DEVELOPMENT OF INDUSTRIAL TECHNOLOGY AND AUTOMATIC PRODUCTION LINE FOR LARGE SCALE PRODUCTION OF CHRISTALINE SILICON PV CELLS

Dimitrij Strebkov, Petar Rakin *

Key words: *christaline silicon,solar cells, solar modules, mass production,*

ABSTRACT:
On the base of great experience of VIESH in development of solar cells production technologies and in very production of PV cells and modules parties decided to proceed on mutual project of large scale PV cells production. IHIS had a long year wish to start with own production of PV cells believing that use of solar energy is the only alternative for mankind. In some literature, 10 years ago IHIS shown that with existed knowledge was possible to built a solar power plant instead of nuclear one with practically same funding for the same eraction time, having a lot of advantages. Now, both parties accepted the objective of this project to achieve cost-competitiveness of solar energy technologies and to enhance the pace of rural electrification in a cost-effective, reliable, environmentally benign and sustainable manner. To be able to fulfil the accepted objective parties decided to create conditions for development of cheap production of PV grade silicon too, for which today exist high shortage on the market.

1. INTRODUCTION

The main objective of the project is the achievement of competitiveness of technologies of conversion and application of solar energy in comparison with the traditional power technologies. On the basis of the analysis of modern technologies, cost of manufacture and market of solar modules, the nearest (2 US$/Wp) and long-term goal (1US$/Wp) for the decrease of the production cost of silicon solar modules are formulated. For realization of the specified objective the search of the new ways an directions in

* Dr Dimitij Strebkov,The all-Russian Institute of Electrification of Agriculture Renewable sector, Moscow, Russia.
Dr Petar Rakin, Chemical Power Sources Institute, Belgrade,Yugoslavia.

technology, the development of new principles, ecologically pure methods and designs of installations are proposed, allowing to lower expenses on manufacture of system components, to increase efficiency of solar cells up to 20%, to exclude pollution in production process, to lower the cost of solar grade silicon. Major factor, constraining development of the world photovoltaic market, is limitation of resources of crystalline silicon of solar quality and its high cost 40-60 US$/Wp, comparing with the cost of uranium fuel for nuclear power stations. As the contents of silicon in earth crust exceeds the contents of uranium in 100000 times and crystalline silicon is not ecologically dangerous product, such high silicon cost should be explained only by absence of cost-effective silicon technology. The existing traditional technologies of crystalline silicon with use of chlorsilane cycles have a low silicon yield, the high energy consumption, they are ecologically dangerous and consequently are unacceptable far large-scale application in the future. Ecologically pure chlorless technologies of raw solar grade silicon will be investigated and developed, to lower the energy consumption in 10 times, to increase a silicon yield during manufacture from quartz in 5 times, to lower raw feed stock silicon cost to 5-10 US$/Wp. There will be developed ecologically clean automated solar cell technology with efficiency up to 20% and at the production cost 1,5 US$/Wp (nearest goal) and 0,6 US$/Wp (long-term goal). On the basis of developed physical principles of solar energy conversion theoretical models and new designs of cascade solar cells on a basis of geterostructures will be offered with limiting efficiency 93 %, diode silicon solar cell structure, with theoretical efficiency of 44%, multifunction high/voltage solar cells. New technologies of manufacturing of concentration solar cell at conversion of concentrated radiation will be increased up to 3,6 kW/cm2 , density of voltage up to 10 -100 V/cm2, maximum voltage of the solar array up to 32 kV, special sensitivity in a range 1000 -1050 nm – 0.7 A/W. One of the important goals of the project is the increase of a operation time of solar photovoltaic modules. To achieve this goal it is necessary to exclude polymer materials in solar module process and to ensure complete hermetic sealing of modules with application of the inorganic materials. Such technology of hermetic encapsulation of solar modules with efficiency up to 17% will be developed and will be mastered by an industry. The use of solar photovoltaic stations with concentrators began in Russia in 1964. New classes of golographical, prism, compound concentrators, optical schemes of solar stations with focusing mirrors, with stationary concentrators, with a sliding beam and other will be developed and tested. The most effective photovoltaic solar modules with concentrators and the solar/fuel modular power plants with new types of concentrators and new type of concentrators and new high efficient steam machines will be mastered by an industry. Practical creation of such station within the framework of the project will allow to lower cost of the electric power and the energy payback time.

New technologies of solar energy utilization will be offered. There will be developed new hermetically sealed solar electric pumps, low energy consumption solar conditioners, solar installations for clean water, solar cookers and solar cookers and solar water heater with concentrators and photovoltaic receivers, combined solar/fuel cogeneration plants, hybrid solar/wind installations, solar/hydrogen systems including high efficient electrolyses and electrochemical generators with new solid polymer electrolytes, complete energy systems for solar houses and solar villages.

2. OBJECTIVES

The main objective of this Project is to achieve cost-competitiveness of solar energy technologies comparing with traditional fossil fuel energy technologies in order to enhance the pace of rural electrification in involved countries and developing countries in a cost-effective reliable, environmentally benign, sustainable manner.

The objectives may be classified as following:

General objectives

- Assist the involved countries to increase the standards of living of their population by means of utilization of modern of Renewable Energy Sources Technology;
- ensure a sustainable energy supply for population in rural and remote areas of the countries;
- reduce consumption of non-renewable organic energy resources;
- promote technology transfer through the international cooperation and encouraging local industry;
- enhance the social and economic growth through the development of remote areas, solution to unemployment, preservation of environment and education.

Specific objectives

- Develop new cost-competitive solar energy technologies and provide high ecological characteristic of the technological processes;
- elaborate new photovoltaic technologies in order to reduce the cost of photovoltaic systems and increase its life time;
- develop new technologies for low cost solar grade silicon fabrication in view of a total vertical integration of the silicon solar cell fabrication process;
- demonstrate a rapid way of reduction energy cost for solar photovoltaic system application.

3. UP TO DATE SITUATION

Use of photovoltaic technology in Russia begins in 1958 with the launch of the third satellite with solar arrays. Space programs stimulated development of photovoltaic technology for the terrestrial application. At the moment Russia has a well developed photovoltaic industry, highly skilled staff of the scientists and technologist. The modern technological level of photovoltaic corresponds to an initial phase of its use for electric power supply of the household appliance in remote regions, pumping of water, telecommunication stations, in transport and electronic devices. The cost of solar cells is 2.5-3 US$/Wp, modules 5-7.5 US$/Wp and photovoltaic systems 9-15 US$/Wp and the cost of the electric power 0.2-0.5 US$/kWh. The solar systems replace kerosene lamps, dry cells, chemical batteries, and at significant removal from electric grid and low power load – diesel electric generators and electric transmission lines. In Russia there are installed more than 200 solar power plants with the capacity from tens watts up to of tens kilowatts. Among practical examples of solar energy applications it should be noted the solar village in Krasnodar region where on a roof of each house is 2 kW of solar modules were installed, the solar station 24 kW capacity on Black Sea coast, 5MW solar thermodynamic station in Crimea.

In Yugoslavia exists developed research in the fields of PV use of solar energy, having in past developed research on semiconductor grade of silicon, which was used for production of first PV silicon monocristaline cells, already in seventies. Up to now exist only laboratory scale production of PV cells on the base of monocrystal and polycrystal silicon.

By the end of eighties IHIS started negotiation with one Italian and one American partner to built in IHIS joint venture production plant of two junction amorphous silicon cells of 3 MW yearly. Destroying of former Yugoslavia and proceeded economic blockade of Yugoslavia from UN stopped all activities.

VIESH and IHIS agreed mutual activities in creation conditions to start with development of large scale production of PV cells, modules and solar systems but cheap production of PV grade silicon, too.

From parties IHIS is authorised to be a constructor of full approach in creation of mentioned condition for organisation of large scale PV cells production. One of main goals of IHIS activities have to be finding of joint venture partner who will be able to give necessary guaranties for getting proper credit line for the Project.

IHIS and VIESH decided to start with realisation of this Project dividing it in two phases. The first phase shall start as only Yugoslav Project in which shall be included experts of VIESH and Know How for this phase will be on experiences of IHIS and VIESH. The second phase shall be a joint research and venture project of IHIS and VIESH with investment in production lines in Yugoslavia and in Russia.

4. THE FIRST PHASE OF THE PROJECT

New technology for the production of PV grade silicon using high purity Russian quartz.

THE ESSENCE OF A PROCESS:

The conventional technology of semiconductor silicon production includes the transferring of metallurgical silicon into volatile compounds (usually chlorsilanes); the purification of chlorsilanes by rectification; the hydrogen reduction of purification compounds into silicon and the ingots growth. This scheme is similar for electronic and solar silicon, so the main direction of conventional process is electronic silicon production and solar silicon produced by treating of the off-grade electronic silicon.

The proposed method of solar silicon production based on the direct reduction of high pure natural raw materials with the employing of specially designed technology and equipment ensuring the sufficient purity of the resulting product.

There are some rich deposits of the high pure quartz and graphite (a content of boron and phosphorous, for example, less than 0.1-1.0 ppm) in Russia. The analysis show that they can be used without additional chemical purification.

It was developed principal new soot carbon producing technology from natural gas in the pulse adiabatic compression heating devices.

The solar silicon production is proposed to realise in new arc furnace by carbothermical reduction of natural quartz. As reduction material there is suggested to use: natural graphite or soot carbon (variant 1) or natural gas (variant 2). The closed reaction chamber ensures the high ecological parameters of device and decreases the expenditures for ventilation systems. The new equipment allowed the decrease of electric energy expenditures in 10 times per solar silicon mass unit. The lowering of labour-intensity and increasing the silicon output to 90% will allow to decrease the solar silicon value to 2 times.

Today the heat calculations of furnace and reduction processes thermodynamic analysis were made. On laboratory equipment it was received the samples of silicon which confirmed the correctness of the choose method.

THE MAIN OUTPUT PRODUCTION ARE:

- the grain 99.999% purity silicon for ingots growth;

- the crystalline solar grade silicon ingots;

- the silicon wafers for solar cells with size to 125 x 125 mm.

Before the beginning of main production output the profit may be received by selling of intermediate products:

- crushed high purity quartz for optical production (optical fibbers, optical glass) manufacturing;
- soot carbon with the 99.99% purity in pounded or in grains for the needs of polygraph, paints, electrocuting and rubber industries.

THE MAIN ADVANTAGES OF THE SUGGESTED TECHNOLOGY ARE:

- the low cost of solar silicon (in 2 times less then for produced by conventional method);
- the reducing of energy consumption for solar silicon production (to 10 times);
- the usage of patent-clear technologies;
- the ecological safety of proposed process.

<u>**Small-scale production of crystalline silicon solar cells production**</u>

How is already mentioned in the first phase will be used VIESH Know How for production technology of crystalline silicon solar cells, which is in sense simple, cheaper and more ecological benign. With satisfactory quality silicon wafers, technology shall enable a production yield not less than 80 % solar cells with efficiencies of 12 – 14 %.

After feasibility study, which is in process in IHIS, will be decided to use VIESH equipment for solar cells production or to use equipment of a Canadian firm with which

IHIS and VIESH already are creating a joint development work on further development of production equipment for the second phase of the Project getting very automatized production line.

3.1. THE ADVANTAGE OF VIESH SOLAR CELLS MANUFACTURING TECHNOLOGY

1.	No usage of silver paste for contact metallization creating. (In paste silver contact deposition technology about 1000 kg of silver paste with the to-day price 260.00US$ per kg is required per 1MW of solar cells).
2.	No limitations for silicon resistivity and crystal orientation. The possibili y of using the silicon wafers even with thick damaged layers.
3.	One step diffusion for creation of $N^-/P/P^-$ diode structures.
4.	The possibility to apply this technology (after some moderation) for the production of other kinds of solar cells, such as low concentration bifocal and space solar cells.
5.	The possibility of line adaptation to the manufacturing of other semiconductor devices, besides the planar solar cells.

3.2. SPECIFICATION OF ROUND SILICON SOLAR CELL

BASE MATERIAL	MONOCRYSTALLINE p-SILICON 0.5 – 20 cm
STRUCTURE	$N^+/P/P^+$
CONTACT METALLIZATION	tin-lead alloy
CONTACT STRUCTURE	grid with two bars on the front side: overall on the back
ANTIREFLECTION COATING	tantalum pentoxide
AVERAGE EFFICIENCY (max)	not less 12.5% (*)
OPERATING CURRENT at 0.45V	not less 2.0 A (*)

*) Measurement conditions:

Spectrum	AM 1.5
Irradiation	1000W sq.m.
Cell temperature	+25°C

In the first phase production lines are foreseen (for cells and modules) with an output of 0.5 MW/year in one shift or 1 MW/year in two shifts operation. In frame of the first investment of the Project will be created a development laboratory, which shall be equipped to make characterisation of raw materials and products. In this phase shall be created a workshop for assembling of solar systems using the best BOS (balance of system) products available on the world market. But in IHIS and specially in VIESH will proceed research and development of new BOS products too.

During the first phase development will be directed to:

- further simplification of the manufacturing process but with increasing of cell efficiency.The goal which can be achieved still in the second phase of the project shall be 20 % of efficiency ,
- to automatization of the production line getting it with a productivity of 5-10 MW in one shift ,
- in development of new production process for solar modules which shall increase lifetime, but efficiency too. Still in the second phase of the project efficiency of the modules shall be of 17 %.
- in direction of development of use of solar modules creating different solar systems.

4. THE SECOND PHASE OF THE PROJECT

How is mentioned second phase of the Project shall be a joint research and venture project of VIESH and IHIS with investment in production of PV grade silicon, solar cells and modules as in workshop for solar systems too.

It is foreseen on every site to have developed PV grade silicon production line with: 150 t/y and of it 100 t/y for own purposes and 50 t of PV grade silicon for market. Market quantity has to increase every year in mass which correspond to decrease of the price.

On every site to have one production line of 5-10 MW yearly in one shift all together at one site 10-20 MW but with yearly increase of quantity which correspond to yearly decrease of cell price - having every year the same income.

It is foreseen 50% of produced cells to sell on free market, 25% of produced cells to implement in modules for free market and 25% of produced cells use for modules which shall be sallied through solar systems, every time doubling of next price(watt price by modules are double of cells and of systems are double of modules).

On such a way realisation of the project will create good condition for credit repayment and enough accumulation for intensive further research and development of mass production of PV grade silicon and PV cells, modules and systems.

5. THE SITUATION AFTER REALIZATION OF THE PROJECT

On the basis of the analysis of production cost of technologies, market of solar cells and modules nearest (2 US$/Wp) and long-term goal (1 US$/Wp) are formulated on decrease of the production cost of solar modules. The specified goals can be realised at the cost of the crystalline silicon wafer 0,8-1 US dollars on peak watt (nearest goal) and 0,3-0,25 US dollars on peak watt (long-term goal) and the cost of raw polycrystalline solar grade silicon 5-10 US$/kg.

6. COST AND VOLUME OF PRODUCTION OF SOLAR PHOTOVOLTAIC MODULES

	Structure of production cost, US$/Wp	World volume of production, MWp/year
Contemporary state		
Manufacturing a silicon wafer	1,5-1,7	~100
Manufacturing a solar cell	1,3-1,5	
Manufacturing of the module	1,5-1,7	
Cost of manufacture of the module	4,3-4,9	
The nearest goal		
Manufacturing of a silicon wafer	0,8-1,0	5.000
Manufacturing of a solar cell	0,4-0,5	
Manufacturing the solar module	0,6-0,7	
Cost of manufacture of the module	2,0	
The long-term goal		
Manufacturing of a silicon wafer	0,25-0,3	50.000
Manufacturing of a solar cell	0,3	
Assembly of the module	0,4-0,45	
Cost of manufacture of the module	1,0	

The world market for the second phase of the project at the production cost 2 US$/Wp will be 100 GW at the rate of 100 W on each of 1 billion persons, living in the present time without electric power. The capacity 100 W is sufficient for providing of the inhabitants in the developing countries and remote agricultural region of Russia by lighting, TV, small refrigerator and the pump. Annual volume of manufacture at 20 years period of filling of the market is 5 GW.

The third phase of development and realisation of the project at the production cost 1,0 US$/Wp corresponds to large scale utilisation use of solar installations connected with the grid. If we assume the volume of solar energy generation as 10% of global electric energy generation, the solar market will be 50 GW in a year. There are no technical restrictions for utilisation of a solar energy technologies in such scales, however it is necessary to solve many scientific, technological and economic problems to reach such scale of application of solar energy technologies.

7. CONCLUSION

PROJECT IMPLEMENTATION

The project will be implemented in Russian Federation and in Yugoslavia. There will be developed special procedure for transfer of developed solar energy technologies to any organisation and country in the world. The co-ordination will be done through a new

joint venture marketing firm GMT Batteries Corp. (Golden Mean Technologies Batteries). Following organisations are accepted to take part in the implementation of the project:
- The all-Russian Institute of Electrification of Agriculture Renewable sector. Moscow, Russia Responsible Prof. D. Strebkov (Director of the Institute)
- IHIS Holding Corp. (Chemical Power Sources Institute). Belgrade, Yugoslavia, Dr. Petar Rakin (General Director of IHIS Holding Corp.)
- Third party with readiness to join to the Project

EXPECTED RESULTS

Technological

1. development, demonstration of technologies to any organisation and country in the world. New photovoltaic technologies for conversion and application of solar energy;
2. decrease of production cost of solar grade silicon;
3. decrease of production cost of solar cells and solar modules;
4. increase of solar module life time up to 3 years.

Socio-economic

1. job creation in participating countries;
2. limiting rural emigration because of insufficient energy resources;
3. enhancing the rural development of the countries;
4. the enhancement of the local industry and photovoltaic market;
5. protection the environment.

Energetical

The total annual save in energy will be based on the total expected production of solar photovoltaic systems and will be 100-200 kWh/m^2.

Energy pay back time of photovoltaic systems will be decreased from 3-4 years to 1-2 years.

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RAZVOJ INDUSTRIJSKE TEHNOLOGIJE I AUTOMATSKE PROIZVODNE LINIJE ZA PROIZVODNJU VELIKIH SERIJA KRISTALNIH SILIKONSKIH PV ĆELIJA

SAŽETAK:

Na bazi velikog iskustva VIESH-a u razvoju proizvodnih tehnologija solarnih ćelija i same proizvodnje PV ćelija i modula, stranke (VIESH, IHIS) su odlučile da nastave sa proizvodnjom PV ćelija na veliko. IHIS već dugo godina želi da započne sa sopstvenom proizvodnjom PV ćelija, verujući da je primena solarne energije jedina alternativa za čovečanstvo. U određenoj literaturi, IHIS je pre više od deset godina

pokazao da je sa postojećim znanjem moguće sagraditi solarnu elektranu umesto nuklearne, za praktično isti novac i isto vreme a sa mnoštvom prednosti. Sada su obe stranke prihvatile da je cilj ovog projekta dovođenje solarne energije u konkuretni položaj, u ubrzanoj elektrifikaciji ruralnog područja sveta na način koji je jeftiniji, pouzdaniji i za životnu sredinu zdraviji.

U saopštenju su detaljno prikazani elementi projekta koji pokazuju opravdanost ulaganja u njega radi razvoja velikoserijske proizvodnje solarnih ćelija cene oko 1$/$W_p$.