Some Trends in the Development of Devices and Systems of Power Electronics

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Abstract

On the basis of the analysis of global trends, the parameters of power electronic devices and systems are compared; the outlooks and tendencies of the application of different types of devices in power electronic systems are estimated. Application areas are outlined both for the systems and for the devices incorporated in them. The perspectives of structural and electronic circuit developments of power electronic systems are presented, taking account of the properties of devices involved, and specific features of potential consumers of the electric power.

Power electronics is one of the foundations for the creation of up-to-date techniques and technology providing multiple increase in the productivity and quality of labour at minimal consumption of various resources. Modern power electronics makes apparatus and equipment highly reliable, multifunctional and ergonomic. Wide use of power electronic systems in various areas of human activities allows in particular saving substantial part of energy resources.

In the opinion of the leading experts in forecasts of the global trends of technological development, the next turn of the scientific and technological revolution will be provided by the success in intellectual power electronics. The importance of power electronics is explained by the fact that at present 60–70 % of the generated electricity is consumed with the parameters different from the generation parameters.

Progress in modern power electronics is provided by the appearance of high-power, practically ideal switches based on transistors (MOSFET, IGBT) and fully controllable thyristors (GTO, IGCT, SGCT). The classification of the types of modern high-power semiconductor devices is shown in Fig. 1. Figure 2 shows current and voltage which these devices are able to commute at present [1].

Within the low-voltage region (200–1000 V), the market is winningly occupied by the MOSFET transistors, modules and intellectual power integrated circuits based on them, by replacing bipolar transistors. This is mainly connected with the decrease of the cost of these devices due to technological improvements (trench-gate, Cool MOS^{TM}) and high performance characteristics of the MOSFET transistors: high commuting rate, low static and dynamic losses, low control power, high stability

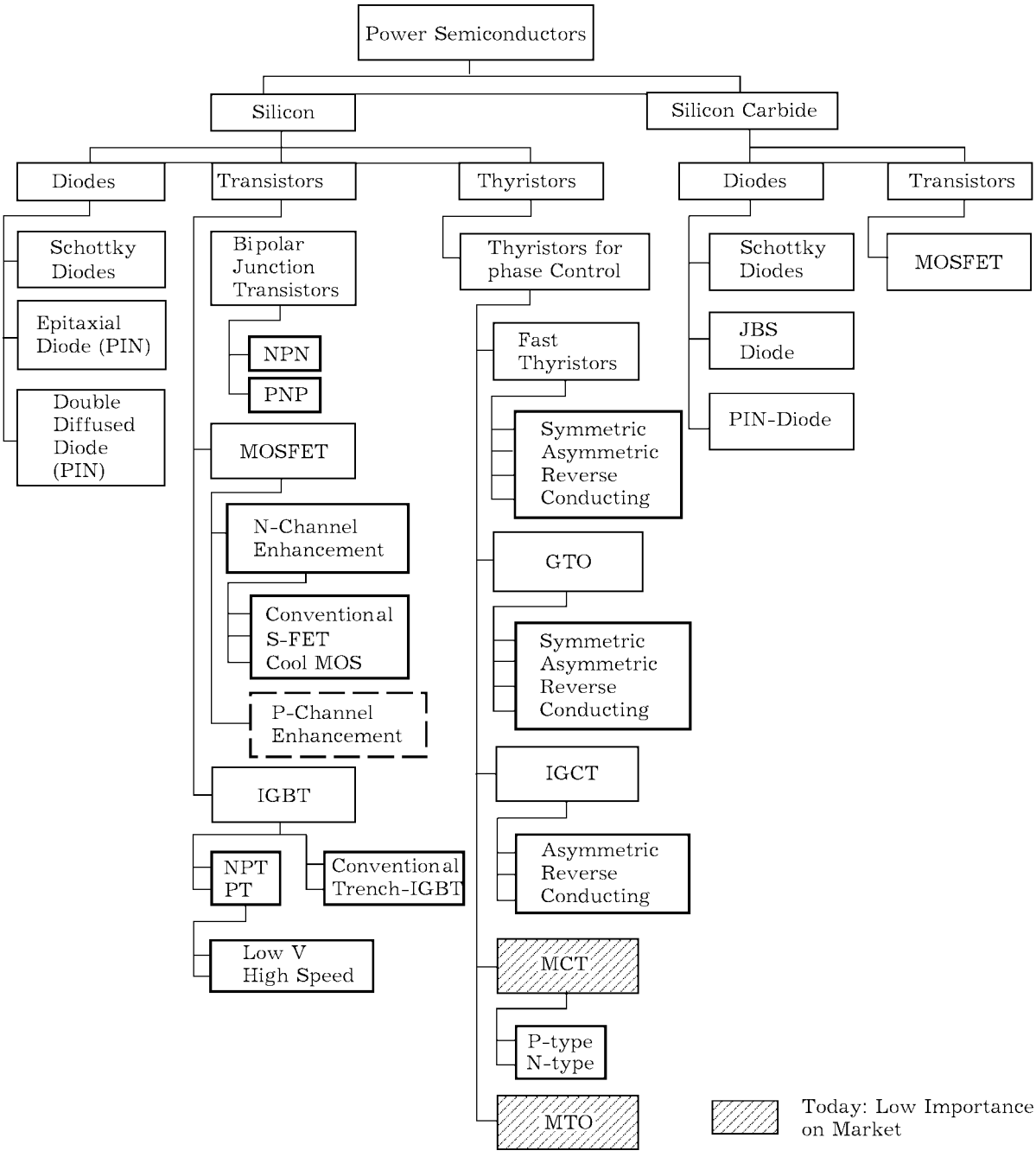

Fig. 1. Classification of power electronic devices.

to overload. The limiting parameters of power MOSFET are doubled every two years, while the annual increase of their production is 45–50 %. The outburst made by the Siemens Company in the area of the creation of high-voltage MOSFET with the specific resistance about 3 Ω mm^2 (MOSFET 600 V with $R_{dc(on)}$= 70 MW in TO-218 housing) will broaden the application area of the devices of this class within commuted voltage range 600–1000 V and power up to 10 kW.

The application area of the MOSFET transistors includes frequency and voltage transformers with the power up to 10 kW and transformation frequencies up to several megahertzes. As a rule, these include secondary power supply units of various destination, uninterrupted power supplies, electronic ballast of modern

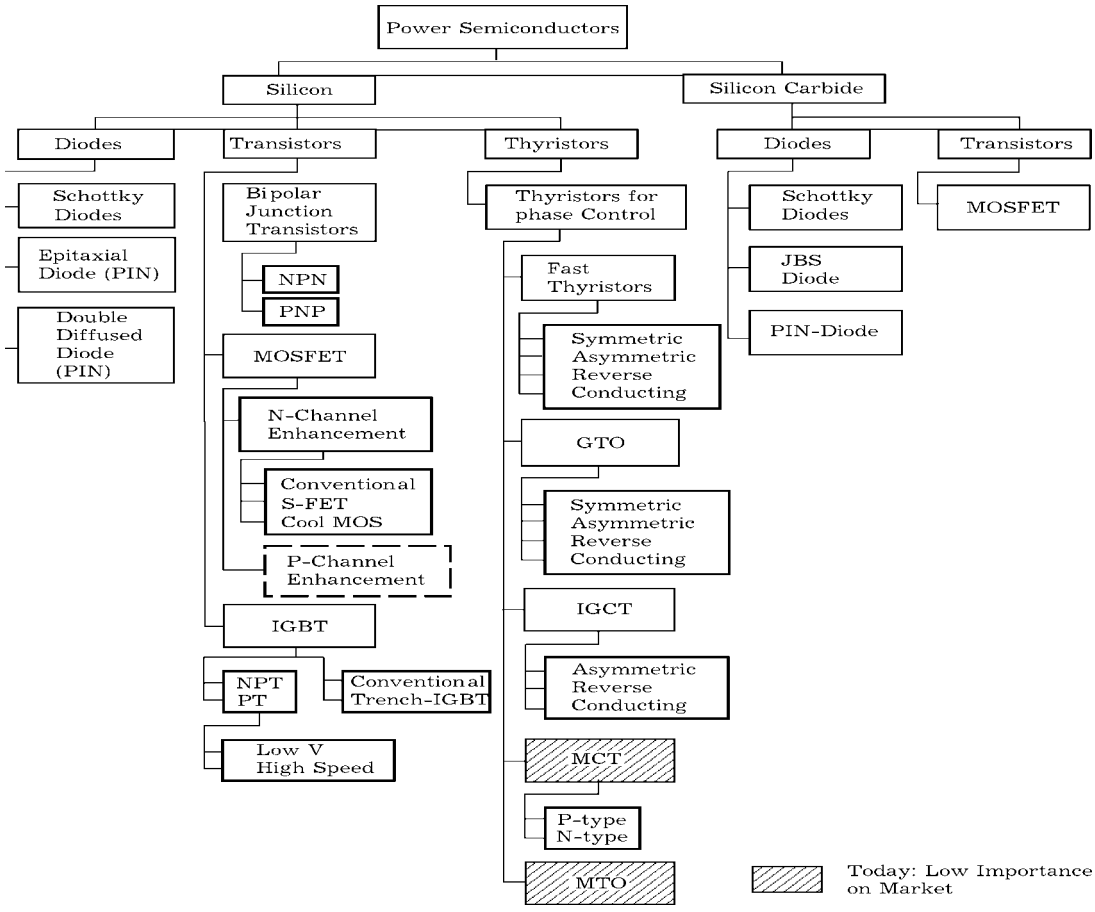

Fig. 2. Commuted currents and voltages.

light sources, automobile electronics (electric rudder amplifiers, starter-generator devices, *etc.*).

A structural scheme of the most widespread secondary power supply is shown in Fig. 3. As a rule, modern SPS contain the corrector of the input power factor; transformation is carried out at high frequency; rectifiers on the side of low voltage involve Schottky diodes, while control is carried out with the help of specialized PDM controllers.

Bipolar transistors with insulated gate (IGBT) first appeared on market in 1985 and began conquering it quickly. A successful combination of the MOSFET properties (small control power, high commute rate, rectangular region of safe operation, ability to operate parallel without aligning elements, small voltage drop in the open state, high limiting voltage) made IGBT practically ideal power switch. IGBT parameters are continuously improved by manufacturers (direct voltage drop decreased from 4 V in the devices of the 1st generation to 1.2 V at present in the devices of the 4th generation, limiting frequency of switching similarly increased from 5 to 150 kHz and above); limiting characteristics of IGBT modules exhibit a three-fold increase every two years. At present, the company Fuji Electric Co. achieved the parameters 2000 A, 4.5 kV in the press-pack IGBT-module. Infineon Technologies Co. together with EUPEC in August, 2000 reported successful tests of IGBT modules for 6.5 kV.

The sales volume of IGBT modules increases continuously (by up to 25 % per year) and has already exceeded US $ 1 billion, which is several times higher than the sales volume of thyristors. The area of IGBT module application is most vast. The use in the most widespread circuits of voltage inverters (Fig. 4), including multilevel ones (Fig. 5), as well as in matrix transformers, allows to embrace the power range from several units to thousands kilowatts. These transformers are used in electrical drives for different purposes (Fig. 6), in-

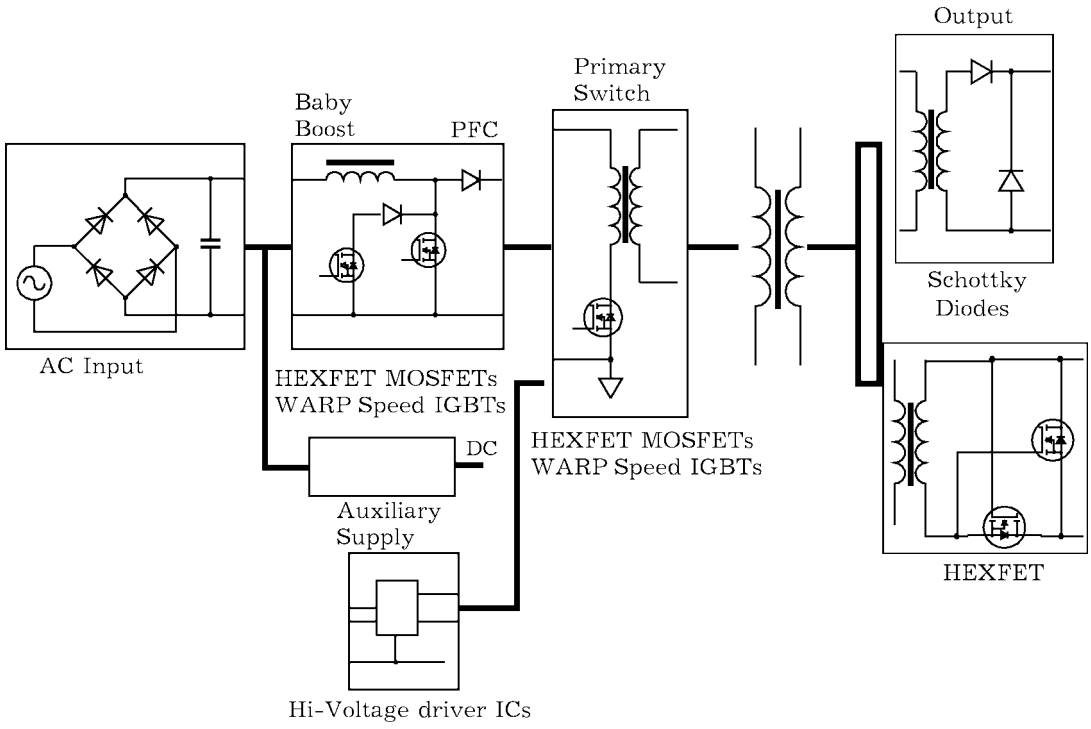

Fig. 3. Structural scheme of SPS.

cluding high-voltage ones (both those with transformers and without them), in powerful systems for generating electrical power at alternate and direct current, in uninterrupted power supplies, in powerful converters of combined automobiles, in electrotechnologies (various versions of welding equipment) and ion plasma technologies.

Some shortcomings of GTO were the reason why they have found only limited application. These shortcomings include: high (up to 4 V) direct drop in voltage, complicated control circuits, necessity to use large snubbers, high dynamic losses. However, modernization of GTO due to the application of novel technologies and due to combining in one device with the control circuit allowed one to increase fast operation of the new type of confinable thyristors (IGCT), decrease static and dynamic losses, providing operation without snubber within the voltage range up to 4.5 V and current 1–10 kA. IGCT overcome IGBT modules in many important parameters: static and dynamic losses, reliability, stability to thermocycling, limiting characteristics, commute power-to-price ratio, possibility of sequential switching without leveling circuits. One more important advantage of IGCT over IGBT is the possibility to block reverse voltage, which is especially important for their use in high-power high-voltage current inverters. Because of this, the leading position in high-voltage applications (above 3.5 kV) is likely to be occupied by IGCT. The following stages are outlined in the development of IGCT in the nearest five years: snubber-free usage, improvement of the du/dt and di/dt parameters, broadening of the commuted voltage range to 6 kV and further to 9 kV, devices with liquid cooling, plastic housing, modules with isolated basement.

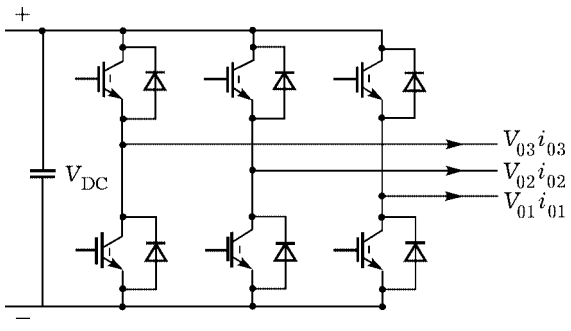

Fig. 4. Voltage inverter.

The main application areas for the confinable IGCT and SGCT thyristors are high-power

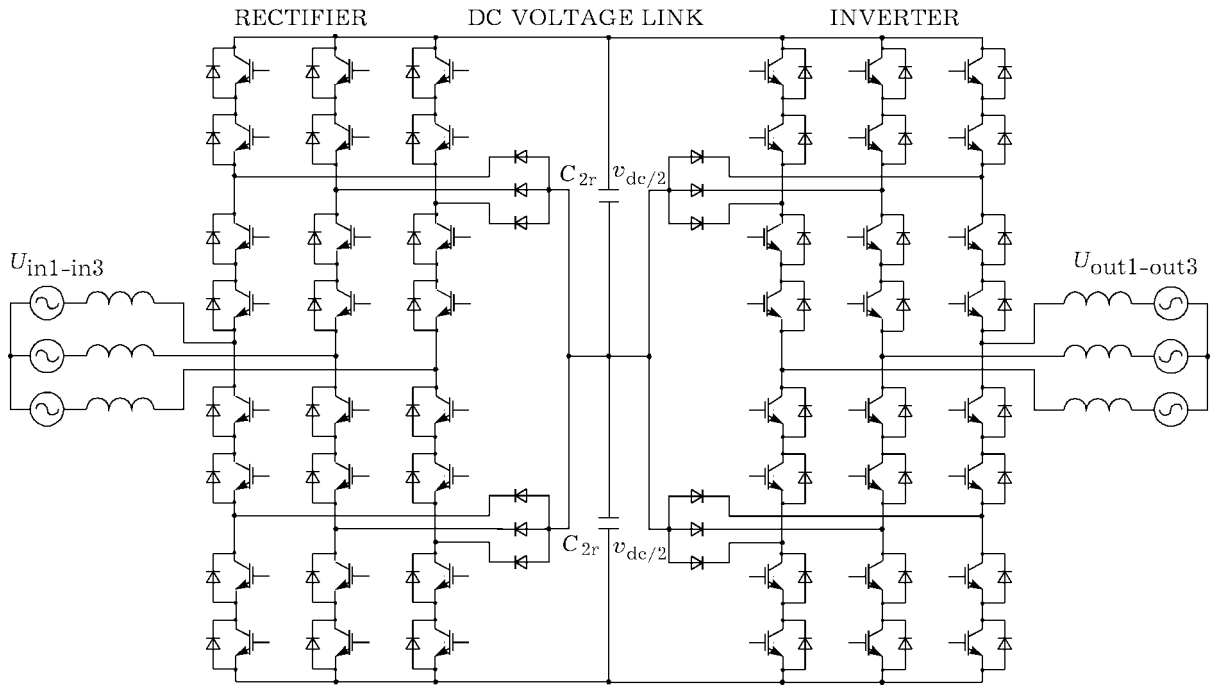

Fig. 5. Multilevel voltage inverter.

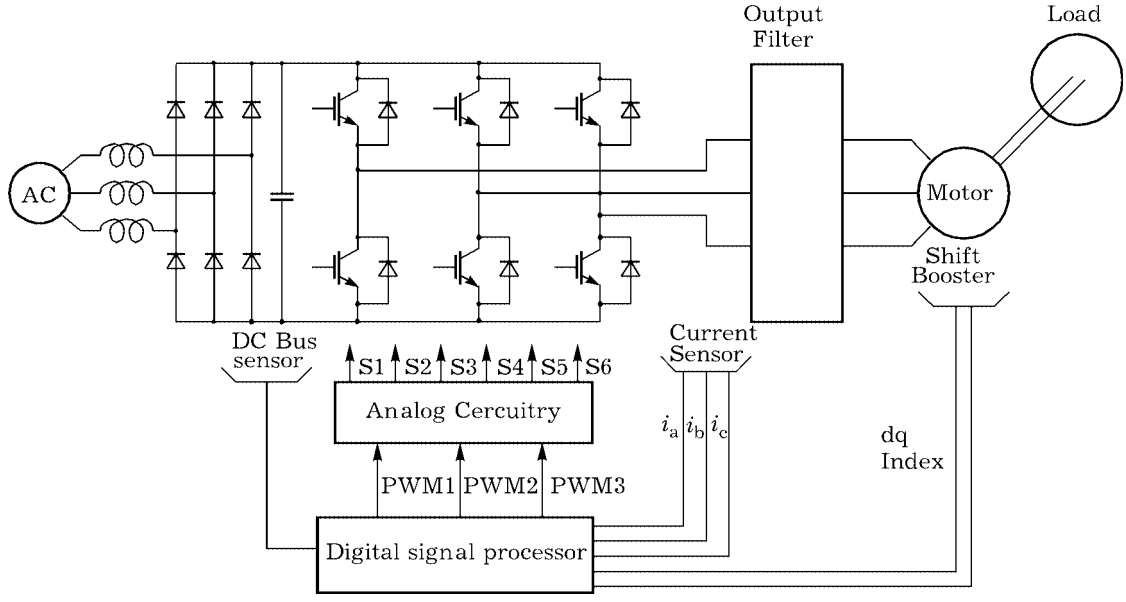

Fig. 6. Alternating current electrical drive.

(several megawatts) high-voltage inverters of voltage and current for electrical drives used in power engineering, metallurgy and railroad electrical transport (Fig. 7).

Classical thyristors (SCR) still hold the highest "commuting power-to-price" index, in spite of the fact that their application area is constantly decreasing. Because of this, preferable areas of their application are those in which the price is the determining factor, as well as superhigh-power and superhigh-current transformers with natural commuting (power engineering, electrotechnologies) (Fig. 8). For example, the market of triacs was US $ 575 mln in 1996; the "microcontroller – triac" combination exhibits substantial growing trend.

The manufacture of standard solid-state drivers much helped wide application of the systems and devices of power electronics, which provided unification of circuit engineering solu-

TABLE 1

Application areas of power electric devices.

Application area	IGBT module	IPM	Transistor module	MOSFET module	Power MOSFET	IGBT	Triacs	GCT/GTO Transistor	Thyristor	HV IGBT
Industrial use										
Electric power transmission	–	–	–	–	–	–	–	×	×	×
Steel manufacture	–	–	–	–	–	–	–	×	×	×
Electric train	×	×	×	–	–	–	–	×	×	×
Automobile	×	×	×	×	×	–	–	–	–	–
UPS power supply	×	×	×	×	×	×	–	–	×	–
Motor control	×	×	×	×	×	×	×	×	×	×
Welding machine	×	×	×	–	–	–	–	–	×	–
Switching power supply	–	–	–	–	×	×	×	–	–	-
Consumer use										
Air conditioner	×	×	×	-	-	-	×	-	-	-
Microwave oven	-	-	-	-	-	×	×	-	-	-
Refrigerator	-	×	-	-	×	-	×	-	-	-
Camera (strobe)	-	-	-	-	-	×	-	-	×	-
Washing machine	×	×	×	-	-	-	×	-	-	-
Induction cooking appliance	×	-	×	-	-	×	-	-	-	-
VTR-audio	-	-	-	-	×	-	-	-	-	-

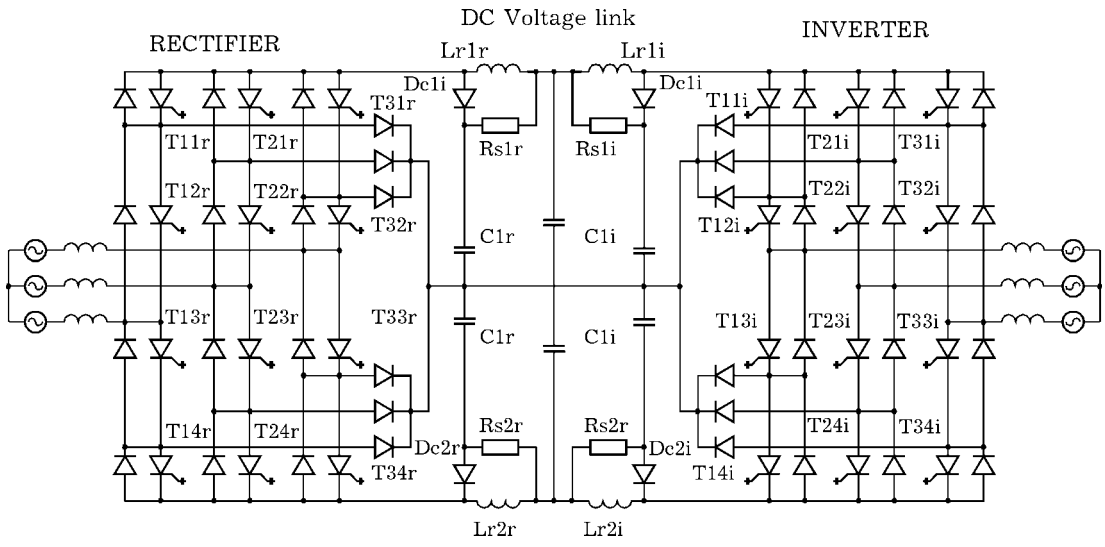

Fig. 7. High-voltage frequency transformer for high-power electrical drive.

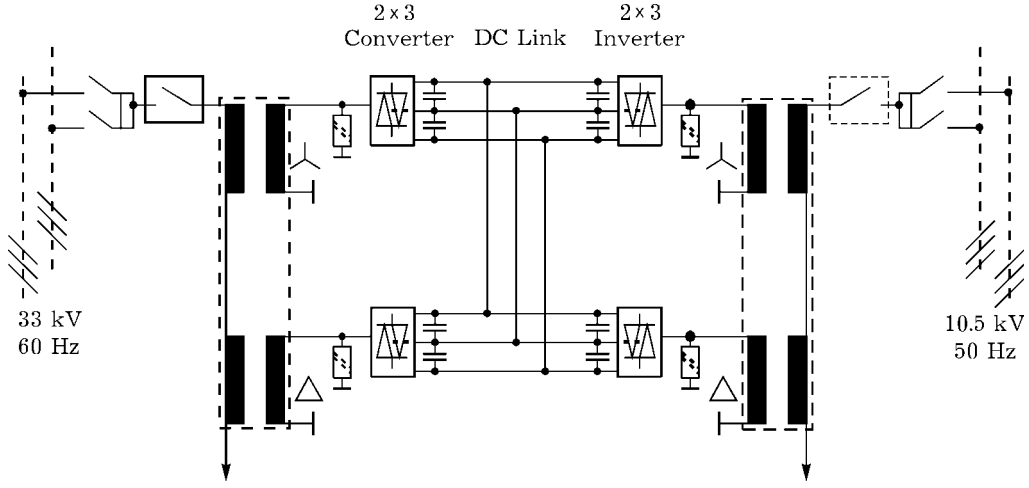

Fig. 8. Direct-current link.

tions and led to the decrease of the cost of both the development works and commercial devices.

Table 1 shows the main application areas of the most widely used power electronic devices.

The determining direction in the development of devices and, as a consequence, systems of power electronics is the system integration [2, 3]. Low level of losses and small control power for MOSFET and IGBT allowed to bring into reality the idea of creating power integrated circuits, in which power key elements, circuits of their switching and protection, the units for control, handling and diagnostics are manufactured on one crystal. The market of intellectual power integrated circuits (Smart Power IC) (accounting for about US $ 3 billion in 1996) is developing dynamically, sales volume increases by 30–35 % per year. Intellectual modules are used in low-power electrical drive and other devices in which the determining factors are mass and size parameters and reliability. As the price decreases and the unit power of modules increases, they will win application in transforming devices of tens watts to several kilowatts.

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