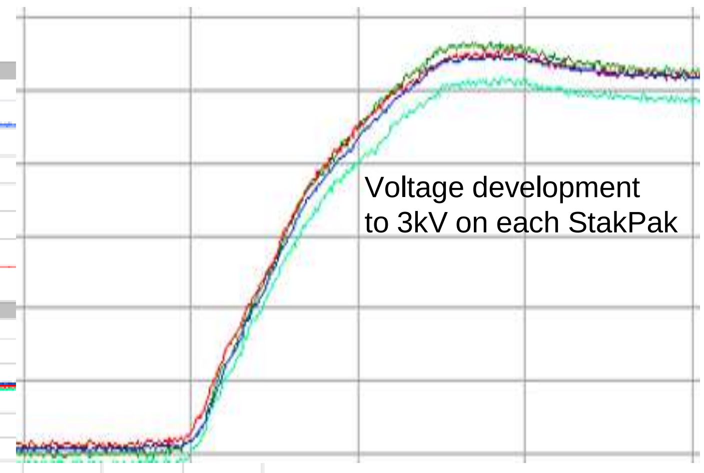
Converter topologies
DC breaker operation

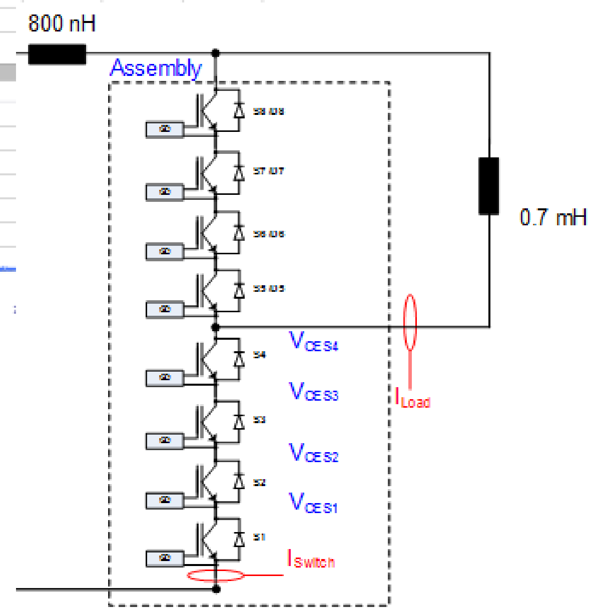
- Ic = 15 kA, Vcc = 3000 V
- Cs = 7.5 µF - value depends on inductance in a main circuit to limit the Turn off overvoltage



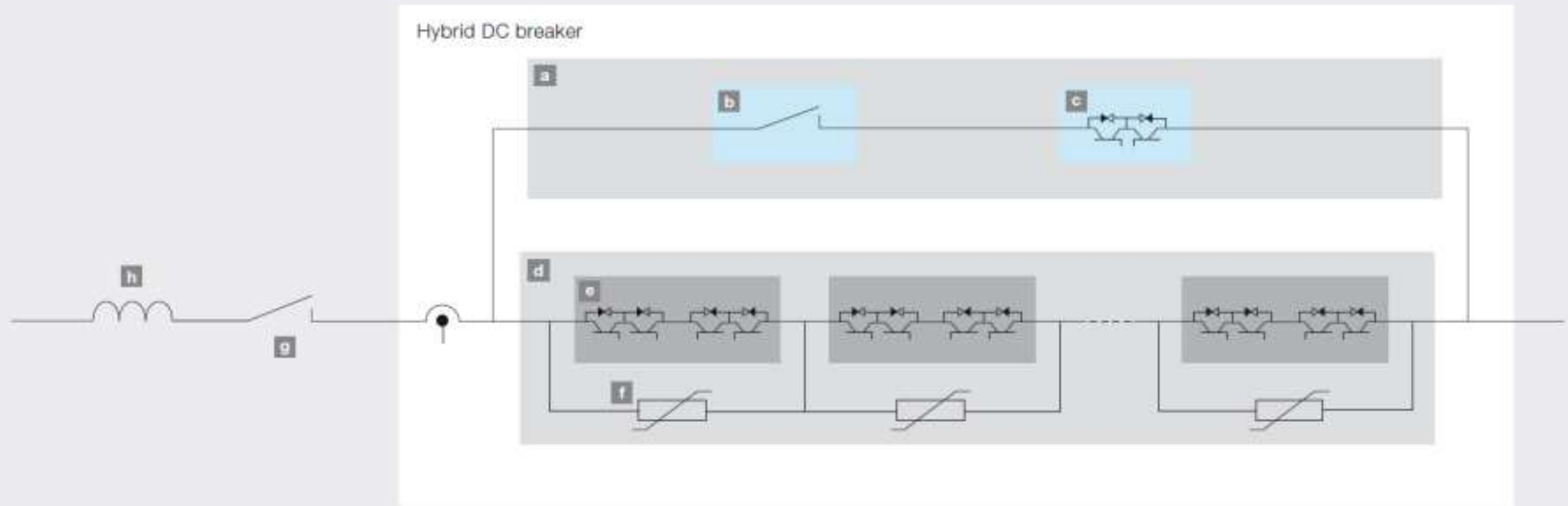
Test of series connected StakPak 4500V/2000A
Uniform IGBT turn-off of 12kV





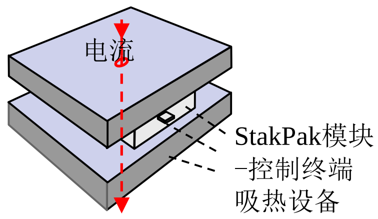


Application example of StakPak
Hybrid DC breaker tested to 80 kV, turn-off 16 kA (5ms)



- a Main current branch (when current is flowing) consisting of:
  - b Fast mechanical disconnector HVDC breaker
  - c Load-commutation switch (semiconductor-based)
- d Main HVDC breaker consisting of:
  - e Semiconductor interrupter
  - f Arrester bank
- g Residual current breaker
- h Current limiting reactor

StakPak –Summary
Most powerful device for VSC-HVDC & DC-Breaker



- StakPak is the most powerful IGBT module available (3000A, turn-off 10kA, IFSM 24kA)
- Fail into shorted stated, long term stability possible
- Flexible current rating with surge current options
- Uniform chip pressure via individual spring
- Enable easy & controlled clamping system for long stack
- Efficient cooling offering high rated power
- Explosion proof
- Tailor-made for T&D applications (→ safe, reliable, redundancy, uninterrupted)
- Some 14+2 HVDC projects in safe operation

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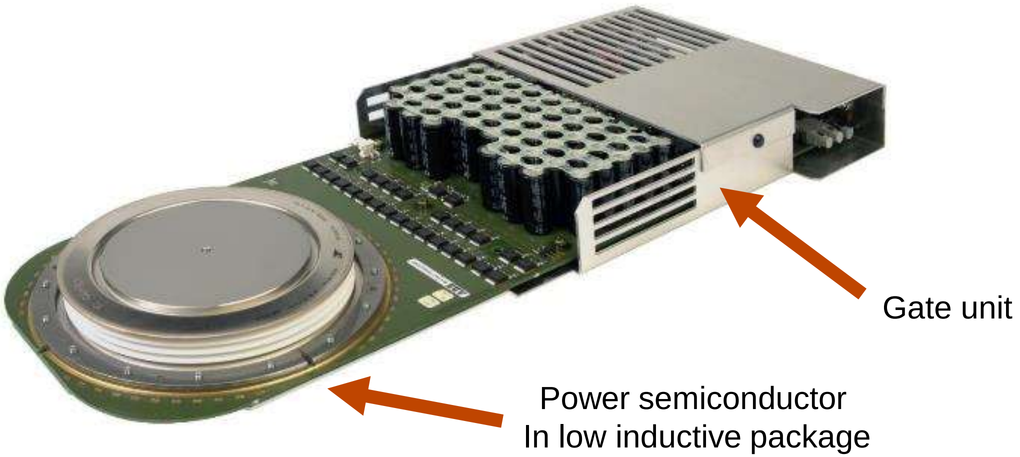
What is an IGCT?

- **An IGCT is...**
  - **An Integrated Gate-Commutated Thyristor**
  - Based on GTO and IGBT technology and requires no turn-off snubber
  - Conducts like a **thyristor** but turns off like an **IGBT**
    - **turn-off loss of an IGBT**
    - **conduction loss of a thyristor**
    - **turn-on loss of a mechanical switch!**
  - Introduced in 1997
  - Three manufacturing locations world-wide:
    - Japan (Mitsubishi)
    - Switzerland & Czech Republic(ABB)
    - ZhuZhou (CSR-TEC)

IGCT
Integration of Gate unit and power semiconductor



- IGCT operation requires low inductive coupling of gate unit and power semiconductor
- Integration of
  - power semiconductor
  - Low inductive device package
  - Gate unit

Product range -IGCT

Part number	VDRM (V)	VDC (V)	ITGQM (A)**	ITAVM (A)	Package (mm)	MW
Asymmetric						
5SHY 35L4520	4500	2800	4000	1700	85/26	8
5SHY 35L4521	4500	2800	4000	1700	85/26	8
5SHY 35L4522	4500	2800	4000	2100	85/26	10
5SHY 40L4511	4500	2800	3600	1430	85/26	7
5SHY 55L4500	4500	2800	5000	1870	85/26	9
5SHY 50L5500	5500	3300	3600	1290	85/26	6
5SHY 42L6500	6500	4000	3800	1290	85/26	6
*5SHY 30L9500 **	*9500*	*5000*	*3000*	*1700*	*85/26*	
Reverse conducting						
5SHX 26L4520	4500	2800	2200	1010	85/26	5
Diode part				390		
5SHX 19L6020	5500	3300	1800	840	85/26	4
Diode part				340		
…F, H…	4500-5500	2800-3300	520-1100			
*5SHX 80Y4500 **	*4500*	*2800*	*8000*	*3400*	*150/26*	16

* under development, ** max turn-off current

Confidential

IGCT for Wind Converter Application
Comparison Results (300Hz) - PLECS Simulation

Converter	Sw. Losses (kW)	Cond. Losses (kW)	P_{Clamp} (kW)	P_{input} (kW)	Losses (%)
3 Level IGCT	13.3	20	10	**8530**	0.5
3 Level IGBT (2 in //)	17	36	-	**8100**	0.65

Losses: -23%

ABB PRODUCT	Tj (Outer position) (°C)	Tj (Inner position) (°C)
IGCT 5SHY 55L4500	112	85
IGBT 5SNA 1200G450350	110	93

→ *Semiconductor losses alone reduced by 23%*

→ *Energy saving per 10 MW power rating*
2x(0.65-0.5)/100 x 10'000'000 = ***30 kW***
x 5 USD = 150 kUSD

→ *Energy saving 3 MW/GW*

IGCT Application Benefits

- Integrated gate unit →higher level integration
- Low parts count → very high reliability & low FIT
- Low on-state losses→ inverter efficiency >99.6%
- High rated current → no paralleling needed (2x “HiPak”)
- Very high power & density (2-side cooling) → compact design
- High load cycling capability →long term reliability
- High current turn-off capability (8kA) → high power
- Classic stable SCFM →ideal for HVDC application
- Competive MW/USD → Cost effective solution
- > 50 kpcs in field → FIT rate comparable to HVDC Thyristors
- →Potential for VSC-HVDC application

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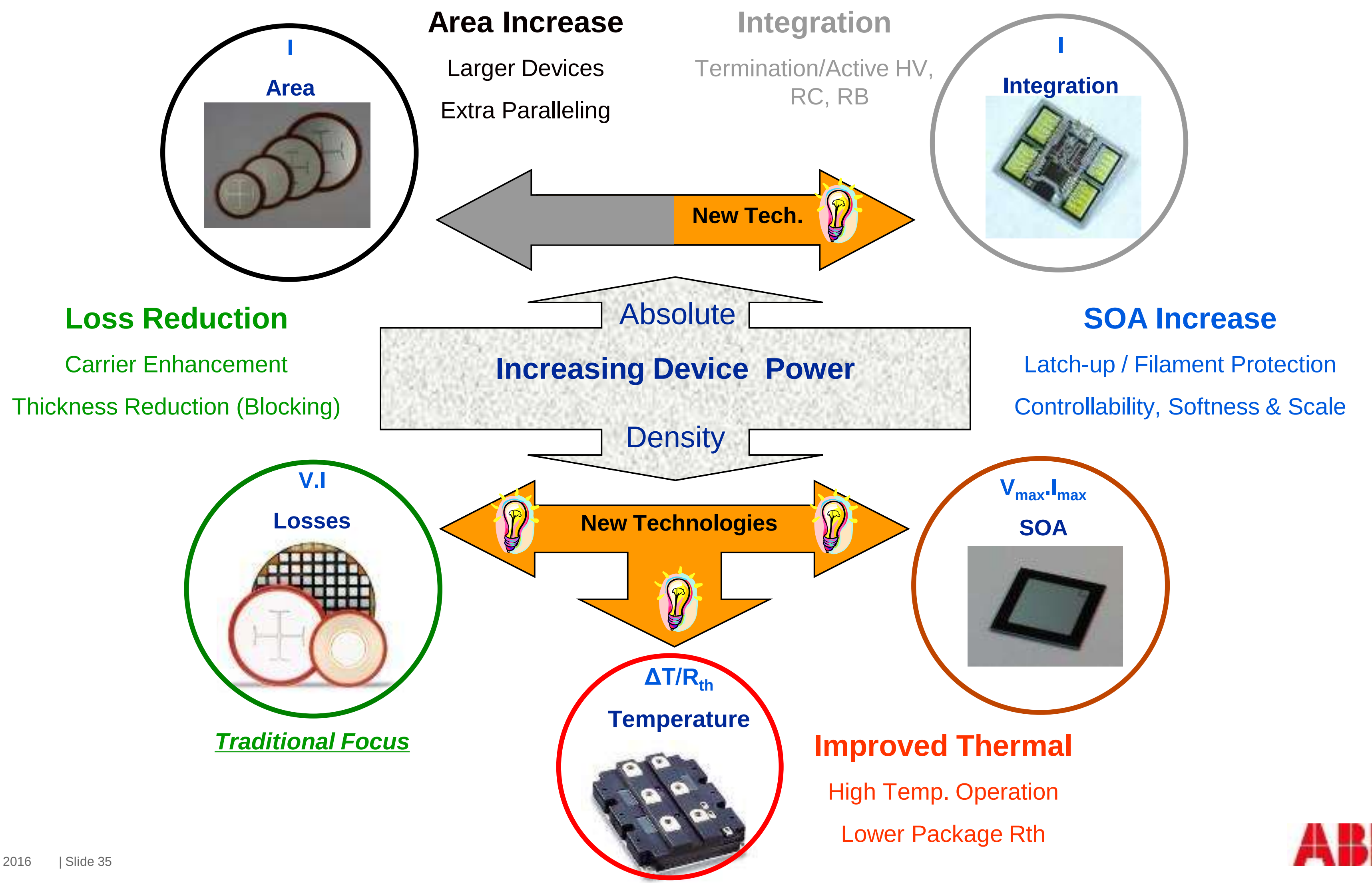
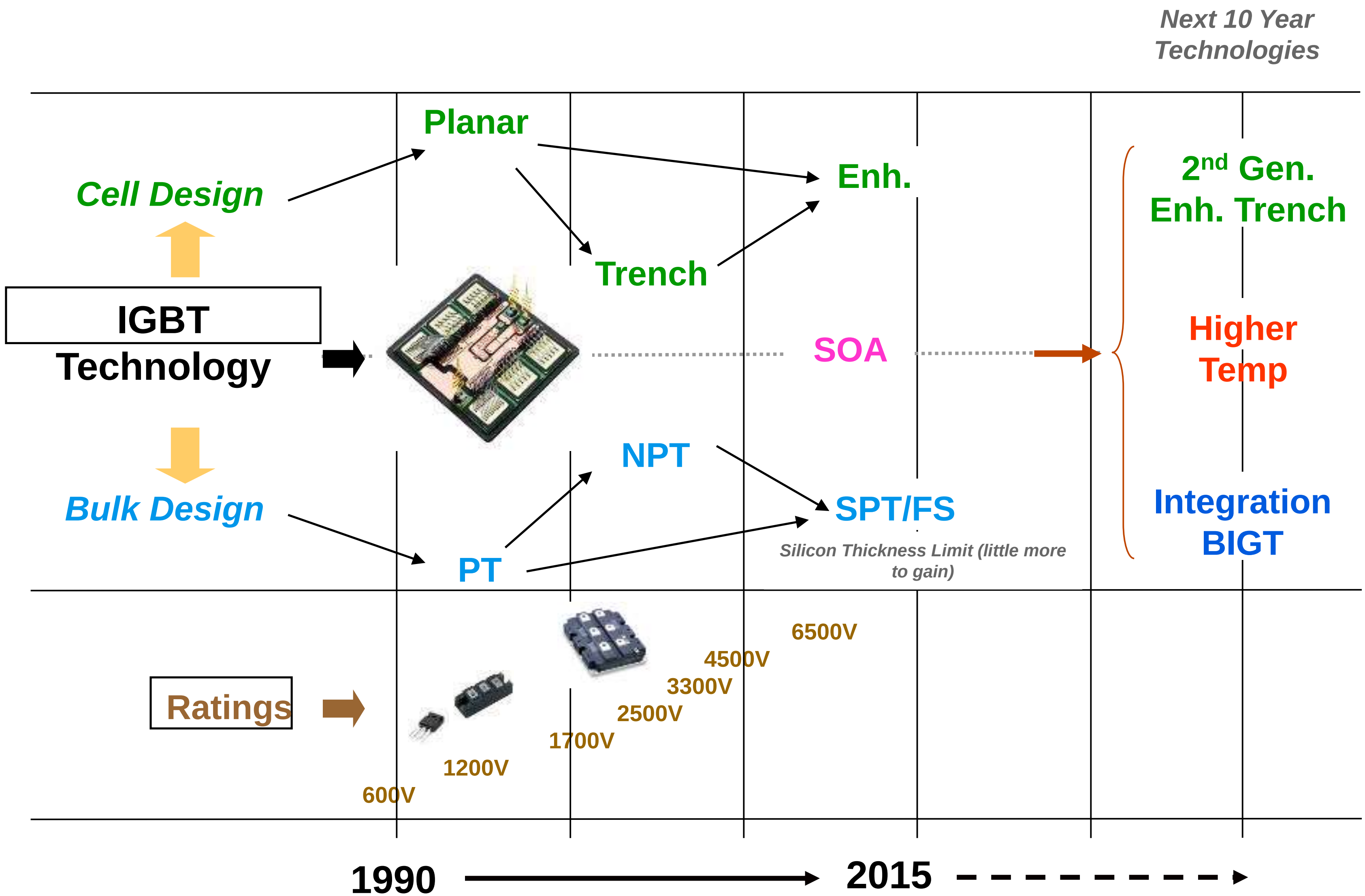
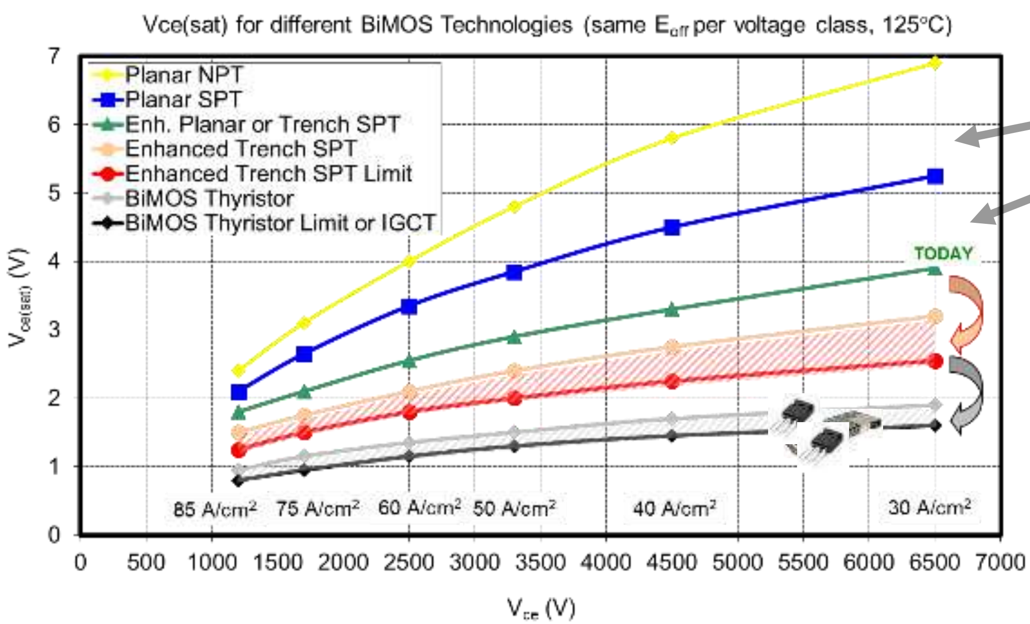
Technology Drivers for Higher Power (the boundaries)

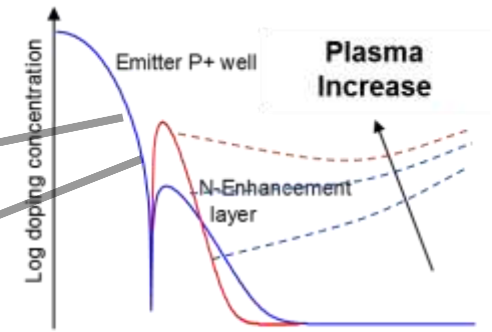


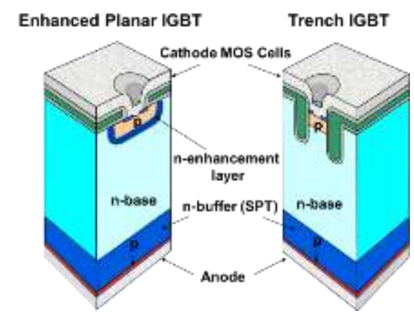
IGBT Technologies

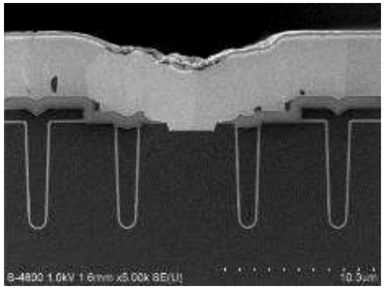


Enhanced Trench (EHT) for IGBT





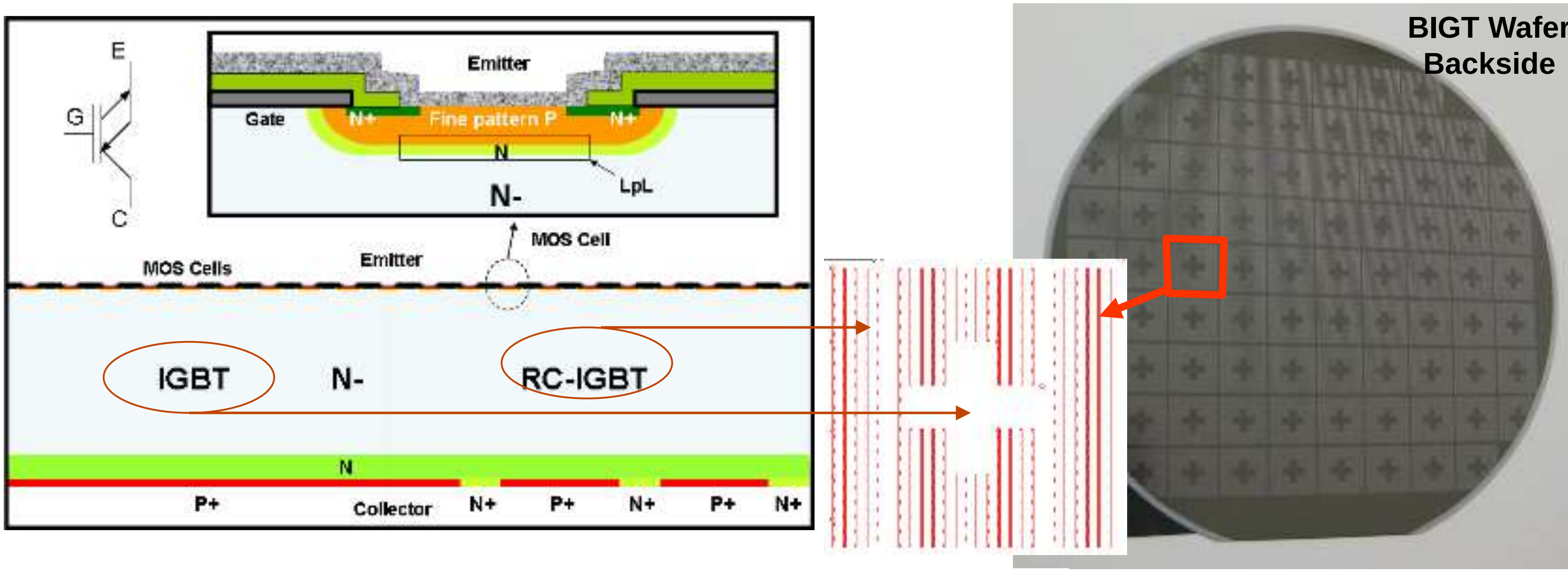


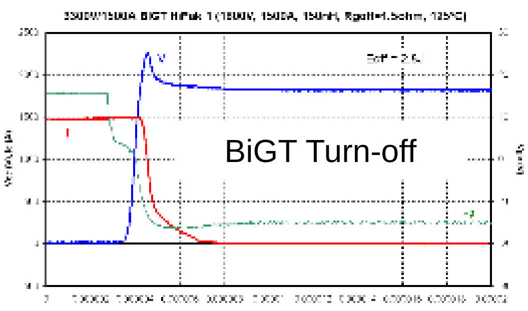


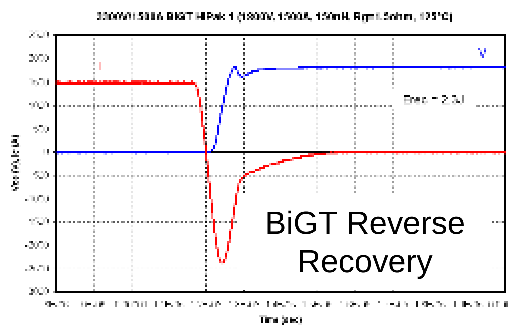
- ABB EHT ready 2016 (1700 - <u>3300</u>V)
- Current density up 20% (3300 - 4500V)
- StakPak 4500V 3000A→ 3600A

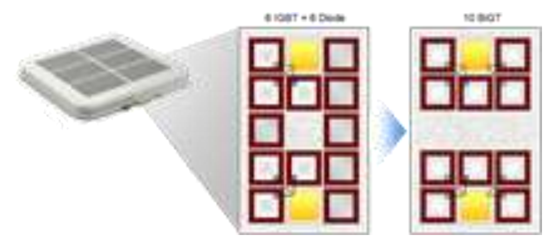
Integration: Bimode Insulated Gate Transistor (BIGT)

Integrates an IGBT & RC-IGBT in one structure to eliminate snap-back effect









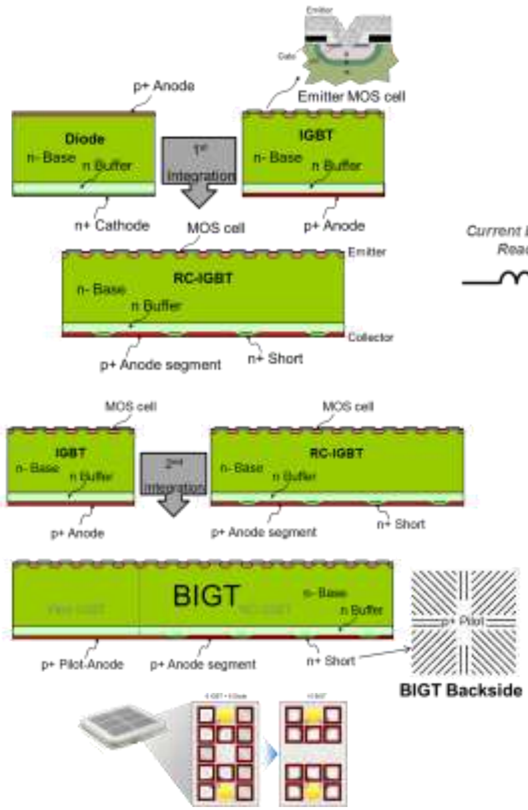
→ Increased IGBT and diode area, MOS control needed for full potential

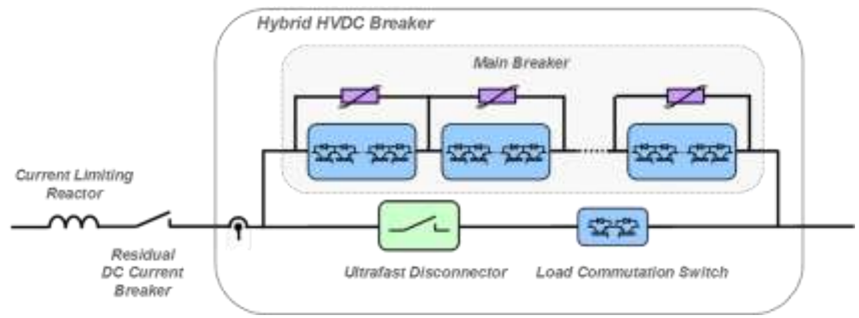
<u>HiPak</u>: *3300V/2000A* shown, Surge current up by 2x

<u>StakPak</u>: *4500V/3000A* demonstrated for DC-Breaker (CIGRE 2014)

ABB

ABB in High Power Semiconductors
Application DC Breakers based on a BIGT Chip and StakPak package



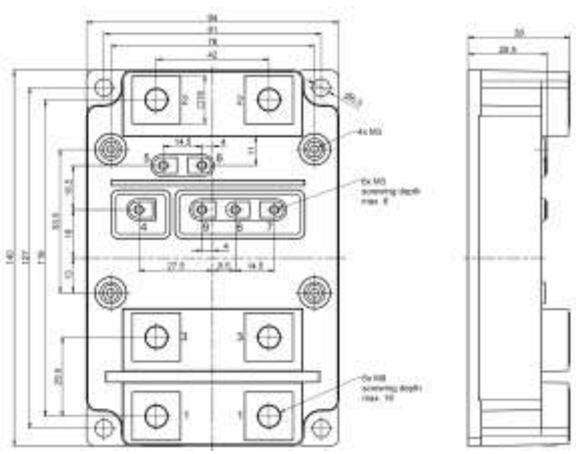


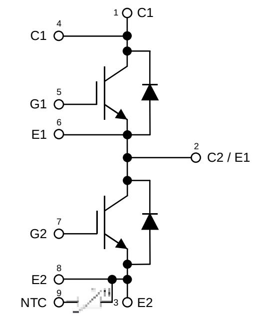
The BIGT (Bimode Insulated Gate Transistor) enables lower losses in both directions and a comfortable maximum breaking current up to 16kA at operating times within 5ms.

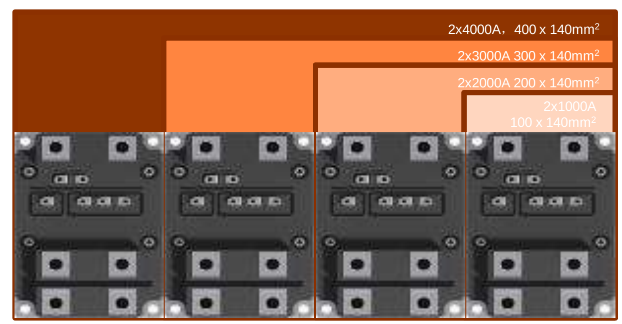
See Munaf Rahimo, Paper B4-302, PS3, Cigré Paris, 2014

The New Module Standard (LinPak)

- Dual Module Concept optimized for low Ls Applications
- High power density, low over-voltage, low switching losses
- 100mm x 140mm typical 3.3kV / 500A
- Ideal for modular parallel connection







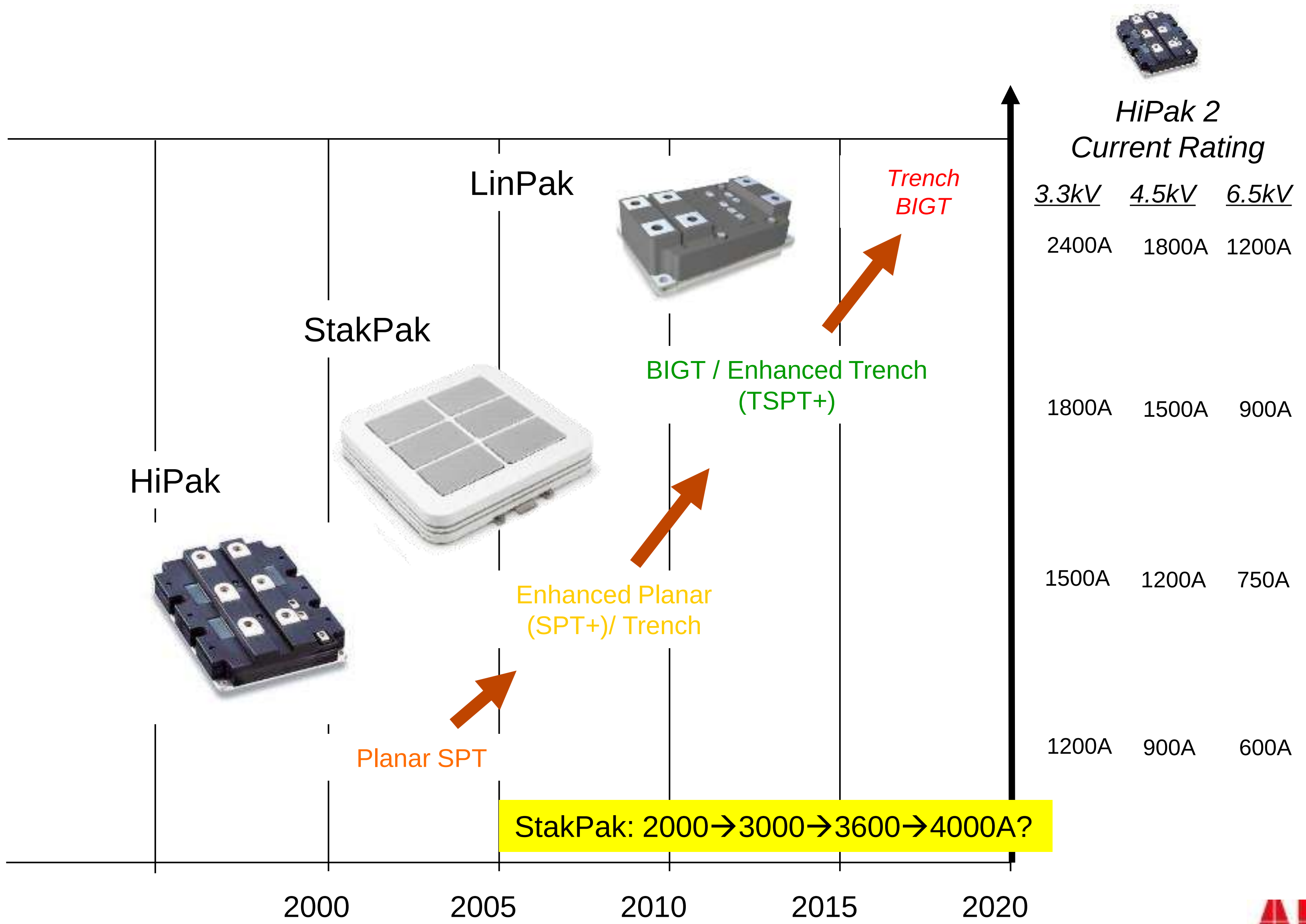
Module	Current Rating	Stray Inductance	Stray Inductance x Current	Module Over-voltage
LinPak	900A	10nH	9µH	15.6%
PrimePack	1400A	10nH	14µH	24.3%
HiPak	3600A	8nH (x2)	57.6µH	100 %

6'' RC-IGCT to turn off 8000 A
Most powerful semiconductor

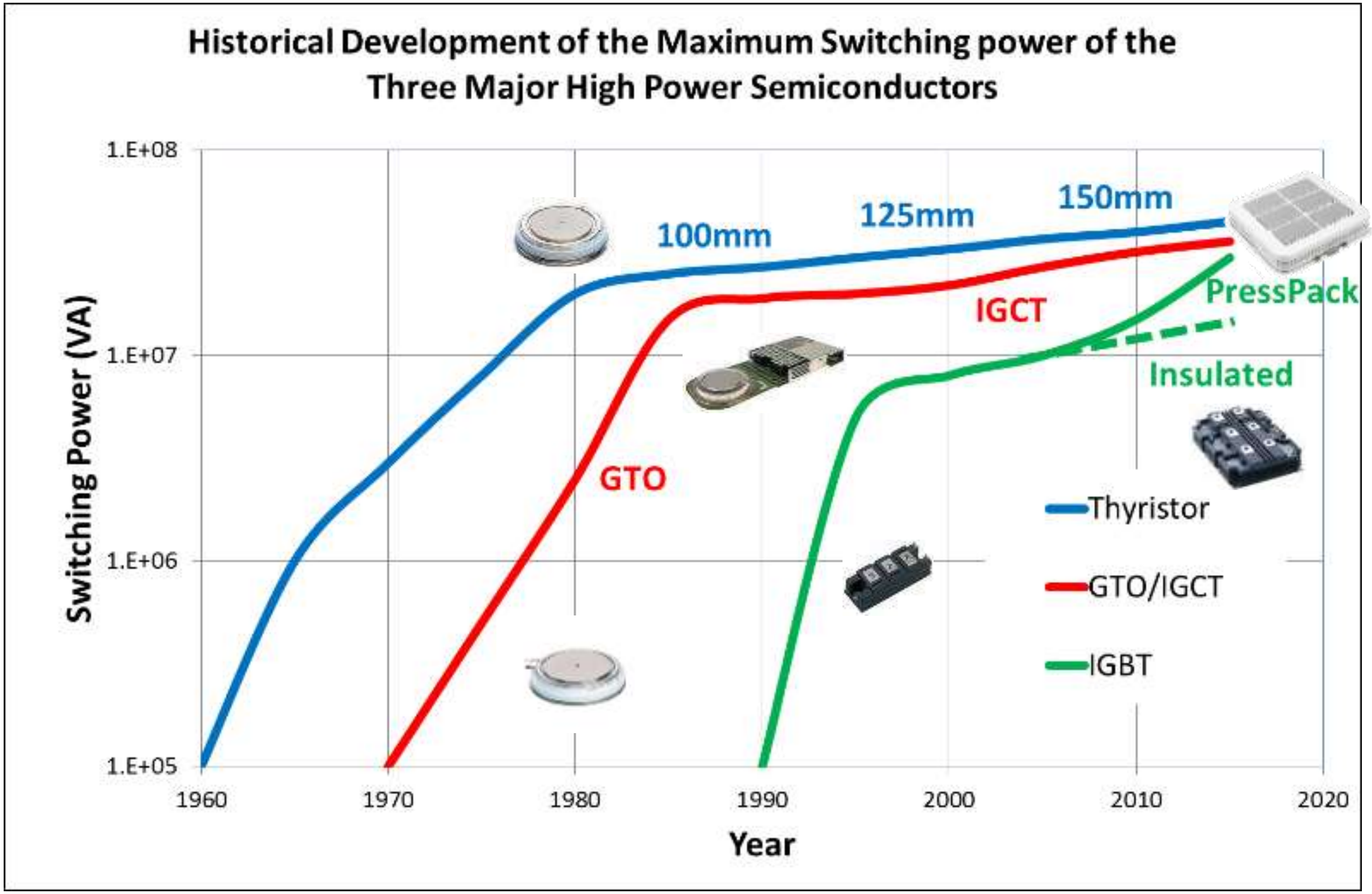


- First prototypes of 150 mm (6") RC-IGCT (RC = reverse conducting)
- Product development pending application
- Voltage: 4.5 & 6.5kV
- Target spec available: VDRM=4500V, ITGQM=8000A/9000A
- →loss reduction by >20%, compact & reliability (simplicity)

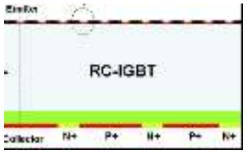
High Power IGBTs and Modules

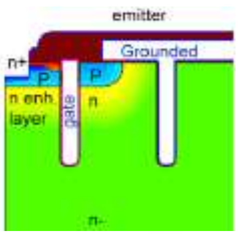


The MAIN THREE High Power MW Devices: POWER



Summary





- Power device pushes physical limit for multi-GW VSC-HVDC application
- 4500V appears a good voltage, up to 3000 A shown, Ic to 4000 A possible with StakPak, but challenge for Ls (< 100nH)
- Enhance reliability, via lower “piece count”, to ensure service availability
- Optimise along technology curve for reduced losses
- Improves chip technology curve via Enhanced trench → +20% Ic
- Increase effective chip area via BiGT → +20% Ic
- Increase of current by 30% via combined improvements feasible
- LinPak low Ls Module platform offers compact & low over-voltage design
- IGCT represents alternative for high power (low losses) application

Power and productivity
for a better world™

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