SIEMENS

A New Compact Inverter Concept with Low Profile Solderable ECONOPACK Modules

Abstract

This paper describes a new economic and compact inverter concept which is based on matched low profile, wave-solderable modules:

– 3-phase bridge rectifier

– and 3-phase fullbridge

Due to a modular package concept with a special terminal configuration manifold 3-phase fullbridge stages can be realized with three module types:

– a single 3-phase fullbridge with current ratings from 10 A to 50 A (1200 V), in a renewed ECONOPACK 2 package;

– a single 3-phase fullbridge with current ratings from 50 A to 100 A (1200 V), in a ECONOPACK 3 package and

– two TRIPACKs containing three single switches with current ratings from 150 A to 200 A (1200 V).

Following design examples will be presented:

Inverter/ (kVA) (380...480 V AC Input)	
16...33	Test INVERTER PCB with 3-phase fullbridge and 3-phase bridge rectifier
33...50	Description of basic circuit: Two 3-phase fullbridges connected in parallel
50...100	Description of basic circuit: 3-phase fullbridges connected into a halfbridge configuration

Introduction

IGBT-Modules are used featuring power electronic systems with high power density, high efficiency and good dynamic characteristics. A part of these features can be created with optimized IGBT semiconductors. In 1995 Siemens has introduced a new generation of NPT-IGBTs with optimized cell structure, semiconductor material and technology to achieve reduced losses and high ruggedness. The other part of these features can only be created with new improved module concepts which enable a developer to optimize space and to simplify manufacturing of power electronic systems. The new generation of NPT-IGBTs introduced in 1995 therefore is housed in smaller, more compact modules. In a first step the range of 3-phase fullbridges in ECONOPACK 2 could be extended to a current rating up to 50 A. In the second step a new range of high current 3-phase fullbridges with a current rating up to 100 A could be designed. Parallel to these steps, the eupec ECONOPACK 3-phase bridge rectifiers were designed with the same package dimensions as the Siemens ECONOPACK 2 modules. In the following the main features of these ECONOPACK modules will be described.

ECONOPACK 2/3-Details of Construction

The well-known ECONOPACK 2 (footprint 44 mm $\times$ 107 mm) was upgraded with shorter terminals to carry currents up to 150 A. The ECONOPACK 3 shown in **Figure 1** has the same height as the ECONOPACK 2 .

The footprint of the ECONOPACK 3 is 62 mm $\times$ 122 mm and it has to be connected to the heatsink with 4 screws. It has the following features:

- The singulated bias and power terminals as shown in **Figure 1** simplify detwisting of the PC-board circuitry.
- The solderable power terminals are designed as triple-terminals to carry DC-currents up to 200 A.
- The module can be assembled onto PC-boards with all other components in a normal two layer PC-board with holes in one wave solder step.
- The ECONOPACK 3 is designed with doubled DC-Power input terminals to halve the internal stray inductance of the module. As an example the inductance in one 75 A halfbridge leg of ECONOPACK 3 is in the area of 30 nH. This is 30 % lower than in the conventional halfbridge module.
- The ECONOPACK 3 is also designed not to blow up the package in case of overdriving the IGBT safe operating area.

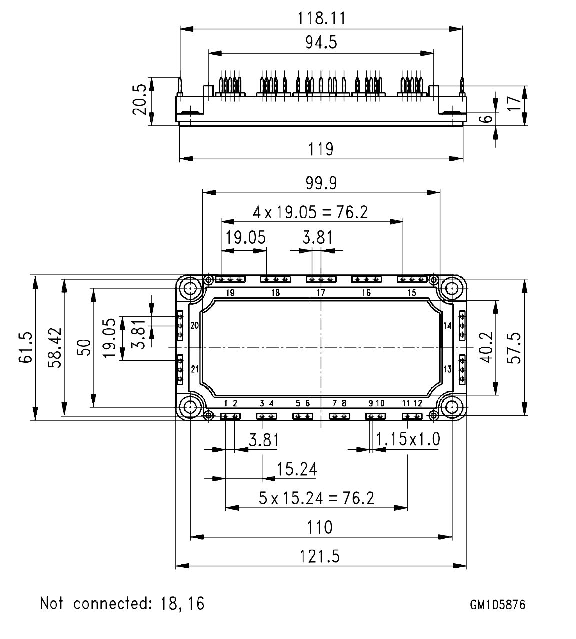


Figure 1
ECONOPACK 3 Layout and Dimension

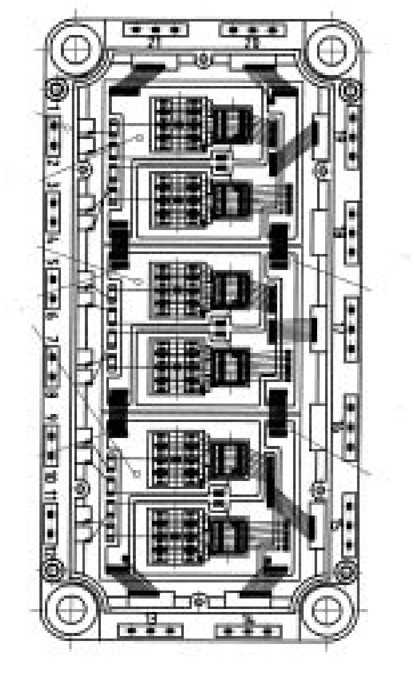


Figure 2
DCB Layout of ECONOPACK 3

The chips are mounted on three identical halfbridge DCBs (direct copper bonded substrates) (see **Figure 2**) to provide the electrical insulation to the copper baseplate with a good thermal contact. Collector, emitter and gate DCB contacts are connected to a frame with molded-in terminals via Al-bondwires. This provides improved reliability (in thermal and load cycling) and reproducibility compared to soldered terminals. The design of each halfbridge DCB has an optimized current path layout of the IGBT to the freewheeling diode, resulting in a low stray inductance of each halfbridge leg (max. value is 30 nH). A further surplus is that the doubled terminals for the DC Input Voltage are connected via a low inductance way to the chips. The one effect is that the inductance is reduced, the other one is that a connection of the bus bar can be performed very easily, especially when ECONOPACKs are paralleled. The gate capacitances in combination with gate drive stray inductances can result in unwanted high frequency oscillations between the paralleled gates, if they are connected directly together. These oscillations can be avoided by a damping gate resistance. This resistor has already been integrated within each chip to ease paralleling of the halfbridges. The design of the three identical DCBs supports the automatic current sharing of paralleled halfbridge legs.

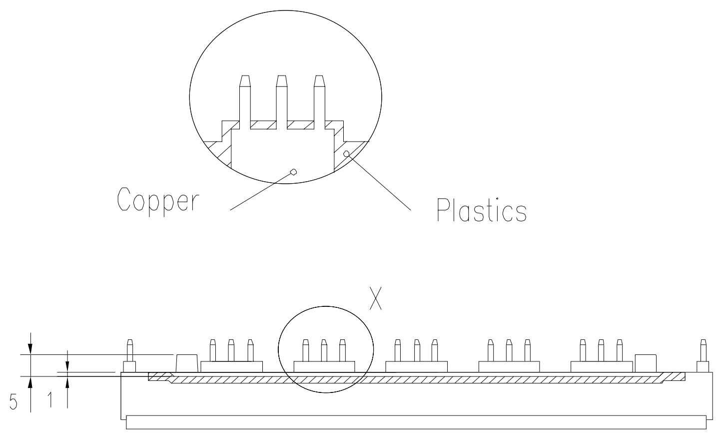


Figure 3
ECONOPACK 3 - Construction Detail of the Solderable Triple Pins

Figure 3 shows the construction detail of the solderable triple pins. Inside the module housing the current is forced on a wide copper bar to provide low resistance for high currents. Outside the module housing this copper bus is split into three solderable pins to provide an excellent solderability in an automated wave solder bath. For absolutely best solderability the pins are covered with a soft solder**.**

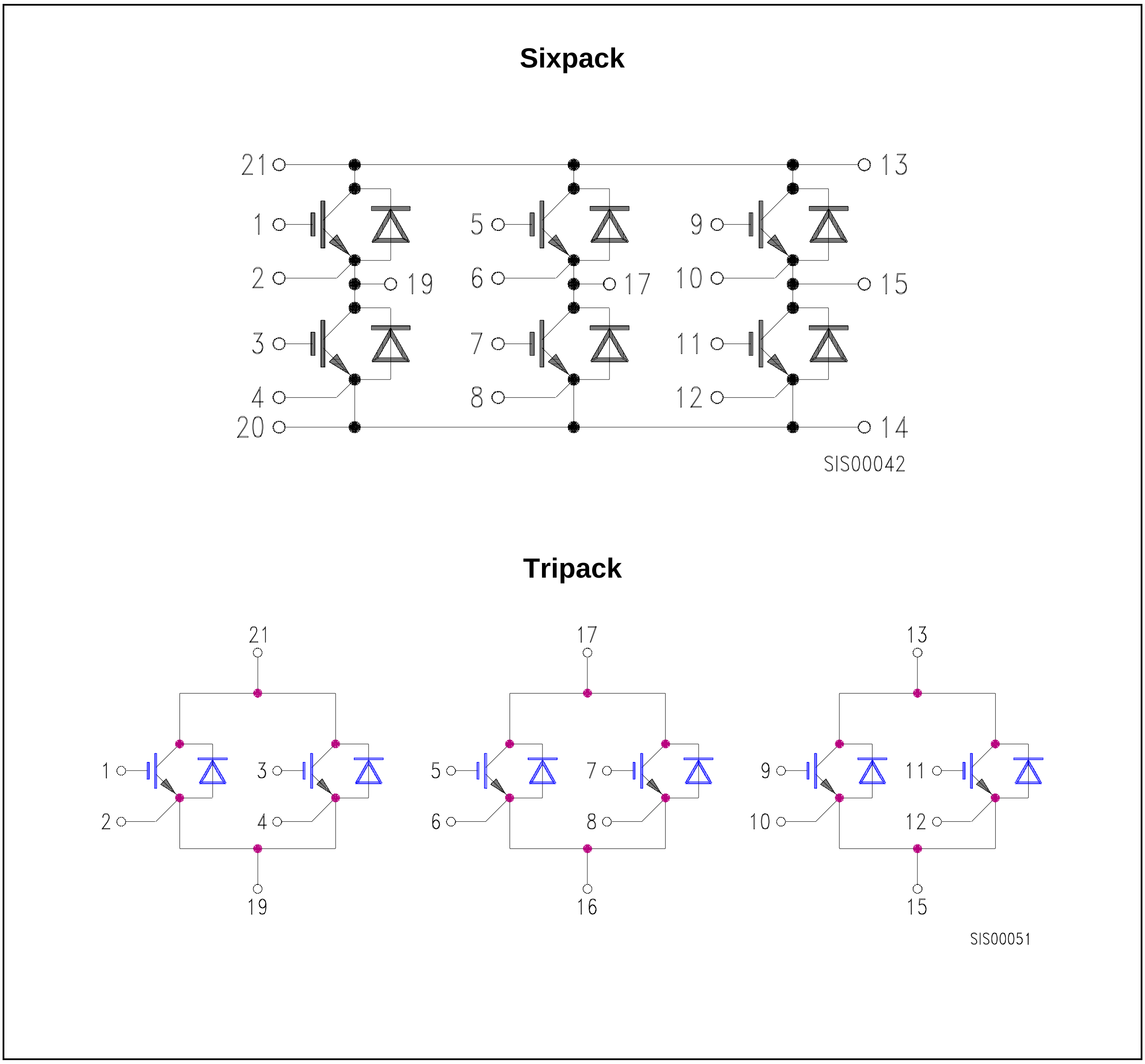


Figure 4
Electrical Configuration of Sixpack and Tripack

The ECONOPACK 3 offers three halfbridge legs in one package, so-called 3-phase fullbridge. The doubled DC-power input terminals (21, 13 and 20, 14) make it possible to configure a rank of halfbridges that can easily be paralleled.

The Tripack offers three single switches in one package. These single switches can easily be paralleled to double or triple the collector current in a high current application. Two Tripacks can be used to set up a 3-phase fullbridge. The possibilities for configuration are very wide in current range. This is visualized in **Table 1**.

ECONOPACK Three Phase Bridge Rectifier

The eupec ECONOPACK 3-phase bridge rectifiers were designed with the same package dimensions as the Siemens ECONOPACK 2 modules, see **Figure 5**. These diodes are available with ratings up to 100 A. Having the same package height and connection style as the ECONOPACK series of IGBTs makes them ideal for completing an inverter design on a PCB. The current rating of the largest diode allows the designer to have a part that is matched not only in package type but in current requirements with the largest ECONOPACK 3 IGBT module.

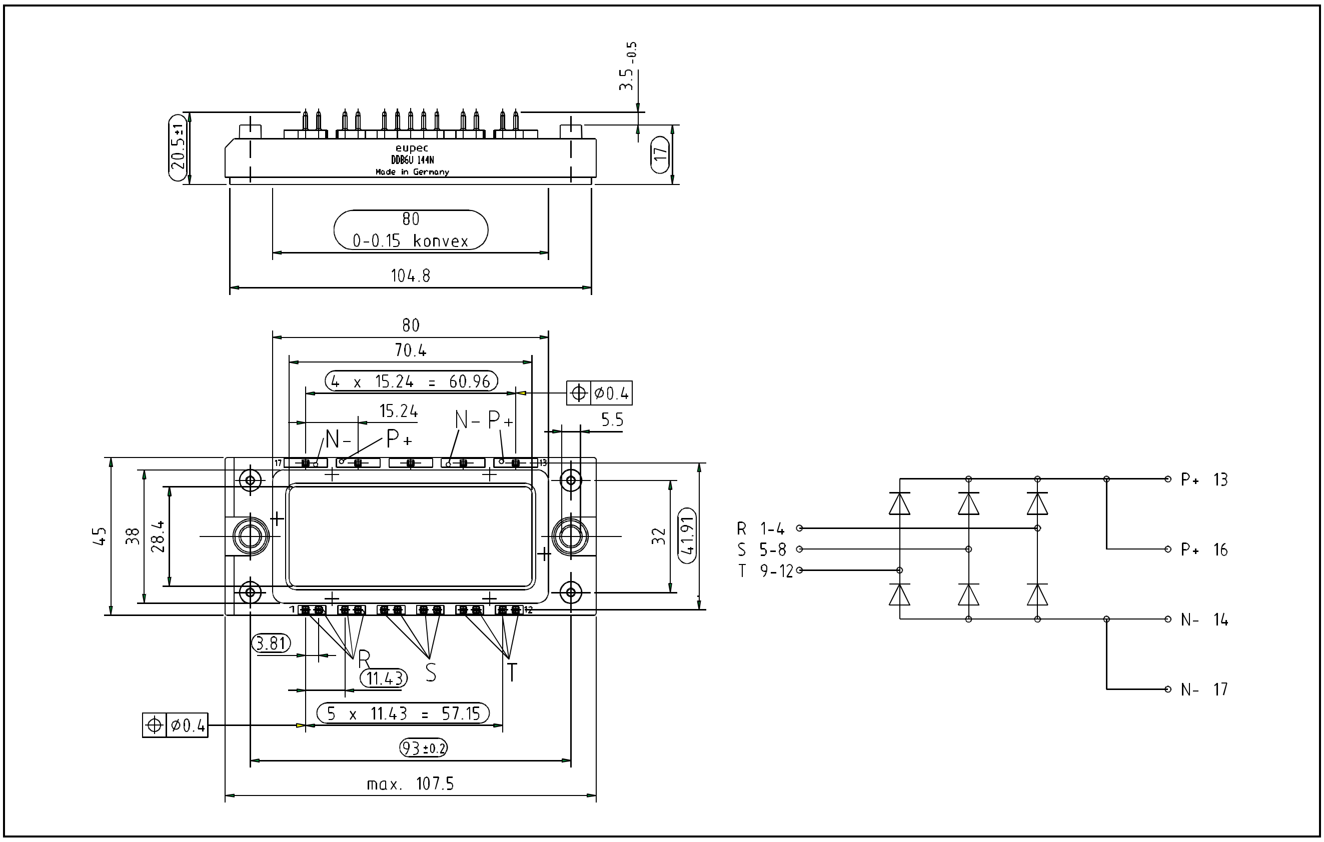


Figure 5
Layout, Dimensions and Electrical Configuration of ECONOPACK Three Phase Bridge Rectifier

Since the diodes were designed in the same ECONOPACK 2 package as the IGBT, all the advantages of the ECONOPACK are the same for the diode design. A low profile soldered package is one of the main advantages. This diode allows designs that in the past required screw connections instead of direct soldering to a PCB. Having the diode soldered directly to the PCB will increase the reliability providing a more consistent connection process, a better voltage clamping, and a part that cannot be installed or wired backwards.

For designs that require parallel ECONOPACK IGBTs for increased output capability, paralleling the diodes to continue to keep a standard package type throughout the design is possible. The diodes can be paralleled to form a higher power dual rectifier where higher currents are required.

30 kW (40 HP) Test Inverter PCB

A 3-phase test inverter was made using the advantages of the ECONOPACK modules. The power section was designed on a single PCB. The PWM controller used had a carrier frequency of 4 kHz with a sine weighted output based on a linear volts to hertz ratio. The test load was a standard induction motor. The inverter had a heatsink that was rated at about 0.08 C/W cooling capacity. A conventional inverter design would be traditionally made with bus bars and standard screw terminal modules. Instead of bus bars and screw terminals this inverter used a standard 0.093'' thick 4 oz. total copper tickness PCB. This new inverter design which does not require many separate pieces of hardware but is designed for automated production is possible using the ECONOPACK module features. The PCB layout (**Figure 6**, **Figure 7**) shows the dual symmetrical pattern of the power connection. The power connections on each half have the + bus and – bus traces and are laid out over each other to reduce PCB wiring inductance. By using a full symmetrical dual power structure the overall inductance to the ECONOPACK module is half of what a conventional design would have and the power requirements per terminal have been reduced to only 25 A RMS per terminal set. This level of current is quite feasible for two layer PCB designs. When this inverter was operated at 100 % speed output, the PCB temperature rise at the module connections was only 25 °C.

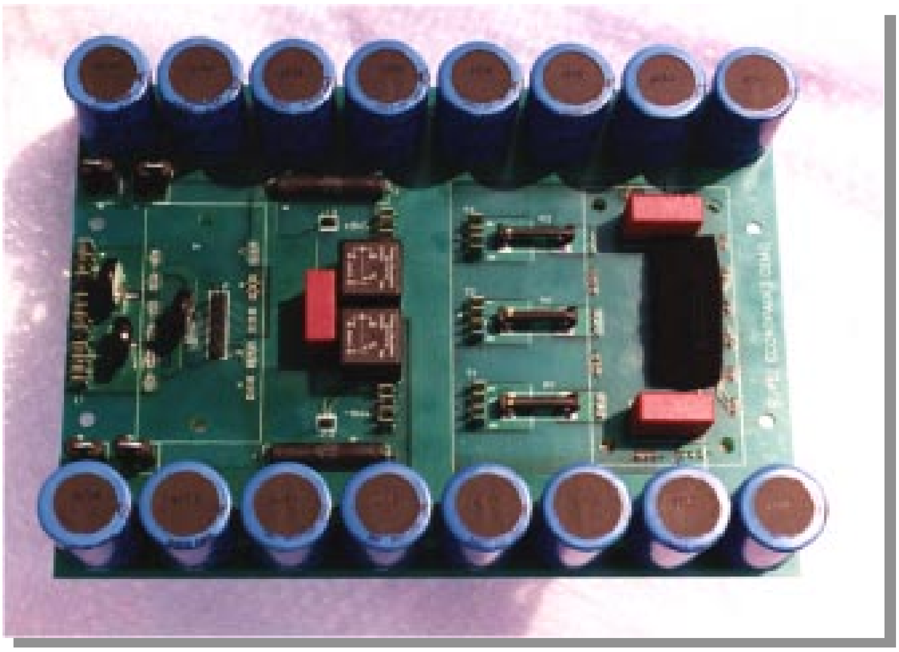


Figure 6
Top View of 30 kW Test Inverter PCB (photo)

The dual power connections also allow for two separate high frequency bypass capacitors to be used efficiently. With a PCB design the high frequency bypass capacitors do not need wire leads terminated with lugs and a mounting system, but can placed within 0.25'' of the module terminals directly mounted on the PCB with very wide traces leading to the module. Essentially all the inductance of the high frequency bypass capacitors is the inductance internal to the capacitor and not due to external wiring. This feature along with the low overall DC-bus inductance, will reduce the overall peak operating voltage of the IGBTs during switching. When this unit is operated with a 40 HP induction motor load, the switching waveforms (at I_c = 70 A, R_g = 6.8 Ω) reveal the overall performance of this type of design. The peak voltage seen on the IGBTs during turn-off was limited to 60 V peak above the DC rail without any output snubber. The parasitic inductances of this PCB design and ECONOPACK module are much lower than conventional designs. By reviewing the parasitic inductance involved in this design, the advantages of the dual power terminal sets are clear, since the high frequency path for the IGBT chip to the power structure is essentially half of a conventional design due to two parallel paths. With the PCB design having the high frequency inductance path equal to that of the external bypass capacitors and the internal wiring of the ECONOPACK IGBT module, the system only yields a topology that is optimum.

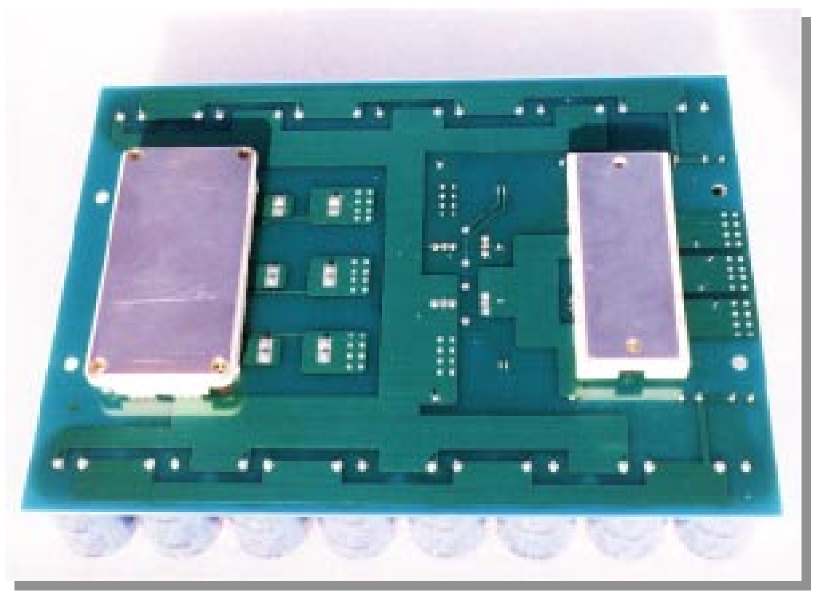


Figure 7
Bottom View of 30 kW Test Inverter PCB (photo)

Above all the performance of this design will exceed the performance of conventional designs in the areas of IGBT voltage stresses, physical size, parts costs, labor costs, production errors, and level of production automation possible.

The overall design will be more cost effective and reliable because of the following inprovements:

– Reliable wave soldered joints replace power connections that require torquing or bus bar thermal expansion causing the module bolts to loosen.
– A fixed PCB design replace the possibility of incorrect discrete power connections.
– The bypass capacitors virtually being placed directly on the module terminals reduce the overall voltage stresses.

Two Parallel Connected 3-phase Fullbridges: Basic Configuration, Switching Behavior and Demo-PCB

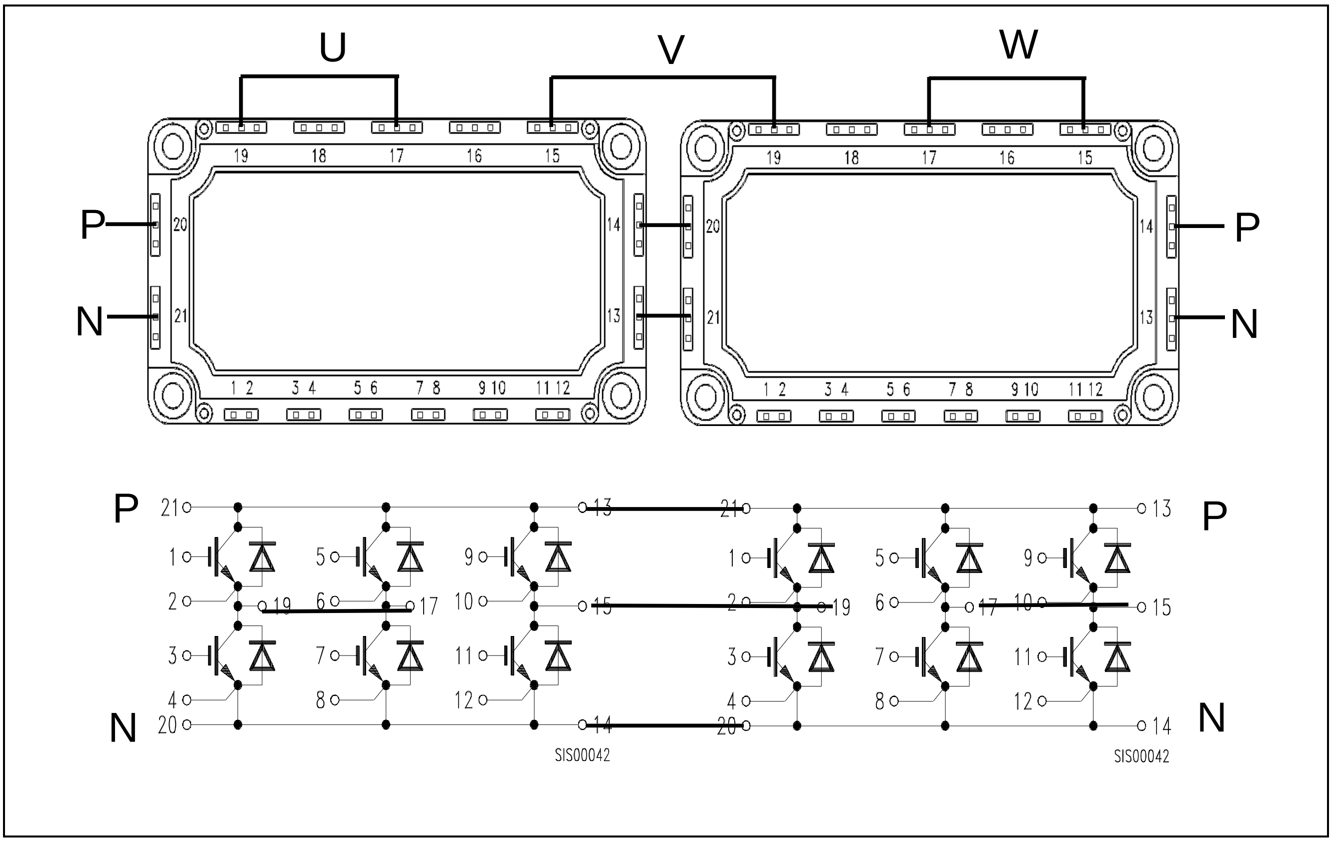


Figure 8
Basic Layout of Two Parallel Connected 3-Phase Fullbridges

Figure 8 shows the basic circuit layout and **Figure 10** shows the Demo-PCB of two parallel connected 3-phase fullbridges. The internal DCB-Layout is designed to be symmetrical. Each halfbridge DCB-system has the same layout that results into identically internal current paths (**Figure 2**). All Layout requirements of connecting halfbridge modules in parallel have been considered. The outer located halfbridge legs can be connected in parallel via the shortest way by connecting terminal 14 of the first module with terminal 20 of the second module and 13 (first) with 21 (second).

Figure 9 shows the time curves of the collector-current and the collector-emitter voltage in the above described parallel connection of ECONOPACK 3 (BSM75GD120DN2) halfbridge legs. To ease the parallel connection of ECONOPACK 3 halfbridge legs new IGBT-chips with an integrated gate resistor have been developed. The value of this integrated gate resistor is approx. 5 Ω per 75 A IGBT Chip, that is the same value as mounted into a 150 A halfbridge module BSM150GB120DN2. The electrical behavior of a 3-phase fullbridge in the ECONOPACK 3 in principle is the same as it is for the conventional halfbridge modules.

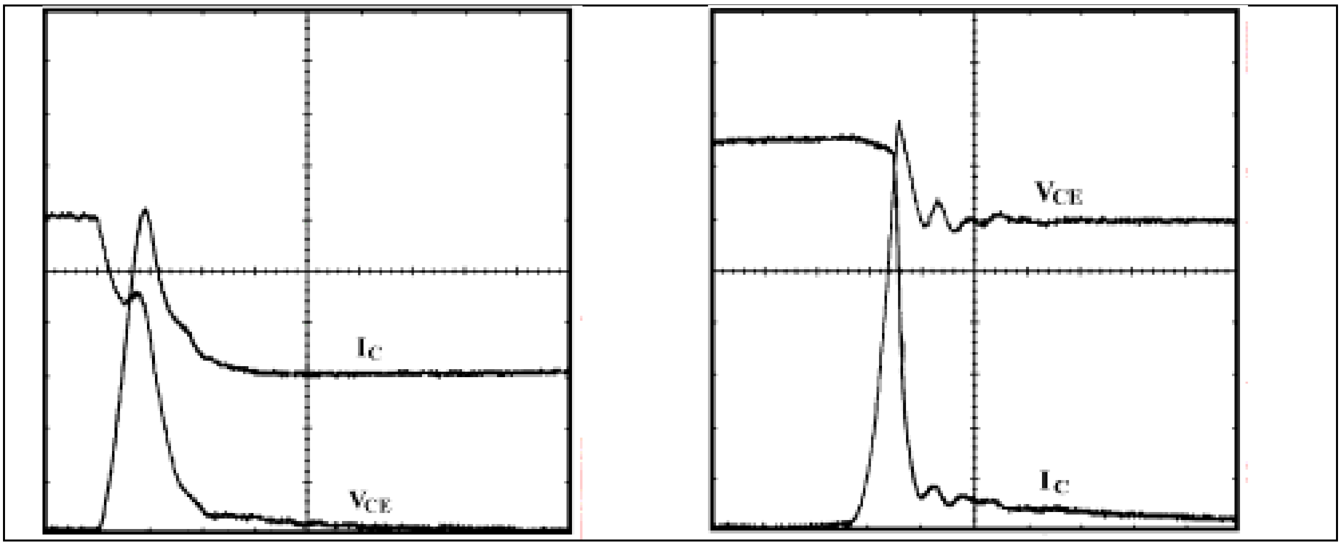
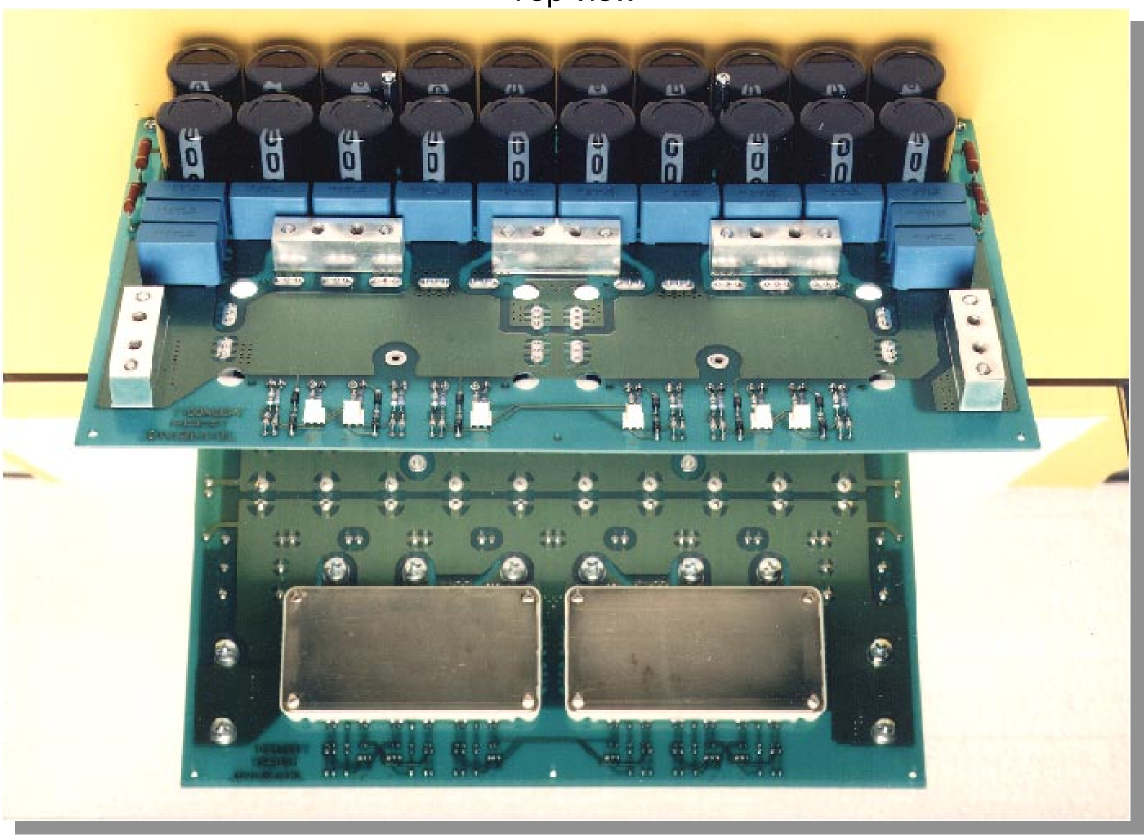


Figure 9
Time Curves of Parallel Connected BSM75GD120DN2 Modules at 600 V, 150 A, 125 °C, R_g = 3.3 Ω, 200 ns/ div.

Top view



Bottom view

Figure 10
Two Parallel Connected 3-phase Fullbridges - Photo of Demo-PCB

ECONOPACK 2 and 3 Fullbridges Converted into a Halfbridge Configuration

In addition the ECONOPACK 3 modules can be used not only as sixpack but also as a halfbridge by simply shorting the AC terminals U, V, W (**Figure 12**). The ECONOPACK 2 can be configured as a single halfbridge by shortening the AC terminals (shown in **Figure 11**) as well. In these configurations the sixpacks are converted to halfbridges with current ratings as shown in **Table 1**. The 3-phase fullbridge BSM75GD120DN2 with shorted AC-taps is driven as a 225 A halfbridge.The user can choose between the parallel connecting of the halfbridge legs of two 3-phase fullbridges ECONOPACK 3 and the connecting of single switches of two Tripacks.

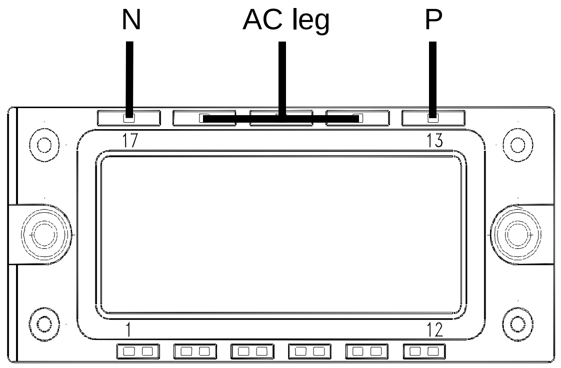


Figure 11
Basic Circuit Layout of ECONOPACK 2 Halfbridge Configuration

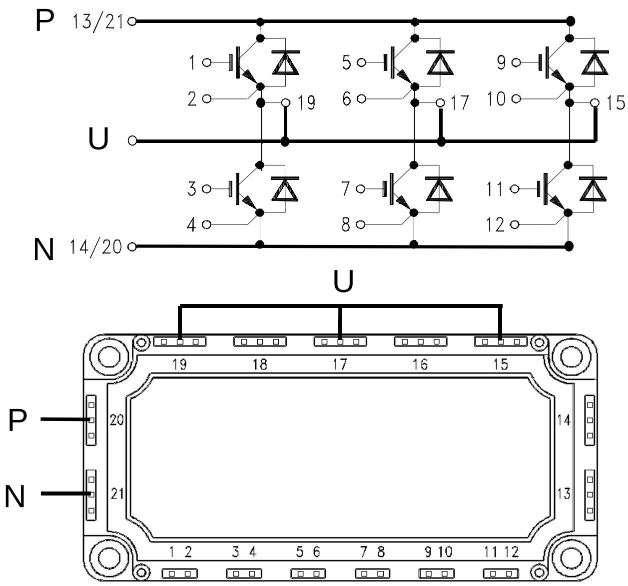


Figure 12
Circuit Layout of ECONOPACK 3 Halfbridge Configuration

Table 1
Possible Current Configurations of ECONOPACK 2/3 and TRIPACK at 1200 V

Current Rating @ Tc 80 °C in A	**Configuration for Fullbridge**
10, 15, 25, 35, 50	1 x ECONO 2 used as a Sixpack
50, 75, 100	1 x ECONO 3 used as a Sixpack
75, 105, 150	3 x ECONO 2 (25 A, 35 A, 50 A) connected as a halfbridge (**Figure 11**)
100, 150, 200	2 x Tripack (100 A, 150 A, 200 A)
100, 150, 200	2 x ECONO 3 (50 A, 75 A, 100 A) two halfbridge legs connected in parallel (**Figure 8**)
150, 225, 300	3 x ECONO 3 (75 A, 100 A) connected as a halfbridge (**Figure 12**)
200, 300, 400	4 x Tripack (150 A, 200 A), two switches connected in parallel
200, 300, 400	4 x ECONO 3 (100 A, 150 A, 200 A) four halfbridge legs in parallel.
300, 450, 600	6 x ECONO 3 (50 A, 75 A, 100 A) connected as a halfbridge
300, 450, 600	6 x Tripack (100 A, 150 A, 200 A) three switches connected in parallel

Benefits of Compact Inverter with Low Profile ECONOPACK Compared to Inverters with Conventional Halfbridge Modules

- Installation height
  Conventional modules have an installation height of 30 mm compared to ECONOPACK modules with an installation height of 17 mm. The smaller size of the ECONOPACK modules leads to a reduction of the final inverter size.
- Reduced manufacturing time of the inverter power circuit to assemble a 100 A 3-phase inverter power circuits with 3 halfbridge modules following manufacturing steps have to be done 3 times:
  1. to unpack each halfbridge module;
  2. to manufacture connectors for the fast on taps;
  3. to fasten each module with screws and the “manufactured fast on connectors” to the PC-board;
  4. to surface the thermal conducting paste over the whole module base plate with a rubber squeegee and
  5. to fix each module onto the heatsink with screws.

To assemble a 100 A 3-phase inverter power circuit with ECONOPACK modules:

a) in general the manufacturing steps 1, 3, 4, 5 have to be carried out only once.

b) the manufacturing steps 2 and 3 will be simplified. The ECONOPACK terminals will be stacked directly into the PC-board and will be fixed with an automatic wave soldering step.

Note: The result of all simplification steps is a reduction of the manufacturing time by a factor of 8 e.g. from 7 minutes to 50 seconds in the above described example.

Conclusion

The new generation of compact ECONOPACK modules enables the designer of inverters to find a most cost effective and a very compact layout for his device. For the power range from 0.5 kVA to 200 kVA he needs only a few packages. For the 3-phase fullbridges 1200 V ten current ratings are available and out of them 26 combinations for other current ratings are possible. The main economical advantages of these modules can be summed up as follows:

– compact and easy power circuit design;

– automated mounting to the power circuit;

– very cost effective packaging solution.

So today inverters can be manufactured more compact and more economical than ever.