Photovoltaics: Promise and performance

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The status of generation of electricity through the solar photovoltaic (SPV) route has been briefly reviewed. The present state of different technologies for producing SPV modules has been discussed. The International and National status of SPV technology has been stated. The strategy to be adopted for lowering the cost of SPV electricity has been suggested.

It is well known that if we can utilize less than 1% of solar insolation on earth's surface the present energy demand of the world can be met. In addition, solar energy is fully renewable and pollution free. There are two main routes of solar energy utilization, viz. (i) solar thermal, and (ii) solar photovoltaics (SPV). In the former route, in general, heat energy from solar radiation is absorbed as heat energy and also utilized as heat energy. It is also possible to produce electricity through solar thermal route by the generation of steam. In the SPV route, solar radiation is directly converted into electricity through a semiconductor device which is known as solar cell. Since energy is obtained in the form of electricity it may be put to different kinds of use including generation of hydrogen through electrolysis. It may be mentioned that hydrogen gas will be a major source of energy in the next century.

A solar cell is basically a p-n junction semiconductor device. The first single crystal solar cell was fabricated in 1954. Since then and specially after the first oil crisis of early seventies considerable investments in R & D and production have been made on SPV so that this energy option may develop and reach its full potential.

Here we shall briefly discuss the status, prospects and potential of SPV technology. We shall specially emphasize the status and problems of this technology in India and what should be done so that India becomes a leader in this area. This is particularly true because of large solar insolation and availability of large market in rural areas of India for which SPV is cost effective even today.

Applications of SPV electricity and its cost effectiveness

The applications of SPV may be divided into following areas.

1. Rural energy: Solar lanterns, street and community lighting, powering irrigation pumps, Stand alone power stations. 2. Urban and industrial energy: domestic source of energy, Peak lead of industries. 3. Feeding into electricity grid. 4. Specialized uses: power source in satellite, off-shore oil platforms.

According to the US and Japanese, cost goals to make SPV electricity cost-competitive with grid electricity (1986 base) the cost per peak watt should be less than US$ 1.00 In addition, the balance of system (BoS) cost (battery, relay, inverter, etc.) should also attain some cost goals and lifetime of SPV modules should be in the range 20–30 years. These calculations do not take into account the social cost of fossil fuels and nuclear energy.

For a developing country like India which has still a large rural area which is not electrified or has very little electricity a much higher SPV electricity cost/pW is acceptable and cost effective. Compared to diesel-generated power the present initial SPV electricity cost is three times higher. However due to lower maintenance cost and no cost of fuel SPV electricity is much cheaper than diesel-generated electricity after three years.

Technology options

The challenge before us is to reduce the cost of SPV electricity. Since this being a forum of scientists specializing in Condensed Matter Science we shall confine our discussion to bringing down the cost of SPV modules. The improvement of BoS is to be dealt with by engineers.

For large scale terrestrial applications of SPV electricity the following technology options are at present available:

1. Single crystal silicon
2. Multicrystalline silicon
3. Thin film technologies, a. Amorphous silicon (a-Si); b. Polycrystalline thin films (PTF)
4. Silicon film.

The single crystal silicon technology is a proven one but due to high material cost the cost/pW is unlikely to go down below $3/pW. In addition, the fabrication is a high energy process so that energy pay back period is high (8–10 years). Multicrystalline silicon technology when fully developed is expected to bring down cost by 20% compared to that of single crystal silicon solar cells.

Of all the technology options only thin film technologies have the potential of bringing down the cost of SPV electricity below $1.00/pW. Since the material cost of a-Si and PTF solar cells is very low, the cost/pW comes down sharply with increase in volume of production. Thus a-Si solar cells at 6% stabilized efficiency and production volume of 1 MW/year will cost $4.0–4.5/pW and at 10 MW/year it will be $1.5/pW.

Of the two thin film technologies mentioned only a-Si solar cell is being produced commercially. It constitutes about 25–30% of total world PV shipment (62 MW in 1993). In the last decade a-Si solar cells were being used mainly for consumer electronics. However large scale investments in R & D and production technology have brought it to the level of small power applications. Within next few years it will be ready for medium range power applications. The PTF solar cells have achieved good efficiencies and stability at the R & D level but is having problems with production. For this reason PTF modules are yet to be produced commercially. Silicon film solar cells are in the feasibility study level.

Status of SPV technologies including production

International

Bulk of SPV modules which are being used for power application is single crystal silicon. The present price is $4–5/pW and life time is estimated to be 20 years. R & D work is going on to reduce the thickness of the silicon wafer to 200 μm (presently 400 μm) and increase conversion efficiencies (e.g. laser grooving technique). In multicrystalline silicon technology attempt is being made to reduce cost by improving production technology.

Maximum investment on R & D and improvement in production technology is being made on a-Si technology. Japan is banking almost wholly on this technology (investment: $30 million/per year). USA and Germany are also investing a large amount on this technology. Amongst the developing countries South Korea and China are trying to develop this technology. a-Si technology is now ready for small power applications at the production level and cost is similar to that for single crystal silicon cells. At the R & D level technology for producing large area modules with stabilized efficiency of 8% has been developed and production of this type of modules has started. These modules will be suitable for medium range power applications. With large capacity production plants which are now being set up the cost/pW will come down to $2–3/pW.

PTF solar cells are yet to be produced commercially and a number of industries specially in USA are engaged in it.

Indian status

In India production of single crystal silicon solar cell started more than a decade ago by Central Electronics Ltd. and Bharat Heavy Electricals Ltd. Recently due to sharp increase in demand a large number of Indian industries have started production. The present installed capacity is 3.5 MW/year and is going to increase rapidly. A number of foreign industries are also likely to start production in India. The present selling price in India is $7.00/pW. These are mainly being used in rural areas for lighting and water pumping and by the Department of Telecommunications, Railways, Defence, etc.

In a-Si solar cell technology a sound R & D base has been set up and a pilot plant having sophisticated features has been commissioned by BHEL under contract from the Ministry of Non-Conventional Energy Sources. The R & D facilities at the Indian Association for the Cultivation of Science have been brought to the international level with major assistance from UNDP and MNES. There has been close interaction and collaboration between IACS and BHEL including transfer of process know-how. At present single junction modules are being produced and attempts are being made to make the plant commercial. It is expected that in 1995–96 the cost/pW of a-Si modules will be significantly cheaper than that for single crystal silicon modules.

Problems of Indian SPV industry

As stated above many Indian manufacturers have started production of single crystal silicon solar cell in view of rapid increase of demand. However, most of these technologies are a little backdated and virtually there is no R & D to upgrade performance and production technology leading to cost reduction. The development of BoS is a neglected area. With globalization policy all these industries will face crisis with foreign manufacturers getting into Indian market.

Although a sound base has been established for the development of a-Si solar cells it has become difficult to obtain funds from industries and Government for R & D and upgradation of the production line including setting up of a much bigger size plant.

Existing groups in India working on various aspects of SPV technology

The following R & D organizations are engaged in various activities linked with SPV technology:

1. Indian Association for the Cultivation of Science—major facility for R & D on a-Si solar cells and is directly linked to industry (BHEL). A group is working

on PTF cells.
2. National Physical Laboratory—single crystal and amorphous silicon solar cells.
3. Jadavpur University—PTF cells.
5. Poona University—a-Si materials.
6. National Chemical Laboratory—a-Si materials.
7. Solar Energy Centre—calibration and reliability test facilities.

A large number of Indians are working in USA on different types of SPV technologies and some of them are in industries holding high positions.

What should be done?

There is no concentrated effort to develop SPV technology in India. It is necessary to set up an Institute for Photovoltaic Science and Technology. Some steps in this direction had been initiated by MNES a few years ago but further action in this regard has not been taken. MNES has formulated very recently new guidelines for R & D activities in the area of renewable energy including SPV. Joint funding of R & D-linked to industry will be preferred although new technologies may have direct funding.

Conclusions

1. In view of the potential of SPV industry in India major investments are needed. Scientists working in the area of condensed matter science may play a key role in improving SPV module technology.
2. With proper investments, planning and execution India should be a leader in SPV technology and should be able to export technology and products.

Condensed matter science and the Department of Atomic Energy

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The present article describes the role of condensed matter science and technology in the development of atomic energy programme as also the role of atomic and nuclear radiations in the study of condensed matter science. It is emphasized that an integrated development of radiation sources, materials and instruments is essential for the healthy growth of condensed matter science.

Radiation and condensed matter

I consider it an honour to have been asked to speak on this special occasion on behalf of my Institution in a Department which has made major contribution to Physics research in India. The subject which I have been asked to touch upon is 'Condensed Matter Science and the Department of Atomic Energy'. In this short presentation I shall not be able to do justice to this very broad title if I talk about specific details. I have therefore chosen to make some general remarks – use broad brush strokes rather than fine brush of a miniaturist.

When it comes to talking about condensed matter science, or science of any kind for that matter, it is possible to take different approaches depending on one's taste. In a lecture de Solla Price, a science historian from Yale has argued that technology gives rise to instruments which are the true drivers of science (Figure 1). Taking a cue from this Rustum Roy, a materials scientist of Pennsylvania has argued that materials technology gives rise to new materials which in turn give rise to new science (Figure 2). Scanning tunnelling microscopy (STM) is an example of the first type whereas purification of Ge and Si may be cited as an example in favour of Roy's case. On the other hand, it has often been said that it is science which pushes the growth of materials as well as technologies. Quantum structures, experiments with which have been labelled as 'playing with quantum mechanics in the laboratory' by Esaki, are examples of this category.

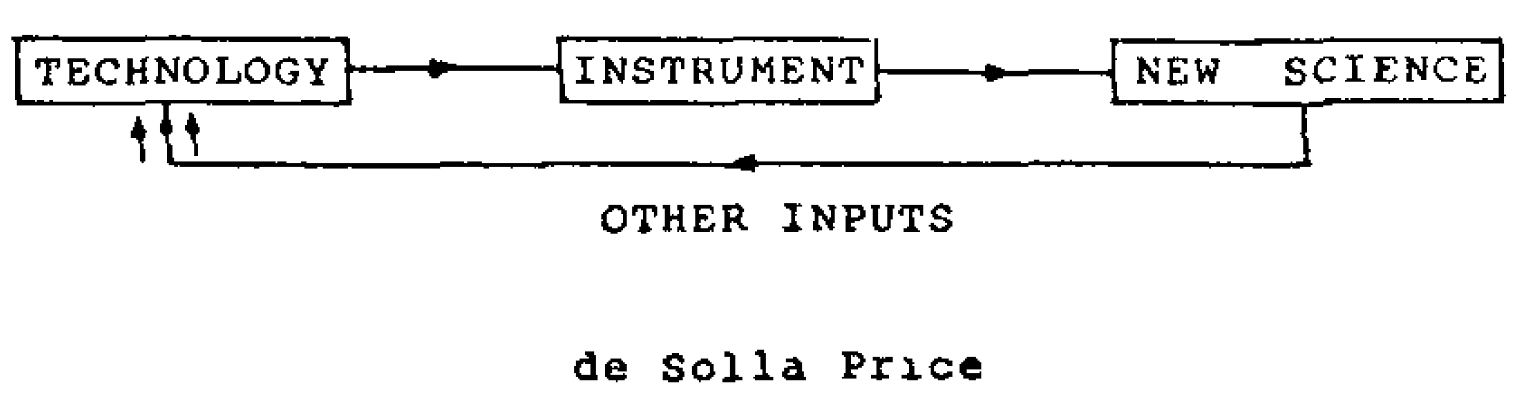

Figure 1. A science historian, de Solla Prices' view of development of science.