High power semiconductors for T&D and industry application
StakPak & IGCT introduction
Content

- StakPak
  - Design – SPT+ & press-pack technology
  - StakPak Characteristic
  - StakPak Design Benefit
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- IGCT
  - Product Family
  - New Developments
  - Application aspect
  - Application and reference
- New 6 inch HVDC Thyristor
- Summary
StakPak 5SNA 2000K451300 –design
\( V_{CE} = 4500 \text{ V}, I_C = 2000 \text{ A} \)

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-based plate \( \rightarrow \) low Rth
- SCFM Fail-safe \( \rightarrow \) for series connection
StakPak™ – ABB proprietary IGBT module technology

Sub-module Cross Section

StakPak press-pack

Semiconductor wafer

IGBT Chip
IGBT StakPak – modular design

\[ n \text{ standard submodules} + \text{Glass fibre reinforced frame} = \]

Possible current ratings
700A – 2000A (2800A)
Key feature
Short circuit failure mode

- Immediate Stable short-circuit in case of a chip failure
- The Press-Pin and the Silicon form a conducting alloy
- ABB offers SCFM lifetime ratings for users requiring this feature and who are able to specify the load current waveforms and profiles
StakPak innovative clamping
Controlled and uniform clamping force

- Top: Classic multi-chip Presspack prone to stress concentration
- Bottom: StakPak spring contact ensure defined uniform pressure
StakPak – explosion proof and efficient cooling

1. High strength and high temperature resistant Moly-alloy Baseplate and Emitter cover
2. Cu Emitter cover plate
3. Glass fibre reinforced frame housing
4. Fails into short circuit in fault
5. Capable to sustain up to 600 kA (0.2ms) \( \rightarrow I^2t \)
   \[ = 3.3 \times 10^7 \text{ A}^2\text{s} \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>vs &quot;HiPak&quot;</th>
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<td>Junction to case</td>
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<td>Rth(j-c) DIODE</td>
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<td>case to heat sink</td>
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<td>Rth(c-h) DIODE</td>
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<td>Rth(c-h) IGBT</td>
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</table>
StakPak – gate drive

- Standard gate IGBT driver can be used
- \( R_{G-on} = 1.8 \ \text{Ohm}, \ R_{G-off} = 8.2 \ \text{Ohm}, \ C_{GE} = 330 \ \text{nF} \)
- Active clamp available
- Standard gate driver interface
- Gate driver with small jitter needed for series connection
RBSOA – waveform

\[ I_C = 4800A, \ V_{DC} = 3400V, \ T_j = 125^\circ C \]
StakPak – short circuit capability

$V_{DC} = 3400V$, $T_j = 125^\circ C$, $R_{\text{Gon/off}}=1.8 / 8.2 \, \Omega$, $C_{GE} = 330 \, \text{nF}$, $L_s = 200 \, \text{nH}$
Phase current simulation (2 level) (300Hz, RMS) 2000K451300 (4500V / 2000A)

T_vj = 115°C, T_c = 80°C, T-heat = 70°C
Total losses dominated by IGBT and conduction losses
Phase current simulation (2 level) (300Hz, RMS) 2000K451300 (4500V / 2000A)
IV Characteristic of StakPak
10 kA reached w/o desaturation -5SNA 2000K451300

\[ I_C [A] \] vs. \[ V_{CE} [V] \]

- \( V = 9V \)
- \( V = 11V \)
- \( V = 13V \)
- \( V = 15V \)
- \( V = 17V \)
- \( V = 19V \)

\( T_{VJ} = 125 \, ^{\circ}C \)
Turning off behavior of StakPak
Safe 10 kA turn-off with snubber -5SNA 2000K451300

IGBT turn off $V_{cc} = 3000 \text{ V}$, $I_{ce} = 10000 \text{ A}$, $C_s = 5 \mu \text{F}$, $5 \text{ Ohm}$,
$L_s = 200 \text{ nH}$, $T_j = 85 \degree \text{C}$, $V_{ge} = 18 \text{ V}$
StakPak – application benefits -1
Ideal IGBT for Grid application

1. SPT+ smooth switching with controllability
2. Lower losses for reduced cooling and conversion losses
3. Large SOA ensures system tolerance
4. SCFM for fail-safe uninterrupted operation
5. Explosion safe → no need for containment
6. Efficient cooling offering high rated power
7. Uniform chip pressure → easy stack clamping system
8. Robust module design → long term reliability
StakPak – application benefits -2
Ideal IGBT for Grid application

1. Ability to turn off 10 kA (with Snubber) → suited for DC breaker application
2. Presspack design → ideal for HV series connection with redundancy
3. Potential high surge current capability
4. High current rating → >1 GW without parallel connection
5. Modular design facilitates design platform
6. Tailored for T&D with good operation record
StakPak
Proprietary press-pack design for series connection

1. HVDC (series connection, redundant)
2. FACTs (StatCom) (compact, high power)
3. DC-Breaker (series connection, redundant)
4. Multi-level inverters (6+ module mech in series reliable, compact)
5. Frequency converters (15, 25 kV AC, traction)
6. Pulse Power (series connection)
7. … (high voltage, high current, high power)
ABB semiconductors enable reliable HVDC operation

2012
- 48 HVDC Classic projects (starting 1970)
- Over 100 projects (Classic + Light + up-grades)
- Incl. 10 HVDC Light projects (IGBT StakPak)
Awarded 1200 MW HVDC Light Project by Scottish Hydro Electric
Off-shore Windpark DolWin in the North Sea

165 km / ±320 kV / 800 MW

4.5 kV/2000 A

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

Power semiconductor
In low inductive package
Gate unit
IGCT Semiconductor package

- Press pack package
  - Double side cooling
  - Low thermal resistivity
  - Hermetic package
  - High reliability
  - Low inductive coupling to gate unit

Very few parts
IGCT Interfaces

- GCT hockey puck housing
- Power supply connection
- Visible LED indicators
- Status Feedback
- Command Signal
- Optical fibre connectors

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IGCT turn-off process
Commutation of phase current to gate

Thyristor
Commutation time: $t_1 = \frac{I_{load} \cdot L_\sigma}{V_{GU}}$
Standard IGCT family

- 49 to 91 mm wafers (…150 mm)
- 520 to 5000 A (…8000 A)
- 4500 V to 6500 V (…10 kA)
- Free-floating wafer technology for high power-cycling capability
- Asymmetric and reverse-conducting devices
## Product range - IGCT

<table>
<thead>
<tr>
<th>Part number</th>
<th>VDRM (V)</th>
<th>VDC (V)</th>
<th>ITGQM (A)</th>
<th>ITAVM (A)</th>
<th>Package* (mm)</th>
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<td>4500-5500</td>
<td>2800-3300</td>
<td>520-1100</td>
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HPT™ IGCT product platform

- 4.5 kV: Ideal for 3- and 5-level Voltage Source Inverters @ 3.3 kV\textsubscript{RMS} and 6.0/6.6 kV\textsubscript{RMS}
  - RC-IGCT in 51, 68 and 91 mm size
  - Asymmetric device in 91 mm size

- 5.5 kV: Ideal for 3- and 5-level VSI @ 4.0/4.16 kV\textsubscript{RMS} and 6.9/7.2 kV\textsubscript{RMS}
  - RC-IGCT: in 51, 68 and 91 mm size
  - Asymmetric device in 91 mm size

- 6.5 kV: Ideal for 2-level Traction & Trackside Converters, and also DC breakers
  - Asymmetric device in 91 mm size

- 10 kV: Ideal for 3-level Voltage Source MVA Inverters @ 6.0-7.2 kV\textsubscript{RMS}
  - Asymmetric device in 91 mm size
  - Sample available
Freewheeling, neutral point and clamp diode

- ABB offers matching freewheeling, neutral point (NPC) and clamp diodes.
Fast recovery diodes
For antiparallel connection with high di/dt

- With 5SDF 11H4505, 20L4520 and 28L4520 released we can cover all applications using the new HPT-IGCTs
- Capable of di/dt up to 5000 A/us
- Allow for higher di/dt IGCT turn-on and reduced inductance
10kV IGCT – static characteristics

Forward blocking, $T_J = 125^\circ$C

On-state characteristics, $T_J = 125^\circ$C

< 20mA at 11kV

new 35mm HV housing

standard gate-unit
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, TGQM=8000A
RB (Reverse Blocking)-IGCT for CSI

- In development 2.5, 6.5 kV and 8.5 kV devices.
- The first engineering samples delivered for selected customers
- Applications:
  - MVD Current Source Inverters (CSI)
  - Static breakers
Outlook

ABB IGCT development using HPT+

- **Asymmetric IGCT**
  - 91 mm
  - 4.5, 5.5, 6.5, 10kV
  - low $V_T$ version
  - low $E_{OFF}$ version

- **RC-IGCT**
  - 91 mm
  - Improved diode softness by FCE

- **RC-IGCT**
  - 51 to 150 mm
  - Large area GCTs

- **RB-IGCT**
  - 38-68 mm
  - 2.5, 6.5 & 8.5kV

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3 level voltage source inverters

- AC-output voltage modulated with PWM, DTC etc. **3 discrete voltage levels** (+DC, 0, -DC) >less harmonics

- Fundamental switching frequency 200 .. 1’000 Hz

**Examples**

- Medium voltage drives (in most cases with IGCTs) 4..6 kV, 1..11 MVA

- Static frequency converters
  - Railway supply 50 to 16.7 Hz conversion up to 400 MW

- STATCOM / Windpower etc.

- Traction (e.g. 3 kVdc) up to 6 MW
ABB’s proven converter technology based on IGCT

PCS 6000 Wind
Frequency converter for application in wind turbines
> 700 MVA delivered

ACS 6000 MV Drive
Frequency converter to drive an electrical motor
> 13 000 MVA delivered

PCS 6000 STATCOM
Frequency converter for reactive power control
> 500 MVA delivered

PCS 6000 Rail
Frequency converter to connect railway with regular grid
> 1000 MVA delivered

PCS 8000
Frequency converter for Pumped storage power plants
ACX Avce, Seebach 2x, Massaboden
XLD 100 MVA Grimsel 2
2nd generation low loss HVDC thyristor – development update on YST140

Design Improvement and Product Features

1. Optimized Si thickness and resistivity for lower On-state voltage, $V_T$
2. Optimized Cathode and AG (Amplifying Gate) shorting pattern for higher $dV/dt$ and lower tq
3. New SF(Snow Flake) gate structure for maximum Si active area
4. Improved packaging for lower thermal resistance, $R_{th_{JC}}$
Relevant electrical parameters of PCT for UHVDC

Record low on-state voltage $V_T$

\[ I_{\text{Tmax}} = 4.2 \rightarrow 5 \, \text{kA} @ V_{R\text{RM}} = 8.5 \, \text{kV} \]
\[ I_{\text{Tmax}} > 6 \, \text{kA} @ V_{R\text{RM}} = 6.7 - 7.2 \, \text{kV} \]

\[ \rightarrow 6250 \, \text{A}, \, V_{T_{\text{max}}} = 1.7 \, \text{V}, \, \text{Qrr: 5100-5700uC, tq: 550 us} \]
Major characteristics with Gen.2 YST140P85

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<tr>
<th>参数</th>
<th>符号</th>
<th>单位</th>
<th>值</th>
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<tr>
<td>1 技术曲线 Qrr - VT</td>
<td>G1→ G2</td>
<td>-200mV</td>
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<td>2 可重复峰值电压 (关断态, 反向)</td>
<td>V_{DRM}, V_{RRM}</td>
<td>V</td>
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<td>3 漏电流 (关断态, 反向) 8500V</td>
<td>I_{DRM}, I_{RRM}</td>
<td>mA</td>
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<td>4 雪崩电压</td>
<td>V_{RSMS}</td>
<td>V</td>
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<td>5 反向恢复电荷</td>
<td>Q_{RR}</td>
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<td>6 换向时间</td>
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<td>μs</td>
<td>600</td>
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<td>V_{TM}, V_{TMean}</td>
<td>V</td>
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<td>V_{GT}, I_{GT}</td>
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<td>11 关断电压的临界上升率</td>
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StakPak – conclusion
DC grid made easy

1. ABB StakPak is the most powerful IGBT module available
2. Safe short-circuit failure mode offering fail safe
3. Flexible current rating with surge current options
4. Uniform chip pressure via individual spring
5. Enable easy and controlled clamping system for long stack
6. Efficient cooling offering high rated power
7. Tailor-made for T&D applications (safe, reliable, redundancy, uninterrupted)
8. Over 10 HVDC projects in safe operation
IGCT summary

Product and technology
- Integrated gate unit for controllability
- Low on-state losses for reduced cooling
- Very high power density and reliability
- Double sided cooling (press-pack design)
- Fail into stable shorted state / explosion proof
- High load cycling capability
- In pipeline: 6” for 8000A, 10 kV, RB-IGCT,

Application
- High power (V & I) → less components needed → low FIT rate
- Less requirement for series and parallel connection, but enabled
- Designed in at key OEM with sound field record
- Ideal for high power conversion for industrial, renewable and T&D applications
Power and productivity
for a better world™