

# Saving money: SiC in UPS applications

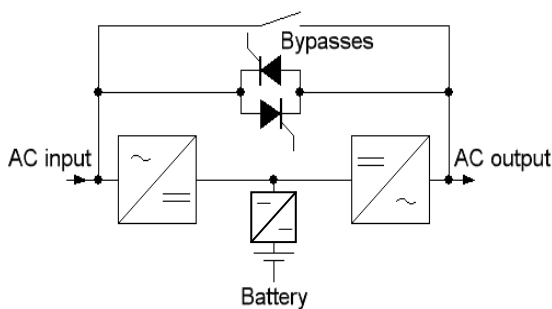
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## Abstract

Efficiency is known as the main lever for cost saving in UPS systems. Based on semiconductor power loss measurements and subsequent calculations, the losses and efficiency for a typical application are compared for Si-IGBT and SiC solutions using various topologies. The resulting costs for investment and operation are estimated for a typical 250kVA UPS system with both chip technologies. A comparison clearly shows the savings for SiC-based solutions, despite the fact of higher power module costs.

## 1. Introduction

In a high-technology world, the demand for continuous and stable power is becoming ever more important. In typical large scale applications, such as data centers, automated production lines, infrastructure control systems, and hospitals, Voltage and Frequency Independent (VFI) uninterruptible power supply (UPS) systems are in use. The left part of Figure 1 shows a schematic, for details on different types of UPS see [1]. A VFI-UPS is comprised of one rectifier and one inverter, a DC-link and a bypass switch for maintenance. The battery is connected via a buck/boost converter and provides power in case of a grid failure. The table in the right side of figure 1 shows typical operating conditions as they are used in this paper for loss and efficiency calculations. The race for efficiency has only recently lead to the implementation of 3-Level topologies. These come, though operating at higher switching frequency ( $f_{sw}$ ), with better overall losses and noise reduction, in comparison to a 2-Level IGBT solution: An efficiency increase from 95% to 96% (typical values) is reached by a change in topology and underlying devices. The additional driver effort required to handle the higher number of switches, and the development effort for implementation is accepted. However, using a 2-Level Silicon Carbide solution comes with even better efficiency and does in general not require special driver effort.



$P_{out}$ [kVA]	250
$I_{out}$ [A]	360
$U_{DC}$ [V]	650
$f_{sw}$ [kHz]	16
$f_{out}$ [Hz]	50
Heat sink	Forced air

Figure 1: Block diagram of a Voltage and Frequency Independent (VFI) UPS system together with design parameters used throughout the analysis.

In the following, different rectifier and inverter topologies for UPS systems will be calculated, and the main differences are discussed. Based on efficiency calculations, the economical benefit will be given for different technical solutions.

## 2. Technical features

### 2.1. Comparison of topologies

Throughout the paper, both the rectifier and inverter part are considered to be identical in design. Figure 2 sketches the three topologies compared in this paper, for clarity only one phase is shown in all cases. In case of a SiC device, the internal body diode may be used instead of an additional device.

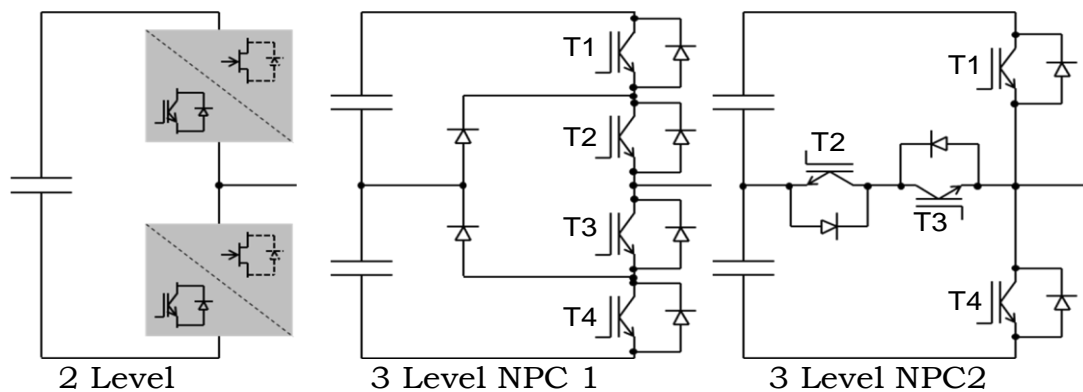


Figure 2: Schematic of the topologies investigated, where switches are IGBT with antiparallel diode, or SiC JFET with intrinsic body diode. The 2-Level solution contains two switches with blocking voltage of 1200V. The 3-Level NPC 1 requires 650V devices, while the NPC 2 has a combination of both.

The main difference between the 2-Level and both 3-Level topologies is an additional output voltage level, which reduces the ripple current at identical switching frequency; Thus a three level topology allows to reduce the size and the cost of the filter, and the option to increase the switching frequency without too much penalty in switching loss[2]. The 2-Level solution requires 1200V switches, and so does the NPC 2 three-level topology namely the fast-switching T1 and T4. The NPC 1, on the other hand, is based on 650V devices with reduced switching losses but larger conduction losses. A detailed comparison of the 3-Level topologies is given elsewhere [3].

### 2.2. Control effort

Depending on combination of topology and chip technology (Si, or SiC), the control effort is obviously different. For the 3-Level topologies, additional drivers are required due to the higher number of switches, and the implementation comes with some development effort. Depending on the required level of reliability, an increased Failure-in-time (FIT) value due to the higher number of electronic components may be critical in a comparison. These negative points can be dealt with, and several companies are offering 3-Level solutions on the market. As an alternative a 2-Level Silicon Carbide solution comes with even better efficiency than a 3-Level topology and does in general not require special driver effort.

### 2.3. Power losses and Efficiency

Table 1 presents an overview of possible solutions for the different topologies given above. Total power losses and resulting switching frequency have been calculated using IPOSIM [5], and are based on datasheet values where available, and experimental results of semiconductor loss measurements otherwise [4][5]. The same heat sink performance was assumed in all cases, The efficiency is given at 50% load, whereas the  $T_{vj,op}$  is given at maximum load. 2-Level solutions with an IGBT are limited at 7.5kHz due to the maximum allowed junction temperature. A clear improvement are 3-Level topologies, where higher  $f_{sw}$  up to 16kHz for noise reduction can be used at reduced  $T_{vj,op}$  and improved efficiency. Today, 3-Level solutions are state-of-the-art for high efficiency UPS systems and used as a reference in the following. The switching frequency is doubled for the full SiC two-level topology to match the ripple current of the 3-Level solution at same output inductance.

Topology	Technology		$\eta_{UPS}$ 50% load	$T_{vj,op}$ 100% load	$f_{sw}$	Solution
	Switch	Diode				
<b>2-Level</b>	<b>Si</b>	<b>Si</b>	<b>95.1</b>	<b>148°C</b>	<b>7.5 kHz</b>	<b>FF450R12ME4</b>
<b>3-Level NPC1</b>	<b>Si</b>	<b>Si</b>	<b>96.0</b>	<b>105°C</b>	<b>16.0 kHz</b>	<b>F3L300R07PE4</b>
3-Level NPC2	Si	Si	96.0	124°C	16.0 kHz	F3L400R12PT4_B26
2-Level	Si	SiC	95.7	146°C	7.5 kHz	prototype
<b>2-Level</b>	<b>SiC</b>	<b>SiC</b>	<b>97.6</b>	<b>109°C</b>	<b>32.0 kHz</b>	<b>virtual prototype</b>

Table 1: This table summarizes the different configurations covered for the technical analysis of a 250kVA UPS system together with the main operating conditions. The solutions given in bold will be considered for cost modeling.

Based on the calculation results, Figure 3 shows the resulting efficiency of a 250kVA UPS as a function of load. The losses for rectifier and inverter are identical, and additional losses due to the inductors, wiring and other electronic components is accounted for by an efficiency reduction of 1.2%.

The 2-Level Si solution resembles the bottom line of the possible solutions, being limited at small  $f_{sw}$  due to power losses and reaching a maximum overall efficiency of 95.3%. Replacing the Si diode by a SiC diode without reverse recovery charge, the efficiency is clearly increased by about 0.5% at identical switching frequency, and reaches almost the performance of the 3-Level solutions. The only difference is the diode, thus the control concept is not changed, which offers a fast implementation for existing 2-Level Si systems by simply replacing one power module with a new solution.

The 3-Level solutions have an overall efficiency around 96% at 50% load, representing a typical value for state-of-the-art UPS solutions. A remarkable feature is the almost constant efficiency, independent of the output power. A clearly superior solution, however, is displayed using a 2-Level full SiC solution: A significant loss reduction supports low junction temperatures at unmatched efficiency of 97.6%. An additional effect related to the unipolar character of the device is an increase in efficiency at lower output, which is in strong contrast with existing Si solutions.

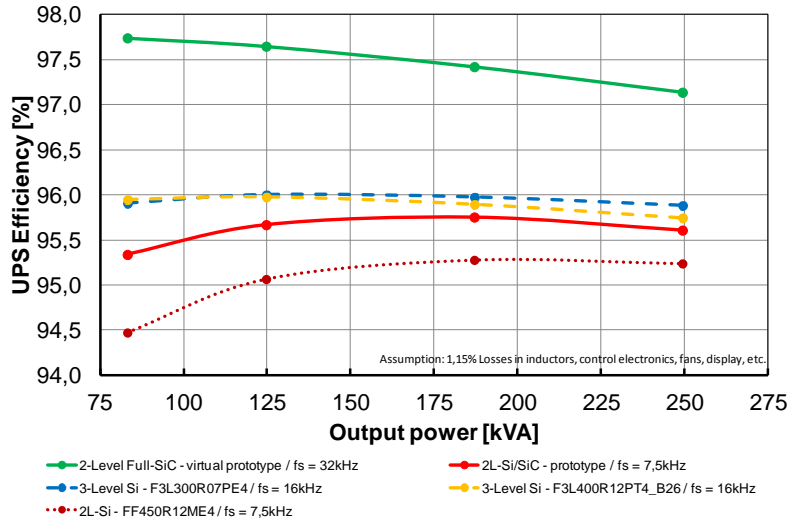


Figure 3: 250kVA UPS efficiency as a function of output power. Results are based on IPOSIM calculations for an inverter using the respective configurations as starting point.

Figure 4 shows the potential savings, where the relative power losses for the considered technical solutions are given. Using the 3-Level NPC2 as reference, superiority with respect to Si-based 2-Level solutions in terms of power losses is easily recognized. However, using SiC switches, additional power loss reduction by more than 40% may be achieved.

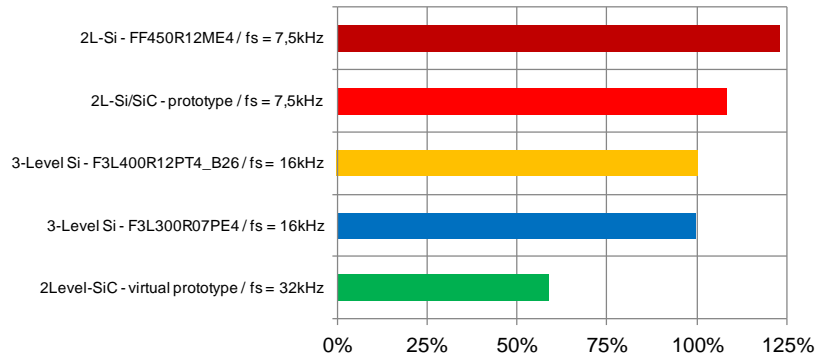


Figure 4: Change of power losses for the different technical solutions at 50% load of a 250kVA UPS. The 3-Level NPC1 topology is used as reference.

The increase in efficiency shown here is immediately linked to savings, as Power losses are equivalent to wasting money. Details are given in section 3.

### 3. UPS system operating costs

#### 3.1. General considerations

An increase in inverter efficiency improves the UPS in several ways: Directly visible are the savings due to reduced power losses. Going from 96% to 97.6% efficiency, or from 3-Level Si to a 2-Level SiC topology, is equivalent to a power loss reduction and thus energy savings of 40%. An additional effect is reduced power consumption for cooling of the data center room, where typically 400W of cooling power are required to remove heat in excess of

1000W [7]. Finally, due to reduced inverter losses, the battery system itself can be reduced accordingly to supply the required power at the UPS output, which reduces the initial investment for a UPS system. The buck/boost converter inside the battery system may also largely benefit from high switching frequencies achievable through use of fast SiC devices: This will come with reduced costs for the magnetic components but is out of the scope of this paper.

### 3.2. Total costs of a UPS system

UPS systems are usually run at medium load, both for redundancy reasons and to cover overload conditions. 50% load at an operation for 24h and seven days a week is the assumed standard operating modus. Operating costs for power losses and cooling under these conditions are shown in Figure 5 at different electricity costs. They may be reduced by more than 50% for an increase in efficiency from 94% to 97%. The table on the right shows typical electricity costs for some European countries.

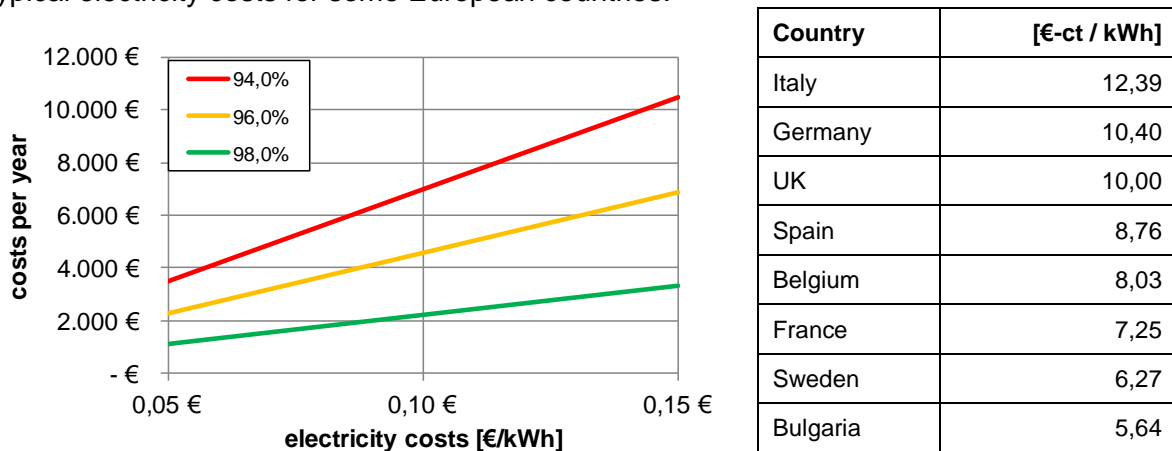


Figure 5: the left part shows electricity costs per year for a 250kVA UPS at different efficiencies. Load conditions are as given in the text, cooling costs are included. On the right side, typical electricity costs are given for some European countries (taken from [8]).

To assess the economical benefit of a 2-Level SiC solution, the costs during the whole life of a UPS system need to be considered. As maintenance costs can be assumed identical for all technical solutions, only the initial investment and power-loss related costs during operation are used in the following to calculate the total cost of ownership (TCO). Initial investment includes a battery system, a bypass and the UPS unit itself, which in turn includes the power modules and control for the respective technical solution. The battery is supposed to provide a certain amount of energy, and can be reduced accordingly for a UPS unit with enhanced inverter efficiency. Depending on the required size of the battery unit, this may already lead to total savings, without looking at the lifecycle costs. Operating costs are taken as electricity costs arising from power losses, plus additional electricity costs for the cooling system, where additional 40% of energy is required.

Figure 6 shows the resulting TCO as a function of operating period. The 2-level Si is shown in comparison to one 3-Level solution at 16kHz and the equivalent 2-Level SiC solution at 32kHz. Both NPC1 and NPC2 topology are based on IGBTs and have similar efficiency and thus TCO. Only the solution with lower  $T_{vj,op}$  is presented for clarity. The SiC switches lead to a power module price which is assumed higher than the 3-Level solution, yet a system benefit is clearly visible.



Figure 6: Total Cost of Ownership for different technical solutions, using electricity costs of 0.10 €/kWh. A 3-Level solution provides significant savings, while a SiC-based solution shows the best overall performance.

Depending on the technical solution, the initial investment is different due to power modules, control effort and battery system. However, this is negligible when looking at the impact of efficiency, i.e. the slope in the graph. Compared to a 2-Level IGBT solution, the 3-Level topologies provide already clear savings; the 2-Level SiC solution is even superior due to the reduced power losses and favorable for the operating company. The savings after five years are shown in Figure 7, where the Si solution is used as a reference. Depending on the electricity costs and technology used, the savings can be a significant part of the initial investment. Thus it is clear that using SiC devices can strongly contribute to cost reductions.

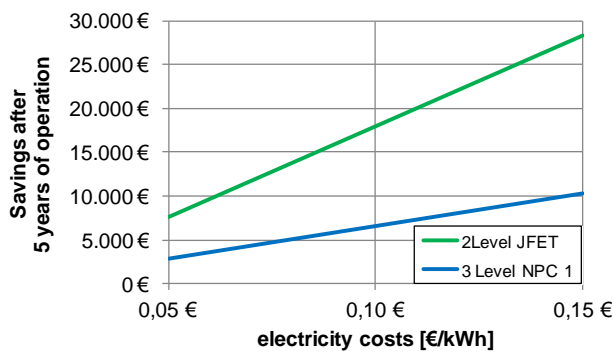


Figure 7: Savings for a 250kVA after five years of operation in comparison to a Si 2-Level solution.

#### 4. Conclusion

Efficiency is the main driver for improvement and savings for UPS systems. In the IT environment, on-line UPS systems are used, where improved efficiency is directly measured in electricity cost savings. 3-Level solutions achieve excellent efficiency and support savings during operation already today, while the use of SiC switches will allow for another huge step in savings in the future.

Technical solutions using SiC switches clearly show superior power loss behavior and thus improve efficiency significantly, without the need for a complex control system in contrast to a 3-Level solution. Despite of assumed higher SiC switch module prices opposed to the 3-Level IGBT modules, these costs are compensated by the efficiency gain after only one year of operation, and 9% of the initial invest is saved after five years of operation. Despite higher power module prices, there is a clear system benefit in using SiC devices.

## 5. References

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