SOLAR ENERGY UTILIZATION IN THE USSR

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ABSTRACT. The conditions for solar energy utilization in the USSR are not too favorable. Only in the country's southern regions is there sufficient insolation to make solar energy utilization economical. In higher latitudes only seasonable use of solar energy is reasonable. Up to now, the main application of solar energy was to produce low temperature heat for hot water production, drying of agricultural goods, space heating and thermal treating of concrete. A substantial part of the solar heating installations is flat plate solar collectors. The total installed area of solar collectors slightly exceeds 100,000 m^2. The collectors are produced by industry, as well as by small enterprises. In some cases selective coatings are used over the absorber plates; black nickel or chromium is the main coating material. Recently, new projects were launched to develop and produce advanced collectors with enhanced efficiency and reliability. Substantial progress has been made in the USSR in developing and producing PV cells, mainly for space applications. Terestrial application of PV is only in a very early stage. About 100 KW of PV cells are produced annually in the USSR, based on mono or polycrystalline silicon. Some experimental PV-arrays in the range of several tenths of KW are installed in different places. R&D work is carried out to produce thin film cells. Efforts are in progress to construct automated production lines for 1 MW per year of crystalline and amorphous silicon. In the Crimea, a solar power plant SES-5 (5 MW peak power) was commissioned some years ago. The plant is of a tower type, with a circular heliostat field. The plant's working fluid is steam. The experience gained demonstrates that this design concept has several disadvantages. The cost of electricity produced by such type plants is extremely high. Recently, alternative types of solar power plants have been under development, in particular, a project to construct a 1 MW parabolic through plant. A combination of thermal solar with PV also has been investigated, to use solar energy in a cogeneration mode.

INTRODUCTION

Renewable energy sources (RES) have a very large potential in the USSR; in particular, solar and wind energy. Large amounts of energy can be derived from different types of wastes (agricultural, industrial, residential). Significant power can be extracted from hydraulic energy of small rivers, which can be utilized by mini- and micro-hydraulic plants.

The mere enumeration gives the idea of the diversity of RES. Therefore, the approaches for their utilization also have to be quite different. But all of them have a common feature — the rather low energy density of the primary energy source. It is particularly valid for solar and wind energy per unit of ground surface. It is obvious, therefore, that facilities for utilizing RES must be rather large, material consuming and, hence, expensive. In addition, the efficiency of the devices which convert RES into useful energy is usually low, mainly due to rather low temperatures of natural heat sources, etc. Taking into account the recent low prices of conventional energy sources and the above-mentioned reasons, RES cannot economically compete with fossil fuels. Therefore the attitude towards RES has been more or less hesitant, and investments in RES R&D and related industries have been insufficient. This low-level funding influences the quality of RES equipment: it has poor availability and reliability, low efficiency and high costs.

On the other hand supporters of wide RES implementation emphasize that they are environmentally benign and their utilization can help to solve some social problems. These advantages are not yet supported by legislation and, therefore, have no reflection in government policy.

STATE OF THE ART IN SOLAR ENERGY APPLICATIONS

At the beginning of 1990 the total energy contribution of RES in the USSR was about 1.2 mln ton of coal equivalent (TCE) per year. The share of different sources was as follows:

- solar energy (heat) — 15%
- geothermal energy (heat) — 45%
- biomass energy (biogas) — 4%

Electricity production by RES (sun, wind, geothermal, tidal) was negligible. The mini- and micro-hydraulic plants (less than 5MW in one unit) were an exception; in 1989, they produced about 1 bln kWh of electricity.

The aforementioned quantities of energy were produced by the simplest installations.

1. Solar heat

Solar heat was produced by flat plate collectors whose total installed area is about 100,000 m^2. In most cases they are fabricated from steel (a small fraction is from aluminium) with one sheet of cover glass. The average heat loss coefficient for these collectors is 6-7 $W/m^2 \cdot {}^\circ K$. In 1989 one of the producing shops started to fabricate steel collectors with black chromium selective coating, having a heat loss coefficient of about 4 $W/m^2 \cdot {}^\circ K$. Initial steps were taken towards production of plastic collectors as well as vacuum tube collectors, etc. (Figure 1).

The cost of industrially produced flat plate solar collectors is now about 50 Rbl/m^2 and the total cost of a solar heat water installation including pipes valves, pumps and storage tanks is about 100 Rbl/m^2. At latitudes of 40-45°, one m^2 of solar collector can produce annually about 0.1 TCE of heat at a temperature of 40-60°C. Using the methodology which was recently adopted in the USSR, the cost of heat produced by such an installation will be 200-220 Rbl/TCE. This is about 2-3 times higher than the cost of heat produced by conventional fuels in most regions of the country.

Presently, most of the solar collectors are used for hot water supply of individual units or groups of consumers. There is some experience in using solar installations for home-space heating. In this case about 50% of the house's annual heat demand is

Table 1. *Prospects of RES utilization*

Year	RES contribution (mln TCE/y)
1991	1.2
1995	6+7
2000	20*

* solar share is about 10% of total RES output

Total collectors area:
about 100,000 m^2 of flat plate collectors.

Heat loss coefficient:
6+7 $W/m^2 \cdot {}^\circ K$ (usual collectors)
4 $W/m^2 \cdot {}^\circ K$ (black chromium selective coating)

Cost of collectors:
50 Rbl/m^2

Cost of installation:
100 Rbl/m^2

Cost of solar heat at latitudes of 40°-45°:
200+220 Rbl/TCE

Cost of heat produced by conventional fuels:
70+100 Rbl/TCE

Fig. 1. *Solar heat in the USSR*

1. TURKMENIA
(combine "Solntze")
- desalination facilities
- drying modules cotton, fruits, grapes, etc.
- chlorella breeding installation
- water pumping
- hot water production

2. UZBEKISTAN
- 1 MW solar furnace (material sciences)

3. DAGESTAN
(Scientific Station "Sun," IVTAN Division)
- several solar houses (active and passive)
- different types of space heating
- combined systems with heat storage and heat pumps
- collectors' testing and certification
- concentrators
- Armenian solar house

4. UKRAINE
(Institute of Technical Thermo-Physics)
- solar refrigeration

5. CRIMEA
- solar conditioners
- concentrators
- hydrogen production

Fig. 2. *USSR solar energy scientific centers*

usually supplied by a conventional fuel. Some solar installations are used for drying of agricultural products and processing of concrete components.

The best conditions for solar energy utilization in the USSR exist in the southern republics. Figure 2 lists solar energy scientific centers. A Scientific-Technological Center Combine, named Solntze (or "Sun" in English), has been operating in the Turkmenian Republic since 1979. During this period the Combine was involved in development and implementation of various installations using low temperature solar heat. A number of solar desalination facilities, greenhouses, hot water producing modules and installations for drying of cotton, grapes, hay and other agricultural products was installed. An interesting unit, constructed at the Combine site, appeared to be an installation for chlorella breeding with a capacity of 1 ton of dry product per year. Similar facilities were placed in different collective farms. The experience gained by their operation is quite positive, but the equipment still needs essential improvements.

A 1 MW solar furnace was erected in Uzbekistan. It is used for development of high temperature technology mainly in material science.

The large "Sun" scientific station, which is an IVTAN division, is located on the Caspian Sea shore near the Daghestan capital Makhachkala. Several houses with solar space heating and hot water supply were installed there, testing different types of collectors. The space heating systems are either conventional-type radiators or more suitable for solar energy low temperature heating loops built into the floor. In some cases the combined systems, including solar collectors, are used to utilize low temperature heat from aquifers. One house was built using passive solar heating principles.

The center is also equiped with facilities for solar collectors testing and certification. For this purpose a large solar radiation simulator was constructed, which facilitates testing of solar collectors with up to 2 m^2 area in steady state conditions. Two solar radiation concentrators are used for accelerated tests of various materials utilized in solar technology.

Several years ago IVTAN, in cooperation with Armenian organizations, designed and constructed a "solar" house near Erevan city. The house is equiped with 40 m^2 solar collectors incorporated into the roof, which are used to provide space heating and hot water. An electrical back-up heater is also provided. This installation is automatically controlled. Over a three year period, records of all the parameters were made to calculate the overall heat balance of the house. This very useful information was used for further improvement of similar installations.

Research and development of solar driven cooling devices is underway at the Institute of Technical Thermophysics in Kiev. Several pilot installations using an absorption concept have been produced and tested. Unfortunately, the equipment is rather expensive.

The Krzhizhanovski Energy Institute (ENIN), is also active in developing and implementing different kinds of equipment for solar energy utilization. Its design office developed different types of flat plate solar collectors. Electrochemical deposition of selective coatings (based on black nickel) for different types of absorber plates were also developed on test sites in Crimea and in Daghestan. Various installations were erected for testing and demonstration of the equipment.

Although this brief description gives the impression of active R&D work in the field of solar energy utilization, there is almost no industrial production of solar installation components. Therefore, all the aforementioned demonstration facilities are very expensive and cannot convince potential customers to use them.

2. Solar thermal electricity

In 1987 the pilot solar plant, SES-5, was commissioned in the USSR. It is a tower type plant with an installed capacity of 5 MW. The heliostat field has an area of 40,000 m^2. A boiler is installed at the top of the 60 m tower, producing steam at 40 atm and 250°C. A heat storage tank with pressurized hot water at 200°C is also provided. The designed electricity production is 5.8 mln kWh per year, but up to now this value still has not been reached.

The SES-5 is an experimental plant and, therefore, its specific capital investment is extremely high — 5,500 Rbl/kW installed. The calculated cost of electricity, at availability of 1650 hours per year, is about 60 kop/kWh! (For comparison, the cost of electricity produced by conventional plants is around 2 kop/kWh; for diesel installations, it is about 7-8 kop/kWh).

3. Photovoltaic cells

During the last decades, photovoltaic cells (PV) were successfully developed for space applications, and in this field reasonably high efficiency and reliability were achieved. But implementation of PV cells for terrestrial application is still in a very early stage. During the last ten years the cost of a PV module dropped from 15 to 7-8 Rbl per peak watt, but nevertheless, it is still too high to be widely used.

During the last few years, about 100 kW mono- and polycrystalline silicon PV cells were produced annually (Figure 3). Several demonstration facilities

I. PILOT SOLAR TOWER, SES-5 (1987)	
• installed capacity area	5 MW
• heliostats area	40,000 m^2
• tower height	60 m
• steam parameters	40 atm, 250°C
• heat storage	water at 200°C
• designed electricity production	5.8 mln. kWh/year
• specific cost	5,500 Rbl/kW inst.
• availability	1,650 hr/year
• cost of electricity	60 kop/kWh
• cost of electricity in conventional plants	2 kop/kWh
II. PV CELLS	
Type of PV Silicon Cells	***Production Rate***
• polycrystalline • monocrystalline • amorphous	100 kW/year

Fig. 3. *Existing solar electricity in the USSR*

in the range of several tenths of kW were installed in different places. Industrial production of PV cells from amorphous silicon has not as yet started.

PROSPECTS OF SOLAR ENERGY UTILIZATION

The energy program for the coming 15-20 years estimates that the contribution of RES would be quite modest, but the rate of their implementation is planned to be rather high. For example, in the five year period 1991-1995, the contribution of RES would increase from 1.2 to 6-7 mln TCE per year. For the year 2000 this figure would be about 20 mln TCE, which is nearly 1% of the projected total energy production for this year. The share of solar energy is estimated to be about 10% of the total RES energy output (Table 1).

To convert these plans into reality , there is a need for measures which could make RES more attractive for individual, as well as for large scale users.

First of all we must recall that the USSR has a highly centralized system of power supply. Most of the country's population is connected to the centralized electricity supply grid. The centralized natural gas supply system is enhanced from year to year. The heat supply in cities is provided by large cogeneration plants or district heating systems. This situation is not favorable for utilization of RES. They either have to compete with the traditional centralized systems, or be used by customers who do not benefit from those systems and receive their energy from expensive fuels transported over long distances. In both cases economical considerations are of paramount importance. The important factors which influence the economic competitiveness of any installation are: the cost of the power unit, the availability factor (i.e., the number of operation hours per year), the service life of the equipment and the operational cost. In the existing equipment, as was already mentioned, all these cannot be considered satisfactory.

For individual consumers a rather important feature is the reliability of installation, supported by proper warranties and servicing facilities. Intensive R&D, therefore, has been initiated to improve dramatically the quality, as well as economical and operational characteristics of the RES equipment. The design and construction proposals were selected, and the winners received government support to develop their projects. Figure 4 lists R&D projects for the next 5 years. Three projects for utilizing solar energy were accepted. The first one is devoted to developing new types of flat plate solar collectors. The existing, industrially fabricated collectors in the

I. Advanced Flat Plate Solar Collectors
- improved insulation
- low iron content glass
- selective coatings
- improved casing (cheap stainless steel, aluminium, plastics)

II. 1 MW Power Plant

Project features:
- parabolic trough collectors
- one water/steam fluid loop
- steam parameters — 130 bar at 425°C
- modules: 51 m long, 400 units
- concentration ratio — 60
- one-axis tracking

Additional features:
- fossil fuel superheater
  steam temperatures — up to 525°C
  maximum cycle efficiency — 28%
- photo-thermal module (silicon PV cells)
  concentration ratio — 20
  capacity — 100 KW
  cells temperature — 60° C
  (provided by cooling)

III. Amorphous Silicon Cells

Project targets:
- production line (modules) — 1 MW/year
- module efficiency — 7%,
- service life — 5 years
- cost of module — 2+3 Rbl/W_{peak}

IV. Combined Units

• solar + biomass • solar + wind	to produce electricity or gas; for water pumping; for agricultural applications, etc.

Fig. 4. *R&D projects for the next five years*

USSR do not meet modern requirements regarding performance, reliability and cost. For example, the steel collectors produced by the Bratsk factory have a weight of 40 kg/m², the thermal insulation is rather poor and the cover glass has a low transparency. The new collectors would be produced from different materials — metals (cheap stainless steel, aluminium) or plastics. Various designs of the collector's casing will be developed. Different insulating materials will be implemented, and low iron content glass sheets with increased strength will be produced. In some cases selective coatings will be provided to enhance the efficiency and, therefore, the temperature of the heated liquid or gas. New production lines will be installed at existing facilities. Along with flat plate solar collectors, vacuum tube collectors are also considered.

The second project deals with the development of a 1 MW solar thermal plant, consisting of parabolic trough collectors. This plant will be constructed at the site of the SES-5 plant to combine some systems and, therefore, decrease expenses. The project has some salient features. First of all, it uses a one loop scheme, i.e., the same water/steam fluid is circulating between the solar receiver and the turbine. The water is heated and partly evaporated in steel tubes, installed inside evacuated glass pipes. The pipes are placed in the linear focus of the parabolic trough concentrators. The steel tube wall thickness is enough to withstand steam pressure of 130 bar at 425°C. The receiver has an aperture of 6 m and provides a concentration ratio of 60. It has a modular design, where each module is 51 m long and supported by a rigid frame. The total receiving array consists of about 400 modules; they are installed horizontally with a north-south directed axis and track the sun by turning around this axis. An important feature of the design is the seal assembly between steel and glass tubes, which is equiped with bellows to allow thermal expansion and flexibility of joints between modules. Several prototypes of this system have been fabricated and tested, demonstrating satisfactory performance. The steam produced in the solar receiver is superheated by fossil fuel up to 535°C, providing a maximum cycle efficiency of 28%.

The second feature of the power plant is a 100 kW photo-thermal module incorporated into it. The silicon PV cells of this module are installed in the linear focus of a parabolic trough, with a concentration ratio of about 20 to increase the cell's efficiency. The cell is cooled to maintain its temperature at about 60°C: the heated coolant then delivers the heat to different consumers. The electricity produced by the PV module can either be used for the plant's needs or be delivered through a DC to AC converter to the grid. It is worthwhile to mention that we are looking for participation of foreign companies in this project.

The third solar project deals with the production of amorphous silicon to produce modules with total annual capacity of 1 MW. The cost of such modules, before the last price increase, was found to be no more than 2-3 Rbl per peak watt.

The aim of the project is to develop a technology which will ensure production of amorphous silicon modules with 7% efficiency and 5 years service life.

There are also some projects, mainly for agricultural applications, which include combined installations of solar, wind and biomass to supply energy to cattle and flock farms, to pump water to remote areas, etc. The objective of these projects is to develop prototypes of equipment which could be transferred to industry for mass production.

ECONOMIC ASPECTS

As was already mentioned, in most cases, energy produced by solar installations (heat as well as electricity) is rather expensive and cannot compete with conventional energy sources.

Still, there are some applications of RES where economic characteristics are not the main criteria to make the best choice. In particular, these are cases where social and environmental aspects become the most important. Some customers at remote sites do not have transmission lines or centralized energy supply systems. For them RES are the only available energy sources which can provide an acceptable standard of living. In these cases, the price of the installation is not the crucial point for the consumer.

Not less important are RES utilization where the protection of the environment becomes crucial. Unfortunately, the evaluation of clean energy costs is yet to be introduced in our country, despite the fact that this problem was often discussed. It is necessary to establish a different pricing system, which considers the ecological features of the delivered energy.

All plants producing electricity and heat should meet ecological standards and install proper cleaning facilities. These measures would increase the cost of energy produced by conventional plants. Therefore, the environmentally benign RES would appear to be more attractive. This could be of particular interest for resort areas, where ecological standards are especially high and therefore the cost increase of traditional energy would be rather high.

Along with the approaches which have to be imposed by law, government also has to play a large role in RES implementation. Recently some measures have been discussed to provide incentives for RES users. They include some grants, loans, tax reduction, etc. In the course of Perestroika these measures appear to be extremely important.

CONCLUSION

Extensive projects to enhance RES and, in particular, solar energy utilization are planned or already have been started. The success of these plans will greatly depend upon industrial investments in RES.

An important impetus can be gained by international cooperation which could accelerate R&D work and enable us to create efficient and cheap installations over a short period of time.