Highly Efficient 3-Level Solutions for Renewable Energy Applications

Energy efficiency is one of the major criteria for photovoltaic (PV) and wind power inverters. The 3-level inverter topology proves to be one of the most attractive candidates for low and medium power, low voltage applications which require high switching frequencies, complex filtering and high efficiency. The same advantages can be seen for Uninterruptable Power Supplies (UPS) which are connected and loaded 24/7. A new line of single modules which contain a full phase leg for a 3-level converter covers a wide power range from 4kW to 120kW. These modules combined with the latest and especially adapted semiconductor chip technology simplify the design of compact and efficient 3-level inverters.

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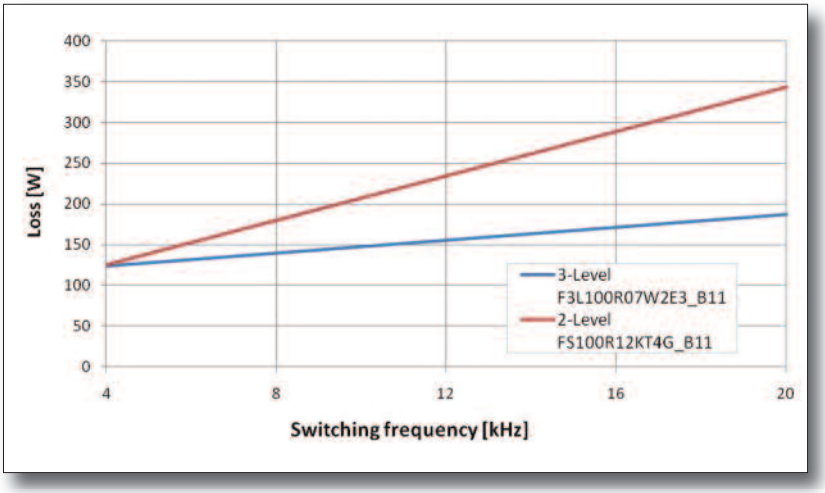
Today's PV-inverter- and UPS designs are searching for new solutions with highest efficiency. The continuous improvement of the power devices is one aspect. Another important item is to find special topologies for optimizing the overall efficiency.



The Neutral-Point-Clamped (NPC) topology leads to an enormous reduction of the switching losses, the size and respectively the costs of the filter by better spectral performance of the output voltage. The key for this gain is the ability to reduce the specific voltage class of implemented IGBTs. In contrast to 2-level inverters the IGBTs just need to block half of the DC-link voltage. A typical range of switching frequency is 15 to 20kHz.

Furthermore, from a legal viewpoint, this topology is uncritical. Contrary to several high performance topologies for PV inverters like the so-called HERIC- (Sunways) or H5-topology (SMA), the NPC-topology is not patented by any

Figure1: Easy2B 3-level module shows up to 50% lower losses compared to 2-level solutions

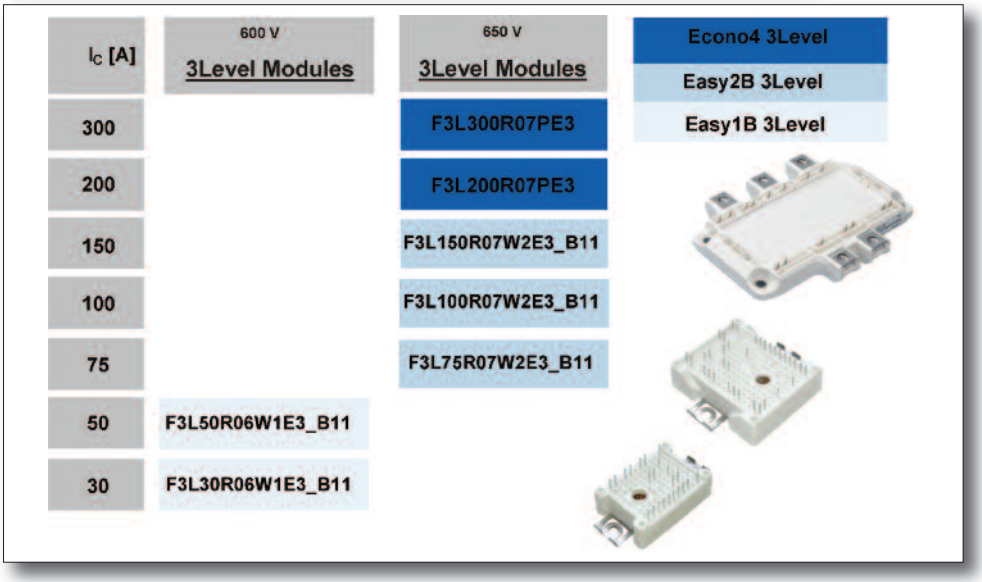


Figure 2: Infineon's 3-level portfolio 30A -300A

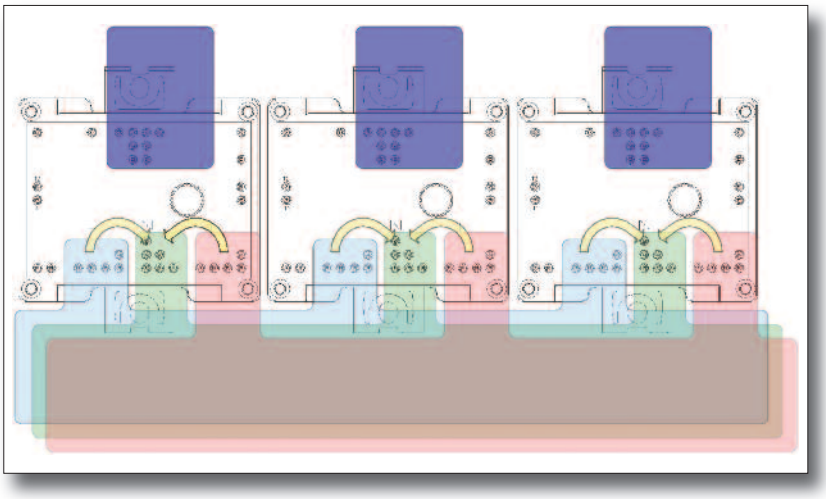


Figure 3: **Simple PCB inverter layout**

specific inverter supplier.

Figure1 shows the difference in losses between an EasyPACK 2B 3-level F3L100R07W2E3_B11 (100A/650V) and a standard 2-level solution in FS100R12KT4G_B11 (100A/1200V). The latest chip generations were compared.

The conventional 2-level solution only shows an advantage in losses at low switching frequencies where on state losses dominate and a single 1200V device has a lower on-state saturation voltage than two 650V devices in series. Above 4kHz switching frequency the lower switching losses of the three level solution overcome the higher on-state losses and a loss reduction of 50% is feasible at 15-20kHz. A big step in efficiency!

NPC-IGBT module scope

For the lower power range up to 40kW, the EasyPACK 1B and 2B package can integrate a complete 3-level phase leg at 50A and 150A respectively. This is facilitated by the grid based design of the package which enables pins to be placed in the optimum position relative to the DCB. For the medium power range the new EconoPACK™ 4 package is used for implementation of a phase module up to 300A. The wide portfolio from 30A up to 300A is shown in Figure 2.

All modules rely on the well-established reliable PressFIT technology which offers the possibility of simple and solder-less PCB mounting. Furthermore all the modules from 75A-300A use new enhanced IGBT and diode chips with an increased blocking voltage of 650V (50V extra compared to standard modules) without compromising conduction and switching losses.

Benchmark with EasyPACK 3-level

The requirement for low switching losses by using fast IGBTs, for example the IGBT3 650V silicon, means that low stray inductance is a critical design parameter especially as the trend is for increased DC-link voltages.

During the design phase of EasyPACK1B and EasyPACK 2B 3-level solutions this was

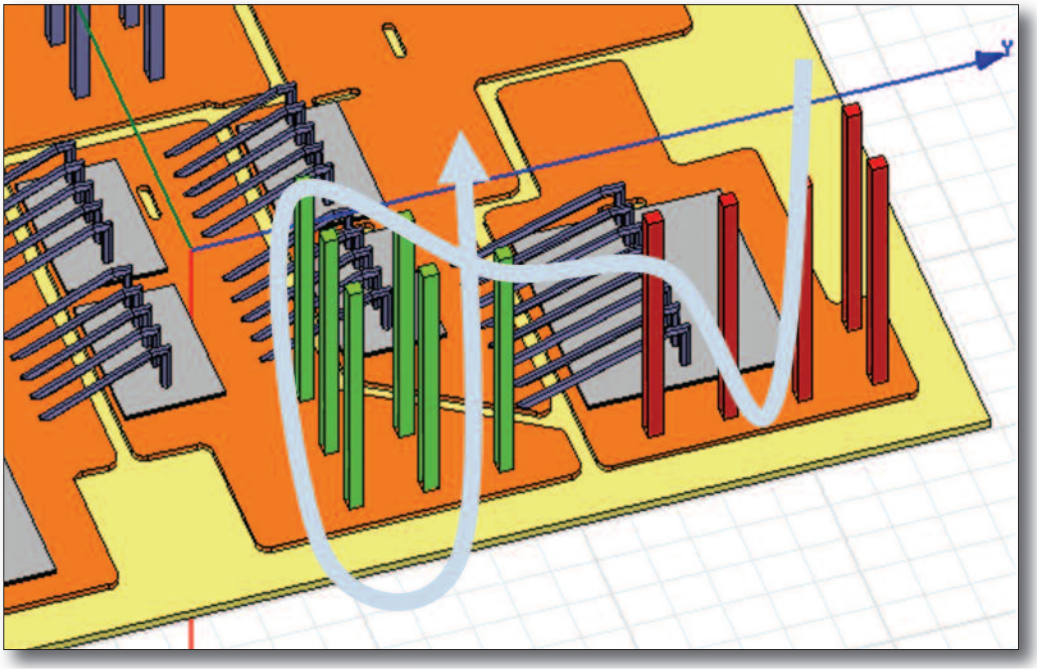


Figure 4: **Ultra-low inductive design of EasyPACK 3-level modules**

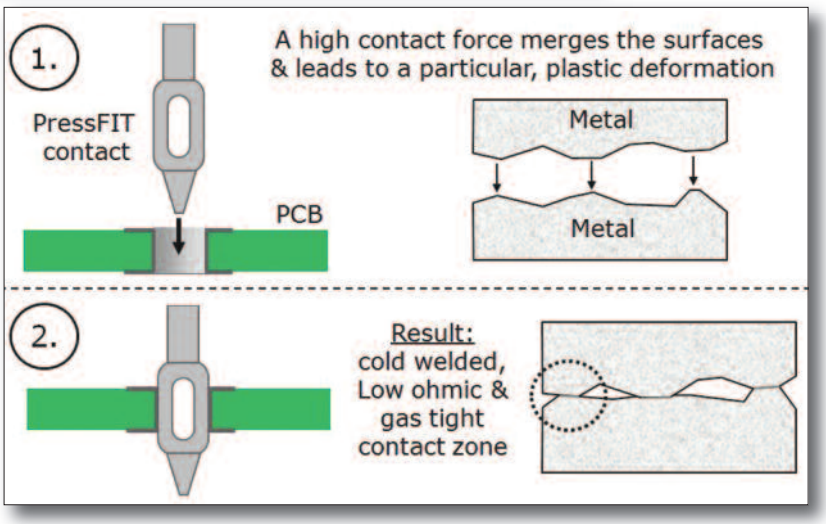


Figure 5: **Fast and simple mounting and highly reliable cold welded interconnections through PressFIT**

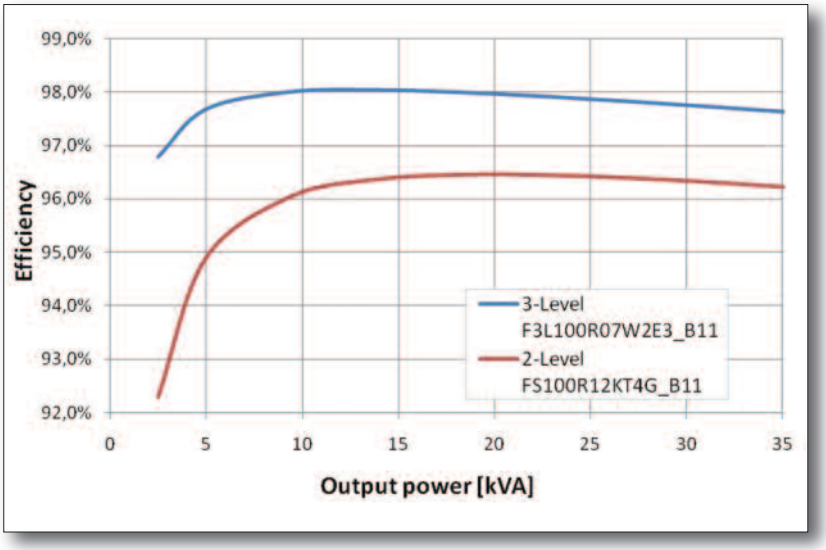


Figure 6: **Increase in efficiency by using EasyPACK 3-level modules**

carefully considered. The external connection of the DC-link is designed to be simple and compact. Figure 3 shows a possible example of the PCB layout. All DC connections are located in a single line next to each other. This greatly simplifies a low inductance PCB layout. The output connections are on the opposite side of the module again facilitating the PCB design process.

An external low inductance design is good, but the module itself also has to have a low internal inductance. With respect to stray inductance the internal structure of the EasyPACK 3-level modules is a benchmark with values as low as 10nH.

All commutation loops are designed to be symmetrical and reduced to a minimum. The most important commutation loop for 3-level applications is between one of the outer IGBTs and the clamping diodes. In Figure 4 can be seen even the bonding direction is optimized. Up to six pins are used in parallel to minimize stray inductance to the DC-link with the added benefit of reducing PCB heating.

Auxiliary emitter terminals are available to enable even faster switching. Last but not least an NTC is fitted to enable feedback of the DCB temperature.

For simple assembly and high quality PCB connections all modules offer the option of PressFIT contacts. This can reduce some of the constraints imposed by wave soldering, for example height and placement of components is faster and can reduce production costs when compared to traditional soldering methods. With this simple procedure of pressing in the pins into the PCB holes a cold welded connection is formed (see Figure 5).

This connection is gas-tight and low ohmic resistance that is highly insensitive to hazardous atmospheres. It is also robust against contact overlays, has a low fretting risk due to high contact forces and works stable also with low level signals.

Data sheet comparison
@I_{Nom}, 25°C (150°C)

	2-Level FS100R12KT4G_B11	EasyPACK 3-Level F3L100R07W1E3_B11	Improvement with EasyPACK 3-Level
E_{on} [mJ]	4 (7,5)	0,55 (0,95)	627 %
E_{off} [mJ]	5,5 (9,50)	2,50 (3,50)	120 %
E_{rec} [mJ]	4,1 (8)	1,20 (2,40)	240 %
V_{CESat} [V]*	1,75 (2,1)	1.45 (1.70)	20 %

* 3-Level uses mostly two IGBTs in series connection

Calculation results per leg @10 kVA,fs 20kHz, U_{DC}800V

	FS100R12KT4G_B11	F3L100R07W1E3_B11
IGBT Switching losses	53 W	15W
IGBT on state losses	12 W	20W
Total losses (incl. Diodes)	92 W	48 W
System Efficiency	96,0%	98,0%

Table 1: **Comparison 3-level to 2-level solutions**

Efficiency

As mentioned before by using the EasyPACK 3-level modules a loss reduction of 50% at 20kHz is possible. A data sheet comparison in Table1 shows the benefits in switching performance of the F3L100R07W2E3_B11 compared to the 2-level FS100R12KT4G_B11 module.

The second part of Table 1 and Figure 6 shows the big gap in loss and efficiency at standard operations. It can clearly be seen that the EasyPACK 3-level modules have essentially much lower switching losses. The efficiency can be improved easily over the whole output power range and achieves value higher than 98% in consideration of assumed copper losses.

Conclusions

The 3-level topology show several advantages especially for solar and UPS inverters. The most important benefit is a reduction of up to 40-60% in semiconductor losses. With this big drop inverter efficiencies higher than 98% are possible. By using Infineon's new 3-level IGBT family a big step in efficiency can be accomplished with the reduced design and assembly effort due to the module packaging and use of PressFIT technology. The module design with 650V IGBT3 silicon and very low stray inductances is optimized for fast switching at high DC-link voltages.