High-Voltage Phase-Leg Modules for Medium Voltage Drives and Inverters

Medium voltage inverters (line voltages of 1000 .. 3300 V) or auxiliary inverters for rail applications rated at rather low power levels of 100 .. 1000 kW suffered by the lack of availability of suitable high voltage IGBT modules rated at lower current. Thus inverter manufacturers had to use modules with too high current ratings which yielded in bulky inverter designs. With the introduction of the new HiPak0 series there is for the first time a high-voltage phase-leg module configuration available. The modules are rated at 2 x 150A, 4500V and 2 x 250A, 3300V. **Raffael Schnell, Manager Application, ABB Switzerland Ltd, Semiconductors**

With the introduction of the HiPak0 series it is now possible to design very compact and efficient inverters for 1000 to 3300V line voltage and an output power rating of 100 to 1000kW. Higher power ratings are possible with parallel connection of the modules.

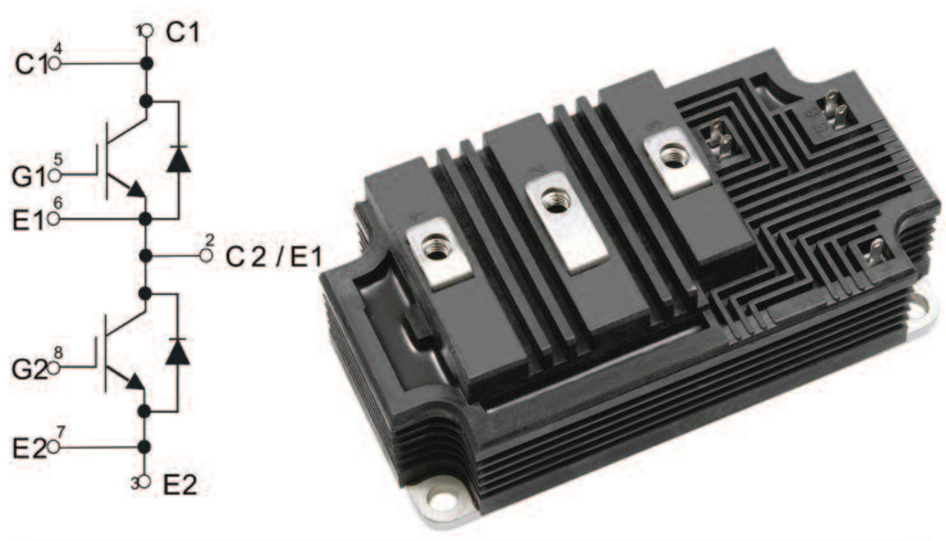
Such inverters can be particularly used in industrial applications such as medium voltage drives for fans, pumps, extruders, paper mills, harbour cranes and conveyor belts, just to name a few. Other applications are auxiliary inverters for rail application or even converters for renewable applications such as converters for wind-power.

The HiPak0 module design compromises a simple phase-leg configuration and a stream-lined electro mechanical interface: All screw type connections (power terminals / base-plate) are realised with M6 screws allowing an easy assembly procedure. The gate/auxiliary connections are done with fast-on plugs. With a foot-print of 70mm x 140mm the HiPak0 module is compatible with heatsinks of similar sized standard IGBT modules.

Figure 1 shows the module and the available ratings. The electrical configuration of the HiPak0 module enables a simple mechanical inverter layout for both 2- and 3-level topologies.

Module properties

The principal mechanical design follows the proven traction module concept and compromises Aluminum Nitride (AlN) ceramics for highest possible insulation rating of 7400Vrms (on request up to 10.2kV) and low thermal resistance. In



Type	Nominal Current	Voltage Rating
5SNG 0150P450300	2 x 150 A	4500 V
5SNG 0250P330300	2 x 250 A	3300 V

Figure 1: The HiPak0 Module line-up

	5SNG 0150P450300	5SNG 0250P330300
V_{CEs}	4500 V	3300 V
I_{nom}	150 A	250 A
V_{CEsat} @ I_{nom} , 125 °C	3.50 V	3.0 V
V_F @ I_{nom} , 125 °C	3.45 V	2.1 V
E_{on} @ I_{nom}, 125 °C	580 mJ*	425 mJ**
E_{off} @ I_{nom}, 125 °C	615 mJ*	450 mJ**
E_{rec} @ I_{nom}, 125 °C	385 mJ*	280 mJ**
$R_{th(j-c), IGBT}$	69 K/kW	52 K/kW
$R_{th(j-c), Diode}$	138 K/kW	100 K/kW
	*2800 V_{DC}	** 1800 V_{DC}

Table 1: Key Data of the HiPak0

order to enable sufficiently high thermal cycling performance the base plate is made of Aluminium Silicon Carbide (AlSiC) that offers a matched coefficient of thermal expansion (CTE) to the AlN ceramic.

Both the 3300 V and 4500 V versions offer the latest SPT+ chip-set technologies [3]. The SPT+ technology offers highest SOA margins and exceptional low conduction and switching losses. Table 1 summarises the key performance figures of both module types.

Thanks to the very narrow parameter spread easy paralleling of the phase-leg modules is possible with minimal de-rating. This allows scaling of the achievable output power nearly linearly with the number of modules in parallel.

Inverter design

With a single module footprint a large range of inverter output power can be realised. In a 2-level topology the standard line voltage range from (690), 1000 and 1700Vrms can be served with two module types (5SNG 0250P330300, 5SNG 0150P450300). For DC-fed traction auxiliaries DC voltages up to 2800V are possible, which is an often used standard DC-voltage for AC-fed trains.

Figure 2 shows the achievable 3-phase output power for 2-level voltage source inverters. With forced air-cooling (dashed lines) 300kW can be reached. Water cooling allows more than 400kW output power.

In case of a 3-level inverter the nominal line voltages of 2300Vrms and 3300Vrms can be served. DC-fed traction auxiliaries up to 5600V are theoretically possible. The 5SNG 0250P330300 in 3-level topology is suited for the nominal 3000VDC traction supply voltage.

Figure 3 shows the output power range for a three phase inverter in 3-level topology. Forced air-cooling allows up to 600kW output power (dashed lines) whereas with water cooling more than 800kW can be reached.

The HiPak0 Module is designed with special focus on simple inverter designs. Figure 4 shows simplified drawing of a possible concept for a 2-level inverter phase leg. Only one type of screw is required for the mechanical connection (M6) and the gate-drive unit can be quickly connected with fast-on plugs. It allows for a simple phase-leg construction for both 2-level and 3-level topologies while maintaining the required clearance and creepage distance values for a proper insulation coordination. Thus a maximum possible clearance distance is designed in for the given package size. The housing material has a CTI > 600.

The clearance and creepage distances are shown in Table 2.

Even in harsh environmental condition such as pollution degree PD3 the HiPak0 needs to fulfil the standards for insulation coordination. Thanks to the high package CTI value the creepage distance allows for 4290Vrms working voltage between

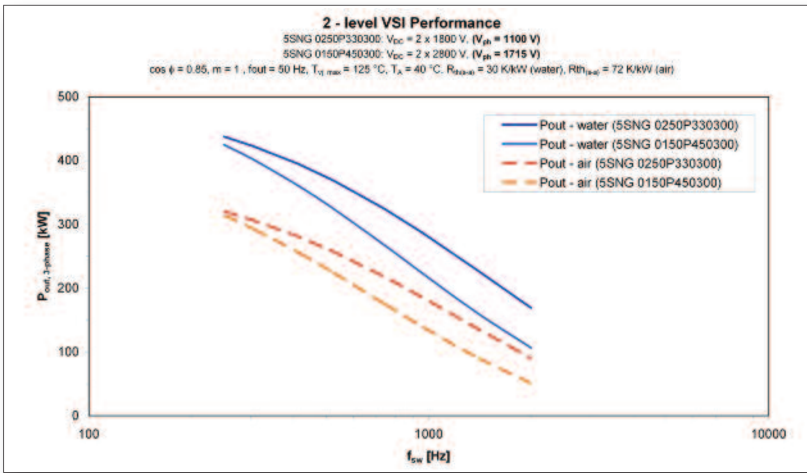


Figure 2: Output power versus switching frequency for a 2-level inverter

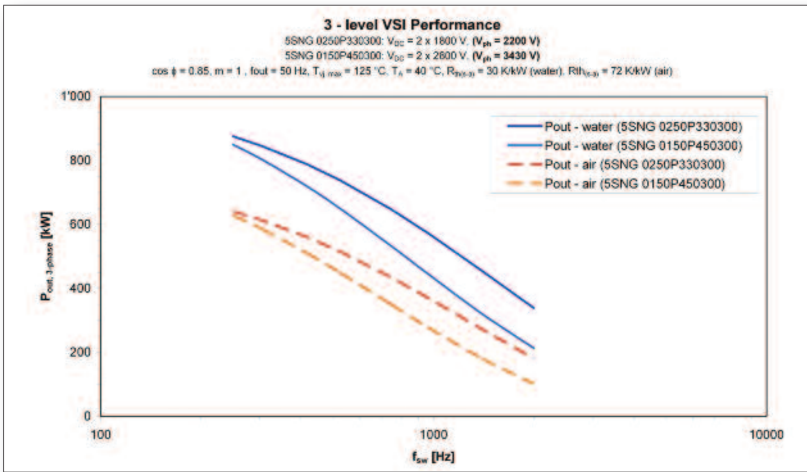


Figure 3: Output power versus switching frequency for a 3-level inverter

Clearance distance in air	d_a	Terminal to base	35 mm
		Terminal to Terminal	19 mm
Surface creepage distance	d_s	Terminal to base	64 mm
		Collector 1 to Emitter 1	54 mm
		Collector 1 to Emitter 2 (+DC to –DC)	78 mm

Table 2: **Clearance and creepage distance for the HiPak0**

collector and emitter, without degradation of the housing due to tracking effects. From +DC to -DC the corresponding working voltage can be up to 6200Vrms. The internal module insulation to the base-plate can be optional up to 10.2kVrms which would correspond to a long term partial discharge free working voltage of max. 5100Vrms.

Thanks to the large creepage distance between terminals and base-plate 5100Vrms is as well the maximum working voltage without tracking in PD3. Regarding the clearance distance in PD3 up to 16kV impulse voltage are allowed between the collector-emitter terminals and 27kV impulse voltage between the terminals and the base-plate according to IEC 60664-1. This is also far beyond the capability of the used silicon chips and the insulating material (AlN cermic). Thus the package insulation coordination is sufficient.

Usually very challenging is the design of 3-level inverters with standard IGBT modules. With the HiPak0 and its phase-leg configuration probably the most compact 3-level phase leg can be realised for its power and voltage class (Figure 5). For the neutral point diode function the integrated free-wheeling diode of the HiPak0 Module with shorted gate-emitter can be utilised. This way there is only one kind of module necessary for the 3-level phase leg.

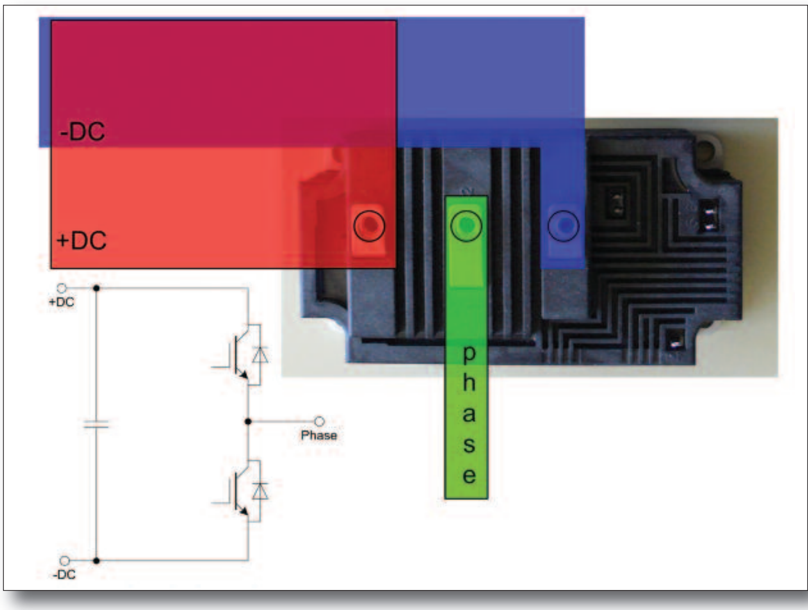


Figure 4: **A 2-level phase-leg**

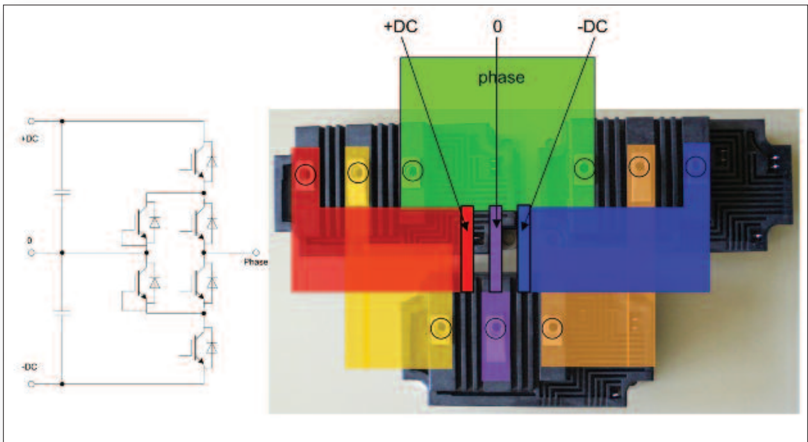


Figure 5: **A 3-level phase-leg**

Conclusion

A new high-voltage module line-up in phase-leg configuration has been presented. These modules rated at rather moderate current ratings are the perfect match for medium voltage inverters in the lower MW or sub MW class. The modules feature the latest chip technologies that offer lowest losses and highest ruggedness. The module design allows a simple effective design of 2-level and 3-level inverters and despite the small dimensions the requirements for insulation coordination according to IEC 60664-1 can be fulfilled even for demanding applications.

Literature

1 IEC 60664-1 Edition 2.0

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3 M. Rahimo, U. Schlapbach, A. Kopta, R. Schnell, S. Linder, "SPT+, the Next Generation of Low-Loss HV-IGBTs", Proc. PCIM'04, Nuremberg, Germany, 2004