New Power Semiconductor Module Combines MNPC Topology with SiC Switches

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This article compares and contrasts two types of modules, one with silicon switches and the other with SiC (silicon carbide) switches. Vincotech *flow*MNPC 0 modules in 12mm *flow* 0 housings serve the purpose of comparative evaluation. These modules feature MNPC (Mixed Voltage Neutral Point Clamping, Figure 1) topology. This type of circuit is designed for two types of applications, solar inverters and uninterruptible power supplies (UPS).
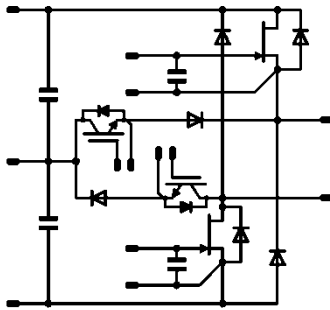

Figure 1: MNPC topology with SiC JFET

MNPC topology is a variant of three-level topology. The MNPC topology and the standard NPC version are today the preferred topologies for applications requiring exceptional efficiency. In this context, the term "three-level" refers to the possibility of generating three voltage levels at the source terminals – positive, negative, and a third level usually midway between the two.

In contrast to NPC topology, MNPC topology exhibits the following properties when used for applications such as solar inverters:

1. The majority of losses are not attributable to switching loss at moderately high switching frequencies of around 16 kHz. While it is true that MNPC topology generally exhibits greater switching loss than NPC topology because of the 1200V switches, the difference is insignificant at 16 kHz.
2. MNPC topology exhibits less conduction loss than NPC topology at a high modulation index and/or high duty cycle for 1200V transistors. Solar inverters and uninterruptible power supplies generally seek to make the most of the intermediate circuit voltage, so the modulation index is usually high.

A comparison of the two topologies (Figure 2) shows that MNPC topology is about 0.5% more efficient at 16 kHz.
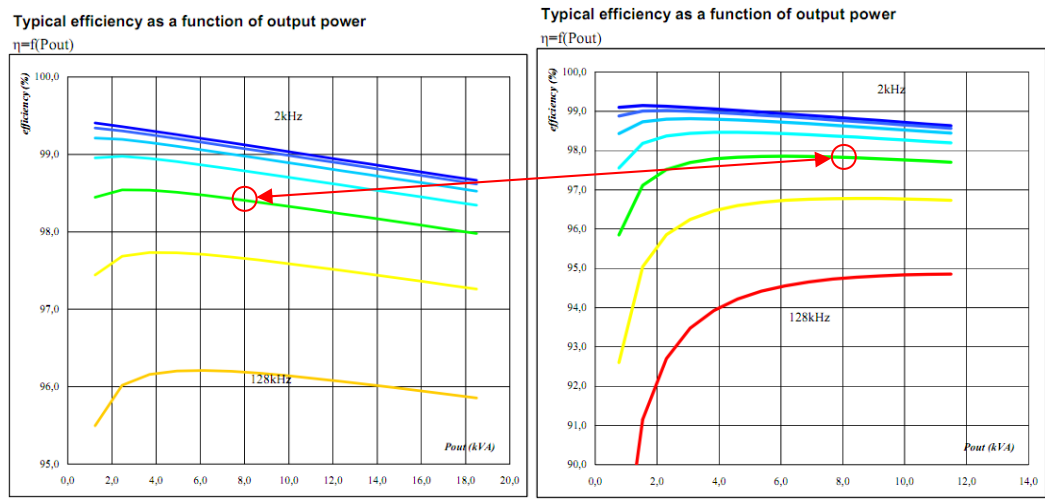
Figure 2: Comparative efficiency of MNPC (on the left) and NPC (on the right) topologies

In recent years, SiC-based Schottky diodes have been used successfully in fast switching applications such as PFC (power factor correction). The diode's excellent reverse recovery characteristics ensure that the increased switching frequency does not adversely effect efficiency. The use of smaller magnetic components also reduces overall system costs.

Today's SiC-based switches are another matter entirely. Modern solar inverters and UPS systems are mainly equipped with Si-based IGBTs (insulated gate bipolar transistor). Although their forward voltage is low, their tail current causes high switching loss. Engineers tasked to develop solar inverters and UPS want a switch that is high in reverse voltage and low in conduction and switching loss. SiC provides the underpinning for this ideal switch.

Among the many ways to implement a SiC switch, two are gaining prevalence, SiC MOSFET and JFET. The MOSFET behaves much like a MOSFET based on silicon. It is compatible with the usual gate drivers, and its temperature coefficient is low. However, the reliability of gate oxide remains a critical issue. The JFET may be configured both ways, normally-off and normally-on. Owing to their diode-like gate source characteristics, they are incompatible with standard gate drivers. JFETs do not incorporate gate oxides so they are more reliable from the perspective of today's technology.

To clear the final hurdle and boost system efficiency to 99%, the new family of modules was equipped with normally-off SiC JFETs sourced from SemiSouth Laboratories, Inc. The switches' forward voltage and switching loss is low. With up to four SiC JEFT chips configured in parallel circuits in the module, Rds (on) is just 25mΩ at room temperature. JFETs are unipolar devices, so they exhibit good switching characteristics much like those of standard silicon-based MOSFETs. Utmost efficiency is achieved by combining MNPC topology with SiC JEFTs for the fast high-voltage switches.

Again, JFETs have diode-like gate source characteristics. Positive voltage must be applied in the diode's direction of flow to open the channel of normally-off JFETs. To retain the JFETs' best properties, this should be done near the diode's forward voltage.

The forward voltage varies considerably from component to component and fluctuates with temperature, so JFETs - unlike IGBTs or MOSFETs – should be controlled by a current source. A standard gate driver must be adapted to limit the forward current. One way to do this is to use low gate resistance for switching and high gate resistance during the final conductive phase. The SemiSouth specification sheet provides an example of such a gate driver (Figure 3):
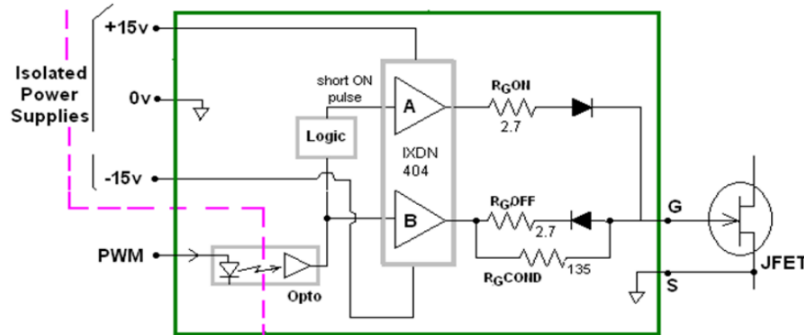

Figure 3: Example of a possible gate driver for normally-off JFETs[1]

Vincotech's new module family features separate outputs for both commutating circuits (see Figure 1). Consequently, both circuits' du / dt are separate. This measure reduces the risk of parasitic turn-on (that is, via the Miller capacitance at high du/dt) and the resultant increase in switching loss.

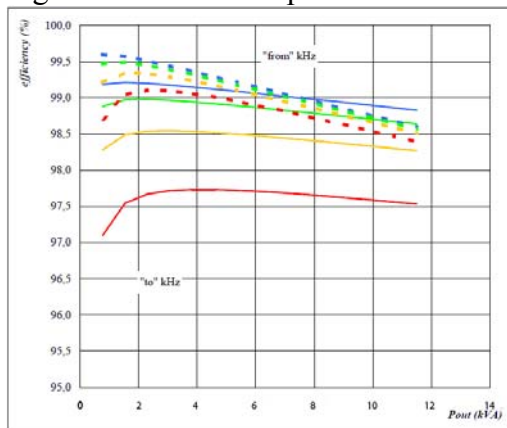Figure 4 shows a comparison of modules equipped with Si IGBTs and SiC JFETs.

Figure 4: Comparative efficiency of MNPC modules with Si IGBTs (solid lines) and SiC JFETs (dotted lines) at switching frequencies of 8 to 64 kHz

This comparison indicates that modules with SiC JFETs achieve higher maximum efficiency, whereby the gains increase at higher switching frequencies. This means the user is able to increase both efficiency and switching frequency. Raising the switching frequency allows smaller passive filter components such as inductors and capacitors to be used, which reduces overall system costs.

The new family's pin-out facilitates an optimum low-inductive PCB layout. The intermediate circuit's positive, negative and neutral terminals are at the center of the module, enabling engineers to implement a low-inductive intermediate circuit layout that is continuous and uninterrupted. What's more, snubber capacitors may be sited very close to the module.

This family of Vincotech module also features versions with a booster configuration – that is, two parallel boosters housed in one module. Variants with 1200V IGBTs and SiC JFETs are available. Given dual boosters to work with, engineers can implement two independent MPPT (maximum power point tracker) channels in one solar inverter to boost efficiency and pulse frequency. The version equipped with SiC JFETs features four chips configured in parallel circuits to achieve Rds (on) as low as 25mΩ at room temperature.

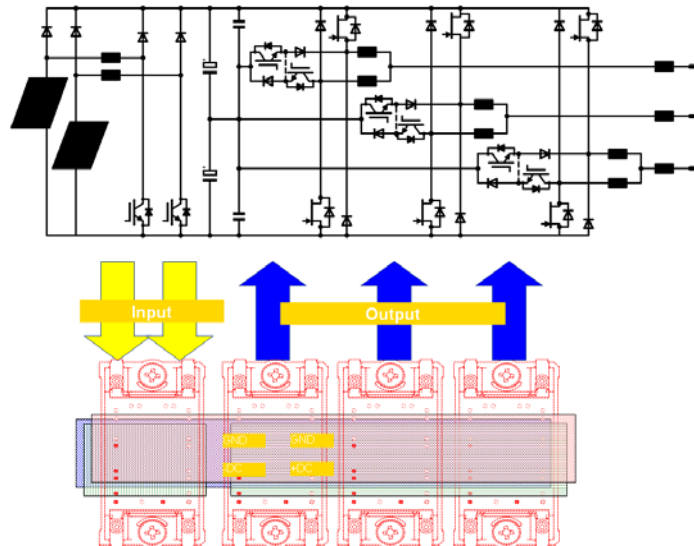Figure 5 depicts an example 30-kW solar inverter.

Figure 5: Example of a 30-kW, 3-phase solar inverter

SiC switches constitute a new class of 1200V switches. They enable engineers to significantly increase efficiency and switching frequency for demanding applications such as solar inverters. With such switches on board, these power semiconductor modules readily adapt to suit the given application and may be deployed to optimum effect. The modules were designed to satisfy such applications' demanding requirements for symmetric control, heat dissipation and a low-inductive layout.

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[1] SemiSouth datasheet SJEP120R100, http://www.semisouth.com