1. Introduction

The purpose of this paper is to identify and describe the key enabling roles that SiC power semiconductor devices will play in future envisaged electricity networks. Prospective SiC devices have higher voltage rating, are faster switching and can operate at higher temperature than their Si counterparts. Hence power electronic (PE) equipment using SiC devices will have, not only much lower dissipation, but also a lower component count and thus be more compact and reliable.

The anticipated arrival of SiC based PE equipment is predicted to lead to an improvement in the reliability of electricity supply networks. This is opportune at a time when the total installed power generation is growing and trying to match increasing global demand, whilst at the same time there are pressures to reduce pollution and CO2 emissions. The increase in demand is not being matched by an expansion in the extent and availability of the power transmission network, so that distribution systems are becoming weaker. A remedy will be a significant growth in the application of PE systems for the control of power quality. Those based on SiC devices offer a distinct advantage over those based on Si, whose potential for improvement is limited, given their already advanced state of development. It is predicted that the potential market will be worth over 1000 M€ [Ref. 1] in 2015 for the PE converters alone without including the cost of connection transformers or civil works. It is anticipated that this market will continue to grow thereafter by a factor of two to three times by 2020.

Two major drivers have been identified which are expected to promote this rapid market growth. One, already in progress and causing increasing pressure on AC grids, includes:
♦ the connection of Distributed Generators (DG) and Renewable Energy Sources (RES) [Ref. 2]. NB the EC is targeting a DG connection level of 40% of the overall supply in the EU.
♦ de-regulation and competition.
♦ unbundling and separation of transmission/distribution from generation
♦ rapid load growth in third world countries or regions,
♦ environmental issues including visual impact, control of CO2 emissions, and EMC issues.

The second driver, which is in the process of emerging, is the introduction of SiC technology. This has the potential to significantly improve the ratings of power semiconductor devices and will lead to a new generation of T&D PE solutions based around Voltage Source Converters (VSC). It will be a revolutionary rather than an evolutionary change and will enable the design of PE systems that are at least 50% cheaper, 50-90% smaller, having 60-90% lower losses than is possible with Si devices. Industry uptake is expected to be rapid because of the perceived benefit from increased business opportunities by supplying equipment of high added value based on SiC devices.

2. Performance of SiC Devices

The properties of 4H-SiC and Si crystals are compared in Fig.1 below.

As a result of its higher energy bandgap compared to Si, SiC has a 10 times higher breakdown field strength. Thus power semiconductor devices based on SiC have a 10 times higher voltage rating for the same thickness of base region than Si devices, or alternatively are 10 times thinner for the same voltage rating. The thinner structure translates into faster switching times for devices of a similar voltage rating. A further consequence of the higher bandgap is lower leakage current flow (edge passivation permitting) so that SiC devices have the potential to operate up to a junction temperature of 225°C, compared with 125°C for Si. However, the higher bandgap also results in a higher on-state voltage.

It is our view that high power SiC devices will be of multi-chip construction in pressure contact housings and will have voltage control. The largest devices will have continuous current ratings in excess of 1000 A, with controllable currents 2-3 times higher.

As an example of the improvement in performance possible, one 10 kV-rated SiC IGBT will have a switching speed equivalent to a 1 kV rated Si IGBT and could replace ten series-connected 1 kV rated Si IGBTs or more practically four
series-connected 3.3 kV rated IGBTs, but the series connected devices would require active control or the use of grading circuits to ensure that they switch together, both of which cause extra losses. Taking these factors into account, the total in-circuit losses with the single 10 kV SiC device have been estimated to be an order of magnitude less than with the series connected 3.3 kV IGBTs.

Today’s cost of semiconductor device grade SiC material is high, but there are sufficient commercial drivers in place in the automotive and military markets to predict a reduced cost within 4 years [Ref. 3]. SiC devices are therefore predicted to become available at an affordable cost to match the expected expansion in DG and RES.

3. Application In Voltage Source Converters

The most likely T&D application for SiC power devices will be in Voltage Source Converters (VSC), illustrated in Fig. 2a, which in the future will be used to connect DG, such as Combined Heat and Power (CHP), wind farm and photovoltaics, and other sources of renewable energy to the electricity network.

![Fig 2a: The VSC converter link](image)

More generally, VSCs will connect:
- multiple supply or load points,
- locations having no generation or rotating plant,
- small to medium power sources/loadss (2-200 MW),
- large discontinuous energy sources e.g. large wind farms ~ 1000 MW and CHP ~ 1000MW, as illustrated below.

![Fig.2b: Wind farm connected via VS HVDC link](image)

Within the general market in T&D applications for SiC based PE systems, two subsidiary markets have been identified. The first is advanced HVDC VSCs. These are used today for links to islands without indigenous ac generation and also for connecting large wind farms. They also form part of some FACTS devices.

The second will occur in the future (2010 onward), when VSC will be used to connect small DG in the range 2 to 100 MW. This may be as part of a self-regulated cells, which conduct their own energy trading, as illustrated in Fig.3.

4 Future Impact for RES and DG

As a result of the increased demands being placed on
electricity supply networks they are becoming progressively weaker, particular large ones. A key factor, which is becoming more important, and is even critical today in some countries such as Germany, is the amount of power originating from renewable sources. Two inconvenient features are the unpredictability of power generation from RES (wind power for example) and that it may be spread over a multiplicity of marginal low power sources that may act independently from one to another. Without adequate Power Electronic control equipment the network could become unstable and frequent blackouts may occur.

The equipment required will include FACTS devices such as STATCOM, TCSC, UPFC, IPFC, [Ref. 5,6,7,8,9] which are able to adjust and balance the impedance of each line and keep the global network free from instabilities. A key issue is the respective fluctuations of real power demand from individual customers and of the available power from sources. Simple analysis has shown that a high dynamic performance is required to optimise line power flow (switching at > 2 kHz). This will only become affordable when SiC based PE technology is available. This view is supported by field experience in the USA (private communication).

With a deep level of market penetration by DG, there will be many low power sources. Associated PE equipment for network connection/control will use low current SiC devices: 5 A to 100 A, 10 kV rated, which will have an even smaller installation footprint than for the higher power equipment and will result in correspondingly reduced civil work.

Despite the significant advances that have been made in recent times (for example by AREVA), existing Si based PE has its limitations (cost, device voltage rating, reliability etc.), which will not allow the levels of PE necessary for new DG networks. These limitations are intrinsic to Si technology and can only be overcome by a change to the new SiC technology. This will only come about if the SiC based PE equipment needed to make connection and ensure the stability of networks is affordable [Ref. 4].

Translating into technical requirements, targets for the new generation of equipment are high dynamic response, low harmonic generation, low loss, compact building/valve hall design, high reliability and low cost.

5. Conclusions

Silicon Carbide (SiC) based power electronic (PE) systems are predicted to improve the reliability of electricity supply networks for the following reasons

- The attractive features of SiC power devices, namely high voltage rating, fast switching speed and high temperature operation, will enable more compact PE equipment with ~10 times lower dissipation than possible with Si.
- The number of power circuit components to be reduced by a factor of up to 50:1 than with existing PE systems, which will contribute to even higher reliability in T&D applications than achieved today.
- Capable of high switching speed (≥2 kHz), SiC devices will enable equipment with high dynamic performance, such as is required to optimise line power flow when sources of intermittent nature are connected to the power network. This will enable deep market penetration of DG at affordable cost.

SiC based PE technology will introduce a revolutionary change in the Power Electronic market when SiC Power Devices become available around 2008. New technological approaches should catalyse the take off of new systems, and help eliminate blackouts to provide a more reliable and better quality supply in the future.

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References: