„Econo“my improvement in inverter-converter-moduldesign

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Abstract:

To realise an economy inverter construction, it is a good solution to use high reliable and flexible mounting technologies with a lot of automated steps like Printed Circuit Board (PCB) technology for all components. This is valid specially for all power elements e.g. rectifiers, inverters and brakes. Now this problem is solved with the completion of the „Economodule-Productfamily“ offered from Siemens HL and eupec. Some extra marginal conditions like the thermal management in- and outside of the module and on the PCB have to be observed. The results of these points, which have been simulated, calculated and tested, e.g. about current capability of thickwire bonds are of great interest, because of all intern module connections are made in this flexible technology.

1. The Econo-Mounting-Technology

Inside a power converter, e.g. for motor control applications, electrical high and low power connections between the sources, the DC link, the control circuits (e.g. for IGBTs) and the drives have to be realised. Up to now different mounting technologies like soldering, screwing, pressing or gluing has to be used. Often the needed parts are not adapted in dimensions or thermal demands so that extra mechanical and thermal constructions are necessary.

But now a high economy converter concept is available, because Siemens HL and eupec completed their Economodule-Productfamily. So inside of three package outlines called Econo 1, 2 and 3 different combinations of rectifier diodes and IGBTs with or without parallel or serial fast diodes for a wide power range are offered.

Figure 1 shows the principal construction of the Econo-modules. On top of a baseplate, a both side copper plated ceramic with good thermal conductivity and good isolation features is soldered. On the topsight of this metalled ceramic, whose copperplates are structured, the chips are fixed. The plastic-frame of the module includes several terminals with bonding areas in the inner and solderable pins at the outer parts of the module. The chips are bonded with the copper-structure and the terminals.

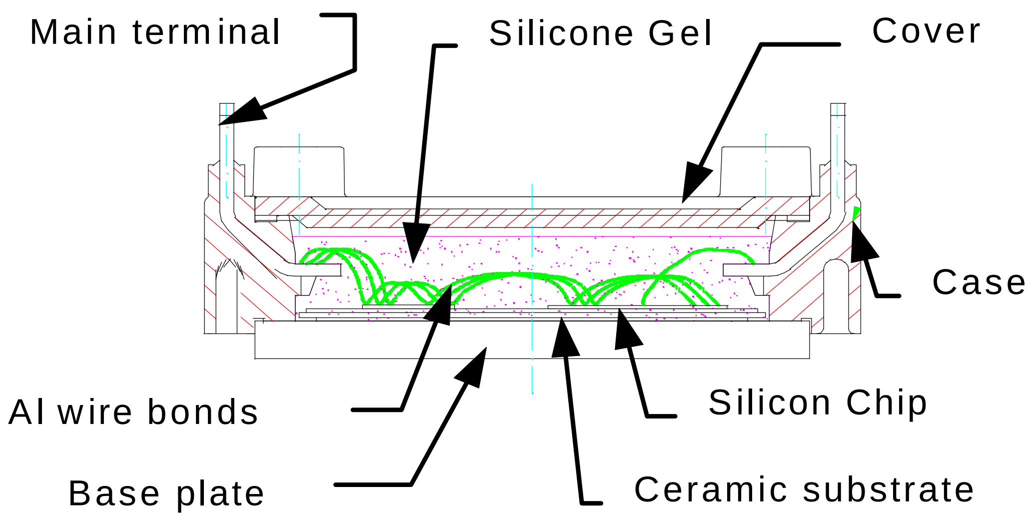


Figure 1: *Principal construction of Economodule*

These Econo-Modules have some decided advantages for our customers.

- Every internal connection between chips, frame-terminals and copper-lines are made in thickwire-bonding-technology. This means a high thermal cycling reliability, because of a bonding wires withstand a lot of more thermal cycling than a soldered connection between a terminal, fixed in the frame, an the internal copper layer.
- Thickwire bonding is a highly automated process step. Except wire bonders, no other special hardware for manufacturing is necessary, because of all variants are realised in use of several software. So this technology gives us a lot of flexibility.
- A most effective economy converter construction is indicated, because of all power components are adapted to each other in thermal and mechanical criteria. The mounting of the modules is very simple: They only have to be inserted into the drilled PCB and can be soldered together with other electrical components e.g. with use of a solder-wave-process without problems and in short time.
- Common heat sink mounting of all power modules and the using of one common PCB yields to a high compact converter design.
- The dividing of the load current to several parallel terminals dues to an optimised power distribution on the PCB.
- The manufacturing of all of these modules is economy also, because of a flexible automated production concept for the hole module-family. Future developments and production improvements pass through all Econo-modules variants.

2. Product scale

The hole product scale is divided into three package outlines called Econo 1 for the smallest one and Econo 3 for the greatest one. Inside of these modules the following variants are available:

1. Rectifier bridges with or without a brake or precharge circuit.
2. IGBT switches with parallel fast diode switched as fullbridge (Sixpack=GD), half-bridge and singleswitch (GX) and three singleswitches (Threepack=GT).

IGBT Blocking voltages from 600V, 1200V are in production (see table 1). Current rating from 10 A up to 200 A are offered. Rectifier bridges are available with blocking voltages between 1200 V and 1600 V (see table 2). Tables 1 and 2 summarise the product scopes.

Some typical rectifier-inverter-combinations with Siemens/eupec power modules for typical converter power are listed in table 3.

380V DS-drive	**Inverter Econo 3 - Type**	**Rectifier Econo 2 - Type**
22 kW	**1x BSM 75 GD 120 DN2**	**1x DD B6U 84N ** R**
37 kW	**1x BSM 100 GD 120 DN2**	**1x DD B6U 100N ** R**
55 kW	**2x BSM 150 GT 120 DN2**	**1x DD B6U 144N ** R**

Table 3: Some rectifier-inverter-combinations with Siemens/eupec power modules for typical converter power

3. Heat sources and thermal management

The compact Econo module design due to some different thermal marginal conditions. Inside an outside of the module there are some possible „heat sources“ which have to be noticed. Table 4 shows, where power originates and is leaded away. Every item is commented with a short list of important points, which must be well known.

The first one are well known losses from the power chips. The thermal resistance between junction and heatsink is well defined.

Second there are losses inside the bonding wires. While a bond leads current, the bondtemperature increases. These losses depends on different parameters, which are exactly described in section 4.

Third the losses due to current leading in the terminals are inevitable. Decreasing and optimisation is possible with the choice of low impedance material and favourable selection of pin-position in the frame, depending on typical load cases. The dissipated heat can only leaded away over the PCB or over the plastic frame. The PCB generates losses themselves (see next point) and the plastic frame is a bad thermal conductor. So these losses have to be minimised extremely. Of course the quality of the solder connection between module terminals an PCB is a very important parameter, too.

Losses originates in:	**Heat is leaded away over:**
IGBT / diodes	-> heatsink
Bonding wires -) Wire temperature -) Notice of bond length	-> terminals -> frame, PCB -> copper -> heatsink
Terminals in the frame -) Choice of cross-section and material -) position of terminals in the frame	-> frame -> PCB
Printed circuit board (PCB) -) Quality of PCB-solder connection -) PCB-copper cross-section (width, thickness, length) -) double sided PCB (if necessary) -) PCB-Cooling (if necessary)	-> ambience

Table 4: *„Heat sources“ and sinks in Econo-Modules*

The last one is to look on the losses inside the PCB. A lot of simulations, calculations and tests have been made, to check this significant part. The generated heat can only be transported into the ambience. Besides the solder quality, the main influences are the cross section of PCB copper, the layout of PCB copper (width and length) and, if necessary, choice of double sided PCB and cooling. With these results, we developed design rules for our customers.

Each of this points has been calculated, tested and dimensioned. The results and dimension rules for the second point, the losses insides the bonding wires, are discussed in the following chapter.

4. Current capability of thickwire-bonds

While realising a power module family with current ratings up to 200 A, whose internal wiring is only made in thickwire-bonding technology, it is necessary to have enough information about the thermal situation of the bonds in different working conditions. The thermal conditions can be influenced by the following parameters:

- Wire-Diameter (here 300 µm - 500 µm)
- Doped Bondwires
- Wirelength (here 3 mm - 25 mm)
- Loopheight
- Temperature-gradient between two bond-feet (here 25°C - 150°C)
- Wires in silicone gel
- Paralleling of wires with equal or unequal length
- Pulse- and DC-load of the bondwires
- Bondwire’s temperature-dependence with different currents

A lot of tests and calculations showed, which parameter is the most important and in which range the parameters have to be chosen.

Inside the module there are only two ways for bondwire's heat removal: The first is the metalled ceramic with the mounted heatsink and the second are the terminals soldered into the PCB. The first one is the better one and is the way with the smaller thermal resistance.

Convection and heat radiation can be neglected. The heat transportation into the silicone gel can be neglected for DC currents too.

Figure 2 shows the relationship between the length of a bondwire and the maximum current, who destroys the wire (wire temperature rises rapidly > 150 °C). The figure shows four different wire diameters between 300 µm and 500 µm.

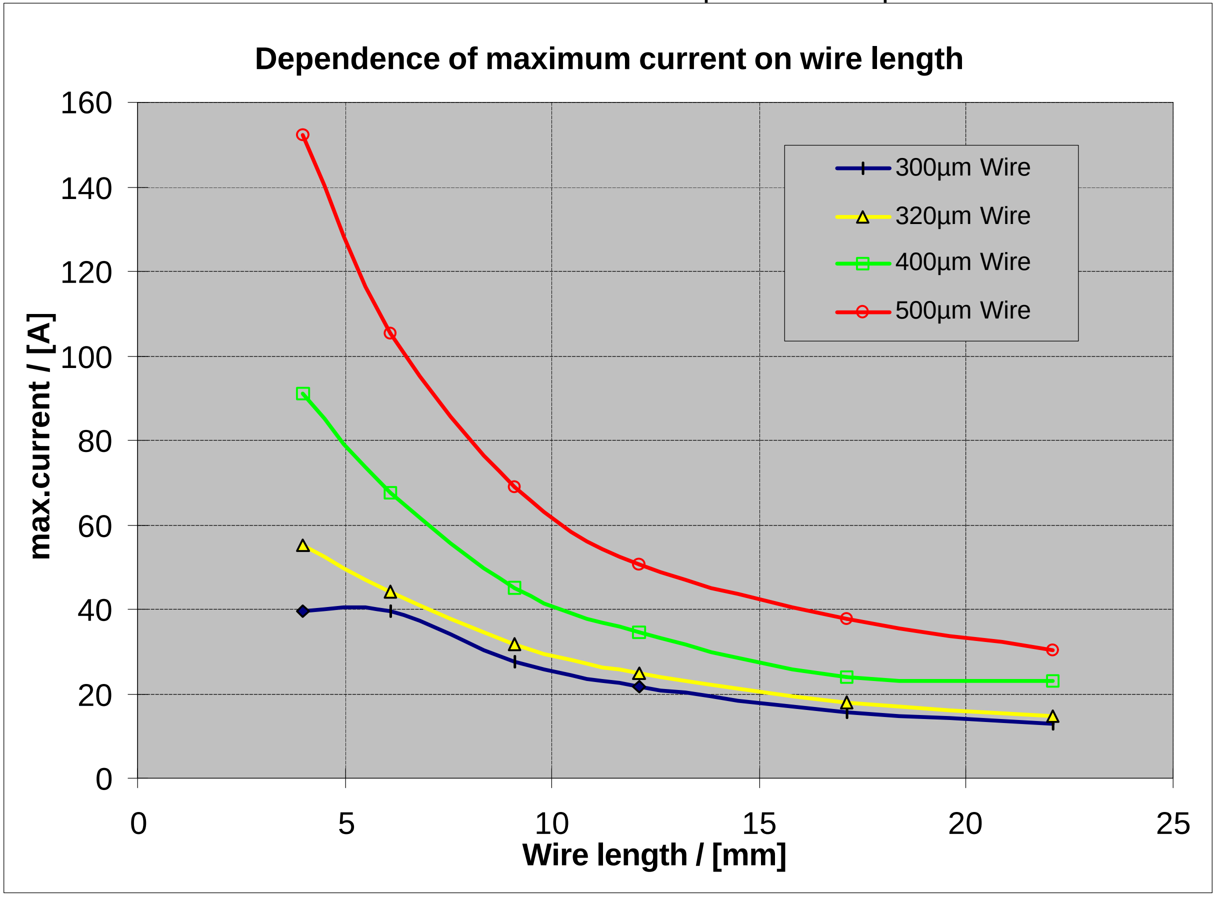


Figure 2: Dependence of maximum current/bondwire on wire-length with parameter wire-diameter (Wire in air / ceramic temperature 25°C)

The wire length is the most important parameter. It depends on the loop height and the distance between the bond-feet. The current capability decreases with the wire length. The current capability increases with greater wire diameters, but the factor of current increase is smaller than the factor of diameter increase. The reason is the not homogenous current density over the wire cross section and the batter heat transportation from the inner cross section area of the wire.

The next item is the optimal degree for current load. Wire-temperature can be calculated with measured wire-resistor and wire power dissipation. Examinations have been made with IR-thermographs. Figure 3 shows the relationship between degree of current load and degree of temperature load (=wire temperature / wire melting temperature = 660 °C for Al). The measurements have been made for several wire length (S=short / L=long) and several wire diameters.

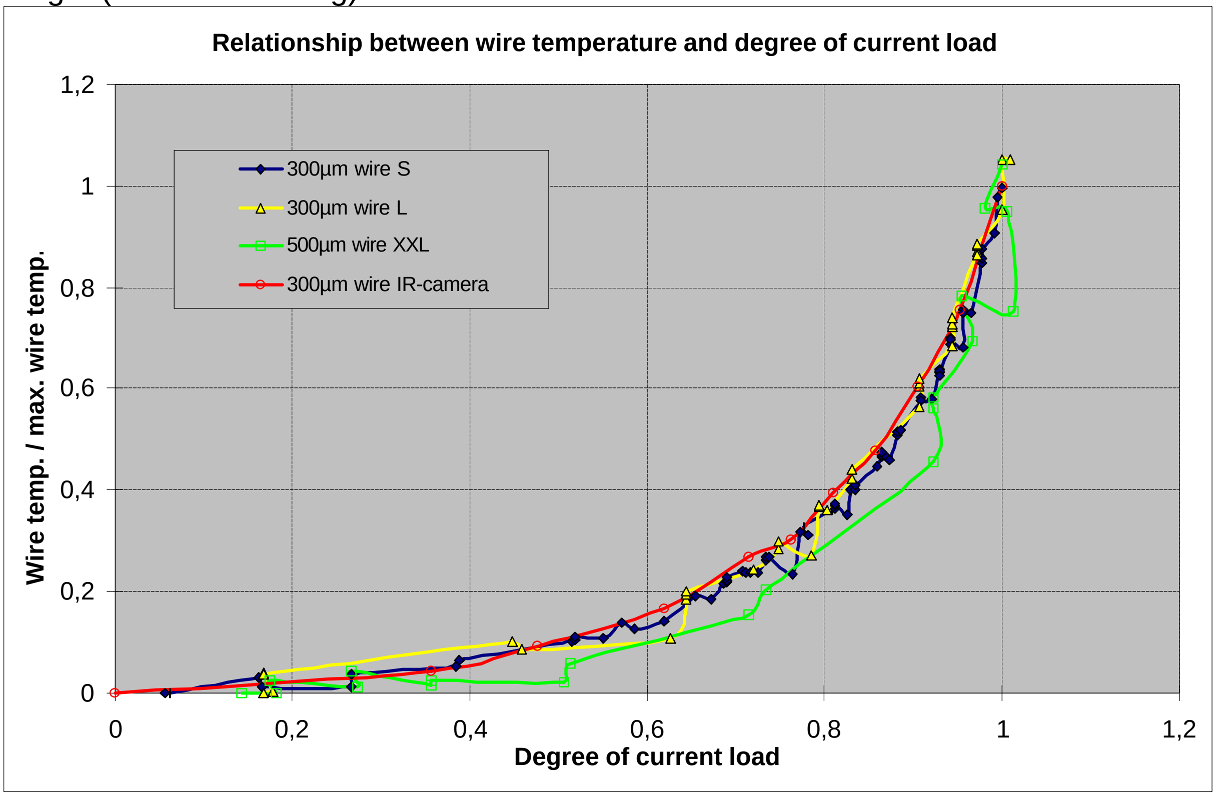


Figure 3: Dependence of wire temperature on degree of current load with parameter wirelength and wirediameter

There is no dependence on wire length and wire diameter. The measured temperatures with IR- thermographs fit well with the calculated ones. This means: When the degree of current load is dimensioned with 50%, the degree of temperature load is only about 10%. An increase of wire current up to 70% or 80% yields to a smaller increase of wire temperature up to 25% or 40%.

With this results the number and diameters of bondwires can be optimised and well chosen.

5. Conclusions

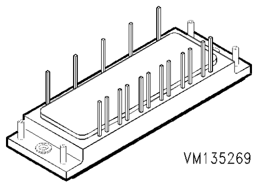
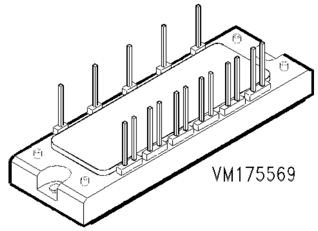
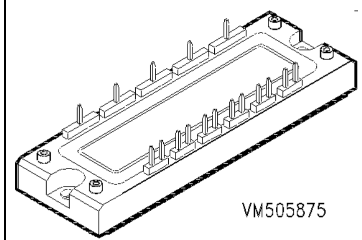
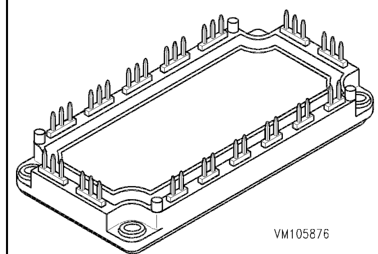
A complete product family with rectifier and inverter for PCB mounting technology called „Econo“ is available. The product scale has been presented. Thermal management of some special parts, which are described, is indicated. The thermal marginal conditions are known and their influences are observed in module design. Specially the results of simulations, calculations and tests about current capability of thickwire bonds are shown:

The wire diameter and the wire length are the dominating parameters. But an increase in wire diameter leads to a smaller increase in current capability. So, from this point of view, if possible, more wires with smaller diameter are better. The wire temperature increases smoothly with the degree of current load. 50 % current load means only 10% „temperature load“. The use of silicone gel doesn’t change anything from thermal point of view. The current capability of a number of parallel wires is the same as the sum of the capabilities of each wire (but pay attention to the longest one). The worst case is the typical DC-current and not alternating current due to short circuit or drives start phase.

With these results a reliable and economy realisation of complete converter in simple PCB-technology is possible now.

6. References

/1/ Auerbach, Schwarzbauer, Lammers, Lenniger, Sommer, „Zuverlässigkeit von Al-Dickdraht-Bondverbindungen“, ISHM Konferenz München 1996.

CE		 **Econopack 1** ***Solderable***	 **Econopack 2** **Long terminals** ***Solderable***	 **Econopack 2** **Short terminals** ***Solderable***	 **Econopack 3** ***Solderable*** ***Low inductance***
600V	10	BSM 10GD60DN2			
	15	BSM 15GD60DN2			
	20		BSM 20GD60DN2	BSM 20GD60DN2E3224	
	30		BSM 30GD60DN2	BSM 30GD60DN2E3224	
	50		BSM 50GD60DN2E3226	BSM 50GD60DN2	
1200V	10		BSM 10GD120DN2	BSM 10GD120DN2E3224	
	15		BSM 15GD120DN2	BSM 15GD120DN2E3224	
	25		BSM 25GD120DN2	BSM 25GD120DN2E3224	
	35		BSM 35GD120DN2	BSM 35GD120DN2E3224	
	50		BSM 50GD120DN2E3226	BSM 50GD120DN2	BSM 50GD120DN2G
	75				BSM 75GD120DN2
	100				BSM 100GD120DN2
	100				BSM 100**GT**120DN2
	150				BSM 150**GT**120DN2
	200				BSM 200**GT**120DN2

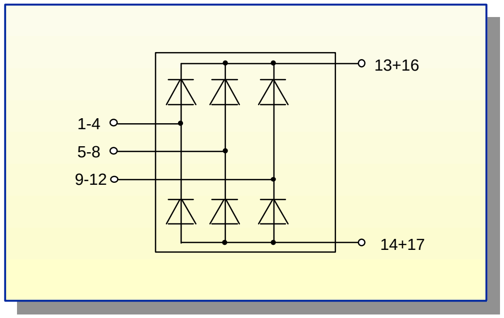
GT...TRIPACK

<u>Table 1:</u> *Overview: Inverter Econo-Productscope*

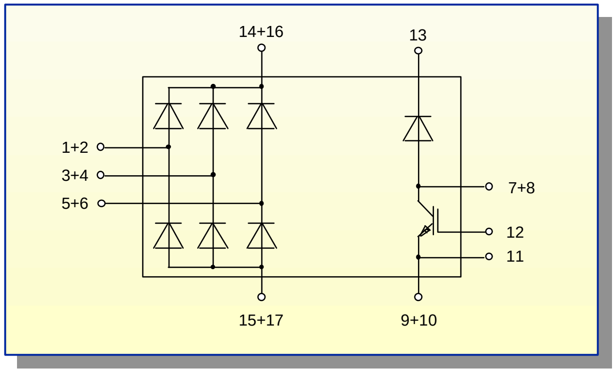
Modules

eupec

Econo2 Bridge Rectifier



Econo2 Bridge Rectifier
with Integrated Brake Chopper



DC-Bus Current	Bridge Rectifier	Bridge Rectifier with Integrated Brake Chopper	IGBT
84 A	DDB6U84N**R	DDB6U84N**RR	50A/1200V
100 A	DDB6U100N**R	DDB6U100N**RR	50A/1200V
Blocking Voltage	** 12 = 1200 V ** 14 = 1400 V ** 16 = 1600 V	** 12 = 1200 V ** 14 = 1400 V ** 16 = 1600 V	

Table 2: *Overview: Rectifier Econo-Productscope*