SIEMENS

The New Generation of MOS-Controlled Power Semiconductor Components

Advantages in Application

Power semiconductor components are the driving force behind the continued development of power electronics system design, particularly in the areas of energy efficiency, increased dynamics, noise reduction, and minimized volume and weight.

Power semiconductors control the flow of energy between the energy source and the point of use. They are therefore key components for drive and control systems, and therefore for mechanical and system engineering as a whole. As energy supply units (these can be DC/DC, DC/AC, AC/DC, or AC/AC converters, depending on the energy source and the point of use) they provide the link between microelectronics and the energy converter. The power semiconductor components for use in future power electronics systems are subject to exacting requirements. Increasing automation and the demand to rationalize energy usage have resulted in a requirement for advanced power components with high switching speeds, low switching losses and minimum-power control. In order to increase system efficiency levels, the power switches must also give low overall losses at high frequencies, i.e. both dynamic and static losses must be low. In order to reduce system overheads in terms of volumes and weight, it is important to develop a consistent switch design for the widest possible power band (1 A $\leq I_L \leq$ 1000 A; 50 V $\leq V_{Br} \leq$ 2.5 kV). The switch timing frequency is also a critical factor in the reduction of volume and weight for many power electronics systems, e.g. UPS systems, switched power supplies, etc. With regard to noise development and control dynamics for drives, significant progress has already been achieved in the timing frequency range of 4 kHz $\leq f_T \leq$ 10 kHz. However, the switches have to reach a timing frequency of $f_T \geq$ 16 kHz, whilst maintaining low loss levels, to achieve noiselessness. Exacting demands are also placed on the robustness and control system of the power switch. Short-circuit-proof, avalanche-proof and latch-up-proof components are essential, as are power semiconductor switches whose parasitic semiconductor structures are not used in practical application areas. In order to implement optimized pulse control techniques without significant electronic overheads, the power switches have to adhere to the pulse control diagram without delay, i.e. without storage and delay times. In addition, drive overheads and drive power must be as low as possible, and the switching times must be individually and repeatedly configurable. This means that the power switch must have a MOS input. Furthermore, MOS-controlled components offer the enormous advantage that they can be directly controlled from microelectronic components at little additional cost. The increased use of microelectronics in power control allows the implementation of more complex drive and control designs, optimized pulse control techniques, automatic motor identification and self-optimization, as well as diagnostic tools. However, it also places greater demands on the semiconductor components used. **Figure 1** shows the development of power semiconductor components up to the end of this decade.

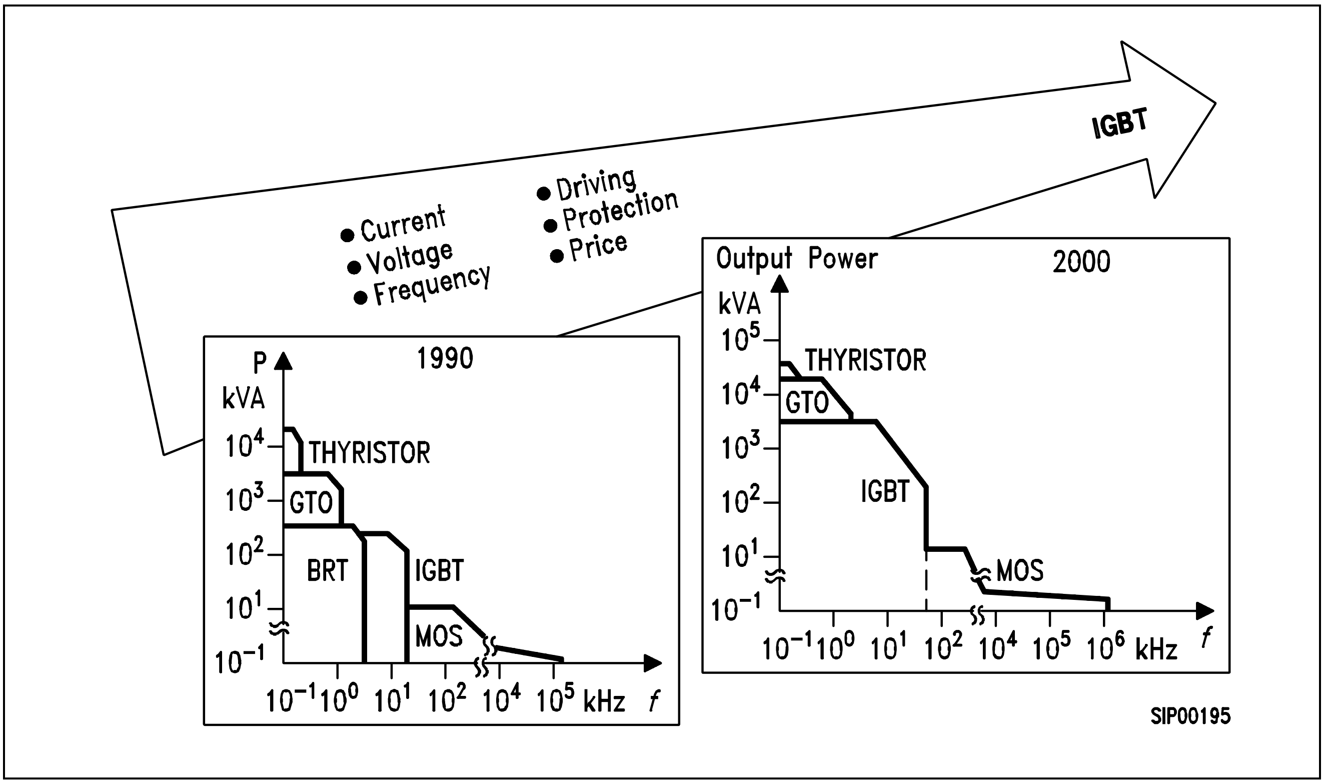

Figure 1
Development of Power Semiconductors up to the Year 2000, Together with the Main Development Objectives

The way ahead is now quite clear, and power MOSFETs or IGBTs are designed into all new system developments. The main development objectives for IGBTs over the coming years are: extend the current range 1 A $\leq I_L \leq$ 1000 A, the voltage range 50 V $\leq V_B \leq$ 3500 V, and the switching frequency 2 kHz $\leq f_T \leq$ 100 kHz; improve the pulse accuracy; reduce the control and protection overheads, and manufacturing costs; and increase robustness. The main development objectives for power MOSFETs are: reduce the on-resistance, particularly in the low voltage range 100 V $\leq V_{Br}$; optimize the losses at high switching frequencies f_T > 100 kHz (control and switching losses, whilst maintaining low static turn-on losses at the same time); and optimize robustness, particularly in dynamic and avalanche mode, and for other important protective functions such as input protection, temperature protection, overcurrent protection, etc.

Selecting the Optimum Semiconductor Switch

The development of IGBTs significantly extended the range of MOS-controlled power semiconductor components, particularly in the area of high-voltage applications. However, there are still areas of overlap. This means that there is no single power semiconductor component which can cover the whole application area, and it is therefore necessary to select the most effective switch from the range available for the individual application concerned. There are nonetheless voltage ranges within which (with certain exceptions) certain switch designs have superior electrical performance to others. For example, the power MOSFET in the lower voltage range (V_{Br} < 500 V) and the IGBT in the medium voltage range (600 V ≤ V_{Br} ≤ 3500 V) offer advantages in their respective typical application areas, when all electrical parameters are taken into consideration. The lower the reverse voltage of the transistor (V_{Br} < 100 V), the bigger the development potential for power MOSFETs, particularly in the reduction of the ON-resistance whilst maintaining all the other important electrical parameters such as dynamic performance, SOA range, short-circuit and avalanche performance, robustness and input capacity. In the voltage range V_{Br} > 60 V, the IGBT in a complete system solution offers clear advantages over the power MOSFET, and particularly over the bipolar transistor.

The higher the reverse voltage of the transistor, the more significant the disadvantages of the switching systems concerned. From approx. 1000 V the power MOSFET is eliminated. The range 1400 V ≤ V_{Br} ≤ 3500 V can only be handled by the IGBT.

In the case of drive systems engineering with switching frequencies of 2 kHz ≤ f_T ≤ 16 kHz, the IGBT can offer advantages over the MOS solution. The MOS transistor is a more effective and therefore more cost-effective component for significantly larger applications at these voltage levels, e.g. switched power supplies, UPS equipment, inductive heating, resonance converters, etc.

The Power MOSFET and Subsequent Developments

The power MOSFET was developed at the end of the 1970s. The outstanding electrical characteristics of this component have pushed bipolar transistors out of many applications, and opened up completely new application areas.

The individual characteristics are as follows:

- Capacitive control input
- Switching times can be configured individually and easily
- Extremely short switching times, high switching frequency
- No storage effects
- No second breakdown
- Optimum thermal stability

Power MOSFETs have been continuously improved with regard to all of these electrical parameters. The new generation of power MOSFETs has been dramatically improved with regard to robustness. This specifically affects overvoltage resistance, dv/dt resistance, and di/dt resistance. Due to the breakdown resistance of transistors, even the reverse voltage safety distance can be reduced, and the static turn-on losses can therefore also be minimized. As a result, the voltage reserve used for the MOSFET no longer has to be designed for the unfavorable event of sporadic supply voltage fluctuations. Turn-off overvoltages are stored by the MOSFET. During this period, additional energy in the component is of course converted into heat, depending on the operating voltage V_B, the breakdown voltage V_D, and the unclamped inductance L of the electric circuit.

$$\left(E = \frac{1}{2} L \times I_C{}^2 \times \frac{V_{DS}}{V_{DS} - V_B} \right)$$

The maximum junction temperature of the transistor must not be exceeded in the event of this operating condition.

For applications in bridge circuits with inductive load, the reverse recovery charge of the integral inverse diode has been improved, so that the parasitic bipolar transistor does not switch on, even in the event of high di/dt or dv/dt values, and the inverse diode continues to operate in “soft” mode. The overall solution (power switch + inverse diode) must always be considered in the case of bridge circuits with inductive load. With regard to dissipated power, it must be ensured in this context that the inverse diodes used in the MOSFET solution are available with an identical chip surface to that of the transistors. For this reason, better values for diode forward voltage are achieved in many cases.

Whilst the on-resistance is largely determined by the epi material (reverse voltage zone) in the upper voltage range (200 V $\leq V_B \leq$ 1000 V), in the lower voltage range ($V_B \leq$ 60 V) the on-resistance of a typical power MOSFET today is composed of a number of partial resistances depending on the layout. As a result, optimized cell design can drastically reduce the on-resistance for the same chip surface. Once again, existing electrical characteristics have been maintained or improved during the course of these developments, particularly the values achieved with regard to robustness.

The State of IGBTs and the Potential for Further Development

The development of IGBTs has extended the range of voltage-controlled transistors, so that semiconductor switches with the same drive mechanism are available from 50 V to 3500 V, finely graded in accordance with reverse voltage and current values. As a result, the new, MOS-controlled generation of transistors covers the whole area of bipolar transistors in terms of current and voltage values, and replaces parts of GTO applications in the upper voltage range.

The new generation of transistors is superior to conventional switches in terms of dynamic data, maximum operating loads, short-circuit resistance, robustness and ease of control.

Furthermore, the ease of control offered by MOS makes this generation of switches ideally suited for the further development of self-protected power semiconductor switches.