Bodo´s Power Systems®

1200V SiC Hybrid IGBT Modules for High Frequency Applications

Dedicated IGBT-modules for high switching frequency operation have been successfully introduced to the market over the past years. Typical applications are X-ray generators, CT-scanners, induction heating, welding, plasma cutters or inverters for isolated or contactless electrical power conversion.

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The switching frequency in those applications is usually higher than 20kHz, thus exceeding the range for which standard industrial IGBT-modules are optimized for. Since several years Mitsubishi Electric is offering a dedicated IGBT-series for those high frequency applications, called NFH-series. For reducing the switching loss it is using IGBT-chips with an optimized trade-off between Vce(sat) and Eoff. As next innovation step Mitsubishi Electric now is introducing it's Silicon Carbide Chip technology to this proven NFH-series design.

Hybrid SiC-IGBT module approach

A series of 1200V dual modules with current ratings between 100A and 600A was developed [1] by using SiC Schottky Barrier Diodes (SBD). This approach is called "Hybrid SiC" module. For better understanding the used terminology, please refer to Figure 1. A hybrid SiC module is containing Silicon-based IGBT in combination with SiC-based Schottky Barrier diodes. The IGBT-chips are kept the same in both the conventional NFH-series and new hybrid SiC NFH-series.

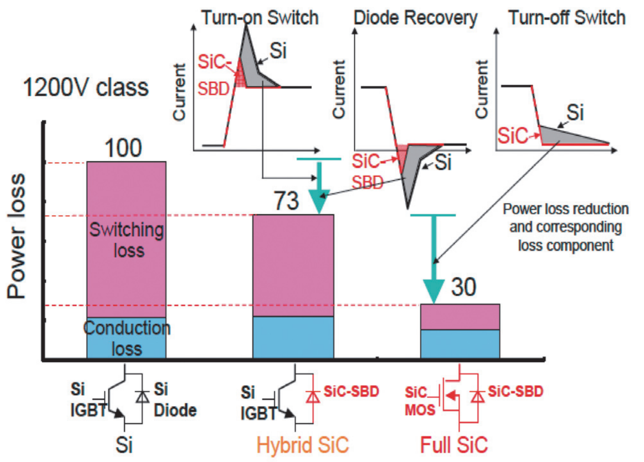


Figure 1: Evolution of SiC technology in power modules

Type	Voltage	Current	Connection	Baseplate size
CMH100DY-24NFH	1200V	100A	2in1	48x94mm
CMH150DY-24NFH		150A		
CMH200DU-24NFH		200A		62x108mm
CMH300DU-24NFH		300A		
CMH400DU-24NFH		400A		80x110mm
CMH600DU-24NFH		600A		

Table 1: Line-up

Series	Connection	V_{CES} (V)	Ic (A)					
			100	150	200	300	400	600
NFH	Dual	1200	Small PKG	Small PKG	Middle PKG	Middle PKG	Large PKG	Large PKG

Figure 2: Line-up and Package outlines

The principle switching waveforms are given in Figure 1. Due to the fact that Schottky diodes as unipolar semiconductors don't have any reverse recovery charge, there is no reverse recovery loss. The absence of diode reverse recovery current on the other hand leads to a substantial reduction of IGBT turn-on energy.

A further reduction of total power loss can be achieved if both the active switch and the free-wheeling diode are made of SiC. This approach is called "Full SiC" module.

Line-up & Package outlines

The line-up of new hybrid SiC NFH-series is shown in table 1; the package outlines are given in Figure 2. For the middle and large size packages the main terminals are located at the side of the housing. This arrangement allows using a laminated main terminal structure in-side the module for reducing the internal package inductance Lint. For all current ratings of both middle and large size package this internal package inductance is in the range of 18…22nH (defined between P- and N- main terminals).

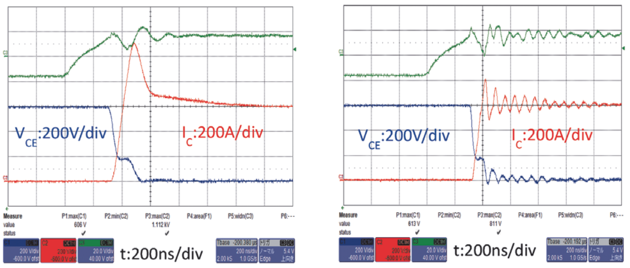
Switching behavior

The turn-on waveforms under inductive load condition of conventional NFH-module CM600DU-24NFH and new hybrid SiC module CMH600DU-24NFH are shown in Figure 3. Taking into account that both module types are using exactly the same IGBT-chips the difference in switching waveform is entirely the result of difference in free-wheel diode behavior. The key difference between both current waveforms can be explained by the lack of reverse recovery charge (and consequently the diode's reverse recovery current) in the hybrid SiC module CMH600DU-24NFH as the Schottky Barrier Diode is a unipolar semiconductor. Consequently both the turn-off loss of freewheeling diode and the turn-on loss of IGBT under inductive load switching are drastically reduced, as it can be seen in the switching energy diagrams given in Figure 4 and 5.

Loss performance comparison

A power loss simulation under inverter operation conditions (hard switching) with sine-wave PWM reveals the big impact of using SiC Schottky diodes instead of conventional Si-diodes for the NFH-series modules: at fc=30kHz the hybrid SiC module has just half of the total losses of its Si-counterpart, see Figure 6.

The dependency of total module power loss on PWM switching frequency fc is given in Figure 7. From this diagram it can be derived that the total power loss of new hybrid SiC type CMH600DU-24NFH at fc=50kHz is at the same level as its full Si-counterpart at fc=17kHz. Considering that both modules CMH600DU-24NFH and CM600DU-24NFH have the same power loss handling capability (same baseplate size and hence the same Rth(c-f); same Rth(j-c) for IGBT) it seems to be possible for such applications to triple the switching frequency fc while keeping the module power loss at the same level.



Conditions: Tj=125degC, V_{GE}=15V, V_{CC}=600V, R_G=0.52ohm

Figure 3: Ic-waveforms at turn-on

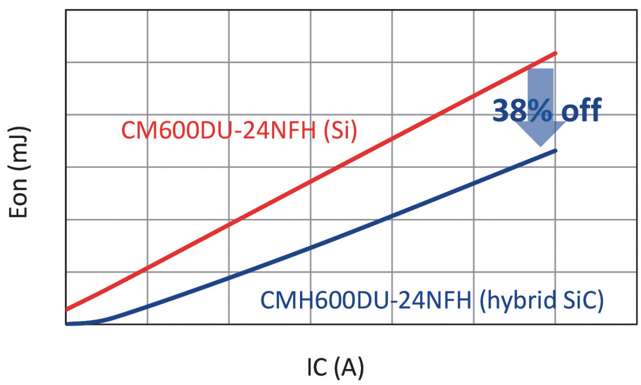


Figure 4: IGBT turn-on energy E(on) vs. current

Application benefits

The described improvements in switching loss performance under hard switching conditions are offering system benefits basically in two directions when using the new hybrid SiC NFH-series:

The most obvious one is the possibility of increasing the switching frequency fc. The size of inductive components in a power electronic system is often determined by the switching frequency.

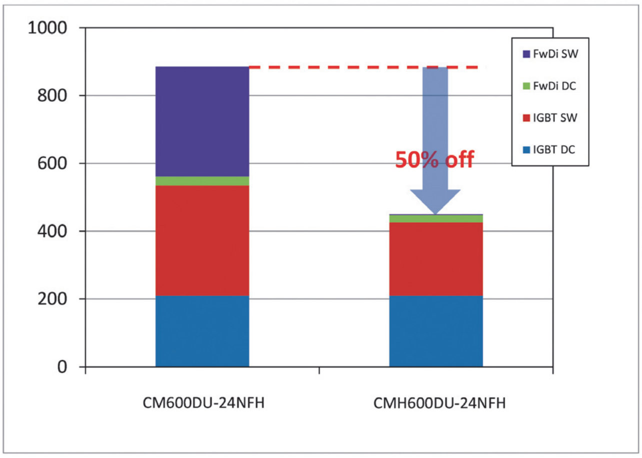
Consequently an increase of fc can help to reduce size (and cost) of those inductive components.

Also the dynamic response of a power electronic system can be improved by increasing fc.

Another direction is improving the energy efficiency of a power electronic system. This is an interesting option especially in application where low system efficiency is penalized.

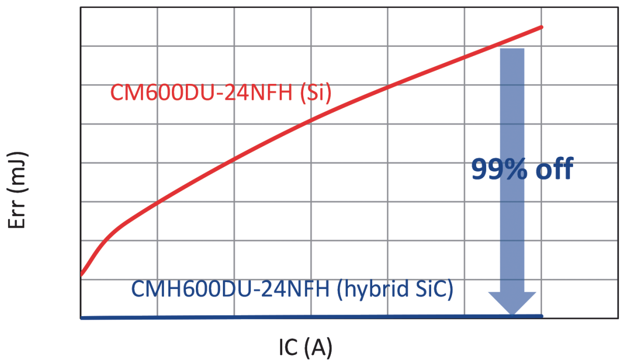
In general reducing the power loss dissipated in the IGBT modules will help to reduce heat sink size. This is interesting for such applications where heat sink is the limiting factor for system size reduction.

Another potential benefit of using the new hybrid SiC series can be expected in soft switching applications. Here the principle absence of reverse recovery charge at diode turn-off can contribute to a further power loss reduction.



Conditions: Io=300A; fc=30kHz; PF=0,8; M=1; Vcc=600V; Vge=+/-15V; Rg=0.52Ω; Tj=125°C

Figure 6: Power loss simulation (inverter operation with sinus PWM)



Conditions: Tj=125degC, V_{GE}=15V, V_{CC}=600V, R_G=0.52ohm, 100A/div; 5mJ/div

Figure 5: Freewheeling diode turn-off energy vs. current

Summary and outlook

By using Mitsubishi's new hybrid SiC IGBT modules for high frequency applications a drastical reduction of switching loss is possible. The use of SiC Schottky Barrier diodes instead of conventional Silicon diodes as freewheeling diodes in the modules of NFH-series is eliminating the reverse recovery charge at freewheeling diode turn-off. Under hard switching inverter operation conditions this allows to increase the switching frequency by a factor of 2…3 compared with conventional Si-based IGBT modules.

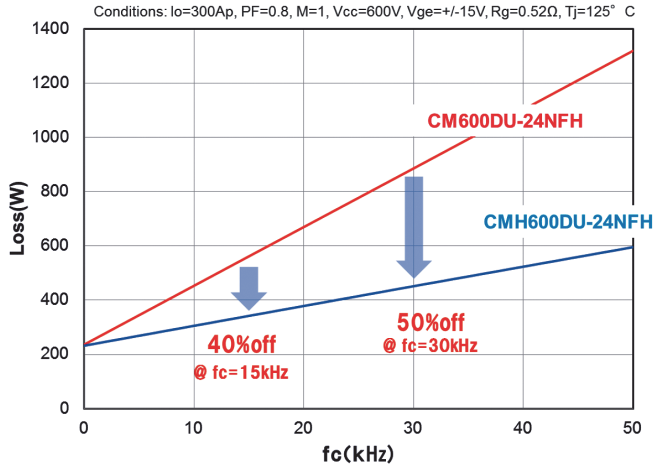


Figure 7: Power loss versus PWM switching frequency fc

Application benefits can be also expected when using the new hybrid SiC modules in soft switching applications due to the absence of reverse recovery charge at diode turn-off. Here further investigations are needed.

Literature

[1] "Mitsubishi Electric to Ship Sample Hybrid SiC Power Semiconductor Modules for High-frequency Switching Applications"; Press Release of Mitsubishi Electric Corporation; Tokyo, May 15, 2014