Estimates of the Devices and Systems of Power Electronics in Russian Federation

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Abstract

A structural analysis of energy consumption over the branches of industry and separate types of consumers is presented. It is demonstrated, on the basis of the development of the power-manufacturing capacities of Russia and global trends in the development of power electronics, that the introduction of energy-saving technologies involving the means of power electronics allows achieving substantial saving of electric power and reducing its deficit. Taking account of the structure of consumers over the branches of industry and specific features of the necessary means of power electronics, the limiting volume of the Russian market is estimated from the financial viewpoint, both with respect to the power electronic units and systems, and with respect to semiconductor devices used in them.

MAJOR CONSUMERS OF ENERGY AND GLOBAL TRENDS IN ENERGY SAVING

In the opinion of foreign and home leading experts in the area of forecasts in global trends of the development of technologies, the next turn of the scientific and technological revolution will be provided by the success in intellectual power electronics. A known American expert in power electronics Professor J. Bose said: "Two most important technologies of the super-automated 21th century will be: computer – intellect and power electronics – muscles".

During the recent decades, humanity has come to acknowledging the necessity to solve the problem of energy and resource saving as soon as possible. Many energy- and resource-saving technologies are based on the achievements of intellectual power electronics. Some facts in confirmation of this statement are listed below.

1. The annual consumption of energy in the world is (40–50) 10^{12} kW h, according to the estimates of the International Energy Agency; the consumption of electric energy is (8–12) 10^{12} kW h. Annual expenses for the production of electric energy are US $ 400–500 billion, $ 72–78 billion being direct losses in generating, transmitting and consuming devices.

2. The major consumers of electric energy are at present:

– electric drives of various destinations – 51 %;
– illumination – 19 %;
– heating/cooling – 16 %;
– telecommunications – 14 %.

3. At present, less than 25 % of energy is used in the world optimally for the required work, in the sense of minimized losses, by applying high-efficiency methods of controlled transformation of energy from the mains into the energy of controlling an object.

4. The resources for the increase of electric energy production in the 21st century, and ecological problems would not make it possible to provide high (or even medium) life standards for the population.

5. An evident solution of this problem is the introduction of energy- and resource-saving technologies. The major part of these technologies is based on the application of high-efficiency transformers of electric energy (power electronic devices) involving high-power semiconductor devices.

6. This strategy of technological development allows obtaining substantial economic effect.

Industrial electric drive controlled with the help of semiconductor transformers of electric energy saves up to 40 % of the generated electric energy. The fraction of controlled electric drives in world technologies at present does not exceed 40 %. The use of controlled electric drive in the areas in which this is possible will lead to annual saving of US $ 72 billion.

For illumination purposes, about 10 billion incandescent lamps and 500 million luminescent lamps are sold every year. Luminescent lamp with electron ballast is 5 times more efficient than the incandescent lamp and serves 10 times longer thus saving up to US $ 30 per service life. The potential saving is US $ 119 billion. High-pressure sodium lamp (HPSL) with electronic start-up controlling device is 2.5 times more efficient than the mercury choke lamps used in street illumination; this allows increasing the saving potential up to $ 200 billion USA.

The increase of the efficiency of the secondary power supplies due to the application of pulsed methods of transforming electric energy has a saving potential of 2.5 billion $.

The use of power electronic devices in the construction of automobiles in such applications as the systems of motor control, electric rudder amplifier, starter-generator system, antiblocking system, electric braking systems, *etc.*, at 10 % fuel saving, can save $ 29 billion USA per total amount of 500 million automobiles.

The application of semiconductor transformers of electric energy to control the productivity of technological chains of thermal power stations decreases the consumption of energy for the own purposes of power plants, which decreases net cost of 1 kW h by 7–10 %.

The increase of the efficiency of electric power consumption causes the decrease of expenses for development and operation of infra-structure (power plants, transmission lines, *etc.*). Estimates of this economic effect are hindered at present.

A mass consumer of power electronic devices is household appliances. Large amount of the production of household appliances determines large reserve of energy saving, in spite of small level of power consumption for a single device.

TABLE 1

Economic effect of the application of power electronic devices

Application data	Economic effect
Use of transforming devices to control the productivity of the technological chains of thermal power stations and hydroelectric power stations	Decreases energy consumption of own needs by 30–40 %. Leads to the decrease of net cost of 1 kW h by 7–10 %
Use of frequency and voltage transformers in controllable general industrial electric drive	$ 60–70 billion
Minicipal services. Street illumination – high-pressure sodium lamps. Illumination of public buildings – small-size luminescent lamps with electronic start-up controlling devices	$ 90–120 billion
Household electronics (vacuum cleaners, refrigerators, illuminants, washing machines, induction furnaces, *etc.*)	Only for 10 % of refrigerators for 3 years $ 1 billion
Automobile electronics	$ 29 billion, at 10 % fuel saving
Increase of the efficiency of electric current sources	$ 2–3 billion

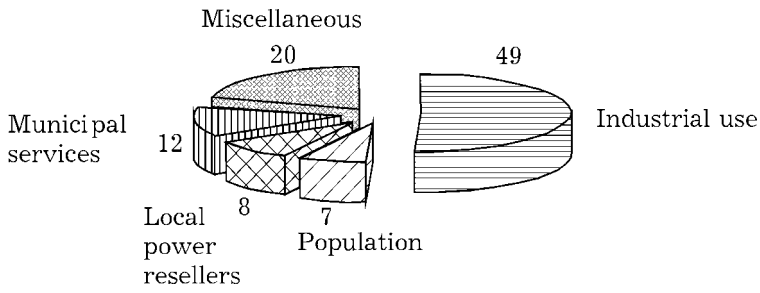

Fig. 1. Consumption of electric power in Russia in 2000.

The most energy consuming household devices are conditioners, induction furnaces, washing machines, refrigerators, illuminants.

The use of controllable electric drive of the refrigerator compressor leads to a mean of 40 % saving of electric energy, as well as to the decrease of the total price of a refrigerator; for 200 l refrigerators, energy saving is $ 70 per year. By 2003, annual saving may be $ 1 billion if 10 % of refrigerators are operated with controllable compressor.

Washing machine with intellectual power regulator of operation modes saves 60 % of water.

Induction furnace has efficiency above 90 %, instead of 50 % for electric furnaces.

An illuminant for household illumination, with a 20 W luminescence lamp, replaces a 100 W incandescent lamp.

Table 1 shows application areas for power electronic devices and economic effect of their introduction.

OUTLOOKS OF THE DEVELOPMENT OF SALES MARKET OF POWER ELECTRONIC DEVICES IN THE RF

A real method to estimate minimal demands for power electronic devices in the Russian Federation at present is to analyse power consumers according to the data of the RAO "United Energy System of Russia" taking account of the global trends in the development of energy-saving technologies which will finally be decisive also in the RF.

By the 1st of January, 2000, the stated power of the generating works of the RAO "UES of

TABLE 2

Composition and structure of electric power consumers

Consumers	Electric power, billion kW h		Heat power, mln Gcal	
	Total	Fraction, %	Total	Fraction, %
Industry	276.2	49	135.3	30
Including:				
fuel	61.9	11	27.4	6
ferrous metallurgy	41.1	7	3.6	1
nonferrous metallurgy	52.1	9	8.1	2
chemistry and petroleum chemistry	31.7	6	46.4	10
mechanical engineering and metal working	38.5	7	20.2	4
wood working, paper and pulp	9.3	2	4.9	1
construction materials	11.4	2	4.1	1
light industry	3.8	1	2.8	1
food	6.3	1	2.4	1
other branches of industry	14.1	2	15.4	3
Agriculture	29.1	5	5.9	1
Forestry	0.3	0	0.8	0
Transport and communications	56.3	10	5.2	1
Construction	4.7	1	3.9	1
Municipal services	67.6	12	59	13
Population	38.5	7	187.4	41
Other branches	94.9	16	56.1	13
Total	567.6	100	453.6	100

TABLE 3

The structure of consumess of the devices systems of power electronics. Limiting capacity of the sales market for devices and equipment of power electronics

Application area	Stated capacity of power electronic systems, kW	Cost of power electronic systems, mln $	Cost of semiconductor devices, mln $	Types of devices
Transducers for decreasing the expenses) for own needs of generating works	1.20E+07	1.20E+03	400	GTO, JGCT, IGBT, diodes, thyristors, drivers, snabbers
Substations for power export (see Table 2)		1.58E+03	546	GTO, IGCT, IGBT, diodes, thyristors, drivers, snabbers
Industry in general	7.65E+07	7.65E+03	2296	GTO, IGCT, IGBT, diodes, thyristors, drivers snabbers
Including:				
fuel		1.69E+03	505	GTO, IGCT, IGBT, diodes, drivers
ferrous metallurgy		1.07E+03	321	GTO, IGCT, IGBT, diodes, thyristors, drivers, snabbers
nonferrous metallurgy		1.38E+03	413.3	GTO, IGCT, IGBT, diodes, thyristors, drivers, snabbers
chemistry and petroleum chemistry		9.18E+02	273	GTO, IGCT, IGBT, diodes, thyristors, drivers, snabbers
mechanical engineering and metal working		1.08E+03	344	IGCT, IGBT, MOSFET, diodes, drivers, snabbers
Communications (SPS, UPS, memory units, heating, *etc.*)	5.00E+06	3.90E+03	1300	IGCT, IGBT, MOSFET, diodes, drivers
Transport:				
railroad and city electric transport (transforming substations, *etc.*)	1.00E+07	4.90E+02	195	diodes, thyristors
automobile (rudder amplifier, starator device, window raisers, injection central and distributed)	3.10E+02	103		IGBT, MOSFET, diodes, drivers
Municipal services and population	2.90E+07	2.94E+03	980	
Including:				
illumination (turn-on controlling, devices, protection systems, *etc.*)		2.40E+03	800	IGBT, MOSFET, diodes, drivers
heating, domestic electronics		5.40E+02	180	Triacs, drivers, IGBT, MOSFET, diodes
Total		1.81E+04	5.82E+03	

Russia". was 156.2 MW, or 72 % of the stated power of the Russian electric power stations.

A generalized structure of electric power consumers in RF is shown in Fig. 1.

A detailed composition and structure of electric power consumers in 1999 according to the data of RAO "UES of Russia" is shown in Table 2.

Table 2 allows determining the structure of the consumers of power electronic devices and estimating the limiting capacity of their sales market. The newest estimations were carried out starting from estimated net cost of each class of the electronic equipment. The range of net costs of power electronic devices covers the range (0.08 – 2 $/W; the cost is practically inversely proportional to the capacity of a device.

The results of the analysis of Table 2 are shown in Table 3.

The first two items of the Table depict the possibility to use power electronic devices at plants generating and transmitting electric power. Table 4 lists the data on the most important investment projects of the development of energy export by the RAO "UES of Russia".

As it follows from Table 1, the capacity of the market of power electronic equipment in Russia is $ 18.1 billion US, while the capacity of the market of power electronic devices is $ 582 mln US.

It should be noted that these values are under-estimated, in particular, because they do not take account of the foregoing growth of the generating capacities in the nearest years (Fig. 2), and expenses for purchasing the power electronic equipment during reconstruction and repair of the objects of power industry (for example, see Table 5). This thesis is confirmed by the following citation: "In order to maintain the safe state of electric power industry, it is necessary to replace about 6000 MW of the basic generating equipment per year", said Secretary of the Safety Council of RF S. B. Ivanov on the 3rd of March, 2000 in Surgut at the All-Russia meeting on the development of

TABLE 4

The most important investment projects for the development of the export of electric power by the RAO "UES of Russia"

Energy bridge, capacity of energy network	Construction steps and their cost	Cost of power electronic equipment, mln $	Cost of power electronic devices, mln $	Types of devices used
Russia – countries of Central and southeastern Europe (L'vov and Poltava sections) 3600 MW	1: 6 billion kW h/year. 2: 13–15 billion kW h/year. Investment for the second step: $ 310 mln	220	55–65	Diodes, thyristors, GTO, IGBT, drivers, snabbers
Russia – countries of the Central and West Europe, through electric networks of Byelarus and Poland 4800 MW	1: 10 billion kW h/year. 2: 16 billion kW h/year. Investment for the first step: $ 250 mln, for the second step $ 180 mln	200	50–60	The same
Russia – Japan 4000 MW	1: 122.0 billion kW h/year. 2: 25 billion kW h/year. Preliminary estimate of investment: $ 9600 mln	480	160	The same
East – West 4000 MW	Preliminary estimate of investment $ 1300 mln	480	160	The same
Russia – China 2000 MW	Export volume: 15–18 billion kW h/year. Preliminary estimate of investment: $ 1500 mln	180	60	The same

TABLE 5

Perspective projects of the reconstruction of power engineering objects

Project title	Project goal	Dates of realization	Designed capacity	Status	Cost, mln $	Viability time
Technical re-equipment and reconstruction of the Kostroma State Regional Electric Power Station (SREPS) JSC	Replacement of worked-out power blocks 4×K-300-240 of the 1st section by steam gas installations 4×PGU-325 to provide reliable power supply for consumers of the UES of the Centre, to increase efficiency of the station and to decrease hazardous exhaust	2 years	The 1st section: 1300 MW. The stated capacity of the station after reconstruction: 3700 MW; power generation: 21.6 billion kW h/year	Pre-design investigations have been carried out	550 own and loan funds	8 years
Reconstruction of water-heaters of the 1st section at the Ryazan' SREPS JSC	Providing reliable power supply to consumers of the UES Centre, increase of the efficiency of the station and improvement of ecological status	2 years	1st section: stated capacity: 1200 MW; power generation: 7.2 billion kW h/year	technical and economical description of the reconstruction of the 1st section	200 own and loan funds	8 years
Reconstruction and technical re-equipment of the first section of the Konakovo SREPS JSC	Replacement of four energy blocks K-300-240 by the steam gas installations 4×PGU-325 to provide reliable power supply to the consumers of the UES centre, increase of the efficiency of the station, improvement of ecological status.	3 years	Stated capacity of the station after reconstruction: 2500 MW, including the 1st section: 1300 MW; power generation: 14.2 billion kW h/year	Reconstruction design is prepared	570 own and loan funds	8 years

Reconstruction and technical re-equipment of the 1st section of the Cherepetsk SREPS JSC	For reliable power supply to consumers of the UES Centre, increase of the efficiency of the station and improvement of the ecological status	2 years	Designed capacity of the reconstructed first section: 600 MW; power generation: 3.6 billion kW h/year	Preliminary technical and economical description	300 own and loan funds	7 years
Reconstruction of the 1st section of the Troitsk SREPS JSC	Increase of the reliability of energy supply to the consumers of UES of Ural, reconstruction of the water-heaters of the 1 section (6×PK-14) by transferring them to gas fuel; increase of the efficiency of the station, improvement of ecological status	3 years	The stated capacity of the 1st section: 1059 MW; power generation: 6.0 billion kW h/year	Preliminary technical decisions	450 own and loan funds	7 years
Reconstruction of the 1st section of the Irikla SREPS JSC	Replacement of the worked-out energy blocks 4×K-300-240 of the 1st section by steam gas installations 4×PGU-325 to provide reliable energy supply for the consumers of UES Centre, to increase the efficiency of the station, to improve ecological status	4 years	Stated capacity of the 1st section: 1300 MW; power generation: 7.5 billion kW h/year	Preliminary technical proposals	620 own and loan funds	8 years

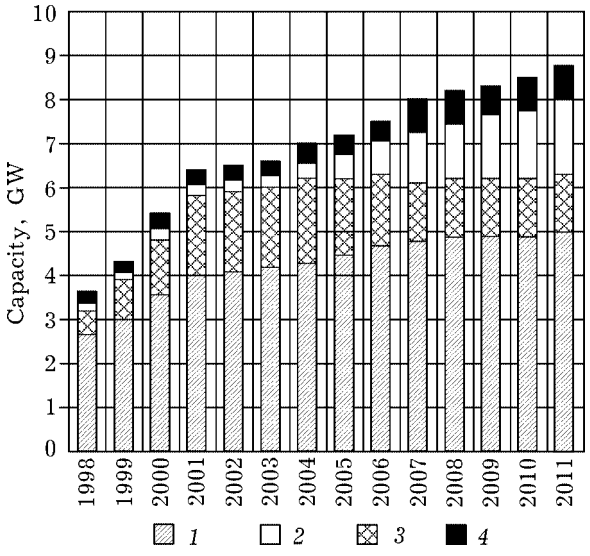

Fig. 2. EStimation of electric power stations capacity in Russia in 1998–2001: *1* – thermal, *2* – gas-turbine, *3* – hydraulic, *4* – nuclear.

the fuel and power complex of Russia. The expenses for reconstruction of power equipment can be estimated using the data of the Table 5 listing perspective real projects aimed at the reconstruction of electric power objects of the RAO "UES of Russia".

CONCLUSIONS

In spite of the recession in the national economy within the recent decade, Russia still occupies one of the leading places in the world in the production and consumption of electric power. The stated capacity of electric power stations of Russia by the end of the year 2000 exceeds 220 GW; more than 850 billion KW h will be produced during the current year. At the same time, the consumption of energy per the production of a unit of the gross domestic product in Russia exceeds the corresponding characteristics of developed countries and the major part of the developing countries of the world more than by a factor of 2.

The state of electric power industry of Russia is not warranted stable. According to the data of the RAO "UES of Russua", by 2005 about 40 % of the acting capacities of electric power stations will have worked out their resources; by 2010 about 55 % will have done so. At present, the increase of the efficiency of energy consumption is not only a method to decrease expenses but also an important means for the revival of economy.

As the world's experience demonstrates, even the introduction of electronic regulation of the existing systems of electric drives and illumination without essential changes of the technology will provide the decrease of the specific power consumption by 20–30 %. The development and large-scale introduction of new technologies, incorporating semiconductor power electronics as an essential part, provides multiple decrease of electric power consumption for the production of a unit of the gross domestic product.

At present, the scale of using energy-saving devices based on the application of modern power electronic systems does not exceed 10 % in Russian economy. Potential value of the Russian market of power electronic systems for the forthcoming decade can be estimated as 4 to 6 billion dollars per year, depending on specific scenario of the development of Russian power industry. The cost of semiconductor power devices in the world practice accounts for one third of the cost of power electronic systems. Correspondingly, the potential volume of the market of semiconductor devices for power electronic systems intended for application in Russia is 1.3 to 2 billion dollars per year.

The fraction of the Siberian region in the Russian market with respect to various power electronic systems is 11 to 14 % and can be estimated as US $ 600–800 mln per year.