P a r t 8

RENEWABLE ENERGY SOURCES

8.3. Solar power plants and heat supply system

8.3.5. Analytics

8.3.5.1. Overview of development of solar power plants and heat supply systems as of 2014

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ABSTRACT

There is a boom of development of solar sources of electrical and thermal energy. According to [1] total capacity of renewables (without hydro) in the world in 2013 constituted 560 GW_e, including photoelectric converters – 139 GW_e (or 25 %), and also solar concentrators – 2,5 GW_e. In 2013 the increase of photovoltaics constituted 38 GW_e (or +37,6 %). Annually 7…9 GW_e of photovoltaics are installed in China, in 2013 this indicator achieved 11,3 GW_e. Japan is number 2 in introducing solar power plants; in the country 6,9 GW_e was achieved. There solar roof panels for heat supply are mainly implemented, and more and more large-scale photovoltaic complexes are introduced. The world leader in the amount of solar power plants is Germany, the total capacity of which reaches 36 GW_e.

Total world capacity of solar panels for hot water production reached 326 GW_{th} (in 2012 it was 282 GW_{th}, i.e. the growth constituted 16 %).

Experts of International Energy Agency predict that in some 40 years with the improvement of technologies solar energy sources may provide about 9 thous TWh or 20…25 % of the total power production [3].

At the time being in RF power and heat production with solar energy is extremely low because of some reasons, among of them there are the following: the possibility of use of such energy source primarily in southern regions; general problems of renewables vast development in RF (as referred to the survey article on renewables); long time of capital return of solar photoelectric converters. Nevertheless, the nearest development plans are rather optimistic: there is a sharp increase in production of solar panels and modules, some big-scale solar projects are under way. For instance, at Altai region in 2014 4.5 MW_e solar power unit was commissioned, the first of the 5 ones to be built in succession, in Astrakhan region by the end of 2015 it is envisaged to build 6 solar power plants with total capacity of 90 MW_e [4].

This article does not cover the issues of materials' base for production of solar panels and technologies of their manufacturing since it represents a specific sector of industry.

The article contains the materials from the first version of section 8 "Renewables" of the Informational System of Moscow Power Engineering Institute (http://osi.ecopower.ru), prepared by JSC ENIN [3] and more recent actual materials.

1. 1. PHOTOELECTRIC CONVERTERS AND MODULES FOR POWER PRODUCTION

Brief description

Photoelectric converters provide direct conversion of solar energy into electric one using the photovoltaic effect.

The most wide spread in the world practice are photoelectric installations in systems of autonomous and local power supply; and among them the priority is given to the so called "solar roofs". They are mainly set of plane photoelectric modules installed on roofs of buildings and living houses. There are many constructive decisions of the so called "building integrated photovoltaics". A wide spread set of such installations is capable to cover the demand of a settlement or a district. At excess of power capacity, power is forwarded to the grid, at the deficit – the needed power is taken from the grid. The scheme of such an installation is the following: direct current from photoelectric installation goes to an inverter, and after it - to the grid and in parallel to a consumer. Such technology is recognized as the most rational one, it permits to use all of the generated electricity without accumulating it; it smoothes the natural disadvantage of mismatch of periods when the electricity is generated and when it is demanded. When power production and consumption are autonomous, an accumulator must be inserted between the photovoltaic panel and inverter with that the system should have a duplicating source of power.

Two types of photoelectric modules are implemented for solar power plants: plane modules which use radiation of natural intensity, as a rule, they are immovable and modules with concentration of radiation and equipped with a system of following the sun. Ordinary concentrators, as a rule, have small rate of radiation concentration and they partly or fully can work without following the position of the sun, they have the air cooling system of the elements.

At the time being building integrated photovoltaics, separately installed photoelectric units and solar power plants from the point of view of their construction and composition are developed to model decisions and the main task of designers is to choose the right serial modules and elements, to evaluate the efficiency, their lifetime, the cost, payback period. These are the issues that will be tackled further on.

Types and capacities of energy equipment at which it is recommended or possible to implement the technology under consideration

It is commonly assumed to distinguish 3 generations of photoelectric panels:

Crystal panels (first generation):

- mono-crystal, silicic;
- poly- (multi-)crystal, silicic;
- EFG (edge defined film-fed crystal growth technique), S-web (Siemens), thin-layer poly-silicic (Apex).

Thin-film panels (second generation):

- silicic: amorphous, micro-crystal,
- nano-crystal, CSG (crystalline silicon on glass);
- based on cadmium telluride (CdTe);
- based on cuprum-indium- (gallium) celenide (CI(G)S);

Panels of the third generation:

- dye-sensitized solar cell, DSC;
- organic (polymeric) (OPV);
- non-organic (CTZSS);
- elements of cascade structure.

Efficiency of industrial solar elements constitutes 12…17%, in some cases reaching 20 %, and this is not the highest figure for the nearest future; a number of R&D results in many countries and experimental samples prove this outlook.

Plane panel crystal silicic modules make over 90 % of the amount of solar elements production.

According to Solarbuzz [5] the greatest increase in the 2014 market is forecasted in the segment of the modern poly-silicic technologies, it will increase from 23.8 % in 2013 to 27.2 % in 2014. At the same time a share of high-efficient cilicic crystal monotype module will decrease from 29.6 % in 2013 to 29.3 % in 2014**,** but production will be increased in 2014 by 2.8 GW_e due to the expansion of the sector as a whole. Thin-film production will lose part of the market from 9,4 in 2013 to 8,9 % in 2014. Investments in a new thin film elements manufacturing equipment in 2013 decreased to a minimal level in 8 year period; but it is forecasted that by 2015 there will be a substantial increase. Thin film elements though have some advantages over mono-crystal ones because of smaller consumption of materials for their manufacturing (mainly silicon), flexibility, smaller weight and smaller thermal coefficient of capacity decrease with growth of temperature but they have lower efficiency and considerable decrease in parameters during their lifetime.

Still expensive panels of the 3rd and the 4th generations despite the declared very high efficiencies cannot compete with indicated above at industrial and common markets of conventional panels (they find application in some specific fields, such as cosmic techniques).

Below some examples of technical indicators of some wide-spread panels manufactured by two leading companies, both foreign and domestic, are presented. Company Yingli (China) [6] has manufactured about 40 mln panels installed in 40 countries. The company offers a wide spectrum of mono- and poly-crystal elements with base dimensions 1310×990×40 mm and peak capacity of 190…225 W. In RF JSC “Solnechnyi veter” (“Solar Wind”) offers the following series of panels with efficiency up to 17 %, they meet all of the world standards [7]:

Type	Capacity, W	Dimensions, mm	Type of crystals	Voltage, V
MSW-250	250…260	1650x990x38	mono	30
MSW-240-3D	230…240	1650x990x38	multi	30
MSW-200	190…200	1575x807x46	mono/multi	36
MSW-150	140…150	1480x682x46	mono/multi	18
MSW-100	95…100	1185x550x46	mono/multi	18
MSW-75	65…75	776x682x46	mono/multi	18
MSW-50	40…50	546x682x46	mono/multi	18

Manufacturers

There is a great number of manufactures of photoelectric modules. The largest ones in 2012 were:

- Yingli (China) — 2300 MW_e;
- First Solar (USA) — 1800 MW_e;
- Trina Solar (China) — 1600 MW_e;
- Canadian Solar (Canada) — 1550 MW_e ;
- Suntech (Sweden) — 1500 MW_e ;
- Sharp (Japan) — 1050 MW_e ;
- Jinko Solar (China) — 900 MW_e;
- SunPower (USA) — 850 MW_e;
- REC Group (Norway) — 750 MW_e;
- Hanwha SolarOne (China) — 750 MW_e.

Two biggest manufactures “First Solar” (USA) and “Solar Frontier” in 2014 will produce almost 85 % of all of thin film modules.

In RF among the main manufacturers of photoelectric modules:

- JSC “Solnechnyi veter” (http://www.solwind.ru);
- Riazan Metalloceramic Devices Works;
- JSC “NPP Kvant” (http://www.npp-kvant.ru)
- R&D Center VIESH (http://www.viesh.ru);
- JSC Telecom-STV (http://www.telstv.ru);
- Company “Hevel” founded in 2009 GK “Renova”;
- JSC “Rosnano”, the first in Russia manufacturer of thin film photoelectric modules.

Range of applicability

According to [1] in regions with the best solar availability 1 m^2 photoelectric module best oriented towards the sun with efficiency 15 % is capable to produce 230…250 kWh/year of electricity. In [1] one can find a map of the country with indication of solar availability of the regions. The above conditions may be considered as optimal for implementation of photoelectric modules in Russia. Though their implementation under other conditions is of course possible. **Restrictions on application of the technology*:***

- low solar availability at the site of photoelectric installation;
- for autonomous solar installations - duplicating source of power is needed.

Advantages and disadvantages

Advantages:

- general advantages characteristic for all of the renewables (no emissions of pollutants and GHGs, organic fuel savings, diversification of energy sources, company’s image increase aspects, etc.) and besides:
- easy to operate; low operational costs (about 0,005 euro/kWh).

Disadvantages:

- Still very high specific capital investments per kW of installed capacity and cost of produced electricity (despite of annual substantial decrease). During 2011 electricity cost decreased by 50%, and from 2008 - by 75 %. In 2011 for the first time the cost of 1 kWh fell down below USD 1. In 2013 the cost of 1 kWh in sunny regions of the world (Southern Africa, California) constituted less than one euro 10 cents. But in RF these indicators are substantially worse. According to [1] compatibility of photovoltaic compared with traditional sources may be achieved when specific capital investments per kW of installed capacity fell down from 4000…5000 euro/kW_{peak} to 1500…2000 euro/kW_{peak}, efficiency increases to 20…24 % and the lifetime extends to 40…50 years.
- Necessity to implement specific methods of utilization of worn out elements with cadmium telluride (CdTe).

Where in RF the technology is introduced:

- At Altai region in 2014 a 4.5 MW unit of a solar power plant was commissioned, the first unit of 5 planned;
- In Astrakhan region by the end of 2015 it is envisaged to build 6 solar power plant with a total capacity over 90 MW_e [4];
- A number of small-scale photovoltaic installations of non-industrial destination.

Information on existence/absence of author’s rights on the implemented technology, developers and/or legal owners of the technology

In the process of creation and improvement of equipment some components and technologies were defended by author’s rights.

2. 2. SOLAR COLLECTORS (THERMODYNAMIC INSTALLATIONS)

In 1980’s in USA, France, Japan and former USSR some experimental steam turbine power plants with solar heating of a tower mantled boiler with capacities from 1 MW_e to 10 MW_e were constructed (in USSR it was 5 MW_e power plant in Crimea, now dismantled). Concentrating of solar energy system comprising a series of plane mirrors-heliostats focusing radiation at steam boiler. Under some reasons in Russia this technology did not find a development; abroad this technology was developed at a limited scale (total capacity in

2013 constituted 2,5 GW_e). Nevertheless, R&D is under way. In JSC ENIN a combined power and heat production technology was developed; photo batteries provide direct conversion of solar radiation into electricity while heat of a liquid cooling heliostats is utilized in a conventional steam turbine cycle. The efficiency is expected at a level of 26…27 %.

Hot water supply systems

Solar hot water supply systems being very simple from the technical point of view have diffused widely in XX century. Capacity of solar panels for water heating reached 326°GW_{th} in 2013 (in 2012 it was 282 GW_{th}, i.e. the increase was 16 %). In RF solar collectors produce over 40 thous GCal, which is as yet negligible in the balance of heat supply systems in RF.

Brief description

Solar heat supply systems can be classified using various criteria:

Destination:

- hot water supply systems;
- heat supply systems;
- combined systems

Heat carrier:

- with liquids;
- with air;

Duration of work:

- year-around;
- seasonal

technical realization of a scheme:

- single-circuit;
- double-circuit;
- multi-circuit.

The core element of a heat supply system is a plane solar collector. Blackened metal (as a rule) panel with canals for heat carrier is placed inside the collector. The panel is placed inside a thermo-insulated box with a glass cover from above. Collectors are assembled as a rule in double-circuit schemes with natural or forced (pumps) circulation. In the first circuit liquid (often antifreeze) is running through the panels, and in the second - water is running heated in a tank-accumulator. But single circuit systems still exist.

Possible systems modes of work:

- participation in covering heating loads and hot water supply (heat supply mode);
- participation in covering only hot water supply loads during the whole year (year–around hot water supply mode);
- participation in covering only hot water supply loads during only non-heating period (seasonal mode of hot water supply).

Realization of the first two modes is possible with double-circuit scheme.

Types and capacities of energy equipment at which it is recommended or possible to implement the technology under consideration

Heat load is defined for each concrete object individually since it depends on volume of a building, its configuration, thermal resistance of walls and floors and other factor. Climate data are represented by monthly average total and dispersed radiation on horizontal furnace and monthly average ambient air temperature. Naturally, those characteristics of panels are among decisive factors.

As an example below there are technical data of solar collectors “Sokol” manufactured by JSC “VPK NPO Mashinostroenie” (quite characteristic):

- directions: 2021x1014x98 mm;
- area: 2,05 m^2;
- aperture 1,9 m^2;
- weight: 49 kg;
- volume of canals: 1,5 l;
- working pressure of heat carrier: 0,7 MPa;
- coefficient of absorption by the cover: 0,92…0,95;
- rate of blackness: 0,05…0,10;
- transparent insulation: 4 mm thick tempered glass, resistant to all kind of outdoor impacts.

Approximate range of capacities and options of systems to implement

Hot water capacity, l/day	System type	Description of the system
< 150	Mono-unit	The most simple system in which solar collector (SC), accumulator tank (AT) and pipelines are united in one module fully assembled by a manufacturer and as a rule nondetachable. It is implemented for seasonal hot water supply for home use and at object which are functioning only in summer time.
150…300	Small-scale without a pump (“Thermo-syphon”)	System in which the heat carrier moves in the collector circuit due to the difference of density heated in SC and cooled in AT. In such systems AT is placed higher than SC and the difference between them is small. Often is implemented for seasonal hot water supply.
300…500 (750)	Small with pumps	System with forced circulation of heat carrier; a pump is placed in the collector circuit; the system is equipped with automated control. Locations of SC and AT are voluntary. The system may be implemented for seasonal hot water supply, as well as for year-around hot water and heat supply.
> 1000	Large-scale multi-circuit (“industri-al”)	Systems with forced circulation of heat carrier. They are implemented for heat supply of objects with large-scale heat load in the mode of seasonal and year-around operation в режиме сезонной.

Cost of solar collectors manufactured in RF constitutes about 4000 RUB/m^2, and specific capital investments per 1 m^2 of a collector about 6000 RUB. Cost of heat in Southern regions of Russia is about 900 RUB/GCal. According to [1] at capital investments and operational costs of 500 Euro per 1 kW-peak of installed capacity and 0,005 Euro/kWh correspondingly, system lifetime is 20 years, efficiency is of 70…75 %, production cost of energy will be 2,1…2,3 Euro/m^3 of hot water in average for the whole period of operation.

Equipment manufacturers

Among manufacturers of solar panels there are domestic companies (the leading one is JSC “VPK NPO Mashinostroenie” – http://www.npomash.ru), and from the neighboring and remote countries (Ukrainean PKK Sintek ltd – www.sintsolar.com.ua, German Vaillant – www.vaillant.ru, Chinese companies).

Range of applicability:

- in regions with sufficient solar availability; according to [1] guaranteed economic efficiency may be provided at latitudes of Orel, Tambov cities and further on to the South;
- in case there is a conventional heat supply system at the object (if the system is not only a seasonal type).

Restrictions on technology application:

- lack of solar availability;
- absence of a doubling conventional heat supply system (if the system is not only a seasonal type).

Advantages and disadvantages

Advantages:

- general advantages characteristic for all of the renewables (no emissions of pollutants and GHGs, organic fuel savings, diversification of energy sources, company's image increase aspects, etc.) and besides:
- serial production equipment by RF companies;
- systems have automated control;
- simple in operation; low operational costs.

Disadvantages.

Dependence on solar intensity during a day and season (there is a minimal productivity of the system at maximal demand in heat in winter time).

References

There are many facilities in Southern regions of Russia. Below there are some examples in Krasnodar region:

- Thermal plant in Tikhoretsk town with collectors area of 96 m^2;
- Resort center "Rassvet" in the settlement Blagovestchenskaya (39 m^2);
- Fleet vehicle OOO "Krug-98" (28,5 m^2);
- Hotel in the settlement Arkhipo-Osipovka (26,2 m^2);
- Resort center "Magadan" in the settlement Loo (30 m^2);
- Resort center "Maiak" in the settlement Veselovka (47 m^2);
- Resort center "Lesnaya Poliana" in the town Novorossiisk (60 m^2);
- Boiler house in the town Anapa (413 m^2);
- Solar-fuel boiler house in the settlement Soloniky (268 m^2);
- Helio-unit at the boiler house №35 in the settlement Anastazievskaya (32,1 m^2);
- Helio-unit at the boiler house №32 in the settlement Nestchadimovskyi (32,1 m^2).

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