SOME TRENDS IN CURRENT PHOTOVOLTAICS

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Abstract

Some tendencies in modern photovoltaics are considered in the context of the studies carried out at the All-Russia Institute for Electrification of Agriculture of the Russian Academy of Agricultural Sciences.

1. Introduction

Along with the escalation of capacities of the electricity production on the basis of conventional technologies in the world, there is an active search for new ways for lowering the price of the electricity produced by solar modules and increasing the efficiency of solar energy conversion in electricity.

Current photovoltaics is one of the most rapidly developing types of renewables. The annual world gain of the installed solar modules exceeds 50% of module manufacturers. The increasing number of countries is included into number of PV module manufacturers.

In PV modules market, there is a large number of modules of new designs; the relative share of solar cells based on polycrystalline silicon as well as the share of solar panels on the basis of film technologies (Fig. 1) is growing [1]. In this connection, works on the search for new technologies for designing solar cells and increasing the efficiency of solar cells and modules on the basis of conventional technologies are being intensively carried out.

Despite the fact that Russia is not included into the list of world leaders on manufacture and installation of PV modules, scientific institutions in the country carry out interesting innovative studies on designing new and modernizing existing technologies of PV conversion of solar energy. All-Russia Research Institute for Electrification of Agriculture (VIESH) is one of the leading scientific institutions working in this direction. It is notable that the Russian delegation to the first exposition of Russia at the international fair on solar power InterSolar Europe 2012 (Munich) was composed of two participants from the domain of science, one of which was Ioffe Physical Technical Institute and the other VIESH. Works at the institute are initiated according to the most urgent tendencies of world photovoltaics. A number of these works conducted at the institute in this direction are considered.

2. Brief Description of Some Trends

2.1 Solar grade silicon.

More than 95% of all solar power plants in the world are made of silicon. The silicon content in the Earth crust is 29.5% of its total mass, so it ranks next to oxygen, the uranium content being 0.0003%. Regardless the fact that the amount of silicon in the Earth crust exceeds that of uranium by 98 300 times, the cost of single-crystal silicon is just insignificantly lower that the uranium cost, which is explained by the use of outdated faulty chlorine technology of silicon production (Siemens process). The SSI VIESH specialists have developed unique chlorine-free technologies of silicon production with low energy consumption protected by 8 RF and US patents.

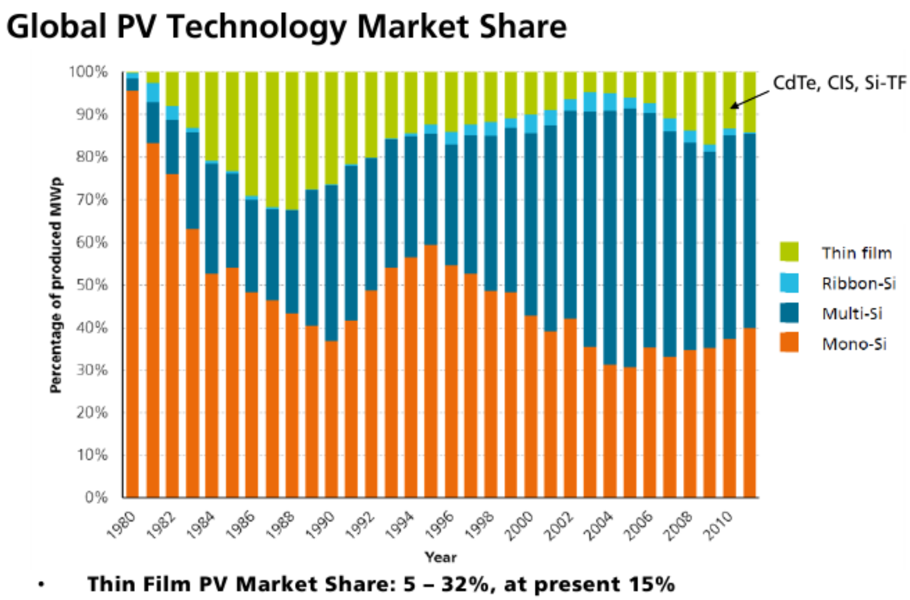

Fig. 1. Share of production of different type modules
(Quelle: Daten: Navigant Consulting, Graphik: PSE AG 2012).

Another approach implies the reduction of silicon consumption from current 6–8 tons per one megawatt by 100–1000 times due to the use of new types of concentrators and matrix silicon solar cells (MSC) developed in Russia.

2.2 Solar concentrators.

SSI VIESH has developed and patented tracking solar concentrators with 100-1000 concentration, and stationary nontracking concentrators with 3–5 concentration [2]. The two types of concentrators provide uniform illumination of photovoltaic solar modules, which is extremely important for operating SPP with concentrators. Nontracking concentrators concentrate not only direct radiation, but also part of diffuse (scattered) radiation within the range of aperture angle, which raises the installed capacity and energy production of solar energy plants.

2.3 Matrix solar cells.

A complex of studies on the development of the theory and technology of practical use of photoelectric conversion of solar energy by means of matrix solar cells, which provide significant efficiency of solar modules and photovoltaic competitiveness, has been performed. Matrix solar cells of third generation have been developed [3–5].

For manufacturing these cells, an original technology was developed, which is schematically illustrated in Fig. 2. It is evident from the figure that the structure with p–n junctions is made of a multijunctional structure. The resulting plate with p–n junctions has a perpendicular orientation to the surface.

The physical form of this system is presented in Fig. 2 to the right. This arrangement of p-n junctions provides a number of advantages, which make it possible to design new interesting devices.

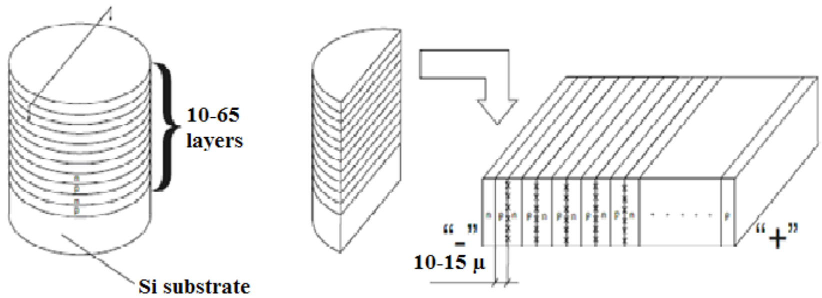

Fig. 2. Scheme of fabrication of matrix solar cells with vertical p–n junctions.

3. Photovoltaic solar modules of new design

The development of matrix solar cells gives the possibility to create PV modules with a new design. (fig.3).

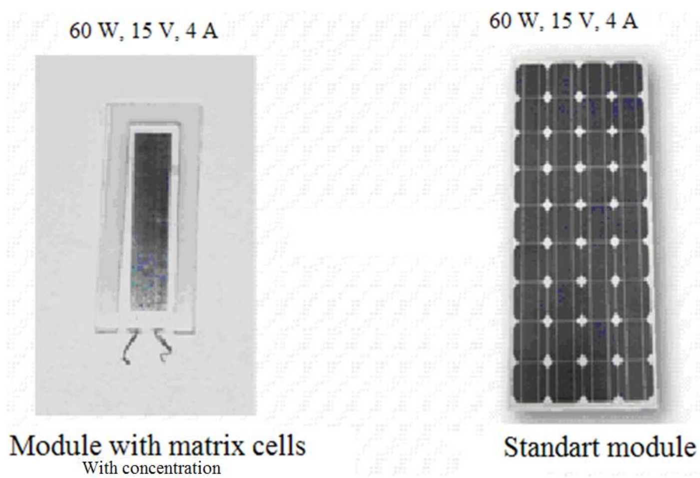

Fig. 3. Appearance of the PV module on matrix elements (left) and a standard PV module (right).

This type of modules based on matrix cells in aggregate with a concentrating system based on Fresnel lenses make it possible to prepare PV modules with efficiency more than 20% (fig. 4).

3.1 Increase of depth of incident solar radiation utilization.

An increase in the range of application of incident solar radiation and wider use of the entire spectrum of sunlight looks to be a very important task. For this purpose, cascade solar cells have been developed [6]. As alternative, another approach was developed and special systems were investigated. By means of spectral decomposition of sunlight with use of prisms and dichroic lenses, they permit using a wider range of solar radiation spectrum with the assistance of cells on a basis of semiconductors with different forbidden gaps.

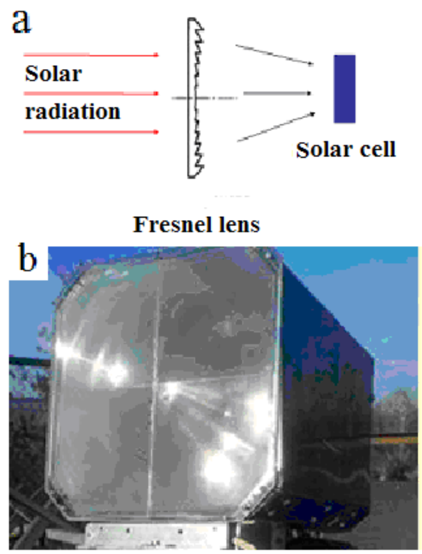

Fig. 4. Basic scheme (a) and appearance (b) of a PV module based on silicon matrix solar cells with a Fresnel lens as a concentrator.

3.2 Estimation and prediction of PV solar cell parameters.

A theoretical method for estimating the parameters of solar cells and modules was proposed and developed [7–9]; it is based on the account of the important feature of the internal photoeffect, which consists in the fact that a photon of sunlight irrespective of the energy level during interaction with the semiconductor creates only one electron-hole pair and the sunlight has a complex nature and is characterized by spectral distribution of photons of various wavelengths.

The main point of the methodology is the consideration the formation of electron-hole pairs under the influence of photons of a given site of the solar spectrum with semiconductor (silicon) used as a solar cell substrate. This calculation was carried out for the determination of a line of solar cell parameters, which is important from theoretical and applied point of view, such as solar cell efficiency coefficient vs the band gap of the semiconductor for different temperatures of operation, FF values for wide range of solar radiation levels, Rx · 103 W/m2 , theoretical (utmost) efficiency of solar cell vs the band gap of the initial semiconductor for standard terrestrial (A) and space (B) spectrum of solar radiation, the same parameters vs the band gap of the semiconductor for different temperatures of operation, silicon layer thickness decreasing light flow density in time vs wavelength, and so on.

4. PV Thermal Module Design

The heat and electricity generation in PV Thermal modules was studied to prove their parameters and to offer recommendations about the optimum modes of operation taking into account the requirements of the user (fig.5).

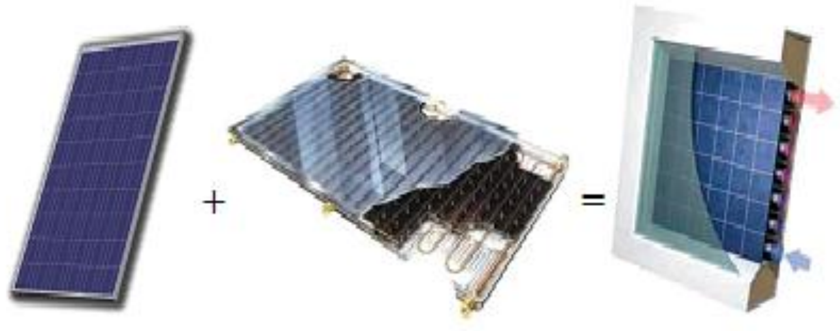

Fig. 5. Photovoltaic-thermal technology concept.

The prepared PV Thermal module breadboard model (fig.6, fig.7) was investigated under natural conditions by specially developed means.

During these experiments, some parameters of the module, such as Uos and Isc, were controlled with the subsequent determination of the PV block efficiency, water temperature in the container, the temperature of the surface of photo cells and the surface of the base on which they were mounted. Temperature distribution both over the height of water in the container and on the surface of the cells of each number was estimated. Results of the study made it possible to formulate specifications for commercially produced samples and to classify the modes of operation according to requirements of the consumer concerning the generation of maximum power of electricity, heat, or both electricity and heat.

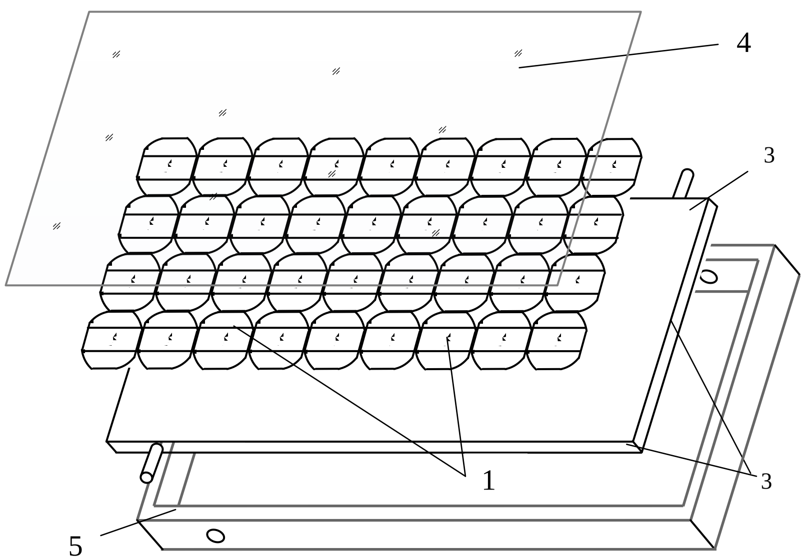

Fig. 6. PV Thermal cogenerative module design: (*1*) PV panel; (*2*) thermal absorbing element (absorber); (*3*) tank with a heat-carrier; (*4*) transparent isolation (glazing); and (*5*) heat-insulating case.

Fig. 7. Photograph of the developed breadboard model of the module.

5. Long-life PV modules

All structures, materials and fabrication technologies existing in the world provide the service life of solar modules of 20 years in tropical climate and 25 years in temperate climate with 20% capacity loss by the end of the life cycle. The cause of this is ultraviolet and temperature degradation of optical polymer sealing materials, i.e., ethylene vinyl acetate and other plastics. The used technology of module lamination includes vacuum processing, heating up to 150^{o}C, and compressing with 80 000 kWh energy consumption per 1 MW of solar modules. An energy saving technology for assembling the modules has been developed; according to estimations, it twice increases the service life of the modules and provides their reliable operation with concentrators under conditions of highly concentrated sunlight.

In the new technology developed at the SSI VIESH, ethylene vinyl acetate and lamination are replaced with a cast silicone composition with further hardening of the liquid component into polysiloxane gels (fig.8).

With the application of a new complete set of the equipment, the PV modules with an individual capacity of 60 W (1180 x 530 mm) to 150 W (1180 x 1040 mm and 1600 x 800 mm) have passed endurance tests under conditions of concentrated sunlight.

As a result, the service life of the solar modules has increased twice, i.e., up to 40–50 years; the electric capacity increases owing to higher gel transparency and SC operating temperature reduction, and the energy consumption in solar module production has reduced by 70 000 kWh/MW. Moreover, the doubled service life increases electricity production by 20 mln kWh per 1 MW of peak capacity.

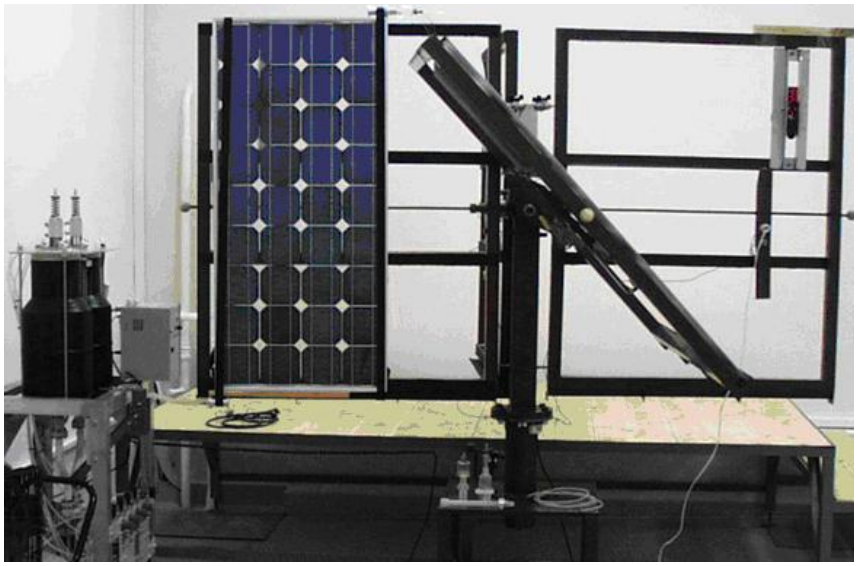

Fig. 8. Photograph of the installation for filling PV modules with a two-component silicone composition and the subsequent hardening of the liquid component into polysiloxane gels.

6. Round-the-clock solar electricity production

Continuous round-the-clock and all-year production of solar electricity is a major problem in the development of the global fuel-free energy industry capable of competing with the fuel power industry. SSI VIESH has developed and patented regional and global solar energy systems providing electricity generation and supply to customers regardless of time, day, and season [10, 11].

A computer simulation of a number of solar energy systems of different location and power was carried out.

The Russian solar energy system comprising two solar power plants (SPP) installed in Chukotka and Kalinigrad (RF) or Pinsk (the Republic of Belarus) and connected to the RF unified power system. The photoactive area of solar power plants with 20% efficiency is a square with 25-km side. Each solar power plant electricity generation is 125 mln kWh. As initial data for calculation, we used long-time average annual values of insolation for the areas of SPP location. This solar power system makes it possible to supply electricity in the amount of 500 TWh on round-the-clock basis for the period of 5 months from the 1st of April to the 1st of September and to satisfy all the Russia demands for electricity in this period. For two more months—March and September—electricity can be supplied for 22 hours per day. In this case, all fuel power plants will be transferred to standby category, and the saved gas, oil, and coal can be exported.

If a solar power system in the Kara Kum desert of Turkmenistan is included into this power system, the amounts of electricity produced on round-the-clock basis will be enough to supply energy to the entire CIS for 6 months.

For creation of the Global power system, it is necessary to solve two problems: (a) the creation of a wide network of the generating centers of high capacity and (b) the development and practical implementation of effective technologies for transfer of the electric power to long distances for maintaining the overflows of energy in the global system.

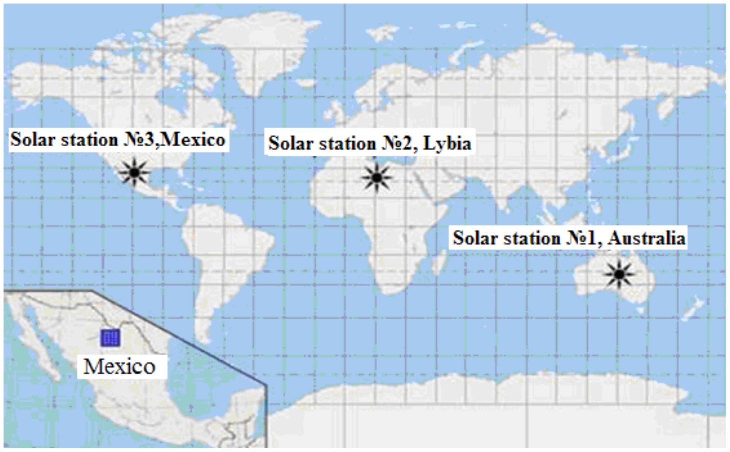

Fig. 9. Global solar power station.

An example of this system is represented in Fig. 9; monthly average production of electric power at the global solar power supply system is shown in Fig. 10.

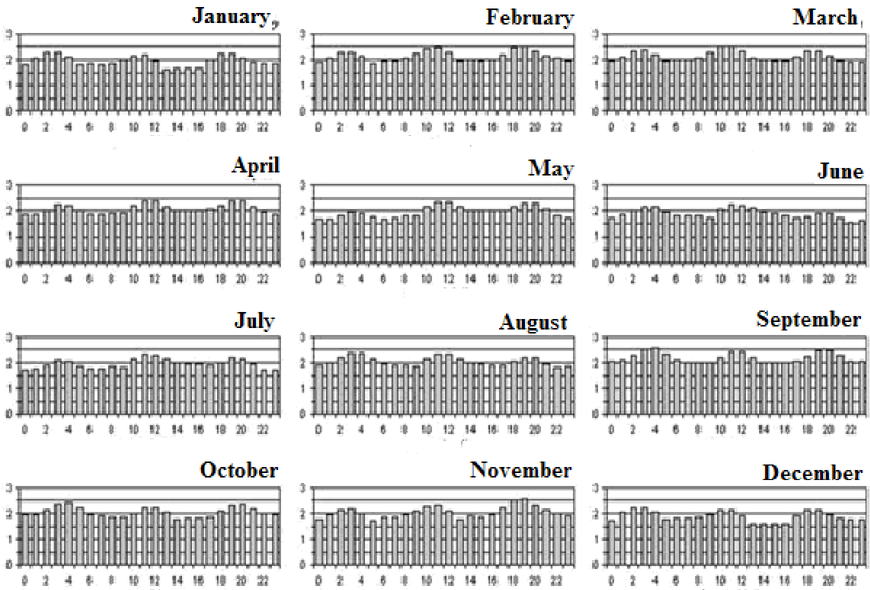

Fig. 10. Monthly average production of electric power at the global solar power supply system.

It is evident from Fig. 10 that the monthly average production of electric power at the global solar power supply system is 17817.6 TW·h, while the annual consumption of electricity in the world is 13810 TW·h (2001).

7. Conclusions

Intensive development of innovative technologies for generation of electric power and its transfer to considerable distances will give the possibility to implement the idea of creation of a global power system. This system will unite large generating capacities in various zones of the terrestrial surface, in the territories that are not used in economic activities, but possess high RES potential, and also to create solar power stations in the circumterraneous space. They will provide an uninterrupted supply of energy to consumers both on the Earth and in space and completely cover the constantly growing demands of the mankind for energy.

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