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SOLAR PHOTOVOLTAICS IN INDIA : A STATUS REVIEW

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Abstracts : Solar Photovoltaics (SPV) in India has become an important renewable source of energy particularly for rural and remote areas. The vastness of the country and the requirements of electricity in far-flung villages makes SPV very attractive, with inherent technological advantages providing additional boost . This has been recognized very early by Govt. Of India and Ministry of Non-Conventional Sources of Energy (MNES) has been entrusted with promoting SPV usage in the country. Rural electrification through SPV systems is one of the programmes which is expected to provide fillip to PV industry in the country. PV Industry in India is very well established with capability of solar cell fabrication and module fabrication as well as Balance of System design and fabrication. There several R& D groups in the academic institutions who are involved in improving solar cells efficiency, thin film solar cells and PV instrumentation. Thus, India provides a ready market for large scale utilization of solar energy through SPV technology.

Nomenclature

MW : mega watts (electrical)
KW : kilo watts
KWH : kilo watt hour
O&M : Operation and Maintenance
R&D : Research and Development
Rs : Indian rupees (~ 22 KWN)
Lakh : 100,000

Subscript

SPV : Solar Photovoltaics
MNES : Ministry of Non-Conventional Sources , Govt. Of India
BIS : Bureau of Indian Standards

1. Introduction

Solar energy has been utilized for various applications in India particularly for agricultural related activities since ancient times. In fact, Sun is treated as a god in Indian traditions and has the status of life-giver and sustainer. This ancient concept has now become more important for the scientific, technological and economic advancement of the country, since the energy requirements have grown enormously over the years [1]. The dependence on imported oil has caused great strain on Indian economy and the situation can worsen given the price rise due to uncertain geo-political situation seen in recent times. The use of Coal for electricity generation has been dominant but the problems associated with CO_2 emission and fly-ash produced after the combustion are severe. Nuclear power plants are getting attention but the dependence on imported nuclear fuel and possibility of controls imposed by other nations makes it a difficult option from a long term perspective. This has provided a great opportunity for Renewable Energy sources to fulfill the needs of Indian people in a sustainable way by ultilizing abundant natural resources available in the country . In fact, in his address in the South Asian Conference on Renewable Energy held on April 2006 in New Delhi, President Kalam has proposed Energy Security for the nation by 2020 leading to Energy Independence by 2030 [2,3]. This requires enhancing the power generation capacity from the current value of about 130,000 MW to about 400,000 MW . He says that "for true Energy Independence, a major shift in the structure of energy sources from fossil to renewable energy sources is mandated". In fact his suggestion is to enhance the contribution from Renewable Energy Sources for current value of 5% to as much as 25%.

2. Photovoltaic Applications in India

Table I gives a list of possible applications for electrical energy generation in rural , remote and urban areas [4,5]. As can be seen , a whole gamut of applications from few tens of watts to KWs or MWs has become possible due to the inherent advantages of PV generation. In India, rural PV systems are mostly implemented through governmental agency called State Nodal Agencies which in turns are supported through subsidy provided under MNES PV programmes. For urban areas no such subsidy is available , instead there are "ADITYA" shops providing different renewable energy based products. Most major companies also support PV deployment through their own dealer networks.

One of the major requirements in rural areas is for lighting after sunset. The use of Kerosene for lanterns has been widespread which has a variety of problems (supply , subsidy , fumes etc.). In fact, Bhargava [6] compared the performance of Solar lantern in order to replace Kerosene lantern and found that there were several economical and performance advantages offered by use of PV for this application . In fact, solar lantern have proven to be very popular in rural areas particularly in hilly areas and islands where maintaining a regular supply of Kerosene can itself be daunting task. The recent Ashden awards [7] for sustainable energy to several Indian organizations working for promotion of such devices is a testimony to the fact that PV for rural areas is very important and can play a major role in meeting the electricity requirements of a large population residing in these areas. Hande and Duffy [8] reported on a successful model for rural solar photovoltaic venture. The SELCO[9] model can be an alternate to the government programme by providing a viable financial and service mechanism. The economic growth in rural areas is important for overall growth of the country , since it may reduce the pressure on urban areas enormously while meeting the aspirations of the people.

The need for PV in urban areas is not so obvious, given the availability of conventional electricity. However, the increased demand in summer and during the daytime can put severe constraints on the grid which can lead to power outages for a long time. In addition, there are problems of brownout which can cause serious damage to equipments and appliances. All this has led to wide spread usage of domestic Uninterruptible Power Supplies (UPS) which store electricity in the lead acid batteries during normal times for use during blackouts. The inexpensive inverter designs used in these result in an inefficient use of electrical power as well as harmonic injection in the grid. The other equipment commonly used for emergency power generation is Diesel generators especially in large stores and apartment complexes.

Use of diesel which is subsidised for agriculture use for electricity generation as captive power generation in industry is of course possible. But for domestic or small applications PV can be a suitable alternative. In fact, our analysis shows that PV electricity will cost less than electricity from Diesel generator for average power outage of less than an hour /day during the year [10]. In fact, the excess power generation can be easily fed into the grid for supporting the grid. The use of such distributed PV generators in countries like Japan and Germany suggests similar possibilities in India, but with an inverter capable of sustaining the unstable grid conditions. In fact, the design for PV inverter for Indian conditions is a challenging problem and work is going on in our lab to achieve this objective [11].

Fig 1. shows the distribution of PV systems for different applications[12] comprising 10,80,000 systems having (122 MW aggregate capacity). There has been an increase in these numbers as reported in recent annual reports of MNES [3]. This suggests that Indian PV market is maturing and will soon be fully market driven. In recent years there has been a spurt of export due to strong demands from countries like Germany for solar cells and modules, which is not indicated in the figure. In fact, this has led to booking for solar cell production for several years in future and may lead to a push for increased production. The impending world wide shortage of Si wafers will become an issue for Indian companies in meeting this surge in demand.

3. Photovoltaic Industry and R&D in India [13,14]

Fig 2 shows the growth of PV industrial production in India [12]. As is the situation world over, this involves mainly single crystal Si and multicrystalline Si cells. It should be pointed out that following the world growth of 25-30% in PV, Indian companies have also shown a strong growth as well to meet the Indian and world market demand. Tata BP Solar 'sale in 2004-05 has been ~ 32 MW and other companies are in process of expanding their production capacity. In fact, more companies are seriously considering starting PV companies . The requirement in India is set to grow to meet the target of 150 MW installed capacity by 2007. This represents a tremendous opportunity in manufacture of solar cell , modules and other PV system components [15]. The stimulus provided by the growth in Indian market should also lead to an increase in export to both the developed and developing countries. In order to install and maintain the relatively maintenance free PV systems will also require trained manpower. There is therefore an equally important need for creating training institutes all over the country. This is particularly true for rural areas. Involvement of local NGOs and creating trained manpower through simple training methods have proven very successful in deployment of Solar Lanterns .

Apart from stand alone applications, demonstration projects on grid-connected systems are also being implemented. Such systems are expected to demonstrate the use of SPV for peak shaving in urban areas (remembering the fact that PV generation is highly correlated with the peak demand time during the day) and for tail-end voltage support in rural areas[16]. In addition, several 25 KWp SPV rooftop systems have been installed in buildings for use as BIPV. Fig. 3 shows the rooftop PV system installed in IIT Delhi. Grid Interactive systems have the advantage of obviating the need for storage batteries which constitute an expensive component of the PV system in terms of both the capital cost as well as O&M cost. But it adds to the system cost by the way of using a PV inverter. Also, since synchronization with the grid require proper voltage and frequency windows, the PV electricity may not be fed into grid at all times due to grid problems. This non-evacuation of the PV electricity can be a great loss and may render the energy payback period very high. Therefore, grid interactive systems have to be combined with some form of storage or local grid which can be brought into operation in case of the problem with grid synchronization. In rural areas, pumped water storage can be one of the options. This requires suitable intelligence in the inverter allowing automatic switching. In fact, a better power generator design can be hybrid systems which may include PV-Diesel, PV-Wind etc.

The R&D in PV is done in both industries and in academic and research institutes. The effort aims at improving Si solar cells, development of PV materials for thin film solar cells and PV instrumentation. The work done in different groups in IITs, IISc, IACS , CSIR labs and universities has kept the programme well abreast with the international scenario. In fact, the amorphous Si technology developed by Energy Research Unit at IACS , which was financial supported by MNES and DST, is being commercialized. BHEL Amorphous Si Power Plant has also demonstrated how one can use a single chamber for depositing p,i and n layers without having the problem of cross-contamination. This can make the capital equipment for amorphous Si very simple against multi-chamber systems otherwise required. CIS solar cells have also been fabricated over a small area by different groups achieving efficiencies ~ 14% . Spray deposited CdTe thin films also offer a cheaper option for making solar cells. The technology is also being used for making Dye Sensitized Solar cells using TiO_2 nanoparticles. Use of II-VI nanoparticles in organic solar cells by spin coating is also being explored. Hence, there is enough expertise available in India for doing world class R&D in all areas of PV. There is a need to channelise this effort towards large scale production , so that the goal of inexpensive solar cells through Thin Film Solar Cell technology[17] can be met. It also calls for stronger collaboration amongst the Indian groups as well as groups working abroad. Such collaboration can indeed make PV electricity affordable even to the poorest nations in the world, giving them an opportunity to alleviate poverty. Poverty alleviation is also one of the goals of Indian govt.

Another important aspect of PV programme in India is testing and standardization. Solar Energy Centre[18] provides a wide ranging testing and evaluation of PV system components. This has led to more reliable PV products meeting the BIS standards which are basically derived from the IEC standards. The solar cell modules fabricated by different companies have been approved by international organizations and have therefore found ready acceptance even in the developed markets.

4. Conclusions

Solar PV has sustained a healthy growth of 25% annually for several years now worldwide and the Indian PV growth can be as high as 20% which will make it one of the major industries in India. It is true that the capital cost of SPV systems remains high (~ Rs. 2.2 lakhs / KW). But it can become economically viable if one considers the life cycle cost (which distributes the capital cost over 20-30 yrs of system operation without much contribution from operation and maintenance cost) and the accrued environmental benefits. Then the estimated cost of solar electricity is ~ Rs. 10-15 / KWH.

The electricity requirements in most villages cannot be met using conventional electricity because of the high cost involved in the transmission and distribution systems for such small loads beyond ~ 3-5 KMs from the grid. Thus, electrification of 18,000 remote villages using SPV has become one of major goals set by MNES. It is proposed that during 10th Five Year Plan (2002-2007) about 200 MW PV generation capacity will be added, which includes 1 Million solar lanterns, 400,000 Solar Home Systems, 15,000 pumps and 30,000 solar generators to replace fossil fuel based generators. This effort has to be supported by domestic manufacturing capacity of ~ 75 MW / year. Such a large scale usage of SPV would provide investment opportunities for companies to develop better SPV systems.

India's role in Internet revolution is well recognized world over. This has resulted in a 'digital' divide amongst the urban and rural population. Use of SPV for powering computers in rural areas can go a long way in ameliorating this situation. This may in fact be the second generation Internet revolution in making with SPV providing much needed reliable electrical power throughout the year even in far flung areas.

A Task Force on Silicon Supply for the Indian PV I ndustry has recommended (i) bulk procurement of Silicon wafers by industry, (ii) expansion of domestic manufacture of Silicon wafers, (iii) R&D to significantly reduce consumption of Silicon material in manufacture of solar cell modules, (iv) feasibility of setting up a 2000 TPA poly Silicon plant in India and (v) preparing a Road Map for development of PV technology in India. With a view to accelerate growth of PV technology development in the country, a Group of Experts has been set up in November 2005 to prepare a Photovoltaic Technology Road Map for India.

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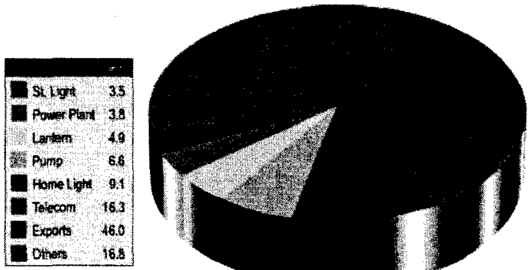

Fig. 1 PV systems for different applications (122 MW aggregate capacity: 10,80,000 systems)

TABLE I. PV Power Generation for different applications

RURAL APPLICATIONS	*REMOTE APPLICATIONS*	*URBAN APPLICATIONS*
LIGHTING SYSTEMS: Street, Solar Lantern, Domestic and Community	Telecommunication and Telemetry	Grid Connected Peak Shaving Applications
WATER PUMPING : Irrigation and Drinking Water	CATHODIC PROTECTION: Oil, Gas , Water Pipelines etc.	Captive /Emergency Power Generation
HEALTH APPLICATIONS : Water Purification and Medical Refrigeration	Light House, Warning Lights at Airports and Railway Level Crossing	Petrol and Diesel Dispensing Station
COMMUNICATION APPLICATIONS : Telephone Sets and Exchanges, Internet Kiosks	Satellite applications, Antarctica and Mount Everest Expeditions, Cell Phone Towers	Green Buildings, Solar Houses, Back-up Power Generation for Mobile Phones
RECREATIONAL AND EDUCATIONAL APPLICATIONS : Power Source for Radio and TV etc.	Hydro, Meteorological Stations, Offshore Platforms	PV in Schools, PV for Advertisement Boards, Traffic Lighting
INDUSTRIAL APPLICATIONS : Village Power Plants	Remote Defense Applications, Solar Fencing	Embedded Power Generation, PV in Metro / Railway Stations

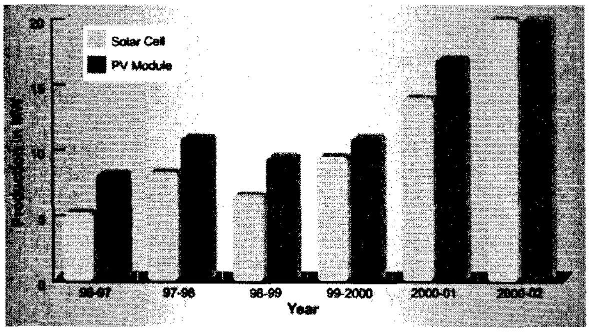

Fig.2 PV Production in India

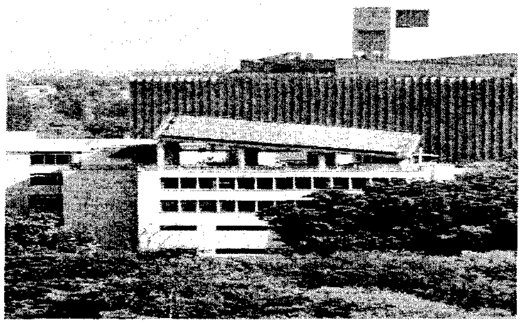

Fig.3 25 KW_P Roof Top System at IIT Delhi

TABLE II. SOLAR CELL PRODUCTION BY INDIAN COMPANIES (adapted from ref. 9)

COMPANY	1995	1996	1997	1998	1999	2000	2001	2002	2003
BEL								1.00	1.00
BHEL	1.15	1.00	1.00	1.00	1.00	1.00	1.50	1.50	2.00
CEL	1.40	1.60	2.00	2.00	2.10	1.50	1.70	1.50	2.00
MAHARISHI									3.00
REIL	0.70	0.70							
RES	0.70	1.00	1.00	1.20	1.20	1.00	1.00		
TATA BP				3.80	4.00	6.46	8.06	13.10	14.11
UDHAYA		0.50	0.50	0.50	0.50	0.50	0.50	0.95	0.95
WEBEL		0.65	0.70	0.70	1.20	1.50	1.20	3.00	4.50
TOTAL	**3.95**	**5.45**	**5.20**	**9.20**	**10.00**	**11.96**	**13.96**	**21.05**	**27.56**