# Unipolar Switching Full Bridge Modules Make Solar Inverters More Efficient.

## *The size, performance, reliability and cost are very important criteria*

*The decrease of fossil fuel resources, the global climate and the environmental problems on the planet requiring a significant reduction of carbon dioxide emissions lead us to use the energy in a more efficient and intelligent manner. There are from now on great economical and health benefits to exploit a renewable energy and an infinite resource like the sun.*

*By Serge Bontemps, Microsemi Power Products Group, Power Modules*

**Introduction**

Solar cells are used to capture the energy from the sun and generate a direct current that is converted into an alternating current compatible with the grid. The inverter performing the DC to AC conversion must exhibit the highest efficiency not to waste the energy provided by the source. A unique solution of power modules for unipolar switching DC/AC inverters has been developed to reduce the power loss.

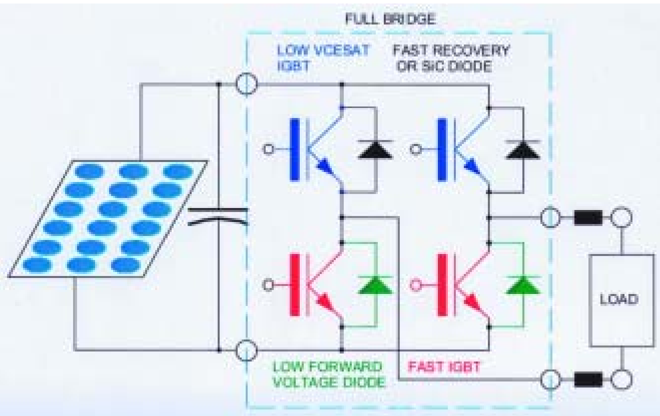


*Figure 1: Solar inverter configuration using unipolar DC/AC full bridge module*

**Mode of operation of the unipolar full bridge**

The size, performance, reliability and cost are very important criteria for a solar inverter and the unipolar switching DC/AC topology allows meeting the highest possible efficiency of the system, not only fundamental not to waste a precious energy but it is also essential for reducing the cost of producing electricity.

The bottom switches are operating at high frequency to minimize output filter size while top switches operate only at line frequency. By this way the inverter takes advantage of the high frequency operation with only two switches of the bridge exhibiting switching losses while the other two have only to dissipate conduction losses.

This configuration is offered in 600V and 1200V voltage rating to address the two main AC grid voltages and meet a wide range of solar cells voltages. To achieve the most compact solution at a competitive price for a frequency operation in the range of 15 kHz to 50 kHz an IGBT technology is preferred. The bottom switches operating at high frequency are built with fast NPT IGBT devices. The top switches working at line frequency feature the lowest saturation voltage, offered by Trench and Field stop IGBTs. It would be possible to implement the fast switches in the top position of the bridge and the low conduction devices in the bottom but usually the opposite is achieved to facilitate the driving of the fast devices and avoid a floating position when placed in the top of the bridge.

The diodes in these new power modules are matched to the power transistors for improved inverter efficiency as well. High speed, soft recovery Microsemi DQ diodes type is implemented in parallel with the top IGBTs to provide low recovery losses in combination with the bottom fast IGBTs. Low forward voltage diodes protect the bottom IGBTs during output zero crossings. These last diodes are much less stressed than the others that are submitted to high frequency reverse recovery which allows sizing them with a lower current rating which is appreciable for size and cost reduction.

In photovoltaic systems the size and cost of magnetic components must be as low as possible. With improved RDS(on) x Qg and RDS(on) x Esw figures of merit, 600V CoolmosTM devices operate at even higher switching frequencies with minimum switching and conduction losses making possible significant system size reduction without losing energy efficiency.

**Efficiency performance evaluation of various combinations of power devices as a function of operating frequency.**

Various combinations of technologies are compared in terms of efficiency as a function of output power. The study is also performed with different operating frequencies to better measure the impact of the switching losses of the different fast switches.

In order to have a fair comparison between solutions, the efficiency is given for the normalized output power P/Pnom.

To compare the largest possible range of power semiconductor types, this study is related to 600V devices. In order to avoid any audible noise and minimize the size of the magnetic components an operating frequency of 20 kHz for the fast switches is generally adopted.

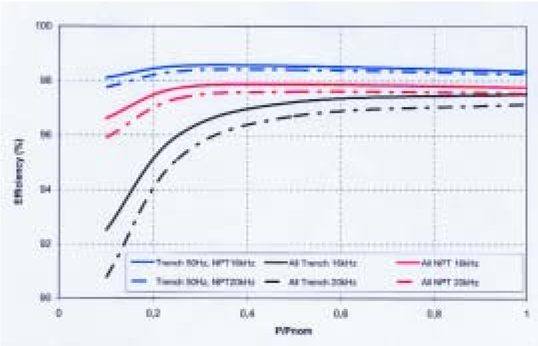


*Figure 2: Efficiency performance as a result of IGBT combinations and operating frequency*

Fig.2 gives the efficiency as a function of P/Pnom for:
- A configuration using only Trench and Field stop IGBTs for all 4 switches of the bridge,
- A configuration using only fast NPT IGBTs.
- The optimized configuration with fast bottom NPT IGBTs and low conduction Trench and Field stop top IGBTs.

600V Trench and Field stop IGBTs are designed to operate up to 20 kHz. Low VCEsat voltage combined with reasonable switching times allow reaching efficiency between 96% and 97%. Despite higher conduction losses, fast NPT IGBT devices enable to improve the efficiency thanks to improved switching losses. The combination of Fast IGBTs for their low switching losses and Trench and Field stop IGBTs for low conduction characteristics outperform the previous versions by almost 1% with an overall efficiency above 98% over a wider range of input power.

In order to further improve the efficiency it is still possible to decrease the operating frequency down to 16 kHz, limit of audible noise without impacting the size of magnetic components.

The decrease from 20 kHz to 16 kHz allows getting efficiency above 97% for Trench and Field stop IGBTs, very close to 98% for fast NPT IGBTs and well above 98% for the mix of IGBT technologies (seeing Fig.2).

In some cases, it makes great interest increasing the operating frequency in the range of 50 kHz to further decrease the magnetic components, particularly on the output filter.

600 V fast NPT IGBTs with low turn off energy are fully capable of operating up to 100 kHz and therefore can achieve acceptable efficiency in the range of 50 kHz. MOSFET devices with even faster switching times can offer lower switching losses than the fastest NPT devices. As long as the MOSFET devices can also offer low conduction losses they can easily exhibit lower overall losses. For 600V, COOLMOSTM transistors offer very low RDson for minimum conduction losses with fast switching times.

The combination of fast NPT and Trench IGBTs allows efficiency still higher than 97% at 50 kHz. The combination of COOLMOSTM transistors with Trench IGBTs provides an even higher efficiency than the previous combination as shown on Fig.3.

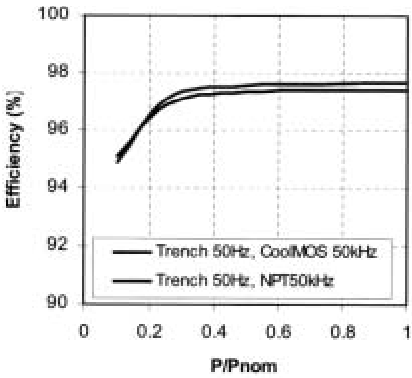


*Figure3 Efficiency results using COOLMOSTM and fast NPT IGBTs combined with Trench & field stop IGBTs at 50 kHz*

If the operation at high frequency is not a must to reduce the size of the inverter and a 16 kHz frequency is acceptable then the association of COOLMOSTM devices and Trench IGBTs will lead to the best efficiency. Despite the low 50Hz line frequency operation of the Trench and field stop IGBTs it is recommended to use FREDFET devices or CoolmosTM transistors with faster intrinsic diode to minimize the EMI disturbance of the system.

Another important characteristic for a solar inverter is the life time and the reliability. Also critical is the EMI/RFI generated by the inverter.

SiC diodes feature essentially zero forward and reverse recovery losses that provide a significant advantage in terms of switching noise generation and performance improvement compared to standard fast silicon diodes.

The diode recovery current affects significantly the switching turn on energy within the power switch when hard switched. Such behaviour generates a significant amount of turn on losses both in the power switch and the diode, with increasing switching frequency. It has to be noted that at the end of the recovery phase some oscillations can appear, leading to a significant amount of noise in the system that may be difficult to cancel by expensive and bulky input filters.

Faster recovery results in much lower switching loss both in the switch and the diode. The small peak current observed while a SiC diode turns off is due to the capacitive junction of the Schottky barrier device rather than to reverse recovery characteristics. As opposed to the configuration using conventional FRED diodes, no ringing or oscillations can be measured. Such quiet switching is of prime interest to reduce the size and complexity of input filters and a great help to meet severe EMI/RFI requirements.

The recovery behaviour of SiC devices is not only excellent at room temperature but also constant over a wide temperature range.

The SiC devices exhibit temperature independent switching behaviour and offer very stable operation even up to elevated junction temperatures. Switching losses using SiC diodes will remain stable compared to silicon devices where the switching losses dramatically increase with temperature.

By this way, the use of SiC diodes can significantly reduce the overall losses of a solar inverter and contribute to reach record efficiencies. Lower losses mean also lower operating junction temperatures that obviously will enhance the life time of the inverter which is crucial in solar applications.

Based on this approach, the best efficiency performance is obtained with an optimized mix of power devices technology; Low conduction loss IGBTs operating at 50Hz, Fast switching devices operating at high frequency and SiC diodes combined with the fast transistors.

Targeting a minimum 16 kHz switching frequency will lead to the maximum possible efficiency as shown on Fig.4

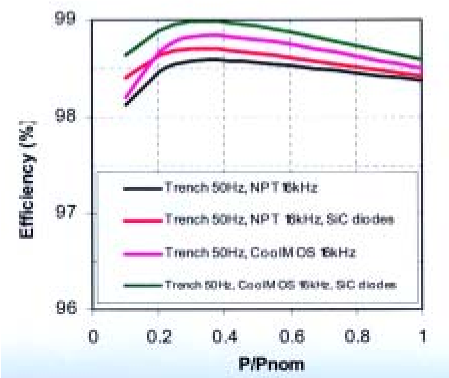


*Figure 4: Efficiency results using COOLMOSTM and fast NPT IGBTs combined with Trench & field stop IGBTs and SiC diodes at 16 kHz*

**Microsemi power module range for Unipolar switching DC/AC solar inverters**

30A to 100A full bridge modules are proposed for 600V range and 15A to 50A devices are offered in 1200V rating. Up to 3kW output power the function is integrated in the SP1 package that exhibits a 40.8 mm x 51.6mm footprint. From 3kW to 10 kW output power the full bridge is proposed in the SP3 with a 40.8mm x 73.4mm footprint. For 600V rating the full bridge is proposed both with a mix of Trench and Field stop – Fast NPT IGBTs and Trench and Field stop – CoolmosTM transistors while 1200V modules are only proposed with a mix of IGBTs.

The solar cell voltage usually varies significantly and it is necessary to implement a step-up converter to supply the full bridge circuit from the photovoltaic devices with a regulated DC voltage. With an operation at the highest possible DC voltage, the overall efficiency of the system is optimized and cabling problems are reduced as the operating current is minimal.

Size and cost are by the same way kept at a minimum. The operating frequency of the boost converter must be as high as possible to decrease the boost inductor to a small size and weight. In general a frequency of 100 kHz is adopted, but it may be very beneficial to specify switching frequencies in the range of several hundred of kHz to significantly reduce the size of the converter. It is possible to use ultrafast IGBTs to operate up to 100 kHz, but above, MOSFETs or super junction transistors are preferred to get minimum switching losses. In the chopper circuit the Boost diode is responsible for switching losses not only in the diode but also in the switch. Microsemi latest DQ generation of Fast Recovery Epitaxial Diodes is the best option for Boost diodes operating at high frequency. However at several hundred of kHz, it makes great sense replacing the FRED diodes by SiC Schottky barrier devices. SiC diodes not only offer minimum switching losses due to their intrinsic electrical properties, but they also contribute to generate a very low level of noise in the system. Microsemi offers a complete range of Boost chopper circuits in SOT227 package that combined with the SP1 unipolar full bridges covers a power range up to 3 kW. For a power between 3kW and 10 kW the Boost switch and diode are integrated in the SP1 package which can be used in combination with the SP3 unipolar full bridges.

All the Boost modules are proposed with the widest range of power semiconductors including fast and ultrafast IGBTs, MOSFETs and super junction transistors. The Boost diodes can be either FRED devices or SiC Schottkys to cover a frequency range from tens of kHz to hundred of kHz.

All packages, SOT-227, SP1 and SP3 exhibit the same 12 mm height such that they can be mounted onto the same heatsink and assembled with the same Printed Circuit Board. The two package combination, Boost and Full bridge modules offer a great flexibility in terms of components placement and layout of the PCB. In addition this allows to better spread the heat on the heatsink that will further contribute to decrease the operating temperature of the converter and increase its reliability.

On the other hand it may be preferred to integrate both the Boost stage and the full bridge into the same package to further optimize the size of the system. To achieve this goal, Microsemi has designed two modules both in 600V and 1200V rating. For each voltage rating

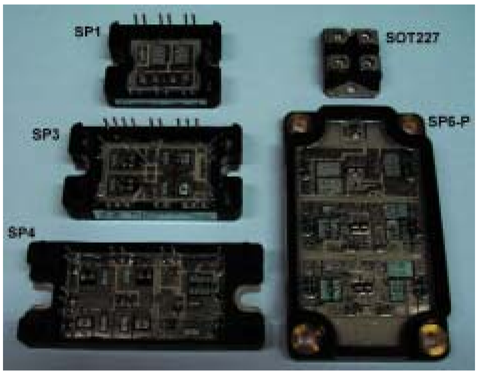


*Figure 5: Microsemi power module packages for Boost and Full Bridge solar inverters applications*

the two lowest power devices are offered in the 40.4mm x 93mm footprint SP4 module. The two higher power ones are integrated in the low profile SP6-P housing (62mm x 108mm footprint). For 600V products, the boost stage is made of CoolmosTM transistors while for 1200V products fast IGBTs have been adopted for space and cost savings reasons.

Fig.5 shows a picture of the Microsemi comprehensive package range for solar inverters including the SOT-227 and SP1 for Boost choppers, SP1 and SP3 for unipolar full bridges, SP4 and SP6-P for integrated Boost and full bridge modules.

**Conclusion**

With a mix of low conduction and fast switching devices, unipolar switching full bridge modules offer the best efficiency performance in modern solar converters. Each of the device brings its own advantages to the system, either low conduction or fast switching properties while its drawbacks have no or minor impact to the system. The function is integrated in very compact and thermally efficient packages to achieve low size and cost and long life systems.

Only the availability of SiC switching devices, MOSFETs or IGBTs will allow to reach efficiencies better than 99% and to perform the maximum that is technically feasible.

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