FROM AUTONOMOUS COMBINED RENEWABLE ENERGY SYSTEMS TO SMART GRIDS, FROM RESEARCH TO EDUCATION

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1. Introduction

The purpose of the paper is to describe two research projects (first completed at the research stage and second is continuing at current phase) and to analyze the trends in developing modern technologies in developing renewable energy systems. First project was devoted to combined PV/T (photovoltaic/thermal) system based on concentrator with vertical p-n junction solar cells. The second project devoted to developing autonomous fully renewable energy system combining solar, wind and micro-hydro energy sources is actually next logical step in creating distribution network supplying electrical energy to many possible areas having such type of resources. Initiator of both projects is the All-Russian Research Institute of Electrical Engineering (VEI), Department Renewable Energy Sources. According to demands of the supporter of these projects - Ministry of Education and Science of the Russian Federation, these projects have strong educational components. Young specialists, students and post graduate students from the UNESCO Chairs of the Moscow State University of Engineering Ecology (MSUEE) and All-Russian Research Institute for Electrification of Agriculture (VIESH) were involving and are involving into the projects.

2. Projects descriptions

The first project started from developing concentrator solar cells with vertical p-n junctions and concentrator system for these solar cells. Project logically transformed to developing concentrator photovoltaic/thermal (PV/T) systems. The prototype of PV/T systems was created and tested at the roof of VEI. At the final stage of the project a concept combined PV/T system based on concentrator with vertical p-n junctions solar cells. The new technology increasing efficiency of the solar cells with vertical p-n junctions was patented.

The second project is carrying out in the framework of the Research-Educational Center VEI-MSUEE which is created for improving interaction between research institutions and universities. The project is devoted to developing autonomous fully renewable energy system combining as a concrete example, solar, wind and micro-hydro energy sources. In fact it is next logical step in creating distribution network supplying electrical energy to many possible areas having such type of resources. 100 % renewable energy system demands many innovative decisions on the resource assessments, correct energy management from generation and distribution to optimal conversion, saving and proper consumption. This work leads us to developing smart grid approach for autonomous combined energy systems.

3. Conceptual discussion of the projects

The main goal of solar industry is to develop cheap technology. By concentrating, a large part of the expensive PV area is replaced by cheap optical concentrator area (mirrors, lenses). It is a way to reduce the payback time. This argument is the driving force behind concentrator PV systems. Also silicon solar cells have been the most important cells of photovoltaic industry. There are many reasons for the dominance of c-Si in PV: stable performance, relative low module manufacturing cost, huge resources of initial raw material (SiO_2) and mostly non-toxic materials used in the final product.

Usually solar cells are classified into three generations. The generations indicate the order of which each became

important. At present there is concurrent research into all three generations. The first generation technologies are still the most highly represented in commercial production accounting for over 85% of all cells produced.

First generation cells consist of large-area, high quality and single junction silicon solar cells. First generation technologies involve high energy and labor inputs. This prevents any significant progress in reducing production costs. Single junction silicon devices are approaching the theoretical limiting efficiency of 33% and achieve cost parity with fossil fuel energy generation after a payback period of 5-7 years. They are not likely to achieve lower than US$1/W if do not consider concentrator approach.

Second generation materials have been developed to address energy payback requirements and production costs of first generation solar cells. Alternative manufacturing techniques such as vapor deposition, electroplating, and other allow creating thin film solar cells. The have many niches for different applications but cannot convert concentrated radiation, so they are not good for concentrator approach.

Third generation solar cells are solar cells that are able to overcome the Shockley–Queisser limit of 31-41%. This is correspondently power efficiency for single band gap solar cells under 1 sun illumination and under maximal concentration of sunlight (46,200 suns, which makes the latter limit more difficult to approach than the former). This includes a range of alternatives to the first generation solar cells and second generation solar cells. Common third-generation systems include multi-layer ("tandem") cells made from more exotic (and unfortunately more toxic) materials like gallium arsenide.

If we put production volume on the known graph - three generations (efficiency against the cost) it is clear that we would be moved to higher efficiency area by shifting from the first generation silicon solar cells technology to the concentrator technology remaining in silicon area (Fig. 1). Here there are two opportunities: the planar concentrator solar cells with very fine contact grid and the solar cells with the vertical p-n-junctions which known as a good alternative of planar concentrator solar cells.

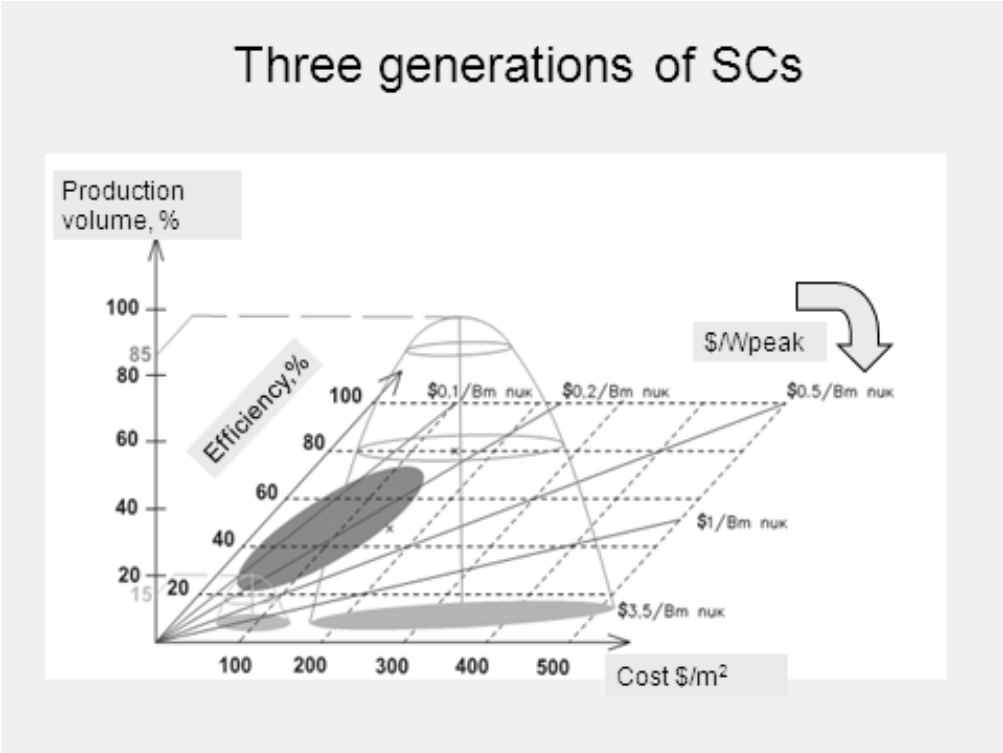

Fig. 1: Approximate volume production of three generation solar cells

At Fig.2 we put arrows indicating mainstream technology and our approach on the famous graph showing the best efficiencies among the different solar cells. All technologies demonstrate progress and have their own niches for applications, but still mainstream is silicon technology. So, if we want to be shifted to higher efficient area with less expenditure, it should be technology of the solar cells with vertical p-n-junctions.

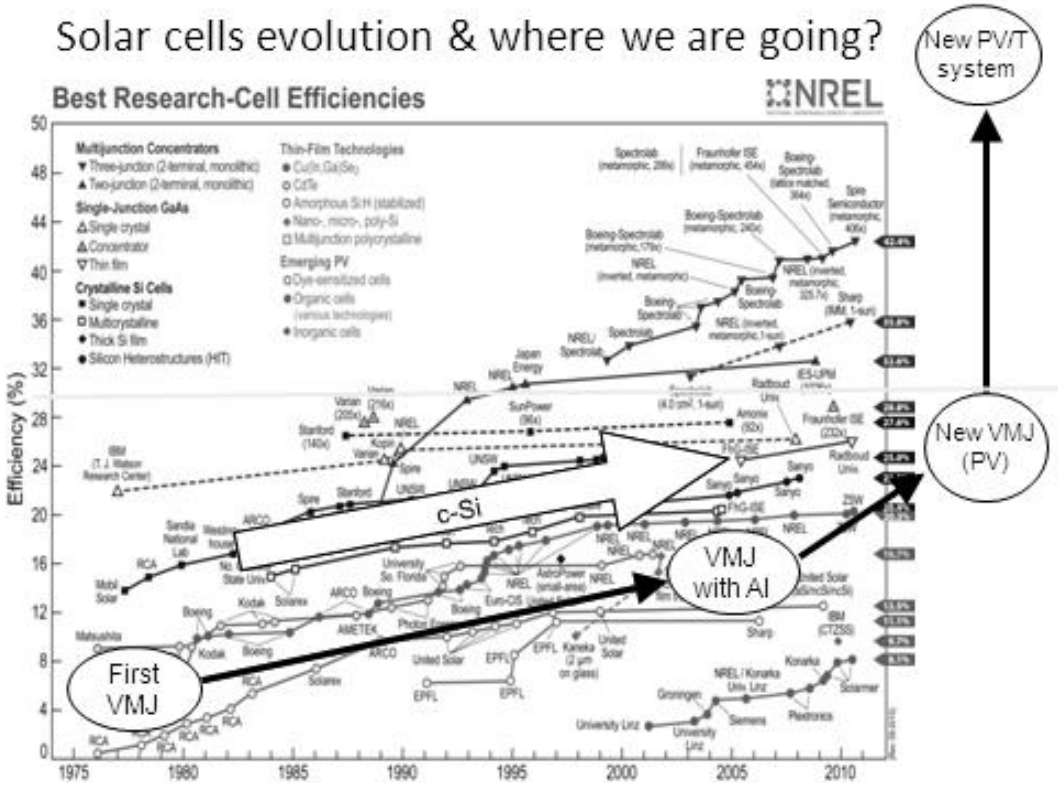

Fig. 2: Increasing efficiency of solar cells and VMJSC with perspective PV/T approach

The vertical multi-junctions solar cells (VMJSC) consist of a number of non-monolithic edge-illuminated junctions connected together in series (Tyukhov et al., 2004, Tyukhov and Vasilev 1995). The VMJSC is fabricated by metallizing, stacking and alloying (bonding) a number of silicon wafers together. Then, cutting and sizing processes take place. The VMJSC have the higher voltage at a lower current. The light is incident on the VMJSC parallel to the junctions rather than perpendicular to them and the charge carriers generated by the long wavelength part of the light spectrum have the same probability to be collected by the junction as those generated by short wavelength part. Thus, these VMJSC have more uniformly wide spectral responses. In comparison to planar bifacial SC, SCVJ have ideal symmetrical frontal and back sensitive surfaces, that allows to use a both side illumination.

From the point of view energy system concentrator approach can be efficient if extracting thermal energy from cooling liquid is used. Actually this PV/T technology combines photovoltaic (PV) generation of electric current and thermal (T) conversion of solar energy. PV/T system is a solar energy system using PV as a thermal absorber. By using the heat generated in the PV, a PV/T device generates not only electrical, but also thermal energy, for example for preheating purposes.

Our first project included developing vertical multi-junctions solar cells, designing concentrator providing

uniform illumination from two sides, designing PV/T receiver for extracting solar electricity and heat. Solar cells with vertical p-n-junctions have a number of advantages: high temperature tolerance, low series resistance, identical bifacial sensitive surfaces suitable for bifacial illumination, low equilibrium temperature, quite simple technology of manufacturing etc. Low series resistance allows solar cells to work under high concentration ratio. There are also some other interesting application of VMJSC as for laser systems of transfer energy, thermo-photovoltaics, metrology and so on.

Silicon solar cells are the most expensive element used in PV systems. This reason and also shortage of monocrystalline silicon lead us to developing concentrator approach.

There are only three companies in the world which can produce VMJSC: in Russia VEI, VIESH and in the US GreenField Solar (http://greenfieldsolar.com/our_technology.php, 14 August 2011).

In the framework of research project in VEI the concentrator PV/T system was built consisting of 2D rotational frame, concentrator made with flat mirror facets and PV/T receiver. The project was devoted to designing, building and testing of concentrator PV/T system based on solar cells with vertical p-n-junctions (Tyukhov et al., 2008).

A method of manufacturing solar cells with vertical p-n-junctions using thermal compression bonding with silumin (compound of aluminum and silicon) was developed and solar cells were investigated in VEI and defended by Russian patents. Also a new technology allowing to create additional p-n-junctions on the frontal surface and under the surface was patented. The vertical multi-junctions solar cells made in VEI are shown at Fig.3.

A new design of concentrator was developed for this project. A special soft was written for calculations of all dimensions in order to insure bifacial uniform illumination PV/T receiver (Fig. 4) with concentration ratio up to 20 from each side (Fig. 5).

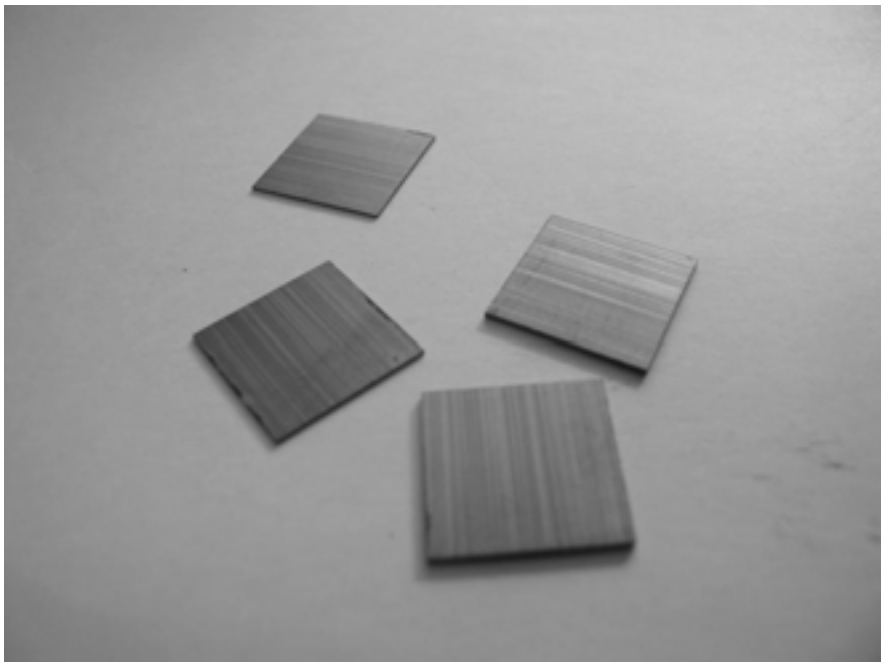

Fig. 3: Solar cells with vertical p-n junctions

The practical steps in realization of the concept concentrator PV/T system with vertical p-n junction's solar cells were demonstrated successfully.

Next project is devoting to combined autonomous energy system.

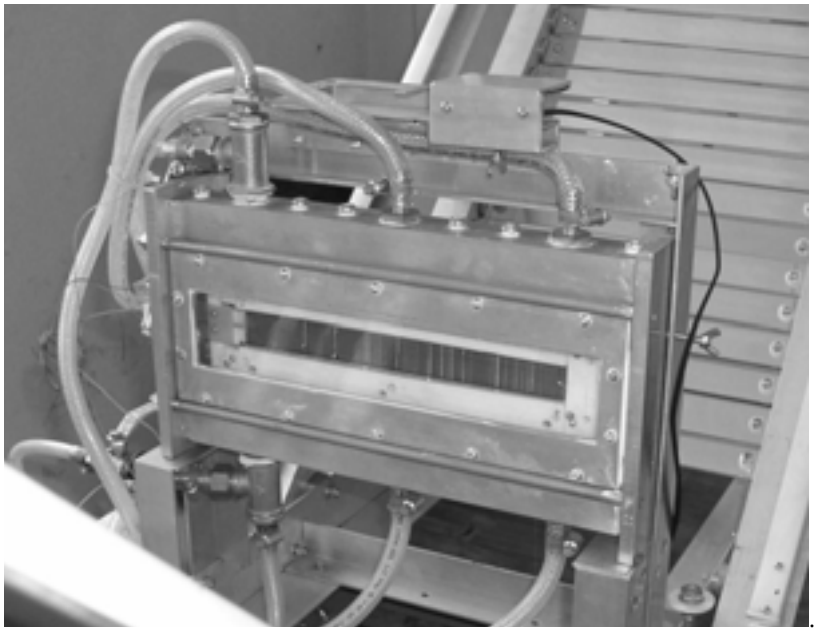

Fig. 4: PV/T receiver with SCVJ

Main trends of integrating different solar energy technologies in buildings were discussed earlier (Tyukhov I., et al., 2005). It is important tendency when we use different types of technologies for supply electricity from photovoltaic modules, heat from solar collectors (traditionally it is separated of technologies), but if we use PV/T modules we can save surface, increase efficiency.

Fig. 5: Experimental concentrator for VEI PV/T system with bifacial illumination of solar cells

As for autonomous energy systems based on renewable energy sources the main tendency for practical applications is integrating of different renewable energy generators which are intermittent by their nature in order to avoid too big accumulating system. In current project an autonomous energy systems based on three renewable energy sources: solar PV, microhydro and wind generators.

Hybrid synergetic renewable energy (REN) systems based on several different sources of REN are developed in our current project – tri-generation (Fig. 6) as well as in the world by several groups. This work leads us to developing smart grid approach for autonomous combined energy systems because of different kind of generators (DC and AC), with the different logical management and control of electrical schemes, intermittent processes of energy generating.

The peculiarities of developing smart grids and possible large scale CPV in Russia are considered in this project in comparison with integrating alternative energy technologies with the electric grid in the world.

Russia starts quite a big project building solar plant based on thin film SC nearby Kislovodsk. Twenty years ago concentrator PV/T (CPV/T) project with higher efficiency SC (based on GaAs compounds), was offered. In our opinion this old project was much more prospective than thin film project. Unfortunately old CPV/T project was not realized due to lack of financial support after "perestroika".

One more new project of building solar settlement nearby of Makhachkala (Dagestan) is discussed now and some first decisions by local government were made. For Russia having vast variety of geographical conditions the hybrid REN systems, combining different sources like solar, wind, micro hydro, biomass, and geothermal energy are very important. The peculiarities of such systems, designed in different combinations depending on concrete location, demand applying smart grids approaches, which are developed in current project for solar, wind and micro-hydro at VEI and MSUEE (Fig.6).

4. Educational aspects of the projects

In the framework of these projects educational component was an important part of research activity. The student, post-graduate students, young researchers are participating as members of whole team. Young specialists, students and post graduate students from the UNESCO Chairs of the Moscow State University of Engineering Ecology (MSUEE) and All-Russian Research Institute for Electrification of Agriculture (VIESH) were involving and are involving into the projects. The scientific-research center VEI-MSUEE was created to attract young generation into scientific-engineering sphere. The new bachelor program in Renewable Energy Systems was developed and startling in this academic year from September.

The program and educational plans integrate the engineering, environmental, technical, social, economic and scientific principles to develop, promote and implement new sustainable energy technologies and improve the efficiency of existing systems.

The system developed at first project will be transferred to MSUEE for developing research activity of students and post-graduate students.

In the framework of second project the educational system simulating three energy generators (solar, wind, micro-hydro) working under the management of electronic equipment is developing. System also includes accumulating unit, electric buffer units, control elements, electrical consumers and other components of real energy system for electricity supply. This system will help to simulate different modes of operation, to develop proper strategy for consumer and designers of renewable energy systems.

New coming activity will involve also school students as it was done in other our projects. The interaction between students of all levels and specialists stimulate generation of new ideas.

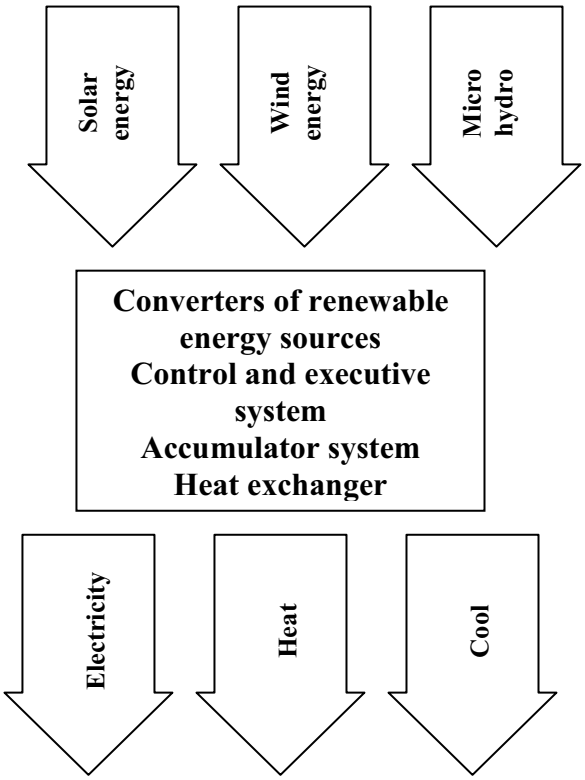

Fig. 6: Experimental concentrator100% REN tri-generation approach

5. Conclusion

The results of two projects (developed and current) show new conceptual point of view for fast developing cheap concentrator systems based on vertical multi-junctions solar cells with bifacial illumination and additional heat generation, new conceptual point of view for simulating and designing autonomous renewable energy systems and involving educational activity.

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6. References

Tyukhov, I., Simakin, V., Strebkov, D., Silicon multi-junctional solar cells with vertical p-n-junctions: evolution, technology, applications, and new opportunities. In Proceedings of 14th International Solar Conference “EuroSun 2004”, PSE GmbN, Freiburg, Germany, v.3. p. 357-366.

Tyukhov, I., Vasilev, A., Limiting efficiency of the ideal planar and edge-illuminated solar cells. Solar World Congress, Harare, Zimbabwe, Abstracts of the ISES (1995), p.74.

Tyukhov, I., Simakin, V., Murashev V., Poulek V. Concept of combined PV/T system based on concentrator with vertical p-n junctions solar cells. In Proceedings 3rd European Photovoltaic Solar Energy Conference and Exhibition, 1-5 September 2008, Valencia, Spain, 2008, 795-798.

Tyukhov I., Strebkov D., Kuzhnurov Y., Tveryanovich E., Kivalov S. Integrating PV/thermal concentrator systems into buildings. In Proceedings of the 2005 Solar World Congress, Edited by D.Y. Goswami, S.Vijayaraghaven, R. Campbell- Howe, American Solar Energy Society, International Solar Energy Society, ASES (2005).