Power Semiconductor Technologies for Renewable Energy Sources

High power semiconductors are key components for controlling the generation and connection to the network of renewable energy sources such as wind-turbines and photovoltaic cells. For a highest efficiency of the energy source, it is therefore essential to select the right device for the given conditions. This article looks at the performance features for the available high power semiconductors of choice and also takes a look at future device technologies and their expected impact on efficiency. **Björn Backlund and Munaf Rahimo, ABB Switzerland Ltd, Semiconductors, Lenzburg, Switzerland**

Renewable energy sources as wind-turbines and photovoltaic cells have reached power levels of several MWs which have resulted in the need for high power semiconductor devices for optimized generation and network connection. The state-of-the-art devices of choice for these power levels are the IGBTs and IGCTs. Due to the power quality requirements, the earlier used solutions with thyristors in the wind turbines are rarely seen today. During the last 15 years, high power semiconductors have gone through a remarkable development. Several new generations of IGBT-dies have lead to a reduction in V_{CEsat} of almost 40 % since the early 1990s, and still a potential for further improvement is available. The Bipolar devices have also seen large improvements where the introduction of the IGCT have had a large impact on the MV-Drive design and higher ratings for them have recently been introduced or are in development. The thyristors have also not been standing still but have moved from 6500 V, 2600 A to 8500 V, 4000 A devices based on 150mm silicon now in production.

The power semiconductors are used for two main tasks in the chain of renewable energy sources such as conversion of the power in the plant, as in wind-turbines, and transmission of the power to the grid. The best solution to determine what semiconductors to use for these tasks is to move top-down by following the path system requirements defining equipment requirements which in turn are defining the power semiconductor requirements. Through this chain the requirements on the devices are determined regarding items as required voltage and current ratings, needed degree of controllability, and operating frequency.

Power semiconductors for inverters

The possibilities to achieve the above requirements will be looked at with focus at power ratings above 0.5 MW. For inverter applications, the IGBTs and IGCTs represent the two main candidates due to the main features listed in Table 1.

As can be seen, both devices have a distinct set of features making the question which one is the best technology obsolete. What it comes down to is to select the device based on application requirements and own capability to utilize the device to its best. Certain comparisons are though helpful to see what is possible to achieve with the two technologies. One example is the possible out-put power for a 2-level inverter as function of the switching frequency at a given set of conditions as seen in Figures 1 and 2. Other comparisons can though have been selected to promote a certain technology over another and should not be used to find out which solution is the best for the given task.

In practice the choice of components will be governed by considerations as standardization by the use of basic building blocks for various applications and requests from customers to use a certain

IGCT features	IGBT features
- Available as asymmetric and reverse conducting (with integrated diode). - Voltage ratings 4500 up to 6500 V with current ratings of 210 up to 5500 A of peak turn-off current. - Integrated gate unit is included; critical to device performance. - Low on-state losses. - Press-pack design for double sided cooling with device assembled between heat sinks on potential, enabling very high power density. - Press-pack design without soldering and bonding for high load cycling capability.	- Devices available in various configurations, as single switch, dual switch and dual diode, - - Voltage ratings 1700 - 6500 V and current ratings 400 – 2400 A. - Module package with insulated base plate enables simple bus bar assembly and mounting on a grounded heat sink. - Voltage control enables simple, low power gate drive. - High controllability through the gate for optimized switching behavior also enabling control at short circuit conditions.

Table 1: **Features for IGCT and IGBT**

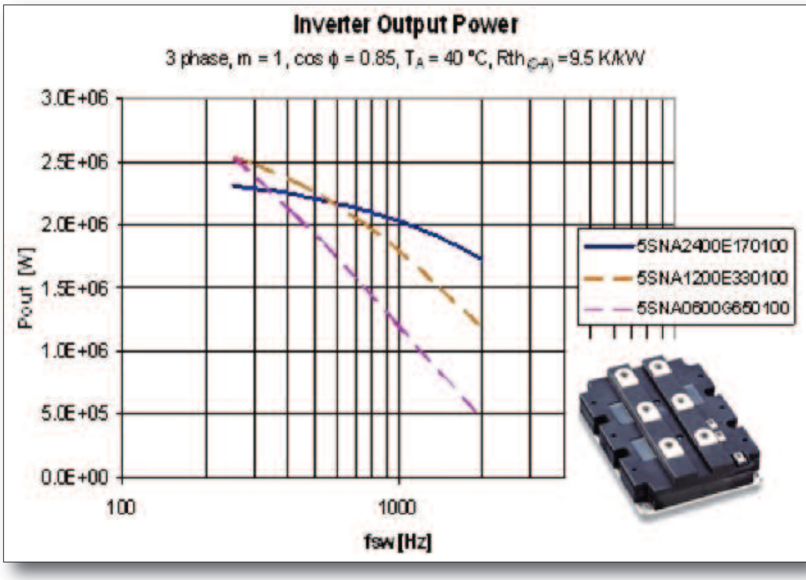

Figure 1: Comparison in current rating for a standard package equipped with SPT dies

solution. The fast development of the devices makes it though necessary to look critically at the used solution from time to time to see if it still is the best possibility to fulfill the requirements or if new designs with new devices can improve the equipment performance.

Since the operating conditions determine the preferred semiconductor technology it is also not possible to give general rules about which component has the highest efficiency. This has to be determined case by case also considering that the different features of the device technologies can have an impact on the complete efficiency for the system. It can though be projected that the efficiency is not static but will improve with time as new improved power semiconductors are continuously being introduced on the market.

Wide band-gap materials

Another interesting item is the development of new wide band-gap semiconductor materials in addition to the dominating silicon starting material. The salient features of Silicon compared with the most developed candidates for new semiconductor materials are listed in Table 2. One important aspect of the high power semiconductor development is its impact on efficiency and energy saving, or in other words how "green" it is. Renewable energy sources are today almost exclusively equipped with power electronics and therefore it makes a difference what power semiconductor are used also due to the large impact of secondary effects as cooling capacity.

One major issue for efficiency comparisons is that SiC and GaN are limited in voltage, current and component types which means that useful comparisons for many systems in renewable energy are not really possible since there are for instance no comparative GaN and SiC components to the Silicon-based IGCTs used in 5MW wind turbines with full power conversion. This often leads to comparisons for special components in special applications where a 1 to 1 comparison is possible thus too often underestimating the potential of energy savings made possible by Silicon or

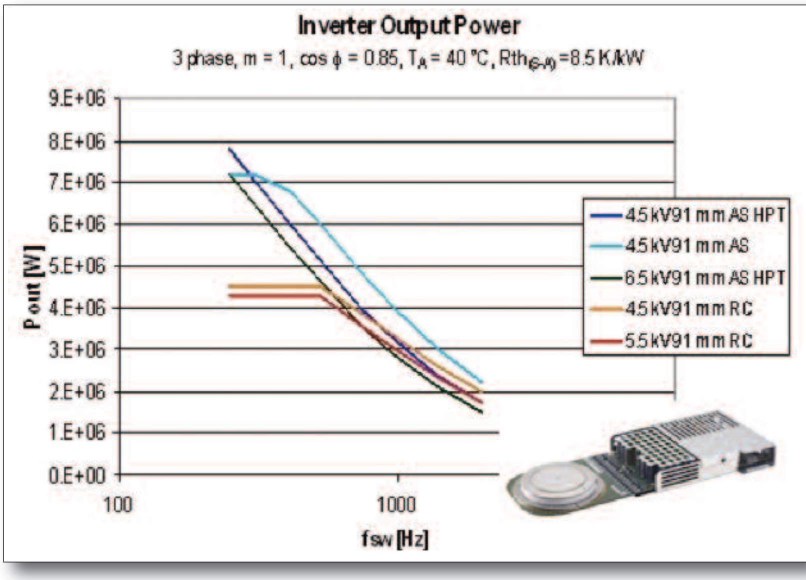

Figure 2: Comparison in current rating for standard IGCTs

Silicon based devices	Wide band-gap (SiC, GaN) based devices
- Well established technology with proven reliability. - Devices up to 8.5 kV available and higher voltages in development [4]. - Single devices available with 5500 A turn-off capability. - Mass production of devices as Diodes, Thyristors, IGCT and IGBT in many different packages and configurations.	- Potential for low statics and switching losses for high switching applications - High junction temperatures capabilities. - Gaining market share in recent years for special applications such as PFC with uni-polar diodes rated up to 1200V. - Current ratings still below 100A in productions.

Table 2: Features for Silicon, Silicon Carbide and Gallium Nitride based devices

showing a decrease in inverter size at equal performance where it is questionable if the small size is of importance. Aspects as EMI and insulation fatigue due to very short switching times also need to be included in the comparisons. This since what may look most promising on equipment level may be a solution that is sub-optimal on system level.

Due to cost, reliability and availability only Silicon is an option for bulk power applications. Other materials are currently only for niche markets where the possible efficiency increase is important enough to compensate for costs, reliability risk, etc.

Although a comparison is very difficult to make at higher power levels we have made an attempt and in Figure 3 a comparison on module level shows the current capability of a standard module size using SPT+ IGBT dies with either a SPT+-diode, extrapolated data for a SiC diode or the new BIGT with IGBT and diode integrated on one die. Based on comparisons like this one, it is also possible to calculate losses and efficiency for the different solutions at one set of conditions in the same way as discussed in the comparison between IGBT and IGCT.

Due to the fast changing landscape of wide band-gap materials and devices, also not forgetting that Silicon-based devices are continuously being improved, it is expected that especially applications below about 0.5MW will see substantial changes during the coming years. As a result of this, and also the development on Silicon-based devices for higher power levels, we will see a gradual improvement in efficiency thus reducing the power lost between generation and consumption having a positive effect both in economical as well an environmental terms.

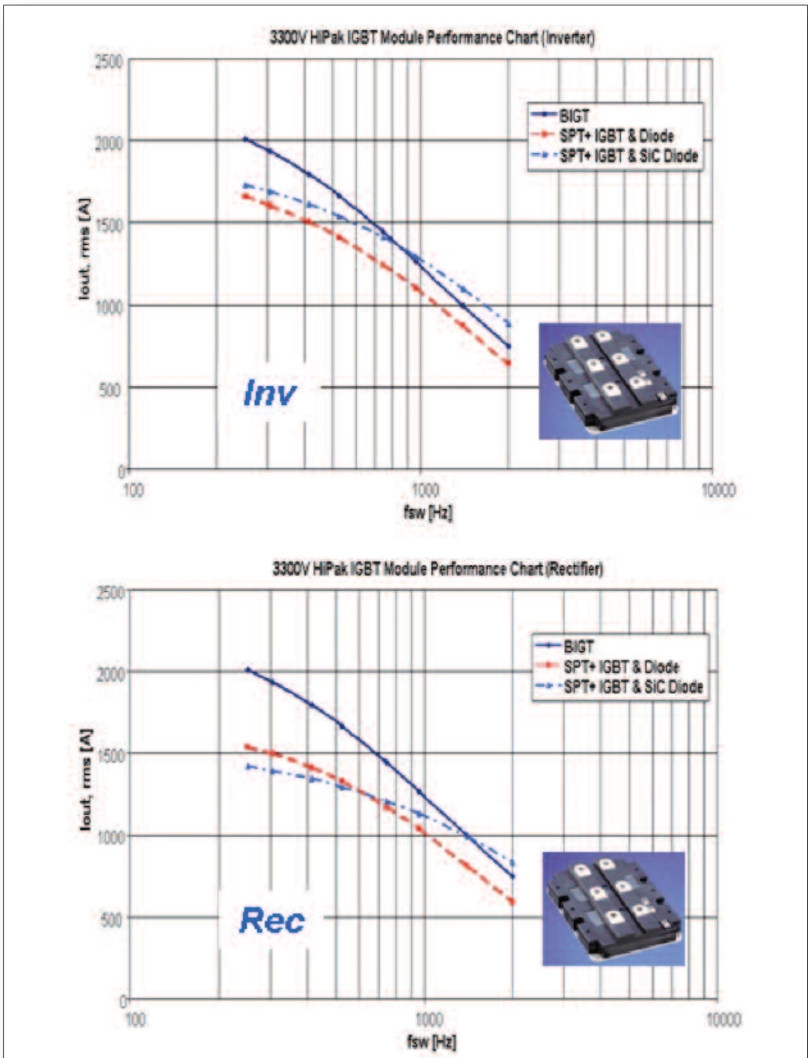

Figure 3: Comparison in current rating for a standard package equipped with BIGT and SPT+ dies vs. SiC carbide diode contribution to an IGBT module (top: inverter mode, bottom: rectifier mode)

Bringing the renewable power into the grid

Renewable energy sources are quite often remotely located without a sufficient infrastructure to feed the electrical energy into the grid. For a complete study of power electronics for renewable energy sources we must therefore also look at the possibilities to transmit the energy in an efficient way.

For hydro power stations as the three Gorges dam in China and Rio Madeira in Brazil, HVDC solutions have been chosen to transmit the power. At these systems with transmission lengths of above 2000km the total losses, including the losses in the converter stations, can be reduced with 50% compared to a standard AC-transmission. This corresponds to savings per project of up to several TWh yearly. This is done simply by using large area high voltage mm thyristors where current systems are equipped with 100 - 125mm thyristors with 150mm devices recently being introduced for use in UHVDC-systems with voltage levels up to 800kV.

Also for other transmission systems the

Figure 4: Sea cable for an HVDC Light™ system is laid out for connection of an off-shore wind park to the main land grid

losses and costs can be largely reduced by the use of HVDC transmission techniques, which is especially apparent for off-shore wind parks where power in the range of 300 - 500MW will be transmitted through the sea to sub-stations on land. The HVDC Light™ system (Figure 4) is based on IGBT technology with a special design that ensures that the module remains shorted in case of a failure enabling a continuation of operation if redundancy is built into the system. Starting at the tender power level of 3MW back in 1997 these systems has gradually grown larger and it is a mere question of time until voltage source converter based HVDC-systems with the use of the latest power semiconductor technologies will brake the GW-barrier.

Small scale renewable energy with a large number of units spread over a large area also create issues for the grid stability which can be solved with different measures normally referred to as smart grids. Although power electronics will play an important part in these systems, we leave them out of the discussion here since they are not directly connected to efficiency of renewable energy sources.

Conclusions

Renewable energy sources as wind turbines and photo-voltaic cells have grown rapidly in size and power in recent years. The requirements on them for network compatibility have also increased since their impact on the grid is far from negligible. Due to a steady development on the high power semiconductor side, devices are available to meet the requirements on controllability and efficiency and new devices and device materials are on the way enabling further improvements. To utilize the possibilities to their optimum the device choice should only be made when the requirements and operating conditions for the high power semiconductors are known. To use a device just because it is popular among other users may not mean that it is the best choice for every case since the best device is determined by the particular circumstances for the actual project.

Literature

Björn Backlund: "Comparison of High Power Semiconductor Technologies for Renewable Energy Sources", PEE Special Session "Power Electronics for Efficient Inverters in Renewable Energy Applications", PCIM Europe 2010, May 4, Room Paris