Power Semiconductors in Transmission and Distribution Applications

Rahul Chokhawala
ABB Semiconductors AG, Switzerland
Tel: 41 62 888 61 26
Rahul.chokhawala@ch.abb.com

Bo Danielsson, Lennart Ängquist
ABB Power Systems AB, Sweden
Tel: 46 240 78 25 12, 46 21 32 49 33
Bo.e.danielsson@se.abb.com, lennart.angquist@se.abb.com

Abstract

Triggered by rapidly changing market conditions in the utility sector and fueled by advances in high power semiconductors, a silent revolution is taking place in development of transmission and distribution (T&D) system technologies. Innovation in high power, high speed gate-controlled semiconductor switches is now making it possible to utilize state-of-the-art voltage source converters (VSC) for systems rated between a few MVA to a few 100s of MVA. The result has been nothing short of spectacular in terms of functionality of the new systems and the resulting application opportunities. The semiconductor contents of such systems have increased many folds in comparison to the traditional current source converters (CSC) - mostly at the expense of bulky passive components. One senses for the first time that the marriage between power electronics and T & D system is finally consummated.

Introduction

The history of power electronics in transmission and distribution applications goes back to 1954 when converters based on mercury arc valves were employed for the first time in High Voltage Direct Current (HVDC) cable transmission system between Sweden and island of Gotland (1). Nine such systems were installed world wide in the subsequent years. The next significant breakthrough came when first HVDC current source converters constructed with semiconductor thyristors were commissioned in 1970. Also as a result of the emergence of thyristors, Static Var Compensators (SVC) were developed to almost completely replace synchronous condensors. HVDC and SVC have since been widely accepted in Electrical Power Systems (EPS) applications as an effective way to control active and reactive power, respectively.

The following forces are impacting the electricity market in the industrialized world and have provided strong incentives for further innovation power electronics for EPS:

1. Utility market restructuring world-wide
2. Environmental and efficiency regulations
3. Hardening public opinion against large infrastructure projects and overhead transmission lines

The restructuring of the utility market is enhancing competition so that independent power producers, transmitters and distributors are replacing regulated monopolies (2, 3). New regulations and public opinion are demanding solutions that would

1. improve utilization of existing generation capacity
2. Provide environmentally acceptable ways of power transmission from less centralized producers: a new era has begun that is creating large opportunities for small-scale technologies.

As a result of massive research and development efforts, high power semiconductor and application technologies have started to bear benefits in a significant way.

This paper provides an overview of semiconductor components utilized in power systems applications and key AC & DC systems available to improve transmission and distribution of electrical power (4). The paper also discusses in some detail the operation and functionality of VSC based HVDC and SVC systems, as well as considerations for voltage source converter and IGBT specific press pack design.

Overview of High Power Semiconductors

A. Thyristors:

Traditionally, electronic conversion of electrical power in the high power region has been made using the principle of line-commutated frequency conversion with thyristors for control of the current flow. The thyristor is the equivalent of a “binary current valve” with two discrete states, either conducting or blocking the current. Turn-on is accomplished by injection of a gate current, while turn-off is made possible by the 50/60 Hz line current passing through zero. The thyristor can not be turned off with the gate terminal, which significantly limits the range of applications for this device. Being used to handle high power for more than 40 years, thyristors are now available with impressive power handling capabilities (8kV/2kA) and often represent a cost-efficient alternative for the highest power levels.

B. GTOs and IGCTs:

Gate controlled turn-off was introduced in the late 70’s with the Gate Turn-Off Thyristor (GTO), making it possible to build efficient converters for control of the output frequency. The GTO opened the way to variable speed AC motor drives and other similar applications. However, power losses are higher than with classical thyristors and elaborate units for supplying the high gate currents became necessary as well as "snubber circuits" for individual device protection. A remarkable performance improvement of gate turn-off thyristors resulted when ABB in 1997 introduced a new device concept, the Integrated Gate Commutated Thyristor (IGCT). This new technology features, for the first time, homogenous and well-controlled injection and extraction of gate currents in thyristors using an integrated gate drive unit. With this concept, the free wheeling diode, needed in anti-parallel to the switches in many converter concepts, can be integrated on the same semiconductor wafer, simplifying the mechanical design of the converter. The homogenous switching across the device area occurring in the IGCT results in a significant loss reduction compared to the GTO. Fewer requirements for converter infrastructure as capacitors and filters mean that the size of the converter will also be reduced.

With its proven high reliability, the IGCT represents an optimal cost-efficient choice in many high power applications requiring turn-off devices and is currently used in large motor drive systems and traction power-supply systems.

C. IGBTs: classical power semiconductors with modern microelectronics

There have been numerous attempts to combine microelectronic technologies used for very precise control of the low voltage signals in integrated circuits with the high power handling capabilities needed for power semiconductor devices. The most successful to date has been the Insulated Gate Bipolar Transistor (IGBT) concept, combining a high-impedance, low-power gate input with the power handling capacity of normal bipolar transistors and thyristors.

In the IGBT the control of the device is accomplished by using a pattern of MOS transistors distributed on the surface of the device. The MOS transistors allow a high impedance control of the current flow through the device, requiring extremely small amounts of power supplied to the control gate. The ability to sustain high voltages and currents are provided by the vertical part of the device, comprising a bipolar transistor structure. This vertical transistor also gives a sufficient thickness for withstanding high voltages. In addition, the vertical transistor effect is crucial to enhance the conductivity of the semiconductor material and hence to reduce excess voltage drop over the device in the conducting stage.

The performance of IGBTs is related directly to the properties of the surface MOS transistor cells and the success of these devices is largely due to continuous development of these cell structures, in many cases using technologies that have been developed for microelectronics circuits addressing significantly larger markets.

Although substantial progress in the area of IGBTs for lower voltages (600 - 1200 volt) was made in the 80's, it was not until the beginning of the 90's that it was realized that this concept also was feasible for higher voltages.

D. Beyond silicon

Although power semiconductors based on silicon will continue to improve their performance, fundamental limitations inherent with this material are within sight. Maximum power handling density (robustness) and thermal stability (losses, cooling) are important device performance parameters, which will be limited by such basic material parameters. Silicon high power diodes are today close to these limits and semiconductor switches are following similar trends. Most converter designs require additional circuitry or are slowed down during switching for device protection. This increases costs and power losses. On the other hand, converters with higher switching frequencies would be attractive for the high (>10MW) power levels in typical transmission and distribution applications. The possibility to operate the converter at high frequencies with low power losses makes it possible to minimize the size and cost of filters and cooling equipment

To satisfy these coming applications, solutions beyond changed device structures or new gate drives must be contrived. One very promising alternative is to build devices based on silicon carbide. This semiconductor material has an inherent potential for 10s of times higher performance level compared to silicon, due to the large atomic binding energy (bandgap) and the high specific electric field strength. In addition, silicon carbide can be operated at considerably higher temperatures than silicon, offering the potential to integrate the power semiconductor directly into other electrical equipment such as generators and motors.

Optimized devices for this new material would offer great leap forward in performance improvement when compared with silicon based devices.

Overview of T&D systems and associated devices

A. HVDC Transmission

The early power converters for use in T&D applications are all based on thyristor technology and are of current-source type. This means that the converter DC current flow is unidirectional and that its magnitude is determined by the DC side voltage equilibrium between two converters connected to one common DC line or DC link. On the AC side the valve controls the power factor by introducing a controllable phase angle delay between the AC side voltage and the line current fundamental component.

The valve consumes reactive power, which normally is balanced by reactive power generation in shunt connected filter banks (Fig. 1). In recent installations also series-connected capacitors have been used for this purpose (Capacitor Commutated Converter, CCC). The classical HVDC requires that the connected networks have sufficient short-circuit capacity. It is well suited for point-to-point transmission, but suffers from some inherent shortcomings in applications involving multiple terminals.

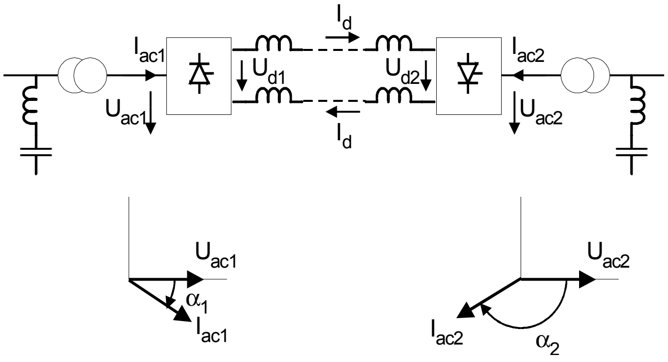

Fig. 1: Classical HVDC arrangement and phasor diagrams.

In the new generation of HVDC systems based on VSC, a power electronic voltage-source produces the inner controlled quantity. Its AC side voltage can freely be determined with respect to amplitude and phase and it determines the AC sideline current in accordance with the established voltage difference across the reactance which is connected between the VSC and the network. Each such AC side line terminal voltage holds two degrees of freedom, which may be utilized to control the active and the reactive power flow or equivalently the active power flow and the voltage in the connected AC node.

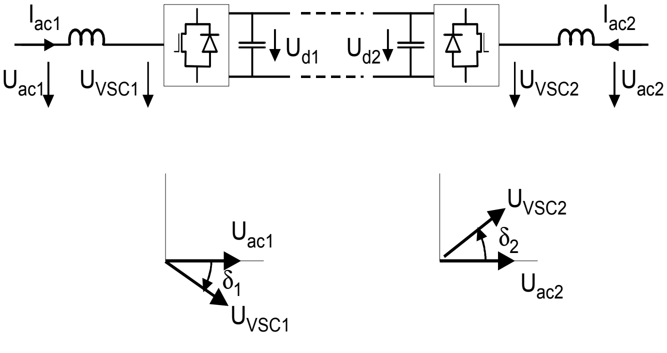

Fig. 2: Principle and phasor diagrams for HVDC-VSC.

The use of VSC eliminates the need for an inner electromotive force in the connected network and such converters may be effective to energize networks which are lacking generating capacity. The reactive power balance may be established by proper control of the VSC and requires no external devices or apparatus. The harmonic generation from the VSC converter is kept low due to the high switching frequency used in the VSC.

The selection of the optimal DC voltage level involves considerations with respect to both the converter as well as to the DC transmission cable. Such optimization most likely results in a DC voltage exceeding ±100 kV.

B. SVC reactive power compensation

Two objectives must be satisfied in order to adequately operate an AC transmission system:

- control of the active power flow in the network
- control of the voltages in the system nodes.

The first matter is determined by the global equilibrium between generation and loads in the system. This balance is monitored and controlled by the system dispatcher. The second subject, the voltage profile throughout the system, reflects the local equilibrium of generation and consumption of reactive power which takes place in the loads as well as in the transmission system itself.

As a general rule, the required speed of control is much higher with respect to reactive power control than for active power flow control. Therefore, when semiconductors suitable for high-power applications became available in the 70's, they were applied at an early stage in equipment for automatic reactive power control. Static Var Compensators (SVC) using the well-known Thyristor Controlled Reactor (TCR) concept utilize a combination of a passive capacitor bank and a branch of thyristor-controlled inductors in parallel. The capacitor bank has the capability to generate the maximum required amount of reactive power. The controlled inductive branch in each instant consumes the excess of reactive power generated, which is not requested by the system. The air-cored or iron-cored inductors are bulky and cause substantial losses. The valve regulates the fundamental component of the current passing through the inductors. The generated harmonic currents are taken care of by designing the capacitor bank as passive filter banks which sink the harmonic current components. Thyristor Switched Capacitor (TSC) banks are often used to enhance the control range of the TCR.

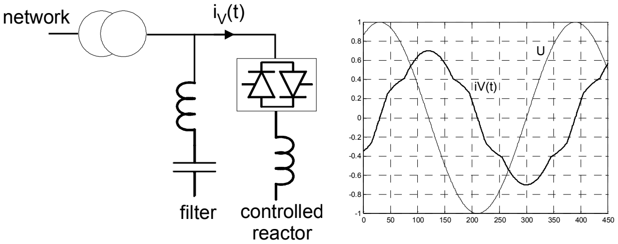

Fig. 3: SVC using TCR and inductor current waveform

The new generation SVC reactive power compensators like its HVDC counterpart is based on the VSC using functionally identical main circuit concepts. However, in the SVC the DC link is not connected externally and accordingly its voltage level may be selected freely at an optimal level considering the VSC's economies. Typically the result would be a DC voltage in the range of ±10 kV to ±35 kV.

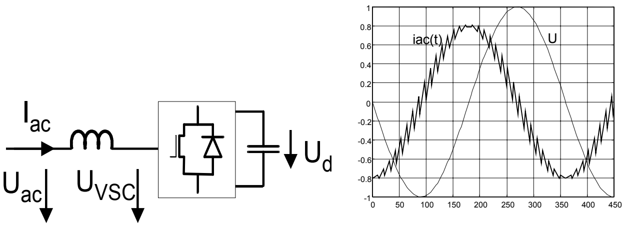

Fig. 4: VSC based SVC and its converter current

The lack of active power infeed to the DC side has the consequence that the current drawn from the network must be in phase quadrature with the AC voltage in the connected node. Both capacitive and inductive current may be exchanged with the network. The AC side current flowing from the VSC is determined by controlling the voltage on the converter side of an inductor having its other end tied to the network.

C. Dynamic compensation / symmetrizing

Due to its higher switching frequency, the VSC based SVC compensator exhibits higher speed of control than its classical SVC counterpart. It therefore has found applications in electrical arc furnace installations where there is a need for fast compensation of the stochastically varying consumption of reactive power during the melting process. Specifically, during the initial stage of scrap melting, short-circuits frequently occur between the electrodes in the furnace, causing heavy reactive power bursts and consequent voltage drops in the transmission system. The disturbances cause fluctuations in the light from incandescent lamps at other consumers connected to the same point in the network. Measurements in practical installations have shown that the flicker level (P_{ST} value according to IEC 868) can be reduced by a factor of 4-5 times using a VSC based SVC system. This result outperforms the classical TCR-based SVC with respect to flicker mitigation.

The high switching frequency used in the IGBT-based VSC promise improved behavior and enhanced compensating capabilities as compared with the classical SVC. Thus the VSC based SVC, in addition to controlling the reactive power at fundamental frequency, may be utilized to sink some existing low-order harmonic currents (e.g. 5^{th}, 7^{th} and 9^{th}) in the network, thereby reducing the harmonic voltage in the node where it is connected.

Another application of interest relates to unbalanced loads which are connected to the transmission system. Such loads may, for instance, be feeders to high-speed railway systems, in which case the loading may be some tens of MW. It is desirable that the load be transformed into a 3-phase symmetrical load with unity power factor. Such compensation may be performed using the VSC-based shunt compensator. In addition low-order harmonics may be suppressed as described above.

D. Dual-purpose SVC Back-to-Back

It was stated above that conceptually there is no major difference between the converter used for SVC and for HVDC. The VSC converter basically is a power conditioner which may handle active as well as reactive power. When two SVCs are installed at a common location it becomes possible to connect their DC sides in a back-to-back (BtB) configuration (Fig. 2) so that it becomes possible to exchange active power between the systems connected to either one of the VSCs. The SVC then serves two purposes: to control the voltages in each of the connection points and to control the active power flow between the connected networks.

E. Series VSC – UPFC, SSSC, DVR

The above mentioned applications all deal with devices which are connected in shunt to the AC grid. However, it is also possible to insert the voltage created in a VSC in series with the line using a booster transformer. If the VSC does not have any active power infeed to its DC side the inserted voltage must be in phase quadrature with the line current. The arrangement then is called a Static Synchronous Series Compensator, SSSC. The impact of the apparatus resembles that of a series reactance which may be inductive or capacitive.

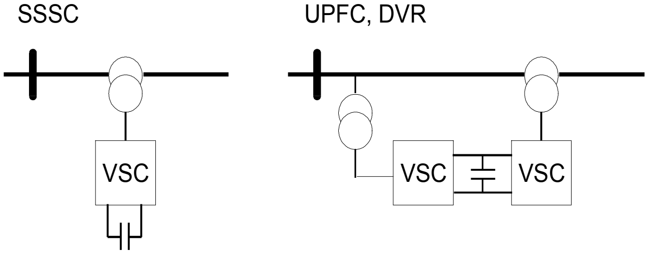

Fig. 5: Series VSC forming SSSC, UPFC and DVR

If the DC side of the series converter is energized from a shunt-connected VSC then the inserted voltage may have any phase relation relative to the line current. It then becomes possible to control several parameters of the transmission line, e.g. active power flow and the voltage on the line. The two VSCs then constitute a Unified Power Flow Controller (UPFC). A similar arrangement also may be used to compensate dips and sags in the voltage that feeds an important industrial load, e.g. a chemical plant, a paper mill or similar. In case that the feeding transmission system is hit by lightning strokes causing a single-line to ground fault the voltage in one phase will collapse. This may be mitigated by

inserting a compensating series voltage. In this way the voltage feeding the sensitive object may appear to be almost undisturbed. The power required for the inserted series voltage is taken from the undisturbed phases. This later arrangement is named a "Dynamic Voltage Restorer", DVR.
From an application point of view the series connected VSC must be carefully protected against over-current/over-voltage. Normally the VSC will have a voltage rating which is only a small portion of the rated voltage in the network. When a short-circuit occurs in the network the fault current will be driven by an EMF having the full rated voltage of the network. This current is minimally impacted by the inserted voltage from the VSC. The VSC has a very limited current handling capability and therefore it is necessary to provide a fast-acting bypass switch across the booster transformer primary or secondary in order to avoid the surge current passing through the series VSC.

Control principles for VSC based HVDC/SVC systems

The basic principle is that the VSC creates a three-phase symmetric voltage with desired frequency. If there is no other generator the created voltage will be supplied to the load as is. When a fault appears in the loading system the VSC will keep voltage up until its current limit is exceeded.

When other generators are present in the network, the VSC voltage must be synchronized with the existing network voltage on connection. When the voltages are equal, no current flows between the VSC and the network. If the phase of the VSC voltage is phase advanced from this equilibrium position, active power flows from the VSC to the network across the reactance in the interconnecting device (reactor and transformer). Similarly, if the VSC voltage is phase-delayed relative to the network voltage, this results in an active power flow from the network towards the VSC.

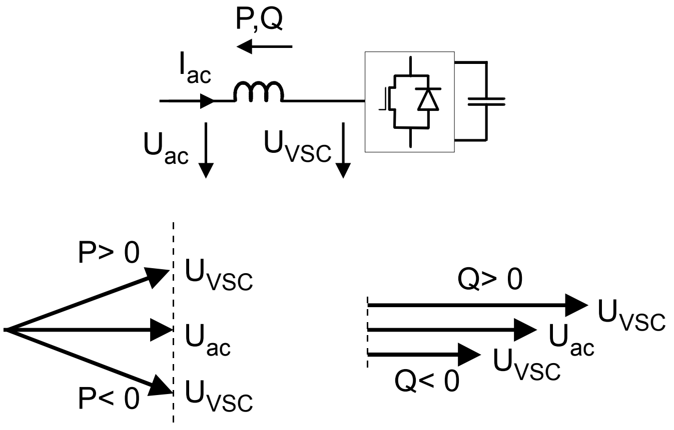

Fig. 6: Control of active and reactive power exchange with the network

The voltage amplitude in the VSC controls the reactive power flow. If its voltage is increased with respect to the network voltage, the VSC compensator delivers reactive power to the network. Correspondingly, if its voltage amplitude is lowered, the VSC will consume reactive power from the network and act as an inductor.

The DC voltage is controlled by creating an active power flow towards the VSC by phase retarding its voltage when the DC level is below its set point and similarly phase advancing it when its voltage exceeds the desired voltage level.

A Growing Field of Applications

Power electronics based solutions are now replacing traditional electromagnetic installations in transmission and distribution applications at an increasing rate (5,6). In many applications this will improve efficiency and functionality of the existing electricity infrastructure - the use of DC links in back-to-back configurations to provide interconnectivity of separate grids and also improving network stability is one well-known example.

Other fast growing areas for power electronics is connecting small scale distributed generation units and renewable energy sources to the individual consumer as well as to the power grid. The economical use of turbines with ratings below 100 kW has been made possible by the availability of cost-efficient power electronic converters. Such units are capable of converting the electrical energy from high-speed generator outputs to the 50/60 Hz AC power required by the application. Electricity from fuel cells, windmills and solar panels will be generated at low DC voltage levels and will require power electronics solutions with high functionality as well as extreme cost-efficiency for conversion of the power to usable voltages and frequencies. As renewable energy resources often are located at some distance from large cities, new power electronic technologies such as VSC based HVDC will provide environmentally friendly possibilities to collect the energy from such sources into the power grid for transmission to consumer areas. The new breed of power semiconductors closely related - both with respect to functionality and manufacturing technologies - to mass-produced integrated circuits, open the possibilities to benefit from the economy of scale, well known from the semiconductor industry.

In addition, the new electronic based technologies make it possible to considerably reduce the size of the electricity infrastructure - thus minimizing the environmental and visual impact and freeing valuable space for other usage. The development of the different technologies for HVDC installations clearly illustrates this trend which will be an important factor in order to make it possible to enhance the performance and functionality of the electrical infrastructure by increased use of power electronics. The ability to make compact installations will be important in a broad spectrum of applications. e.g. in off-shore applications, when feeding power into large cities and when connecting large numbers of distributed generation units, located in sensitive locations, to the power grid.

Voltage Source Converter Considerations

Today, the IGBT is the preferred choice for VSC-based converters in T&D applications because of the following characteristic features:

1. Low-power control, since it is a MOS-controlled device. This is advantageous when operating at very high voltage levels (several 100 kV).
2. Transistor action, which enables precise control of the device in a manner that is not possible with latching alternatives. For instance, the converter can be turned off even in short circuit conditions.
3. High switching speed, thus making high switching frequency feasible.

The large T&D installations, however, pose demanding challenges for switching devices like IGBTs. Today's conventional HVDC transmissions utilize thyristors with very high power handling capability and excellent reliability records. Converter losses are low and equipment costs are minimized in this comparatively mature technology. Moreover, the converter must sustain different types of overload conditions emanating from various contingencies in the electrical network. The IGBT will in principle experience the same tough requirements on electrical and mechanical performance and robustness as the thyristor does.

A. General comments on converter losses

A main obstacle for using today's voltage source converters in bulk power transmission is the comparatively high power losses. As indicated in Fig. 7, the losses of the first generation of VSC-based HVDC converters are much higher than the asymptotic value presented by the traditional HVDC solution.

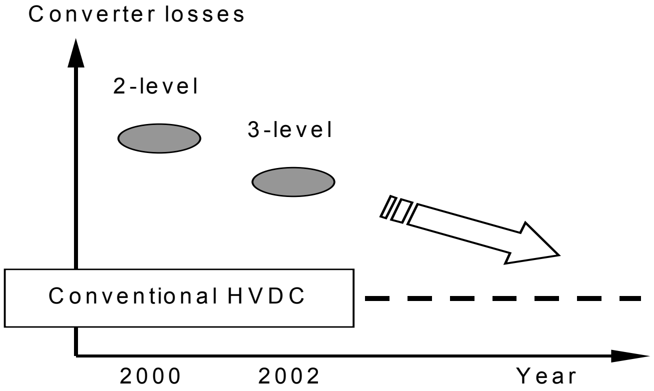

Fig. 7: Voltage source converter losses in HVDC applications compared with those of conventional converters.

The 2-level VSC topology utilized in this first generation is attractive for simplicity reasons. The switching frequency, however, must then be chosen comparatively high in order to keep the current ripple reasonably low, and this will result in high switching losses. One way of reducing the losses is to use more advanced converter topologies at the expense of simplicity. In fact, 3-level converters are already in production for new 300 MW VSC based HVDC projects to be commissioned in 2002. In parallel, semiconductor device development and optimization will contribute to further reduction in overall losses. Finally, a leap forward in loss improvement might be accomplished by employing new semiconductor materials like SiC as discussed above.

B. Switching losses in today's converters

High power dissipation at IGBT turn-on and turn-off is due to the fact that the device will be subjected to high current and high voltage simultaneously during a substantial part of the switching sequence. In order to reduce the associated losses, the device should switch as fast as possible, that is, at as high di_C/dt and dv_{CE}/dt as possible.

In practice, however, the dv_{CE}/dt at turn-off is controlled to rather moderate values (a few kV/µs per device) for series-connection reasons. Furthermore, the converter itself is comparatively bulky due to heavy insulation requirements, which makes the stray inductance of the switching loop several times higher than in for instance motor drive applications. Both of these facts contribute to a comparatively high power dissipation at IGBT turn-off.

The loss cost will become the most significant challenge as T&D converter manufacturers, with the intention of driving system cost down, demand higher and higher voltage ratings for IGBTs. This pursuit is quite predictable based on semiconductor manufacturing experience with HVDC thyristors. Taking IGBTs to levels comparable with thyristors will only become feasible if the impediment posed by the famous three-way trade-off between on-state losses, switching losses and Safe Operating Area is overcome. This in turn will necessitate, as ever-close partnership between component and system manufacturer in the quest for new solutions.

C. Series connection and protection issues

Because of the very high voltage rating of an HVDC converter, each single valve may comprise hundreds or more of series-connected IGBTs. Proper voltage sharing is therefore crucial in order to ensure similar operating conditions for all devices. However, traditional snubber circuits will not be used for protecting the individual IGBTs in order to minimize overall losses. Sufficient voltage sharing in both switching and blocking conditions must therefore be maintained by the IGBTs themselves to a large extent. This, in turn, requires a small spread in device data concerning characteristic switching times, switching transient properties and leakage currents in the blocking state.

Besides controlling the switching device in regular operation, the gate unit should keep the switching device within the safe operating area in all other operational and short circuit conditions. IGBTs have proven comparatively easy to handle in this respect which facilitates precise control of switching waveforms. This, in turn, is necessary for achieving proper control and protection strategies for the converter.

D. Reliability aspects

In addition to the number of series-connected IGBTs that is needed to sustain the converter voltage rating, each single valve includes a few redundant devices to enable continued operation in case of failure of an individual component. A faulty IGBT, however, must not create an open circuit since the valve current will continue and the source voltage is very high and stiff. Instead, the device must enter the short-circuit condition and stay there for a long time until it will be exchanged at, for instance, a scheduled maintenance period. This capability of Short Circuit Failure Mode (SCFM) operation is very critical for series-connected IGBTs and has to be verified by long term tests under conditions that are relevant for the particular application.

In contrast to the case of conventional thyristor-based converters, each individual semiconductor device in a VSC will be subjected to high voltage for a substantial part of its operation time, that is, about half the rated voltage at 50% duty cycle. The probability that an incident cosmic particle will initiate a destructive current avalanche in blocking mode will therefore be substantially increased. This effect must be counteracted by proper design of the IGBT in order to keep the failure rate (FIT) below specified limits.

Conventional thyristor-based HVDC converters operate normally in relatively stable conditions and the power flow changes at moderate rates. In contrast, the unique controllability of voltage source converters makes them attractive for applications that benefit from rather rapid changes in power flow. As an example, de-regulation of the electrical power market has resulted in altering exchange of power between separate networks. This, in turn, makes new and heavy demands upon the power cycling capability of the semiconductor device, which, again, must be verified by long-term testing.

E. Mechanical requirements

Because of the high number of series-connected IGBTs, the converter valve must be divided into several stacks that each consists of a manageable number of series-connected devices. Furthermore, the stacks must be very compact to ensure low stray inductance of the commutation loops. As shown in Fig. 8, each semiconductor component is clamped between heat sinks and the entire IGBT level, including the gate control unit, is surrounded by shields to equalize the electric field around the stack. This very compact design requires IGBTs of limited height that are well adapted for stack mounting. Their mechanical robustness must also be sufficient to withstand high mounting force for ensuring the necessary mechanical stability of the whole assembly. Furthermore, the IGBT housing must be explosion-proof to prevent fire or any other severe damage in the converter if the valve, by accident, should be subjected to a heavy short-circuit current.

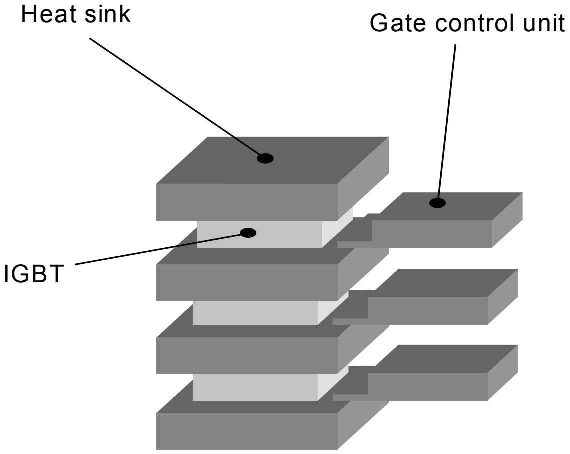

Fig. 8: Principle of the IGBT stack assembly. Each level contains an IGBT clamped to heat sinks and an adjacent gate control unit. Metallic shields (not shown) surround the active parts for equalizing the electrical field.

IGBT-specific press pack package design

While well suited electrically, IGBTs, did not gain much ground in such high power, high profile applications until the advent of a new press pack technology. Advancing from traditional thyristor-based line-commutated converter technology to IGBT-based voltage source technology was made possible only after redesigning for some of the key packaging aspects.

The competing IGBT press pack packages available today are adapted from traditional thyristor “Hockey Puck” packages. This rigid pressure contact technology is not optimized to protect sensitive microstructures on the surface of IGBT chips. As a consequence users are required to provide near-perfect cooler surfaces and handle such devices with good deal of care during assembly. The issue is further aggravated when the module size is increased for higher current ratings. There is a significant cost impact on system production cost as a result of these shortcomings.
As described below, ABB Semiconductors has developed an IGBT-specific press-pack package by taking a fresh approach in meeting this requirement (7).

A. Pressure Management: Individual press pin

A new pressure-contact technology decouples the external clamping force from the direct pressure on the chip. This is achieved by the use of a flexible emitter contact (individual press-pin) in combination with a stiff housing made of fiber reinforced plastic materials to provide explosion resistance in case of accidental valve failure (Fig. 9).

To further reduce the stress coming from mechanical unevenness, an individual flexible pin contacts each chip. During mounting, a certain amount of the applied pressure is transferred onto the chip by compression of the individual press pin contacts whereas the excess pressure is taken over by the robust housing. At the same time, the robust housing limits the compression of the flexible contacts. With this design, the pressure on the chip can be adjusted by the stress-strain characteristic of the individual pressure contact.

The significant advantage of this concept is that it is much less sensitive to pressure non-uniformity as compared to competing designs with stiff copper pole pieces and allows very high mounting force as well as much wider mechanical tolerances. The result is a gain in mechanical reliability at reduced costs.

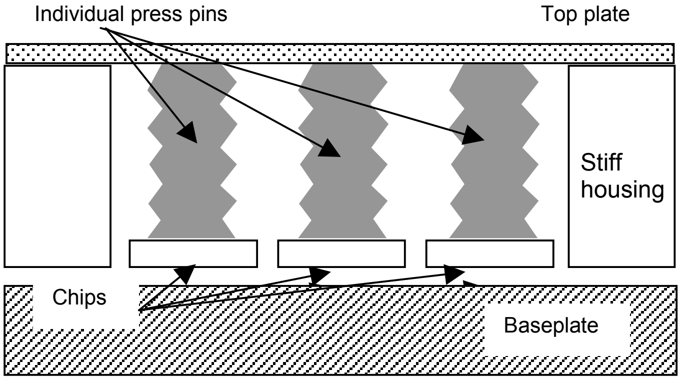

Fig 9: Schematic view of the pressure scheme used to decouple the external clamping force from the direct pressure on the chip. The contact partners on the chips (individual press pins) are flexible and upon clamping, they are compressed until the top plate and the base plate touch the stiff housing material. When the external force is further increased, the pressure on the chips will remain stable, whereas the housing will take the additional force.

B. Short Circuit Failure Mode

So far, the state-of-the-art to obtain a SCFM has been to place a chip or a thyristor between two molybdenum discs. This construction is once again inherited from thyristor devices. As described below, molybdenum is not a suitable contact material in forming a stable conductive path. From this it is evident that the SCFM mechanism was not sufficiently investigated. A new technology was developed to adequately address this issue. The basic idea is to facilitate formation of metallurgical alloy between silicon and an optimized contact partner. If the partners are chosen properly, a low melting compound is formed leading to a highly conductive path through the chip. The result is a reliable SCFM performance during “after-life” operation in the system.

C. Modular Approach

A versatile (sub) modular design is developed to achieve simultaneously a high degree of standardization and flexibility. If preferred, as discussed earlier, IGBT package size can be fixed to cover the required current range. Basically each sub-module is assembled and fully tested according to its rating. Overall current rating of a device is then determined by a number of sub modules placed inside the housing. An excellent paralleling is achieved to minimize current de-rating. The most desirable aspect of modular design is its cost effectiveness. This is principally brought about by significantly higher production yields. Small sub-modules can be produced in high volumes at high yields. Whole module yields are near perfect as sub modules are fully pre-tested and in the event of some failing in the final testing, the faulty submodule is simply lifted up from the housing and promptly replaced.

Conclusions

Ever increasing demand for electrical power combined with dramatic structural changes in the electricity market has triggered great demand for versatile power electronics based T&D systems. Utilization of state-of-the-art voltage source converters – a key to success for thorough integration of power electronics in T&D systems – is made possible by development of advanced high power semiconductors. The IGBT, being amenable to precise control with a voltage signal, has become the preferred switch, particularly for large converter systems such as HVDC.

Acknowledgments

Authors wish to thank Eric Carroll, Bo Bijlenga, Stefan Linder, Stefan Kaufmann, Christer Ovren and Heinz Lendenmann for their contribution to this paper.

References

1. A. Ekstroem, “High Power Elctronics in HVDC and SVC, ” The Royal Institute of Technology, Sweden, June 1990
2. J. Garte, T. Kaarsberg, J. Laitner “Electricity restructuring, innovation, and efficiency” A study conducted by the Northeast-Midwest Institute, 1991
3. Y. Rudenko and V. Yershevich “Is it possible and expedient to creat a global energy network” International Journal of Global Energy Issues, Volume 3, No. 3, 1991
4. C. Ovren, H. Lendenmann, S. Linder, B. Bijlenga “Electronics with power” Focus on Transmission and Distribution, ABB review, 2000
5. G. Asplund, K. Eriksson, O. Tollerz “HVDC light, a tool for electric power transmission to distant loads,” VI SEPOPE, Sweden, May 98R.
6. G. Asplund et al, “DC transmission based on voltage source converters,” *CIGRE' SC14, South Africa*, 1997
7. S. Kaufmann, T. Lang, R. Chokhawala, “Innovative press pack modules for high power IGBTs,” ISPSD’01, Osaka, June 2001