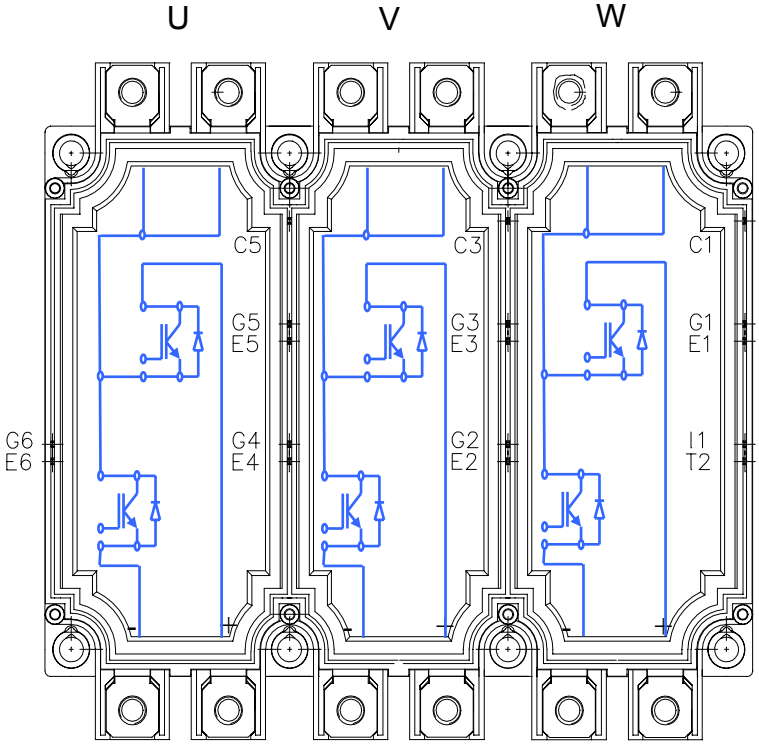
Paralleling of EconoPACK™+

1. EconoPACK™+ Design
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1. EconoPACK™+ Design

The EconoPACK™+ is designed for flexible use in various applications, ranging from the “SixPACK” configuration to a multi-parallel circuit. Whilst it is an internal parallel circuit when using the EconoPACK™+ modules as a “SixPACK”, for additional external paralleling of the half-bridge sections of the EconoPACK™+ some application rules have to be observed to make full use of the parallel configuration.



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2. Paralleling of IGBT^3 and EmCon HE diodes

The EconoPACK^{TM}+ module is exclusively equipped with IGBT^3 and EmCon HE or EmCon3 diodes. Both semiconductors are developed and manufactured by Infineon in co-operation with eupec. The advantage for paralleling is given by the NPT Fieldstop technology.

This offers a positive temperature coefficient over the entire range for the IGBTs as well as a positive temperature coefficient at and above rated current for the diodes. Notably beneficial is the very low distribution of the $V_{CE\ sat}$, V_F and the V_{Geth} values. All these features result in excellent parallel switching performance.

3. Methods of paralleling EconoPACK^{TM}+

In a dual parallel configuration 3 times 2 half-bridges are connected in parallel. The paralleling is done by externally connecting of the phase outputs.

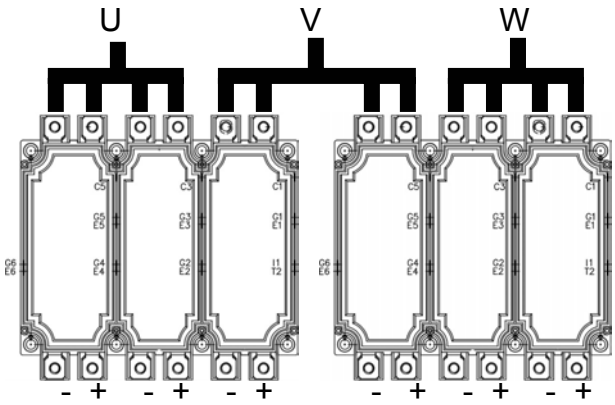


Fig. 2 : Dual parallel connection

In a threefold parallel configuration each EconoPACK^{TM}+ is connected as a half-bridge. Here too the paralleling is done externally, yet more care has to be taken with the symmetrical connection of the three half-bridge sections.

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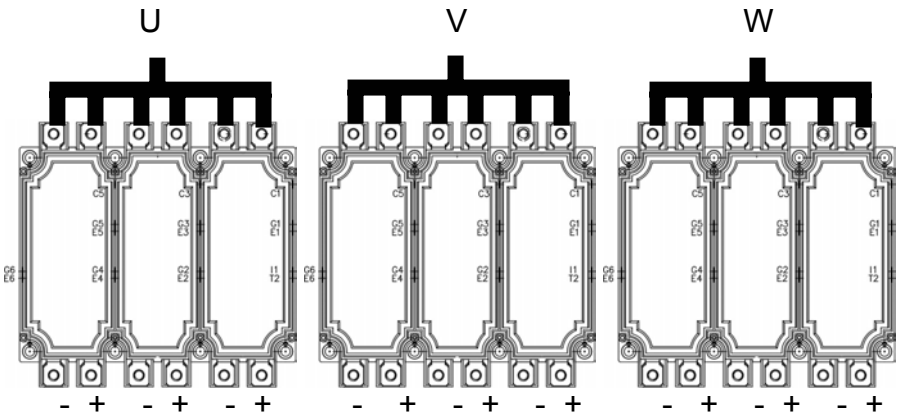


Fig. 3: Threefold parallel configuration

Paralleling more than three half-bridges is possible. However, it is recommended to parallel stacks or to use eupec IHM-modules.

4. Dynamic and static current sharing of parallel circuits

The symmetry of the current sharing among IGBT modules connected in parallel depends on several factors. We need to differentiate between static and dynamic current sharing.

The static current sharing can be defined with turned-on IGBT and current flowing by:

a) The difference of the resistive components of each half-bridge up to the point of paralleling.

b) $V_{CE\ sat}$ and V_F distribution of the chips connected in parallel

c) Temperature difference between the half-bridges connected in parallel.

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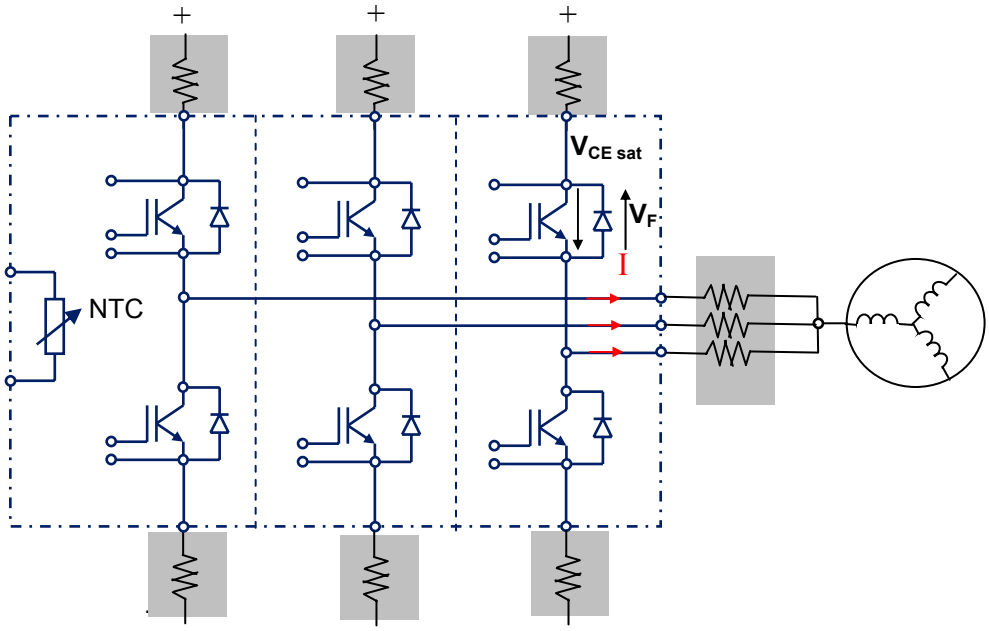


Fig. 4: Static current sharing for the EconoPACK™+ in parallel connection

Re a) The internal resistances in the module consisting of the bond wires and copper tracks (on the DCBs) are almost identical since the EconoPACK™+ is of symmetrical construction for the three systems. This value is defined in the data sheet as $R_{CC'/EE'}$. The mechanical construction of the bus bars should definitely be symmetrical. Otherwise, if unsymmetrical, different track resistances may result.

Apart from the symmetrical construction it is the power terminals which need particular attention with regard to corrosion or contamination.

Re b) The $V_{CE\ sat}$ and V_F values are subject to production variance which, for the NPT Fieldstop technology, is so low that a parallel design may be realised with minimal de-rating. In connection with the above mentioned positive temperature coefficient a selection of the chips for saturation voltage is **not necessary**.

Re c) V_{CEsat} values and V_F values depend on temperature. Significant temperature asymmetries within the cooling medium result in current asymmetries.

Cooling evenly counteracts this.

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The dynamic current sharing during the turn-on and turn-off periods can be defined as:

A) V_{GEth} distribution of the IGBT Chips

B) Difference of the stray inductances Lδ in the DC-bus between the individual half-bridges.

C) Magnetic field distribution during commutation.

D) Temperature difference between the paralleled half-bridges.

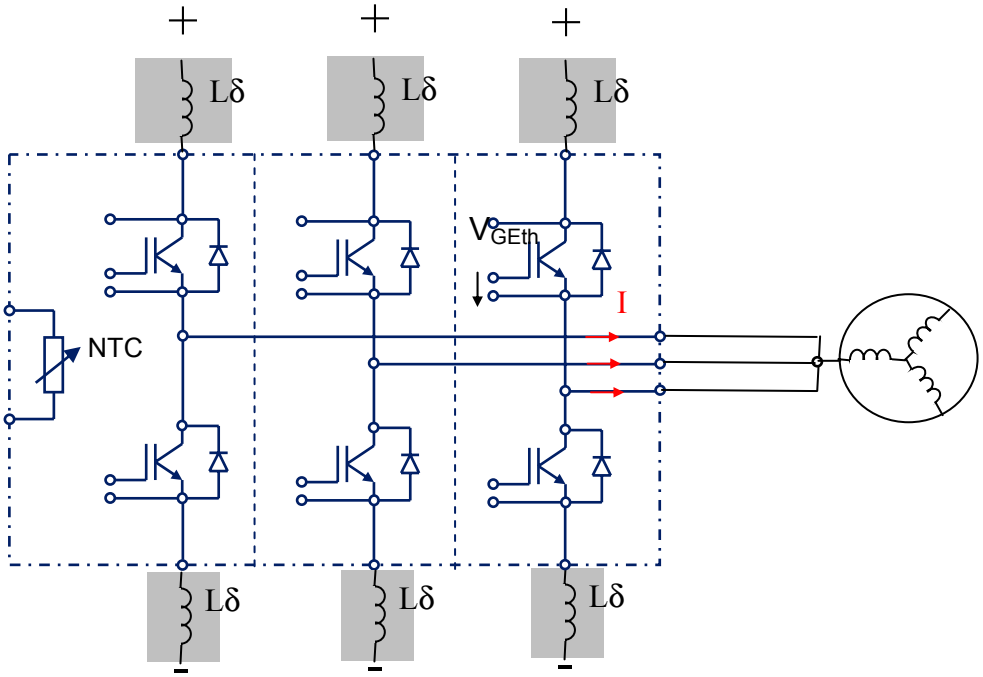


Fig. 5: Dynamical current sharing of the EconoPACK™+ in parallel connections

Re A) The V_{GEth} values are subject to production variance which, for the NPT Fieldstop technology, is also so low that no major asymmetries in the switched currents result from this.

Re B) Much more influence on the symmetry of IGBT and diode switching stems from the external DC-bus stray inductance Lδ. Different stray inductances will cause different switching behaviour of the IGBTs. A DC-bus construction once correctly adapted will optimise the switching behaviour.

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Re C) Surrounding a current carrying conductor will always be a magnetic field with the magnetic field strength H. In a parallel configuration of several half-bridge sections concentric circular magnetic field lines with the same direction of rotation will hence develop . Fig. 6.

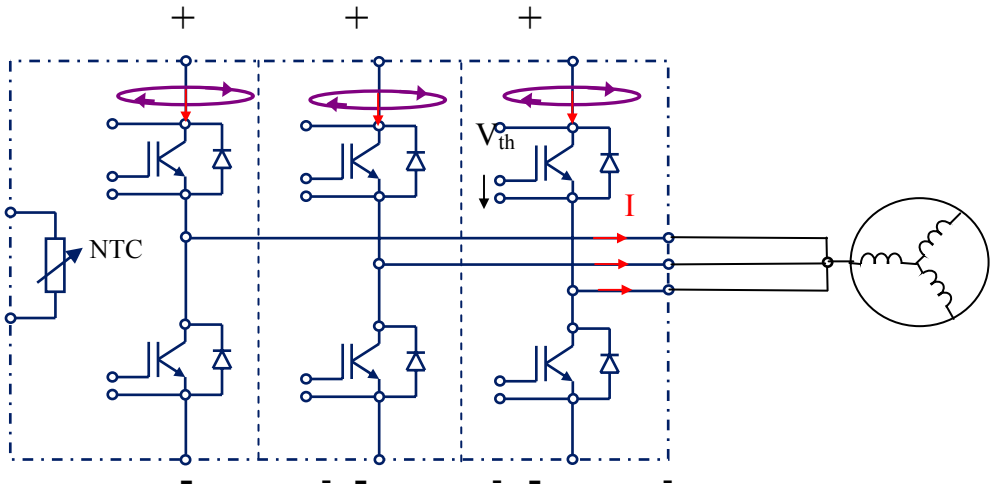


Fig. 6: Magnetic fields with paralleled EconoPACK™+

For commutation in parallel circuits the current flow, due to differently coupled neighbouring systems, will result in magnetic fields with different strengths. Fig 7. This produces differences in speed of the switching processes of the paralleled half-bridges. A compensation of this effect is achieved by adapting the external stray inductance or phase inductance. See section B.

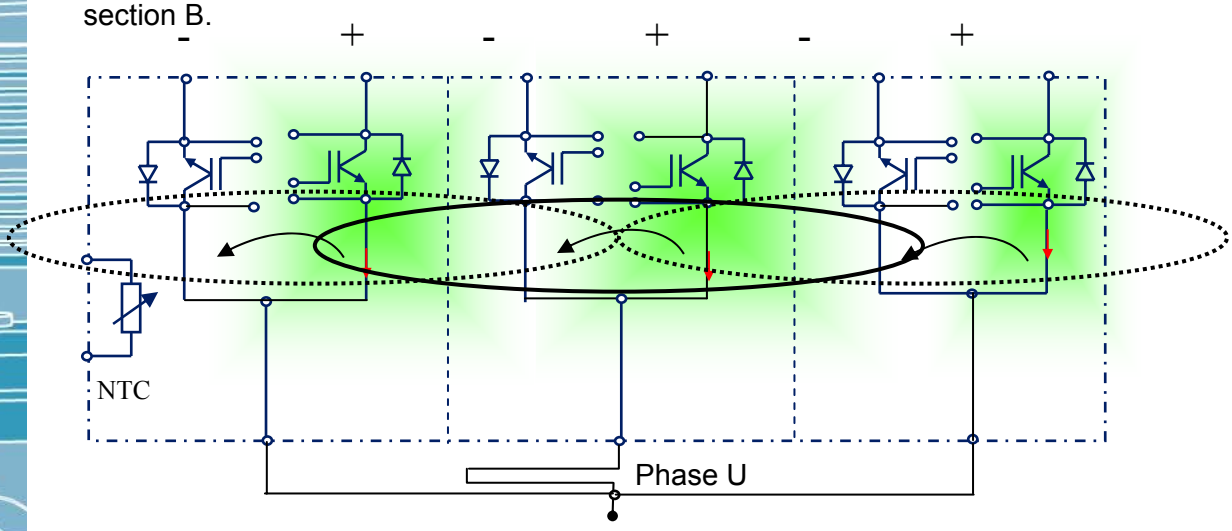


Fig. 7: Commutation process for paralleled EconoPACK™+ .

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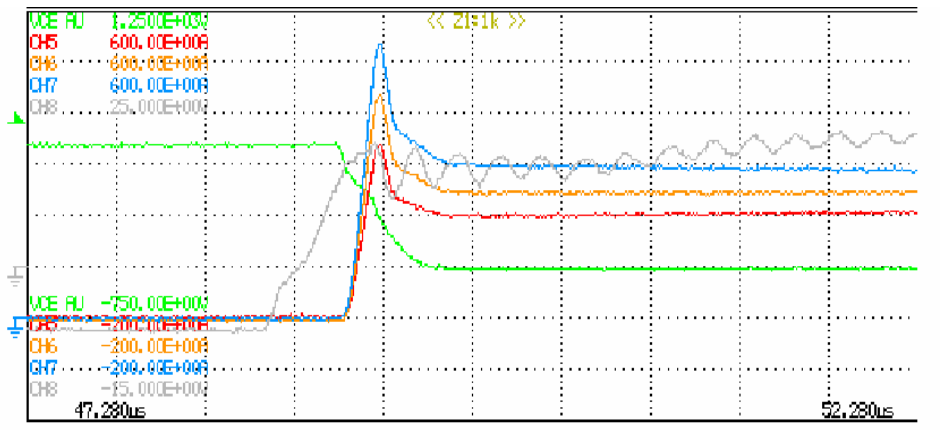


Fig. 8: Three half-bridges EconoPACK™+ in parallel. Current sharing without matching. *[Courtesy General Electric Co., Salem VA]*

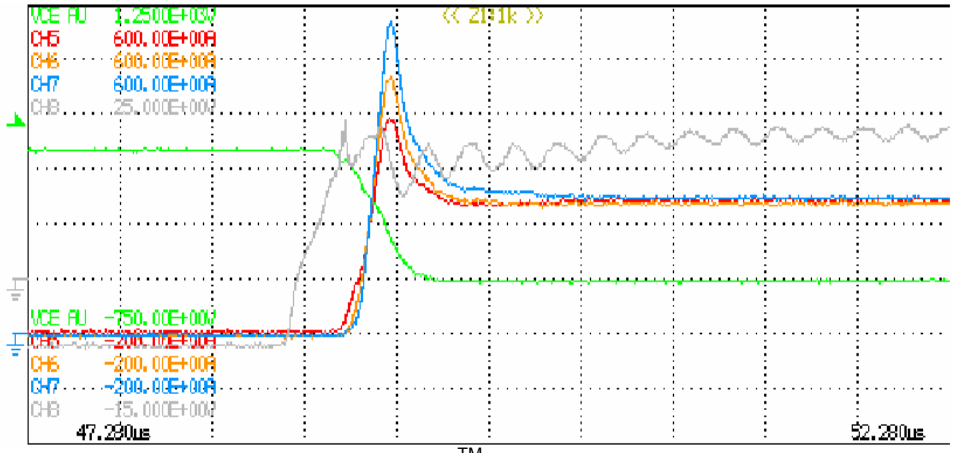


Fig. 9: Three half-bridges EconoPACK™+ in parallel. Current sharing during turn on by matching gate resistors. *[Courtesy General Electric Co., Salem VA]*

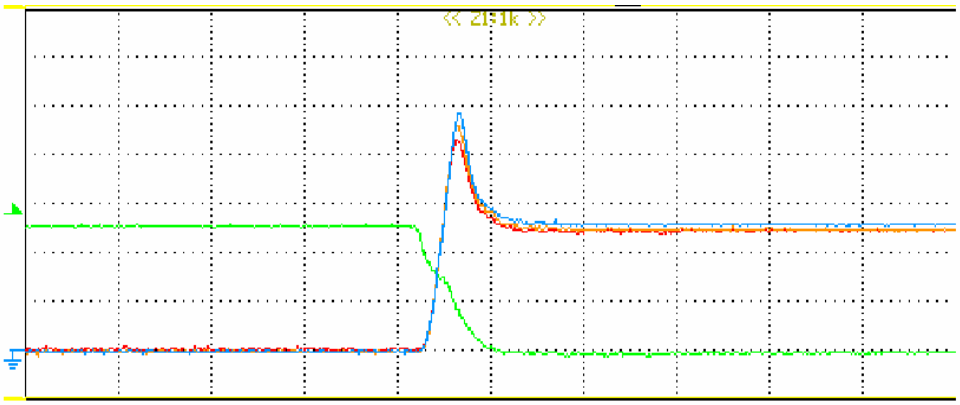


Fig. 10: Three half-bridges EconoPACK™+ in parallel. Current sharing by matching the DC-bus stray inductance. *[Courtesy General Electric Co., Salem VA]*

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5. IGBT Control

In a parallel circuit the paralleled IGBTs should switch on and off simultaneously. Non-simultaneous switching will also result in dynamic current asymmetry. To assure simultaneous switching one IGBT-driver channel can drive all paralleled IGBTs. Paralleled IGBTs may also be driven via separate driver channels. This has the disadvantage of transition time differences in the signal coupling path and has the advantage that equalising processes via auxiliary collector and auxiliary emitter will not occur. The more cost effective option is to control all paralleled IGBTs with one driver channel. (Fig. 11 and Fig.12).

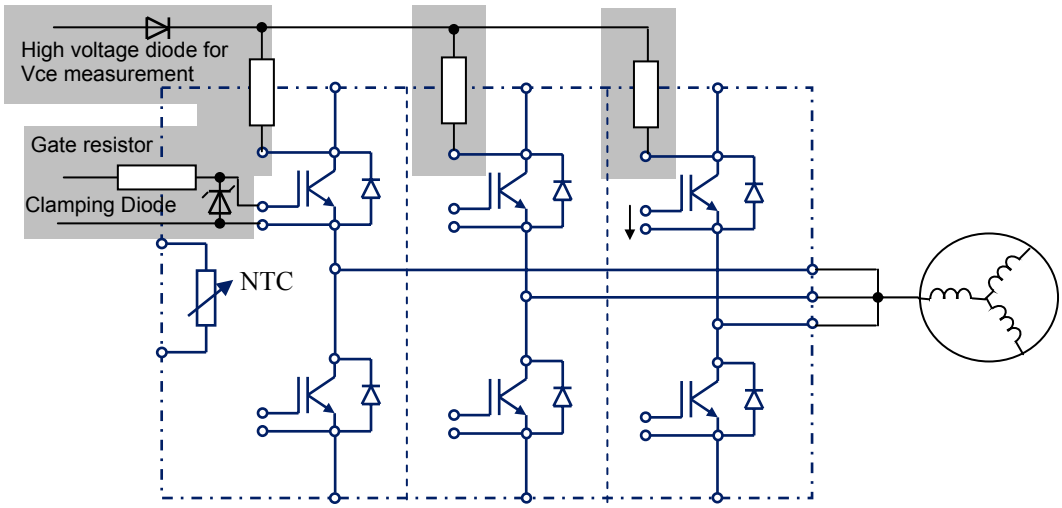


Fig. 11: Drive circuit EconoPACK™+ in parallel.

It is important that each IGBT is provided with its own gate resistor and clamping diode between gate and emitter. This is to be located as closely to the IGBT module as possible. The **collectors** of the top switches are to be decoupled with resistors. The value of these collector resistors should be chosen as low as possible.

Equalising currents flowing through the auxiliary collectors must not exceed $25A_{RMS}$. Attention has to be given to the pulse current capability of the collector resistors. The high voltage diodes for potential V_{CE} measurements

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or active clamping should also be located as closely as possible to the module. Fig.11.

In parallel circuits equalising currents may flow via the **auxiliary emitters**. These currents increase along with the necessary modification to achieve symmetry of the phase currents. For the auxiliary emitters it is recommended to keep the resistors as low as possible. These have the major disadvantage that a voltage drop occurs across the resistors which, depending on the direction of the equalising current, may be added to or subtracted from the gate voltage. A unequal turn-on or turn-off of the IGBTs is the result. Should, however, equalising currents of $\underline{>25A_{RMS}}$ flow in the auxiliary emitters, these currents need to be limited with resistors. Attention has to be given to the pulse current capability of the resistors. The gate resistor is calculated by: $R = R_{gate} + R_{Emitter}$. As shown in figure 13b, one can also use current compensating chokes. They limit the current in case of non-symmetric currents in the gate- and the respective emitter lead.

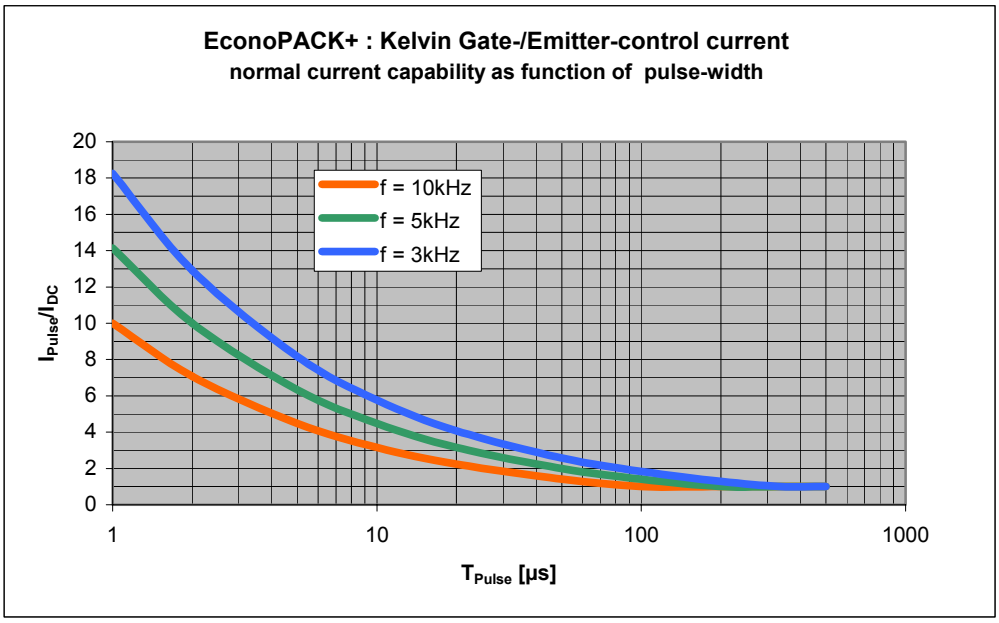


Fig. 12: Auxiliary collector, gate and auxiliary emitter load table EconoPACK™+

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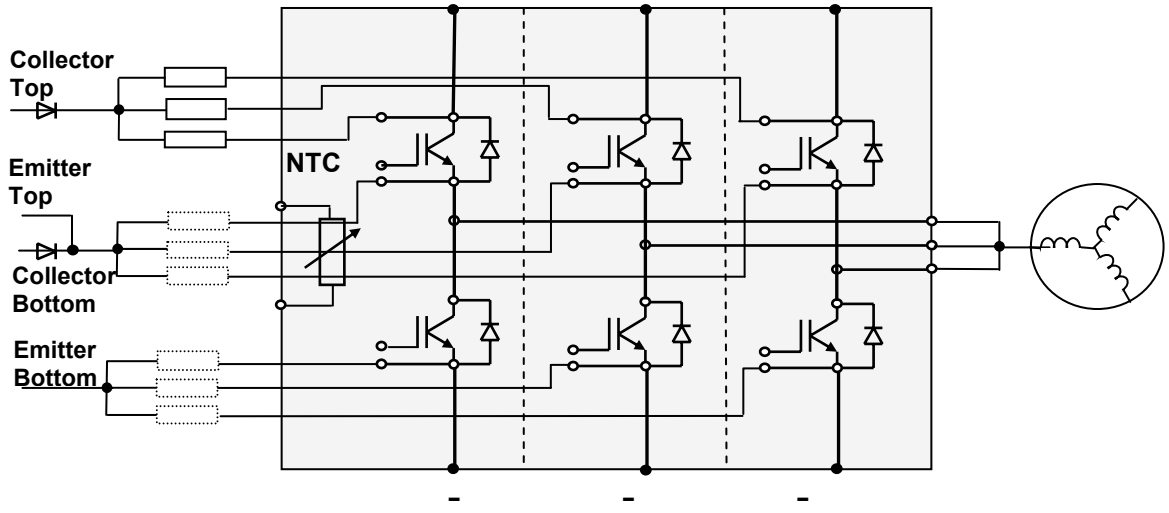


Fig. 13a: Control circuit components EconoPACK™+ for paralleled systems.

The auxiliary collector of the bottom IGBTs is derived from the auxiliary emitters of the top IGBTs. To utilise the auxiliary emitters of the top IGBTs for V_{CE} measuring or operation of an active clamping circuit for the bottom IGBTs the high voltage diodes have to be located as closely to the module as possible and connected as depicted in Fig. 13.

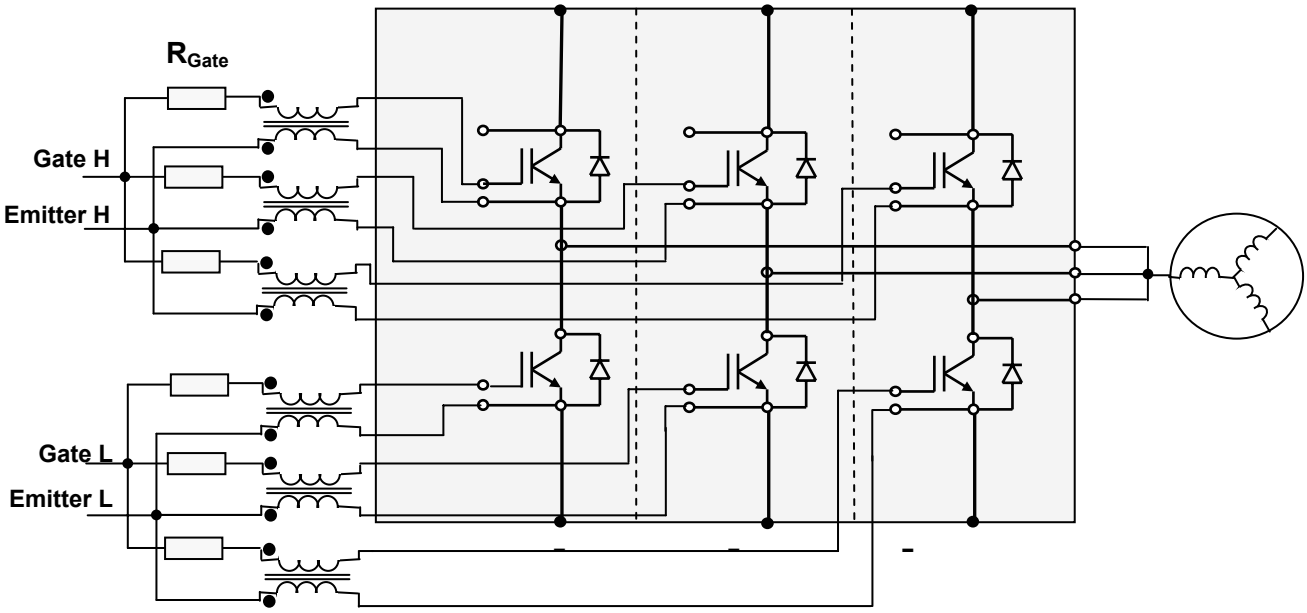


Fig 13b: Current limitation in the aux. leads by current compensating chokes.

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6. Symmetry by means of output inductors

Implementation of inductors in the output of each half-bridge affects a dynamic decoupling of the paralleled sections. If the impedance Z=ωL of the inductance Lσ is greater than the impedance of the IGBT modules, then the currents will be shared symmetrically through the output chokes. Fig.10.

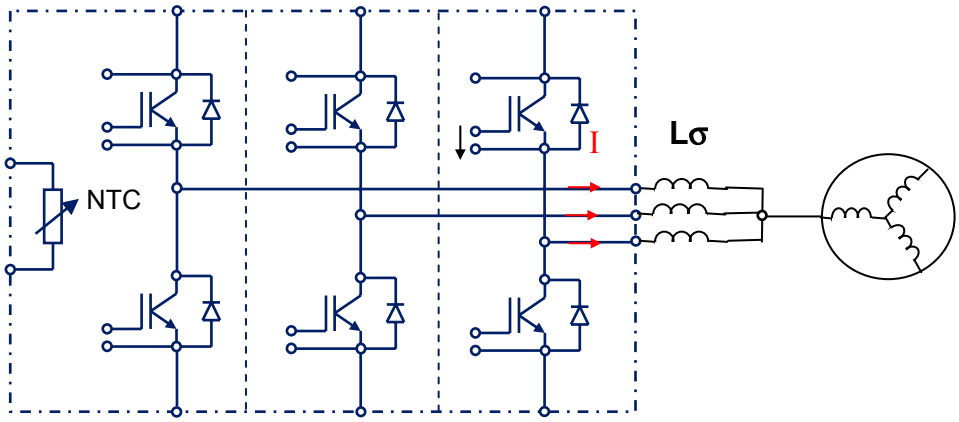


Fig. 14: Symmetry by means of output inductors.

Apart from the current sharing effect the inductors Lσ may be used to reduce the dv/dt at the load. The output chokes are here in series with the load inductance. If the cable resistances are disregarded, you get an inductive voltage divider. A capacitance connected in parallel with the load inductance will achieve additional reduction of the dv/dt at the load

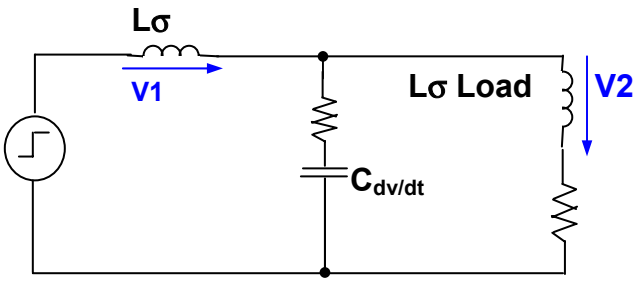


Fig. 15. Reduction of the dv/dt by means of an LC-network

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7. Symmetry by means of a ring circuit of chokes

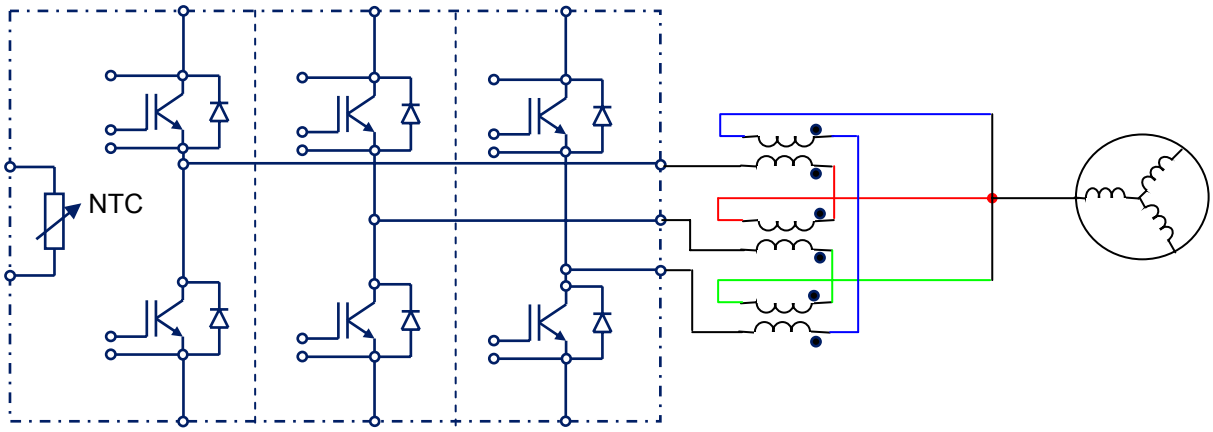


Fig. 17. Example: EconoPACK™+ parallel circuit with current symmetry realised by a ring circuit of chokes.

By using current-compensation chokes in the output phases of the parallel circuit, one by the so-called “ring circuit“has found a further way how to minimize current asymmetries in the IGBT parallel circuit. The principle can be compared to that shown in figure 13b. The inductance of each choke is a function of the current difference L= f(Δi) and is applicable only for the difference current. If the current in the phases is identical, the inductance of the choke equals to zero.

The simplest way is to use powdered iron cores as shown as an example in figure 18.

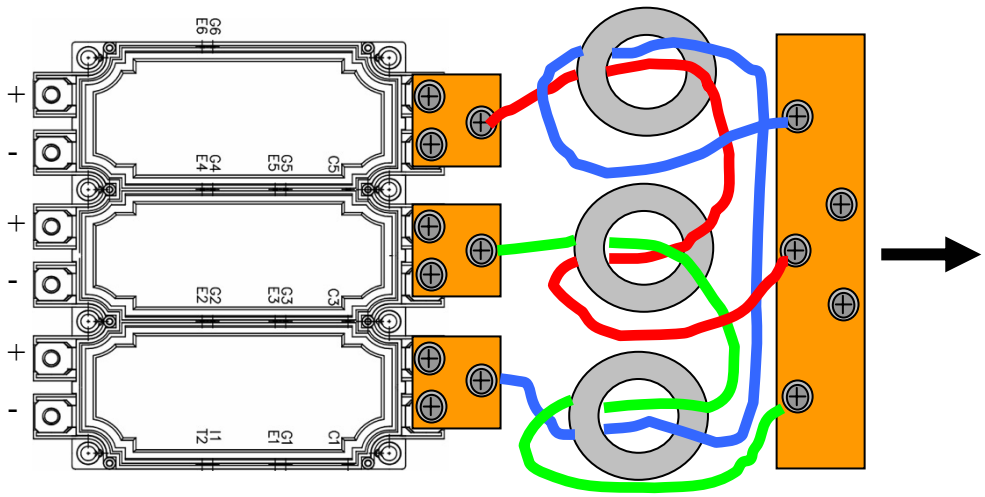


Fig. 18: Simple current symmetry by ring connection of iron cores.

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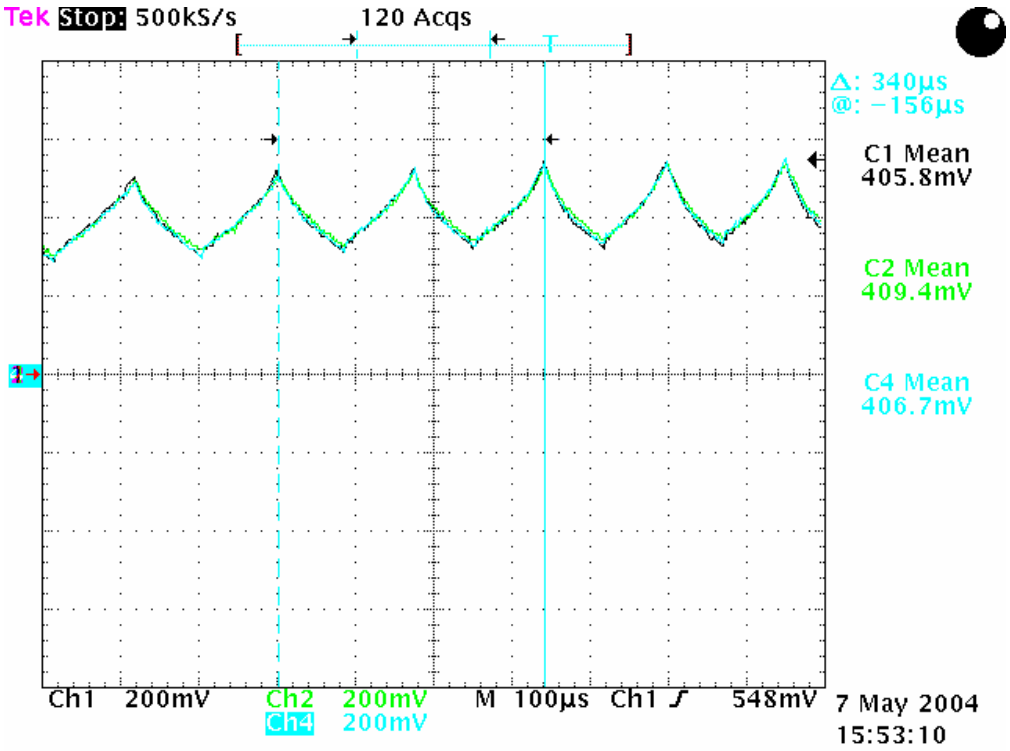


Fig.19: Current sharing in the triple parallel circuit with EconoPACK™+. Measured at the three output phases ∑1410A.

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