

Inverter manufacturers can quickly decide which topology and which module

In inverter development – whether 2-level or 3-level topology – an important step at the outset is correct dimensioning for module power, cooling system and driver. Due to the greater number of switches in the current path, the 3-level circuit has more commutation possibilities, making it very difficult to calculate power losses. Many manufacturers offer thermal dimensioning for 3-level circuits which does not even touch on the precision of numerical calculations.

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Semikron, for its part, has added the 3-level topology 3L NPC (Neutral Point Clamped) to its thermal calculation tool SemiSel, which can be used to make the right choice of 3-level modules from 10 kVA - 300 kVA (Figure 1).



Figure 1: The range includes 600V 3-level modules from 10 kVA to 300 kVA as soldered modules (SEMITOP), spring contact modules (MiniSKiiP) and screw-connection modules with base plate (SEMITRANS) and without base plate (SKiM).

The first 3-level topology came about almost 30 years ago [1]. Up till now technical developments in this direction have been somewhat sluggish. Owing to its high efficiency, this type of configuration was initially used in high-voltage applications. For some time now, however, 3-level topologies have been used in the markets for uninterrupt-

ible power supply systems (UPS) and solar inverters; this is down to the ever increasing demands on these markets for high efficiency factors and high grid quality. Applications with the demand for high switching frequencies can be optimised by implementing 3-level modules. Costly grid side filtering can be reduced thanks to lower output current THD (total harmonic distortion). Permanent noise emission could additionally be reduced especially in office environments. With four semiconductors in the current path, the forward losses of a 3-level inverter are higher than in a conventional 2-level solution. Thanks to the far lower switching losses, however, the overall losses can be reduced by up to 44% [2], especially at high switching frequencies.

For such applications, where the use of 3-level technology brings about significant benefits, Semikron has built up a wide product range. To enable the customer to select the optimum topology and the right module in terms of power losses and operating temperature, Semikron has implemented the 3-level topology in its simulation program SemiSel.

Wide 3-level product range

3-level technology has been expanded to include higher power classes. Semikron offers 3-level modules for 10 kVA to 300 kVA in various connection technologies. Each module has one 3-level inverter phase leg (Figure 1).

Typical 3-level soldered module for 10 - 80 kVA

For output ratings of up to 100 kVA, Semikron has 3-level modules in two different connection technologies. Owing to their compact and low-inductive design, these modules boast considerable advantages over discrete solutions or solutions with half-bridge modules. The conventional soldered module Semitop is available in the 600V voltage class and for $I_{c,nom} = 20 - 150$ A.

Low-inductive spring contact module for quick and easy converter manufacture

Thanks to the use of spring contact technology, MiniSKiiP modules enable fast single-screw or double-screw assembly, facilitating quick

and reliable converter manufacture. With more than 14 years of field experience and more than 12 million modules in the field, this module platform for 3-level topologies has proven successful in every standard application.

In the MiniSKiiP, the 3-level module layout was optimised in a number of respects. The DBC layout was designed such that the four different commutation paths take up a reduced space and their connections are as close as possible to minimize module inductance and resulting overvoltages. The conducting paths on the DBC and the copper areas around the semiconductor chips were optimised to improve thermal contact with the heat sink and optimise thermal

spreading.

The maximum blocking voltage V_{CES} of the IGBTs and diodes was increased to 650V, meaning that DC link voltages of up to 900V, which are needed for the 3x480V grid in North America, can be handled.

Compact design for rated power of 100 kVA and above

For higher power classes, Semikron offers the screw-connection modules SKiM and SEMITRANS with $V_{CES} = 600V$ and $I_{c,nom} = 150 - 600 A$. For high-power photovoltaic inverter systems with DC link voltages of up to 1500V, a SKiM module with $V_{CES} = 1200V$ and $I_{c,nom} = 200 A$ is also available.

Calculating power losses in a 3-level module

SemiSel is a software program that is used to calculate the operating temperatures of semiconductor modules. This program has been available online since 2001 [3] and has undergone three subsequent updates to include every new Semikron module to calculate the common uncontrolled and half-controlled rectifier topologies, H-bridge and sixpack inverter topologies, step-up and step-down converters, as well as solutions for system and driver selection.

Unlike complex iterative simulation programs, SemiSel uses a numerical approach and linearised semiconductor characteristics. The advantage of this is the shorter calculation time, even for complex load cycles.

Experience shows that SemiSel calculations for standard topologies correspond very closely to the actual values measured in the power module. For the 3-level NPC topology, numerical formulae have been developed to give converter manufacturers a fast and precise 3-level dimensioning tool. This function will be in place by early 2011 (Figure 2).

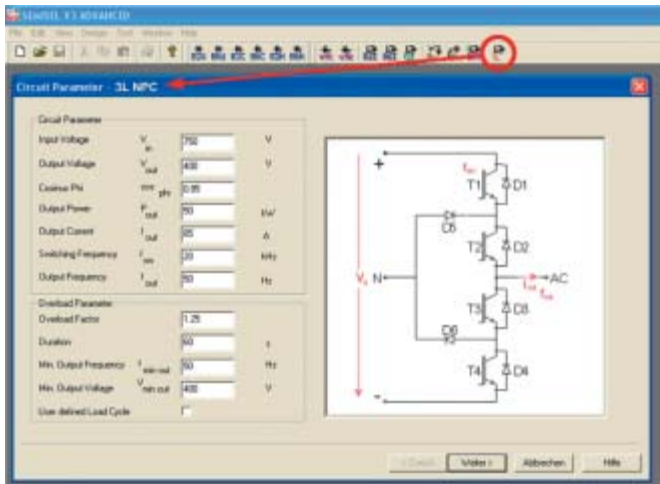


Figure 2: The operating values of the inverter can be entered in the 3-level user interface in SemiSel. The program uses this data to calculate the chip operating temperatures.

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To determine chip operating temperatures from baseline values such as voltage and current, a number of steps have to be taken. Firstly, the mean and the effective current through every IGBT and every diode in the 3-level module have to be calculated. With the help of these current values, conduction and switching losses can then be determined. Finally, the losses and thermal properties of the module can be used to calculate the temperature cycles.

While the calculation of power losses and of temperature cycles for 2-level and 3-level modules is comparable, a differentiation must be made when it comes to the calculation of chip currents: in a 3-level module each phase leg has ten semiconductors (four IGBTs in series plus anti-parallel diodes and two clamping diodes), while 2-level modules have four semiconductors. This results in a greater number of possible switching states with more complex switching patterns for the individual switches.

The easiest way to determine the switching patterns of the IGBTs is to compare two triangular signals with a sinusoidal signal (see Figure 3), and the duty cycle for the individual switches are determined. While the external IGBTs (T1 and T4) clock the current in the active IGBT phase, the internal switches (T2 and T3) can be permanently switched on, even up to a complete half wave, depending on the phase angle.

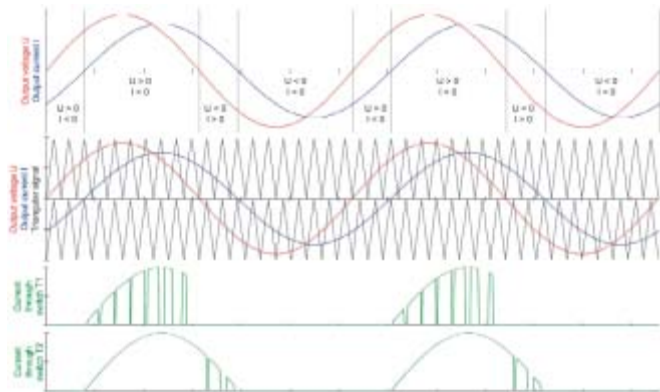


Figure 3: This diagram shows the output voltage U and the output current I shifted by the phase angle shown on the example of an inductive load. The arithmetic signs in front of U and I determine which switches are active. The duty cycle, here for switches T1 and T2, is determined by comparing the reference voltage with a triangular signal.

The general approach for calculating current is as follows:
Formula 1:

$$I_{avg} = \frac{1}{2\pi} \int_0^{2\pi} DC(\omega t) \cdot I_{pk} \cdot \sin(\omega t - \varphi) d(\omega t)$$

Formula 2:

$$I_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} DC(\omega t) \cdot I_{pk}^2 \cdot \sin^2(\omega t - \varphi) d(\omega t)}$$

These two formulae have to be applied to and solved for every single one of the ten switches; this is done using the corresponding duty cycles and integral limits and in dependence of the phase angle. The integral solutions can be used to determine the conduction and switching losses in the semiconductors. Only in the case of the switching losses of the internal IGBTs is it necessary to re-determine

the integrals using other limits: these two switches are not actively switching for the entire half-wave, but are in fact fully conducting for a given period. During this time, no switching losses occur. This is why the integral limits have to be set such that the calculation is performed within the switching time only and switching losses are determined for this time.

An initial plausibility test of the mean current values is obtained by applying Kirchoff's first law to the three nodes shown in Figure 4. The final verification is done by comparing the numerical approach with simulations and measurement results.

To calculate the conduction losses from the mean and effective current values, the forward characteristic of the semiconductors is linearised such that it describes the range of rated current as precisely as possible. This is why SemiSel produces very accurate results in this range. For very low power, i.e. small current amplitudes such as < 20% rated current, static power losses are calculated that are slightly greater than in reality. As the cooling system in an inverter is designed for the rated operating point and overload conditions, it is important to precisely determine the power loss at the rated operating point. At low power, the deviation is negligible.

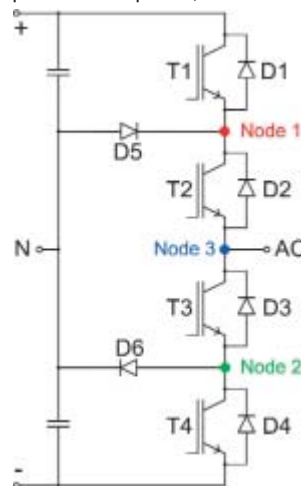


Figure 4: These ten semiconductors are contained in a Semikron 3-level module. An NPC (Neutral Point Clamped) 3-level inverter includes three of these phase legs.

Conclusion

Semikron boasts a wide range of 3-level modules for different connection and assembly technologies for use in 3-level inverters with output ratings of between 10 and 300 kVA. The new SemiSel program delivers fast and reliable results through numerical calculations of the operating temperatures of the semiconductor chips. In this way, inverter manufacturers can quickly decide which topology and which module is the most effective and least expensive solution for their applications.

www.semikron.com

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