# More Efficiency for 3-Level Inverters

The use of renewable energy sources is one of the key issues when it comes to creating a new basis for worldwide energy supply. Wind power has been in use for over 20 years now, with technical advances leading to improvements in efficiency and reliability. The output of wind power units is steadily increasing. The switchover from 2 to 3 MW per unit is currently underway. Unlike wind power converters, central solar inverters bear huge potential for technical optimisation. At the moment, photovoltaic systems bear the biggest potential for increasing the efficiency of solar panels as well as of the overall system design.
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For applications below 250kVA a number of different solar power inverter concepts exist, similar to the string inverter for applications under 10kVA. To increase efficiency, higher switching frequencies are used. This is done to reduce what are known as copper losses and boost overall efficiency. Connecting photovoltaic modules in series can lead to an increase in DC current in the system, which in turn reduces losses.

The higher switching frequencies produce higher losses in the IGBTs, thus reducing the efficiency of the solar inverter. State-of-the-art IGBTs allow for junction temperatures of 175°C. This increase in junction temperature from 150°C to 175°C, however, also results in a higher collector-emitter voltage (positive IGBT temperature coefficient), which again affects the efficiency factor. Compromises in circuit dimensioning are therefore needed to find the optimum in face of these conflicting physical effects.

## 3-level modules for high switching frequencies

The SEMIKRON range includes 3-level modules for high-frequency applications. In the past, when designing a 3-level inverter, half bridge or chopper modules had to be used. Now, the integration of a phase into an individual module allows for a simpler driver concept and less costly overall solution for 3-level inverters. In the development of the modules, the focus was placed on the internal chip arrangement design and user-friendly connections within the device. These modules are suitable for applications from 50A to 400A for a collector-emitter blocking voltage of 600V. The modules feature integrated high-speed clamping diodes.

The 2-level and 3-level inverters are similar in function to DC/AC converters (see Figure 1). Both systems can produce a variable frequency and voltage from a DC voltage. The main difference between these two inverters is the number of IGBTs, diodes and capacitors required. The 3-level phase in NPC topology (Neutral Clamping Point) comprises four series connected IGBTs with corresponding freewheeling diodes and two clamping diodes for connection to the split DC link circuit.

2-level inverters have a two-state output stage, while a 3-level inverter can feature three states. Unlike the 2-le el design, where the IGBT has to switch the entire DC link voltage, in the 3-level architecture only half the DC link voltage is switched across the IGBT. The DC link capacitor has to be designed such that it is capable of halving the DC link voltage. In a 3-level phase, various commutation paths exist. The short commutation path runs between the clamping diode and an IGBT

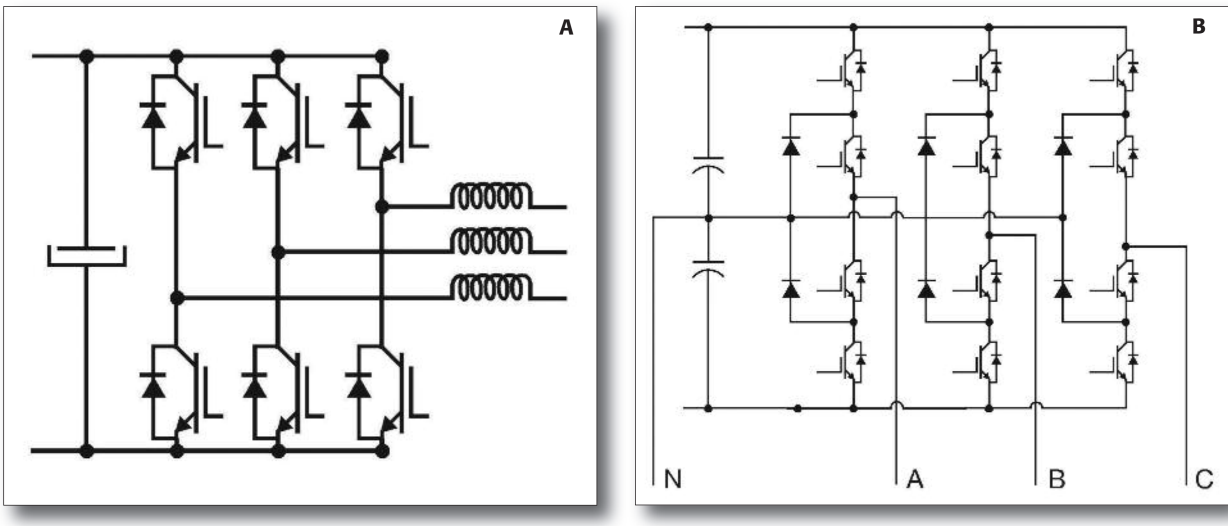


Figure 1: **The 2-level a) and 3-level inverters b) are similar in function to DC/AC converters, both systems can produce a variable frequency and voltage from a DC voltage**

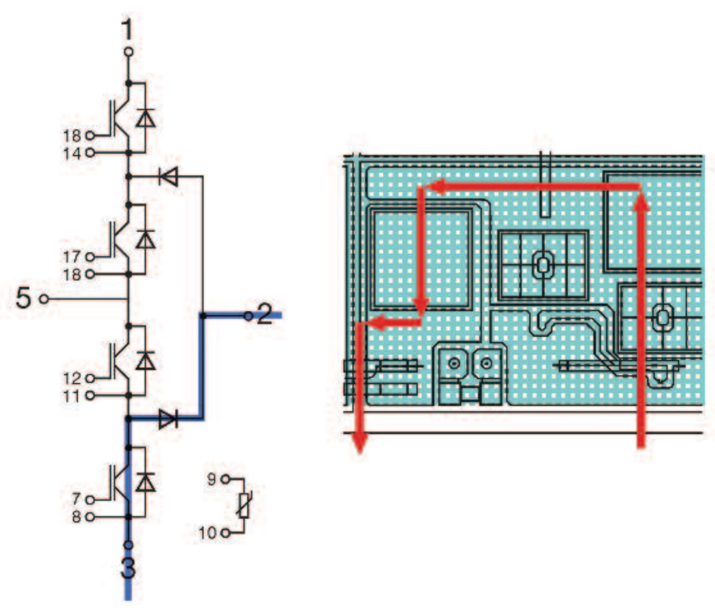


**Figure 2: The internal chip arrangement is based on a clever DBC design and ensures that the commutation path has a very small stray inductance and that the outermost IGBTs are arranged symmetrically**

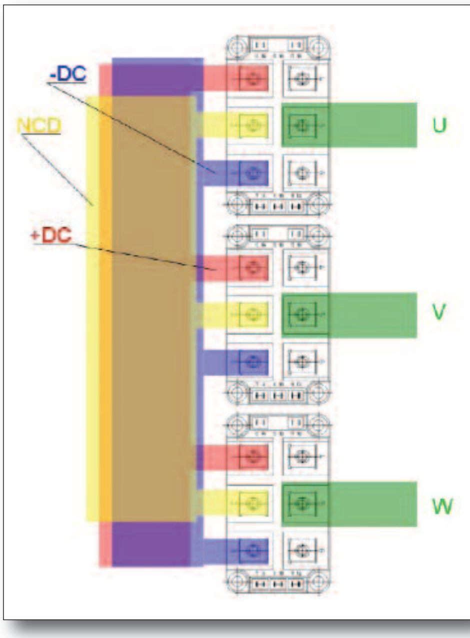


**Figure 3: Layout of a 150KVA 3-level inverter. The 3-level modules feature 600V IGBTs (in future 650V) boasting low switching losses and low forward voltage drop**

connected to the DC link circuit, while the long commutation path goes through three series connected IGBTs and the clamping diode. For this to happen, short current paths are needed and a symmetrical internal module layout. This is the only way of producing small switching over-voltages and using high DC link voltages to achieve a high efficiency factor.

The new 3-level IGBT modules are intended for use in compact, low-inductance 3-level inverters. When developing the new modules, our wealth of experience in the design of standard IGBT modules was drawn upon. The

**Table 1: Comparison of inverter losses clearly illustrates the benefits of the 3-level concept for switching frequencies over 10kHz**

| | 3-level inverter | | 2-level inverter | |
|---|---|---|---|---|
| | SKM 150 MLI 066 T | | SKM 400 GB 12 E4 | |
| Conduction losses IGBT | Q1/Q4 | 88,1 W | Q1/Q2 | 61 W |
| Conduction losses IGBT | Q2/Q3 | 118,8 W | Q1/Q2 | 226 W |
| Switching losses IGBT | Q1/Q4 | 18,1 W | | |
| Switching losses IGBT | Q2/Q3 | negligible | | |
| | | | | |
| Total losses IGBT | Q1/Q4 | 106,2 W | Q1/Q2 | 288 W |
| Total losses IGBT | Q2/Q3 | 118,8 W | | |
| **IGBT: total losses per arm** | | **450 W** | | **576 W** |
| | | | | |
| Clamp diodes | D5/D6 | | | |
| Conduction losses | | 56,6 W | | 31 W |
| Switching losses | | 13,6 W | | 89 W |
| Total losses per diode | | 70,2 W | | 120 W |
| **Clamp diodes total losses** | | **140,4 W** | | 240 W |
| | | | | |
| **IGBT: total losses per arm** | | **590 W** | | **816 W** |
| **Total losses per inverter** | | **1770 W** | | **2448 W** |
| | | | | |
| **Junction temperature IGBT** | | **111° C** | | **132** |
| **Junction temperature diode** | | **117°** | | **128** |

internal chip arrangement (Figure 2) which is based on a clever DBC design, ensures a very small stray inductance in the commutation path and comprises symmetrically positioned outermost IGBTs in order to keep the commutation inductances symmetric.

A further advantage is the layout of the main terminals of the 3-level modules, which easily allow for low-inductance 3-level inverter designs (see Figure 3 - Layout of a 150KVA 3-level inverter) The 3-level modules feature 600V IGBTs (650V IGBTs are planned for the future), which are marked by their low switching losses and low forward voltage. A direct comparison of the IGBT data is given in Table 1. What can be seen here is that at higher switching frequencies, 600V IGBTs produce lower losses than 1200V or 1700V IGBTs. The gate resistance should be taken into account here, too.

## Why are 3-level inverters so important?

The move towards higher switching frequencies results in reduced output filter requirements for solar power inverters or UPS converters, thus allowing for compact and inexpensive system designs. Smaller currents hand in hand with a higher DC link voltage reduce overall system losses. The more complex semiconductor requirements for 3-level architecture are compensated far by the lower requirements for chokes and filter capacitors. A cost comparison shows that integrating a phase into a module is a less costly solution than one featuring several modules.

Gate driving in the 3-level phase results in increased driver requirements (to drive 12 rather than 6 IGBTs), as well as reaction time requirements. Specifically, in 3-level inverters the chosen IGBT driver has to have a short reaction time to ensure high switching frequencies. Short dead times reduce non-linearities in the system and reduce the workload of the controller.

Protection concepts in the drivers are easy to achieve, as a direct bridge short circuit can never occur, as the top and bottom IGBT switch simultaneously. The drivers for the outer IGBTs should feature a monitoring function, while the inner IGBTs can be operated using simple IGBT drivers. What is very important here, however, is that the turn-on sequence of the IGBTs in a 3-level inverter has to be monitored, in order to ensure that the entire DC link voltage is not applied across one single IGBT. Discrete protection concepts are easy to achieve.

3-level inverters require more complex DC link monitoring than 2-level inverters, as the DC link circuit is actually split into two intermediate circuits. The high efficiency factor and the reduced filtering requirements achieved thanks to the high switching frequency force the design engineer to consider the 3-level concept.

A comparison of inverter losses clearly shows the benefits of the 3-level concept for switching frequencies over 10 kHz. (see also Table 1). Thanks to the low switching losses, IGBT junction temperatures are reduced.

In medium-output solar inverters (250KVA), a clear trend towards frequencies over 20kHz can be seen. Here, the use of 3-level topologies is the future, and many companies across the world, in particular Asia, are already developing 3-level solutions.

High switching frequencies also mean high switching speeds (du/dt), meaning that the harmonic distortion in the system has to be filtered using complex filtering technology. In a standard half-bridge circuit, a voltage of 800V can be switched in 100ns, which is equivalent to a switching speed of 8kV/µs. In the 3-level topology, a DC link voltage of 800V can be switched in half the time, as the individual IGBT only has half the voltage (400V) to switch. Less complex EMI filter designs can therefore be used.

## Conclusion

Thanks to the integration of a 3-level phase in a power module, SEMIKRON is now offering attractive solutions for the design of complex 3-level inverters. Driver concept scaling from 10KVA to 250kVA is possible, and the driver concept is ideal for both UPS systems and photovoltaic applications, where high efficiency and an inexpensive design are crucial.