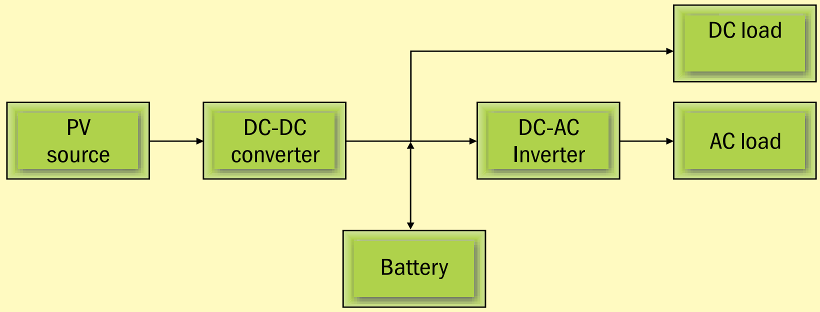

Figure 6 Block diagram of standalone PV system

conditions, a battery can be used as a backup to these systems. The battery gets charged, when the PV source delivers excess power than required, which prevents the wastage of energy. However, batteries require additional cost and maintenance. They also increase the complexity of the control besides a periodic replacement.

Grid-connected PV systems

Grid-connected PV systems, which are relatively more popular at least overseas, can be interfaced to grid as shown in Figure 7. The interface requirements depend on the size and application.

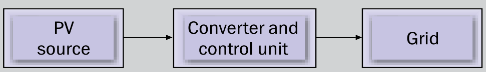

Figure 7 Schematic diagram of grid-connected PV application

Small (<10kW) residential PV systems typically are interconnected with single-phase distribution lines. Intermediate size (>10 kW) industrial/commercial PV systems are usually interconnected with three-phase distribution systems. Large PV systems, with ratings of 100s of kW to a few MWs, are usually interconnected at either the distribution level or sub-transmission level.

To feed the continuously increasing number of electricity customers, the distribution lines are generally extended beyond acceptable lengths. This results in a poor voltage profile for the customers at the far end. Moreover, feeding the power through transmission lines to various load centres often results in significant amount of power loss. To remedy such a situation, the installation of PV sources at the distribution level overcomes these problems. The addition of generating sources in distribution systems eliminates the need of upgrading transmission lines and associated switchgear equipment.

Thus, a grid-connected PV system improves the voltage profile of a distribution system and reduces the losses incurred in the transmission and distribution of power at various voltage levels. Unlike in stand-alone systems, a grid-connected system does not require any back-up.

Grid-connected PV systems, particularly low-power, single-phase systems (up to 5 kW) are becoming more popular in the de-regulated electricity markets. The great advantage in installing these systems are utilization of roofs of buildings for PV installations, which saves the additional land requirement and the PV generation can be at the load point. These PV systems are, generally, used to inject only real power to the grid.

Configurations of grid-connected PV systems

Grid-connected PV systems basically have two different topologies. The conventionally used topology is a two stage configuration. Recently another topology has been proposed, which utilizes a single-stage configuration. The following sub-sections explain these two configurations.

Two-stage configuration

The schematic diagram of a PV system, with a two-stage energy conversion system, is shown in Figure 1.8. It has two power converter stages between the PV source and the grid. Hence, it is called as two-stage configuration. In the first stage, the DC–DC converter is controlled so as to track the maximum power point of the PV array. A PV array has peculiar characteristics as shown in Figure 1, which generates the maximum power at particular voltage, , across its terminals. This process of searching (or tracking) for the voltage at which maximum power is generated is called MPPT (maximum power point tracking). The output of the DC–DC converter is fed to an inverter, which is a DC-AC converter, and is controlled to produce output current in phase with the utility voltage to obtain a UPF (unity power factor). The harmonics in the inverter output current are attenuated by using a low pass filtre.

As the DC–DC and DC–AC converters have independent control goals and architecture, the controllers are easy to design. Yet, the efficiency of the entire conversion system is compromised because of the large number of individual devices, like the passive elements of DC–DC converter and switching devices of both the converters. Moreover, excessive size, heavy weight, and high cost are amongst the major disadvantages of a two-stage energy conversion system.

Single-stage configuration

As the conversion efficiency of the PV array is inherently very low (12%–20%), the addition of more number of power processing stages further reduces

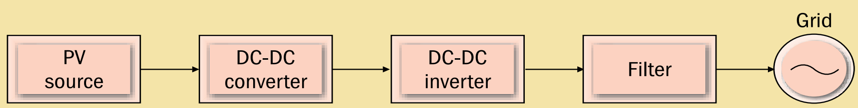

Figure 8 Two-stage PV energy conversion system

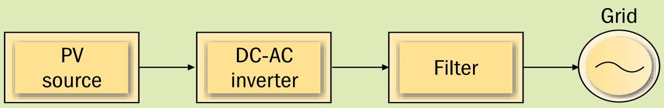

Figure 9 Single-stage PV energy conversion system

the overall efficiency. Therefore, a PV system with higher efficiency can be realised by having single-stage power conversion scheme. A single-stage PV system eliminates intermediate DC–DC conversion stage as shown in Figure 9. It results in smaller physical volume, lower weight, and higher overall efficiency.

Comparison of GCPS configuration

The single-stage configuration uses one converter and its controller must be designed such that the maximum power is extracted from the PV source, while maintaining the sinusoidal current at UPF on the grid side. This results in complexity of the controller design. Also, the magnitude of the DC-link voltage (the input voltage to the inverter), and, hence, the PV array output voltage is based on the AC grid voltage. Hence, in single-stage PV systems, large number of PV modules should be connected in series to form the PV array to get the required voltage for the DC-link. However, this is not advisable because the shading on one or several PV modules will affect the entire array output power substantially. Hence, it is preferred to connect the maximum possible PV modules in parallel to form the PV array and hence a two-stage GCPS is preferred in this case. The two stage GCPS with power conditioning unit is shown in Figure 10. In a two stage GCPS the DC–DC boost converter is used to boost the output voltage of PV array according to the requirement of DC-link and also responsible for maximum power point tracking of PV array. The DC–AC inverter is responsible for the following tasks.

1. Control of active power supplied to the grid
2. Control of DC link voltage
3. Ensure high quality of injected power
4. Grid synchronization.

MPP tracking of photovoltaic array

It is evident that the PV arrays have a single operating terminal voltage, only at which the array gives maximum power under a particular insolation and temperature conditions. The objective of MPPT is to track the MPP irrespective of variations in insolation and temperature. This is achieved by adjusting the voltage across the solar array to , voltage at which maximum power is delivered. Operation of MPPT algorithm is explained with the help of Figure 11. The voltage across the PV array, V, should be corresponding to MPP. This can be achieved by adjusting the load resistance across it, which adjusts the voltage across the array. But, under practical conditions, it is not realistic to predict the load. For a maximum power transfer from the PV array, a power converter is necessary that adjusts the load resistance to a value equal to an optimum resistance of the PV array, as shown in Figure 12. In other words, the converter evaluates the resistance corresponding to the MPP across PV array under all conditions irrespective of the load changes. For the impedance matching, DC-DC converters are generally used. Variation in the duty ratio of DC-DC converter gives variable resistance across the PV array corresponding to the MPP.

Perturb and observe algorithm for MPPT

As explained earlier, the MPP of the PV array can be obtained by adjusting the voltage across its terminals. One of the simple methods for tracking MPP is P&O (perturb and observe) or hill climbing algorithm proposed. This method is widely used due to its easy implementation. This method involves perturbation of the voltage, V, and observing the change in power output, P. If, the perturbation in one direction increases the power output of

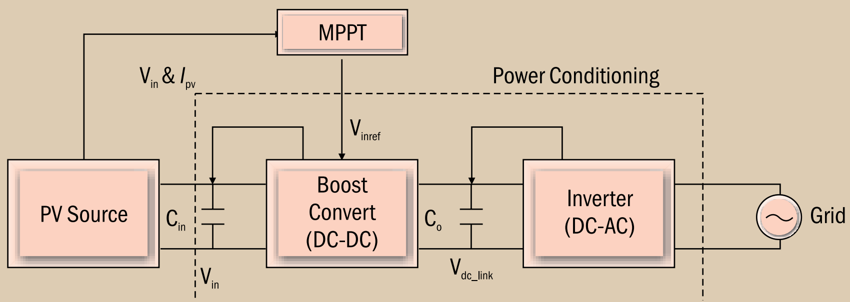

Figure 10 Two stage grid-connected PV system with power conditioning unit

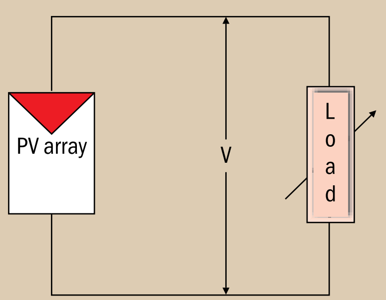

Figure 11 Circuit for MPP tracking of PV array with a variable load

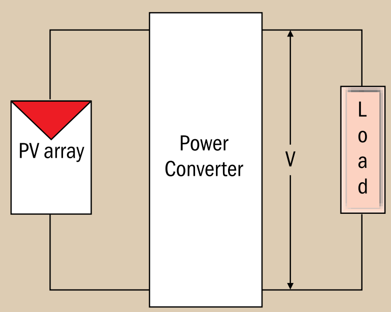

Figure 12 Circuit for MPP tracking of PV array with a power converter

a PV array, then the same direction of perturbation is continued. Otherwise, the direction of perturbation is reversed. Thus, it is a continuous process of searching for the voltage on P–V (power vs voltage) curve, which increases the power output of the PV array. In the Figure 13, from the operating point A, for a positive voltage perturbation, the operating point moves towards right. The decision on direction of perturbation is obtained from δV and δP data as listed in Table 3. From the operating point B, the next voltage perturbation is positive, because the previous perturbations in voltage and power are positive. Hence, the operating point moves towards right from B in fixed voltage perturbation steps until it reaches to MPP approximately, and then oscillates within a small limited cycle.

Table 3 Perturb and observe algorithm's logic table

δV(k)	*δV(k)*	*δV(k +1)*
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

This method of tracking has a drawback because of the use of constant voltage step. With a small voltage step, the tracking takes longer time, which leads to poor tracking speed. On the other hand, usage of large voltage step leads to large oscillations in steady state power and the averaged power output is significantly less than the maximum power. Hence, there is a trade-off between voltage step size and accuracy of the MPPT. This method can fail under rapidly changing atmospheric conditions, as shown in Figure 14. Starting from an operating point A, if, atmospheric conditions stay approximately constant, a perturbation ΔV in the PV voltage V will bring the operating point to B and the perturbation will be reversed due to a decrease in the power. However, if, the irradiance increases and shifts the power curve from to within one sampling period, the operating point will move from A to C. This represents an increase in power and the perturbation is kept the same. Consequently, the operating point diverges from the MPP and will keep diverging if, the irradiance steadily increases. This is the drawback of P&O method. The flow chart of this method is shown in Figure 15.

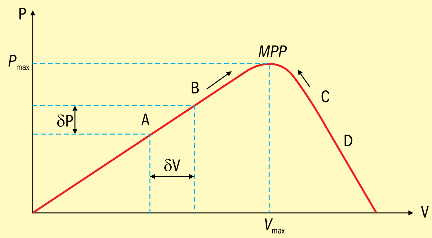

Figure 13 Description of P&O algorithm of MPPT

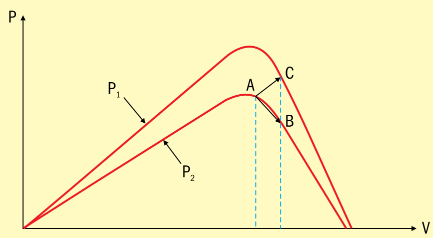

Figure 14 Divergence of P&O algorithm from MPP

Incremental conductance algorithm for MPPT

The disadvantage of the P&O method to track the peak power under fast varying atmospheric condition is overcome by an incremental conductance method. The IncCond (incremental conductance) method is based on the fact that the slope of the PV array power curve (Figure 1.13) is zero at the MPP, positive on the left of the MPP, and negative on the right.

$$dP/dV = 0, \text{ at MPP}$$
$$dP/dV > 0, \text{ left of MPP}$$
$$dP/dV < 0, \text{ right of MPP} \qquad (1.1)$$

Since

$$dP/dV = d\,(IV)/dV$$
$$= I + V\,dI/dV$$
$$\cong I + V\,\Delta I/\Delta V \qquad (1.2)$$

Equation (1.1) can be written as

$$dI/dV = -I/V, \text{ at MPP}$$
$$dI/dV > -I/V, \text{ left of MPP}$$
$$dI/dV < -I/V, \text{ right of MPP} \qquad (1.3)$$

The MPP can, thus, be tracked by comparing the instantaneous conductance (I/V) to the incremental

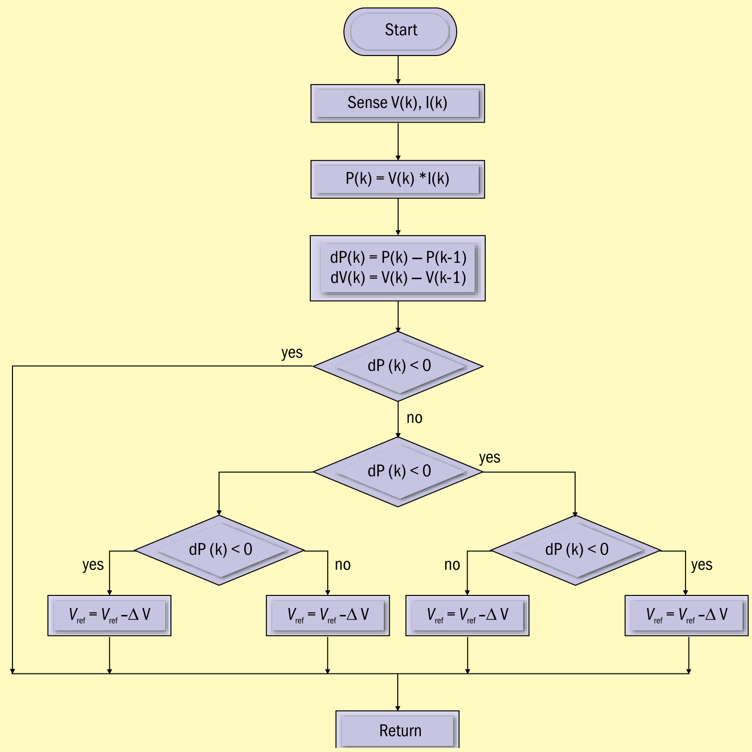

Figure 15 Flow chart of P&O algorithm

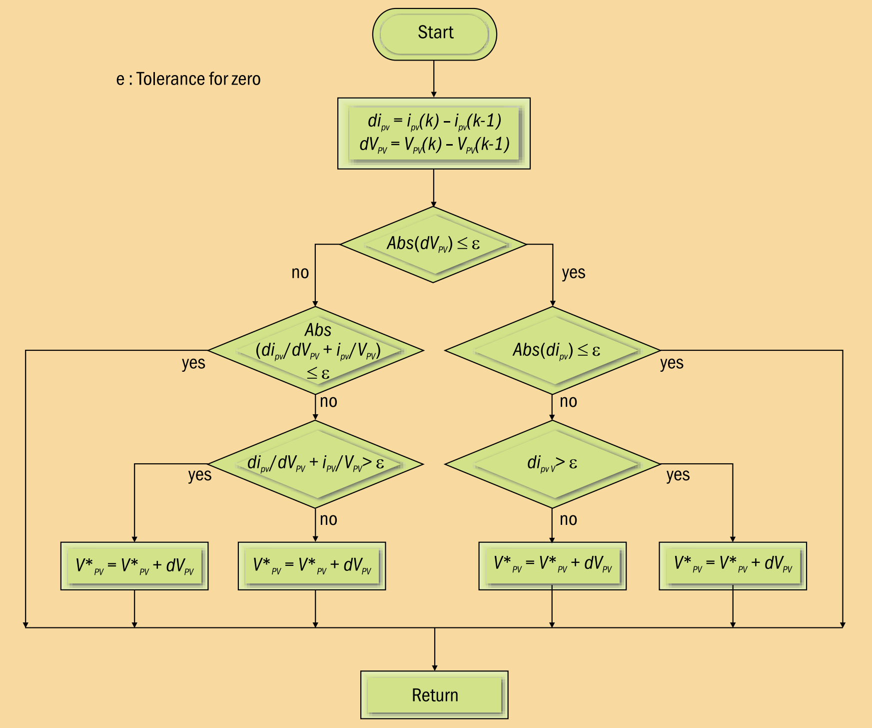

Figure 16 Flow chart of incremental conductance method

conductance ($\Delta I/\Delta V$) as shown in the flowchart in Figure 16. V^*_{pv} is the reference voltage at which the PV array is forced to operate. At the MPP, V^*_{pv} equals to V_{MPP}. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in ΔI (di_{pv}) is noted, indicating a change in atmospheric conditions and the MPP. Then, the algorithm decrements or increments are used to track the new MPP. Let, be approximately equal to zero. All conditions in the algorithm are checked for this tolerance.

Simulation results for MPPT of 5.6 kW PV array (P&O algorithm)

The simulation results for MPPT of 5.6 kW PV array (specifications given in Table 2) using P&O for standard and varying atmospheric conditions are given in this section. For MPPT, the reference voltage for the voltage controller comes from the MPPT controller. It generates the reference voltage for the PV array using P&O algorithm. Starting from an initial voltage, the MPPT generates reference voltage, which moves the operation of the PV array towards MPP. This is achieved by the calculations and logic shown in the flowchart given in Figure 15. Finally, when the voltage reaches the corresponding MPP, it oscillates around that point. The step change (or perturbation size) in voltage decides the time for tracking, which is at the cost of accuracy.

A. Simulation results for standard test conditions (STC) T= 25°C and S = 1000 W/m²

A perturbation size (ΔV) of 2 V is chosen and the corresponding step time (t_s) is taken as 0.02 s for the simulation. Thus, MPPT controller generates voltages with perturbation size of 2 V at every 0.02 s, which makes the operation close to the MPP (210V). Figures 17a, 17b, 17c, and 17d shows the tracking of MPP from open circuit voltage of the PV array (264.5 V) when PV array is operating at STC (standard test conditions). It is assumed that the PV array modules are operating under uniform insolation. It is observed that the PV array voltage changes with a perturbation size of 2V, for every 0.02s, and finally oscillating around the MPP. The PV array produces a power equal to 5.7 kW, which is incidentally its peak power.

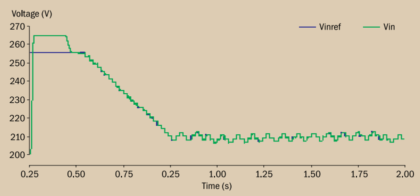

Figure 17a 5.6kW PV array voltage at STC using P& O MPPT (from open circuit voltage (264.5V) for voltage perturbation ΔV = 2V and step time (t_s) = 0.02s at STC)

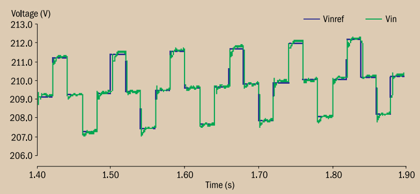

Figure 17b Zoomed view of Figure 1.17 a

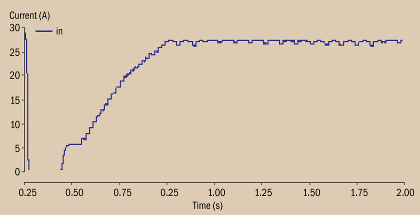

Figure 17c 5.6kW PV array current for ΔV = 2V and = 0.02s at STC using P&O MPPT

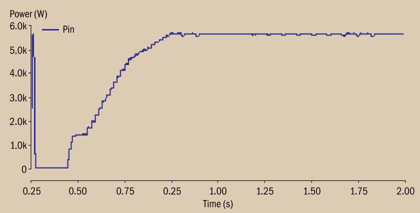

Figure 17d 5.6kW PV array output power for ΔV = 2V and = 0.02s at STC using P&O MPPT

B. Simulation results for different atmospheric conditions

Performance of a complete PV system for step change in insolation is given in Figure 18a, 18b and 18c. Initially it is assumed that the PV array is operating at STC, and is operated at the corresponding MPP. At t = 2 s, the solar insolation is decreased by 40% from 1000 to 600) and then the PV array settles at its new MPP. Here, a voltage perturbation size (ΔV) of 2 V is chosen and the corresponding step time (t_s) is taken as 0.02 s for the simulation.

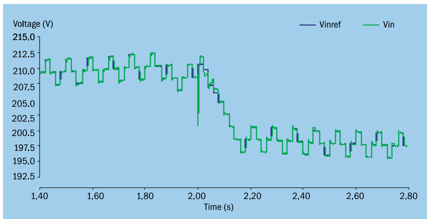

Figure 18a 5.6kW PV array output voltage tracking MPP (at t = 2 s insolation S is dropped from 1000 W/m² to 600 W/m²)

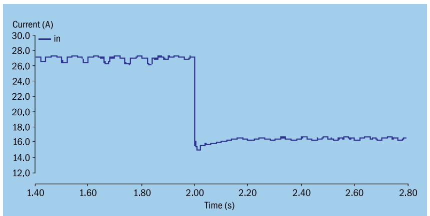

Figure 18b 5.6kW PV array output current for step change in insolation

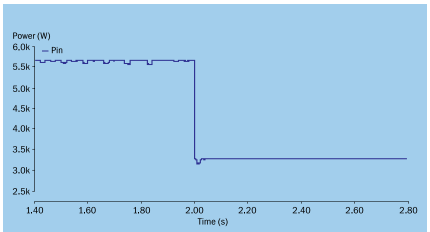

Figure 18c 5.6kW PV array output power for step change in insolation

Performance of the complete system for step change in atmospheric temperature is given in Figure 19a, 19b and 19c. Initially it is assumed that the PV array is operating at STC, and is operated at the corresponding MPP. At t = 2 s, the temperature is increased by 15 °C (from 25 °C–40 °C), then the PV array settles at its new MPP.

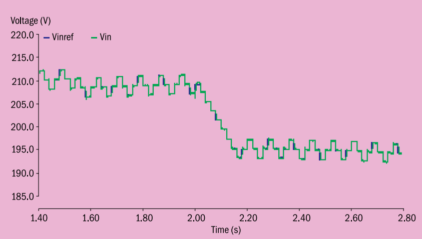

Figure 19a 5.6kW PV array voltage (at t= 2s temperature is changed from 25°C to 40°C)

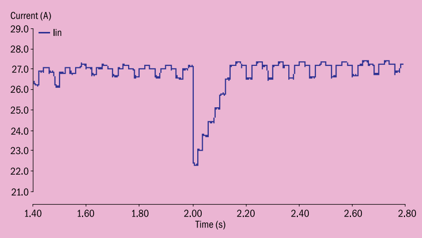

Figure 19b 5.6kW PV array current (at t= 2s temperature is changed from 25°C to 40°C)

Conclusion

The characteristics of photovoltaic array have been simulated using PSCAD/EMTDC, industry standard power system simulation software. The overview of different configurations of grid-connected photovoltaic system has been given and the control objectives of DC–DC and DC–AC converters have been explained. Further, the significance and operating principle of the MPPT have been explained. Perturb and Observe algorithm and Incremental Conductance algorithm to extract maximum power of PV array have also been discussed and tested on 5.6 kW PV array under standard and variable atmospheric conditions.

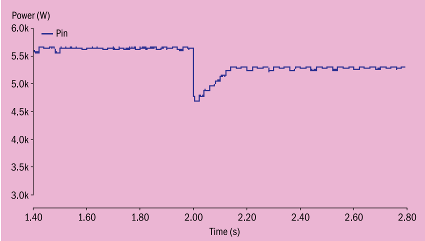

Figure 19c 5.6kW PV array power (at t= 2s temperature is changed from 25 °C to 40 °C)

This article is a product of the author's Mtech thesis. We invite researchers and academicians to write articles and papers based on their thesis.

Analysing the building integrated solar photovoltaic system

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Building from the past

It dates back to many years when solar PV (photovoltaic) systems were just making inroads into rural environs of our country. While some village folks were rejoicing in its use leaving others in the adjacent areas craving for the same. There were also a few voices who simply laughed at the idea of sun rays turning into electricity. Incidentally, the solar lighting systems stopped working in a few households with no one available around to set them right within the next fortnight or so. Impatience got the better of these people, who out of sheer frustration began to use solar module to cover the open space in their one room hutments. This idea of using solar panel for an entirely indifferent purpose was a gullible move at that time, which has now been transformed into a practical reality. The move is a pleasing one with a clear intention to use PV within a building envelope. This is known as the 'building integrated PV' or simply BIPV.

Solar photovoltaics—getting bigger and better

Solar PV technology is slowly but surely catching the attention of every one. People are fed up with the frequent power cuts and the sense of investing in a clean and silent energy source like PV is finally dawning upon them. Perhaps, of all the RE (renewable energy) technologies, PV seems suitable for distributed applications in the buildings. PV elements are practically becoming an integral part of the building, acting as the exterior weather skin. In countries like Japan, Europe, and US, more innovative ways of incorporating PV in a building envelope are being explored.

Why BIPV

There are quite a few reasons for us to take either an instant or a distant liking for a BIPV system. Some of these are mentioned below.

- GHG emission related impacts—climate change
- Growing need for a sustainable energy supply
- Dwindling stock of fossil fuels
- Rising cost of conventional energy
- Need for energy efficient and environment-friendly building

Understanding BIPV

Simply put, BIPV are PV systems built into a building, rather than being added on at a later date. PV systems use solar cells, which convert the energy of sun into useful electricity. Electricity available can be used to power a building or it can be fed into the electrical grid. Present day architecture includes BIPV and many governments (including India) have launched programmes to promote the use of advanced BIPV systems. The plain intention is to make use of PV array in the construction stages itself. BIPV is incorporated into the design of a building during the

conceptualization stages of a building often mixing the expertise of a PV professional with an architect. The outcome is an aesthetically pleasing and effective building configuration. A BIPV system can be installed in place of regular building materials thereby saving some money on construction.

For example, glass with specialized solar cells embedded in it can be used on the façade of a building in place of conventional glass. Thus, glass with solar cells can collect the solar energy and change it into electricity. That is not all, as it can shade a building, it can keep the rooms cooler. It would then mean a reduced cooling cost. It is also possible to make roofing out of BIPV. Using a BIPV system has a number of advantages in comparison to the PV modules, which find place in a building after its construction.

BIPV—a clear advantage

PV still does not come cheap, even though optimism about its being affordable in the near future is lurking around. With threat of climate change looming large and urban landscapes looking desperate for a clean source of power, BIPV may very well respond to such concerns even though to a limited extent. Various important advantages that can accrue through the use of a BIPV system are as under:

- Produces electricity from freely available sunlight
- Replaces the need for conventional building material
- Curtails the amount of thermal radiation into a building
- Makes way for natural daylight to come through
- Savings to the utility in the losses associated with transmission and distribution losses (known as grid support)
- Savings for the consumer through lower electric bills due to peak shaving (matching peak production with periods of peak demand)
- Saves on expensive urban space otherwise needed to mount the solar modules
- Adds novelty to the building structure

Placing BIPV modules

Solar modules can be placed in any location that is shadow free such as building roof top, car-parks, integrated into landscape design or even the boundary walls. Opaque solar modules can be aesthetically integrated onto South facades of building similar to aluminium claddings over a structural grid. The modules can be designed to have visible grid in required finish (colour) or modules can be flushed with one another to create a uniform façade. Ideally it is recommended that the facade is designed to have a slight tilt so as to ensure an optimum output from the solar PV modules. Transparent BIPV panels can be thought of similar to the structural glazing. These can be designed as single, double or triple glazing with a variety of structural framing. The glazing panels are often designed in a variety of sizes and cell spacing (for varying the light passing through). As such, the design options are limited only by imagination of the architect. Table 1 sums up these aspects.

Making of a BIPV system

Obviously, PV module is a core component of a BIPV system. It may be a thin film, crystalline, transparent, semi-transparent or opaque depending on the type of structure. Other than that, it is usually made up of the following components.

- Charge controller to regulate the power into and out of the battery storage bank (in case of stand-alone systems).
- A power storage system, generally comprising of the utility grid in utility-interactive systems or a number of batteries in a stand-alone system
- Power conversion equipment including an inverter to convert the PV modules DC output into AC compatible with the utility grid backup power supplies such as the diesel generators.
- Appropriate support and mounting hardware, wiring, and safety disconnects.
- Can either be interfaced with the available utility grid or designed as stand-alone, off-grid systems.

Table 1 Design aspects of BIPV

Type of laminate	Application	Advantages	Remarks
Single glass	Roof	Improved aesthetics and security	Clearly, triple glass laminates offer the maximum possible solutions
Double glass	Roof, skylight and facade	Reduced sound, improved security, ultraviolet filtering and better aesthetics	
Triple glass	Facades	Acoustic insulation, thermal insulation, UV filtering and improved aesthetics	

Table 2 Important features of building integrated with PV

Building element	Salient features	Remarks
Rooftop	• Designed to take advantage of the retrofit market • Not fully integrated into the roof structure • Mounted onto the existing roofs	• Fully integrated BIPV roofing systems should perform the function of a standard roof and issues such as water-tightness, drainage, and insulation are addressed
Flat rooftop installation	• Seem to present the least degree of engineering difficulty for BIPV installations • Akin to ground based array installations	• Differ from inclined roofs primarily in the nature of water tight layer
Facades	• Primary roles of a building façade are weather protection and appearance	• Five general types of building facades into which PV can be integrated have been identified – profiled metal cladding – panel curtain wall systems – structural glazing mullion – pressure plate mullion – rain screen over cladding
Atria and Skylights	• Typically constructed by securing and sealing transparent glazing units to a pre-installed metal frame (aluminium or steel) • Technique is similar to that used in the glasshouse construction • Atria in commercial buildings usually span large areas and are considered to be the roofing structure	• As glass roof becomes more inclined, the building technology becomes increasingly similar to that of a façade, particularly in the methods used to secure laminates • Skylights on the other hand penetrate a conventional roof structure to provide light and in some cases ventilation • Atria and skylights well established and are very suitable for PV integration with semi-transparent PV laminates directly replacing the glazing units • PV cell limits the amount of light transmitted, semi-transparent modules are made either by spacing opaque cells in an otherwise transparent module
Shading elements	• Typically secured on to the outside of the building envelope to limit the amount of daylight and heat entering through a window • Well suited to accommodate PV laminates as they are oriented towards the sun • Often have a flat surface and allow rear ventilation	• For shading elements which track the sun, a trade-off between day lighting requirements and PV generation can be achieved by the use of holographic concentrating systems

Choices for building integration of PV

There are different types of building elements. These can have room for PV such as curtain walls, atria, and roofs. Efforts are underway to develop new products with PV as an integral component such as active shading elements and combined heat and power units. Table 2 gives an insight into the important features of building integrated with PV.

Key considerations in designing a BIPV system

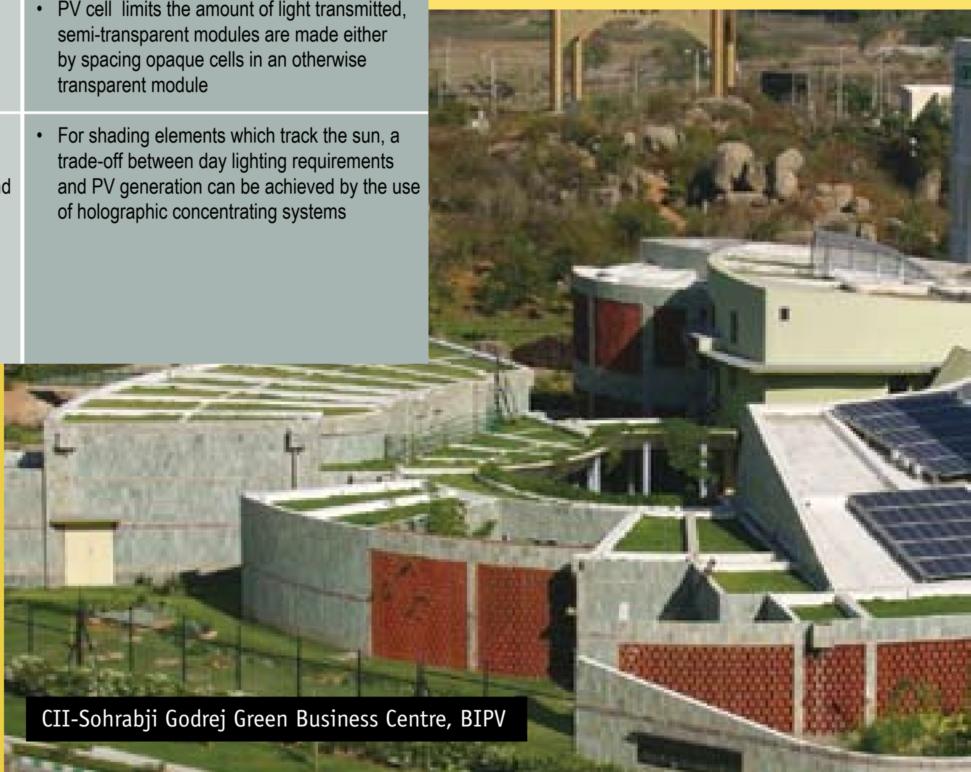
It is absolutely important to design a BIPV system with sufficient care and caution. Table 3 sums up the most important aspects.

BIPV buildings in India

In this part of the world, BIPV is a recent phenomenon. The number of BIPV buildings within the country can just be counted on the finger tips. It is not out of place to mention here that all such buildings have installed PV capacities well below 50 kWp. In sharp contrast, BIPV installations abroad have even crossed a megawatt capacity limit. Perhaps this novel PV technology use may receive a well desired impetus with a practical launch of activities under the just approved national solar mission. Table 4 includes BIPV buildings present within various energy sectors.

Indicative specifications of a residential type BIPV system

Let us now take a close look at the bare minimum technical specifications of a BIPV system intended for a residential



CII-Sohrabji Godrej Green Business Centre, BIPV

Table 3 Key consideration in designing a BIPV system

Aspect	Likely gain/considerations
Use of energy conscious design practices and/or energy efficiency measures	• Reduced energy demand of the building • BIPV may meet a larger percentage of the given load requirement
Selection of a proper interface	Grid interface may result as a storage and backup
Adequate ventilation	Ensure sufficient ventilation behind the modules to dissipate heat
Use of a PV/T system	• Try to make use of solar thermal resource developed via heating of the modules • May be useful in cold climatic regions for the pre-heating of incoming ventilation
Use of an integrated day lighting and photovoltaic collection	• Make use of crystalline modules with custom-spaced cells between layers of glass or semi-transparent thin film modules • Design considerations may hover around creating unique day lighting features in roofing, façade or skylight PV system • BIPV element may bring down the undesired cooling load and glare often witnessed in case of large expanses of architectural glazing
Incorporate modules into the shading devices	May result in suitable passive solar shading
Site specific climate/Environment	• Evaluate the effects of climate and surrounding environment on the array output- (cold and clear days yield more power than hot and overcast days) • Ensure no shading to the PV array from any neighbouring buildings or tall trees • Explore the possibility of having tilted arrays as generation goes up by more than 50% in comparison to a vertical facade

use. A power pack of 1.5 kWp is deemed sufficient to run lighting and cooling loads (excluding air conditioners) of a residence for a duration of 5–6 hours daily. Needless to say, higher load

Table 4 Various buildings integrated with PV

Organization/Individual	Type of System	Capacity (kWp)	Location
INSTITUTIONAL			
CII-Sohrabji Godrej Green Business Centre	PV-AC hybrid	20.0	Hyderabad
TERI (The Energy and Resources Institute)	PV-Gasifier hybrid	10.0	Gual Pahari (Haryana)
IIT (Indian Institute of Technology)	PV-Mains hybrid	3.0	Kanpur
Indian Oil Corporation Ltd. (Corporate Office)	PV-AC Hybrid	14.0	Delhi
CSE (Centre for Science and Environment)	PV-AC Hybrid	10.0	Delhi
Alliance Francaise	PV-AC Hybrid	4.0	Delhi
Executive Ship Management Ltd.	PV-AC hybrid	30.0	Lonavala (Pune)
RESIDENTIAL			
D Padmanabhan	PV-AC Hybrid	1.8	Bangalore
Dr Vineet Nayar	PV-AC Hybrid	0.9	Bangalore
Tripti Prasad	PV-AC Hybrid	0.9	Bangalore
INDUSTRIAL			
Delta Factory	PV-AC Hybrid	9.5	Rudrapur (Uttrakhand)
Suzlon Corporate Building	PV-AC Hybrid	14.0	Pune

Table 5 Indicative specifications of a residential type BIPV system

Parameter	Value
Array capacity	1.5 kWp
Percentage contribution of PV	60%
Approximate area	15.5 sq. mtrs.
System voltage	48 V
Battery capacity	48 V, 400 Ah
Power conditioning unit capacity	2500 VA
Design load Tube lights (10) Fans (4) Television (1) Air Cooler (1)	1000 W
Hours of use per day	About six hours
System autonomy	2 days
Expected annual generation	2200 kWh
Approximate System Cost	Rs 6–7 lakhs

IIT Kanpur, another BIPV

operation seeks an added PV capacity. Table 5 gives a quick glimpse into such specifications.

PV Technology choices

Today, a wide range of PV technologies are readily available in the marketplace. The issue is not so much about their individual performance as it about their full adaptability to the building under active consideration. For example, thin-film technology like amorphous silicon is deemed as a suitable choice mainly on account of its high material flexibility. However, it scores low in terms of the installation area related requirement. Table 6 takes a close look at the technology choices from important considerations of associated solar to electric conversion efficiencies and area needed for installation.

BIPV—looking beyond the national frontiers

BIPV market is currently being viewed as a high growth market. The underlying fact being that European BIPV market represents a huge potential market. Today, Europe is not alone in promoting the use of BIPV systems, but several countries around the world are offering cushioned support to it. As per the available estimates, European BIPV market was pegged at about 143 million euros aggregating to about 26 MW in the capacity terms. Such a usage is across all the sectors of economy—residential, commercial, industrial, and public markets included. In fact, major accruals have matured lately from the industrial and commercial markets. Residential sector has edged past rest of the sectors recording the maximum growth. It has become the largest sector for BIPV.

Primary reason for such a growth has been the fast emergence of the French and Italian markets. These two markets have implemented the high feed-in-tariff for BIPV systems moreso during the last few years or so. Small capacity systems have been a definite favourite within these two markets. In particular, French market has shown appreciable growth rates due to a high rate of adoption of BIPV within the residential sector. In contrast, Italian market has also recorded this trend though to a diminished extent. If, we talk further about the market penetration of BIPV systems, then Luxembourg has fared exceedingly well on this specific front. Residential sector is not the only one to gain from advancements in the BIPV segment. Lately, commercial sector is finding an increasing acceptance in countries with a clear legislative support. Expectedly, the commercial use of BIPV may become more streamlined and acceptable once it becomes truly affordable. That is not to underestimate a growing significance

Table 6 PV technology choices

Technology	Cell efficiency (%)	Module efficiency (%)	Area requirement (m^2)	Remarks
Single crystal Silicon	16–22	13–19	~ 7.0	Here single crystal silicon emerges a clear winner. However, material flexibility as offered by the thin film technology like a-Si may be difficult to match for integration purpose within a building envelope
Poly crystal silicon	14–16	12–15	~8.0	
Amorphous silicon		6–8	~12.0	
Cadmium telluride		8–10	~11.0	
Copper indium (G) selenide		7–11	10.0	
Dye sensitized cells	2–4			

Gual Pahari, Haryana

of BIPV systems in the public sector via government support.

Feed-in-tariffs have been the mainstay of the BIPV programme in countries like Germany and Japan. In fact, Germany is the largest market for BIPV in Europe having launched the programme as early as in 1999. This programme was popularly known as 100 000 PV roof programme. The availability of interest free loans catalysed a large and fast development of BIPV market here. Such an early development has led to wide spread expertise amongst the designers, architects, manufacturers, installation, and commissioning companies and importantly, the public or end users at large.

In technical terms, following few points is of increasing significance.

- Grid connected BIPV installations account for as much as 95% of such systems in Europe
- Single crystal silicon is a clear choice of use mainly in view of aesthetic benefits leaving aside the performance
- Thin film and other technologies make up for less than 10% of the market demand. Commercial projects place aesthetics considerations over and above the general performance.
- Growing linkage of BIPV with the construction industry is being observed for practical reasons

BIPV outlook for the future

There are several market studies available in respect of BIPV application segment. Quite recently, Nano Markets has released a report entitled, 'Building Integrated Photovoltaics Markets: 2008'. Following few are its key findings.

- Technology choice of BIPV will not be limited to crystalline silicon alone. In fact, major opportunities exist for new thin-film and organic materials. These two technologies offer the facility of laminating products onto curved surfaces and integrate into the buildings
- There will be an installed capacity of about 10.8 GWp of BIPV by 2013. Out of which, 4.6 GWp will emerge from Europe and 3.7 GWp from US. Residential applications will account for about 7 GWp of total BIPV capacity by 2013
- Rooftop installations will be the dominant choice of building integration technology and façade based BIPV will account for around 1.1. GW by 2013.
- New generation BIPV products (PV-encapsulated roofing product market) comprising of solar tiles, slates, and shingles will generate about $2.5 billion in revenues.
- Façade based products such as solar curtain walls, building cladding, and atrium glass are expected to generate revenues of roughly $430 million by 2013
- Solar cladding is being seen as quite a competitive alternative to conventional cladding materials

Summing up the Indian perspective

Large number of high rise buildings is being constructed in India. Accordingly, energy consumption in such structures is increasing. Power interruptions during the day mean an instant switchover to the diesel generators, which needs separate space and maintenance personnel too. BIPV systems can offer a healthy and aesthetically pleasing solution to such vexing issues. There is no second opinion about a BIPV system not coming cheap. However, it will accrue savings over a longer period of such system use. Incidentally, there is still not enough experience in India related to use of BIPV systems. MNRE in coordination with several other ministries like urban development must actively promote BIPV concept across different sectors of our economy. Important to mention here is that selective few state nodal agencies for renewable energy like GEDA (Gujarat Energy Development Agency) had earlier proposed to meet around 80% cost of the modules actually used in such projects as a grant to the building organizations.

Presently, MNRE supports BIPV systems up to a module capacity of 5 kWp. It should cover a minimum roof/wall panel area of 10 sq m per kWp. Financial support is available up to 50% of the cost or Rs 20 000 per kWp or whichever is less. The ongoing five-year plan envisages the installation of about 85 MW worth of BIPV systems. It is certainly no mean target considering the miniscule capacity put up so far. Perhaps solar cities development plan of the ministry can open a window of opportunity for BIPV installations as well.

Building outlook

Let us foresee a day when solar PV and the building housing will welcome the morning sun together. Its use will not be akin to a rural situation, when solar lighting systems for example come alive every day in the evenings. BIPV use will not wait for the day to get over, but benefit its occupants even before they land up in their offices for instance. So, is this not a case of mighty sun waiting for the ordinary masses? Surely, Indians then may have one more reason to worship the early morning sun.

Solar Lighting

edging out the traditional practice for eco-balancing

JURNAIL SINGH, Research Associate, LaBl, TERI <jarnails@teri.res.in>

The bare truth

Sadly enough, nearly one-fourth of humanity has no access to electricity even in this modern age. Incidentally, almost 25% of such population – 68 million – resides in India alone. They are predominantly from the poor rural communities, who are forced to light up their homes at night with kerosene lanterns or oil wick lamps. However, the negative fallout of burning kerosene is that it releases about 6 000 000 MT of CO_2 (carbon dioxide) in our atmosphere. Thus today, the need for renewable energy-based lighting devices is being recognized. Out of several technologies available, perhaps SPV (solar photovoltaic) based lighting provides the most effective solution.

Cognizant of this fact, TERI (The Energy and Resources Institute), through its flagship campaign LaBL (Lighting a Billion Lives) is facilitating and empowering rural communities to take up the innovatively designed Solar Lighting Enterprise. It is available in the form of SLCS (Solar Lantern Charging Station).

Reaping the environmental benefits

LaBL campaign hinges around a two pronged approach—provide light to the deprived communities and contain environmental degradation from kerosene combustion. Thus, it exemplifies sustainable development goals of this campaign. Conservative estimates suggest that one solar lantern offsets about 1.5 MT of CO_2 in its lifetime of 10 years. This has been calculated simply on the basis of kerosene that would be saved after introduction of a solar lighting option. However, LaBL targets to light up about 200 million households by 2015. Thus, an equivalent number of solar lanterns would be needed. The enormity of the targeted coverage could give us a fair idea of the total carbon offsets that would accrue from such a transition. The catch lies here now! Are the offsets only limited to kerosene consumption or something else as well? This article tries to bring up this facet of rural solar lighting technologies under the conceptual modality of eco-balance (also known as life cycle analysis).

LCA (life cycle analysis): a key determinant

As per the European Commission, 'LCA is a methodological tool that applies life cycle thinking in a quantitative way on environmental analysis of activities related to processes or products (goods and services).' This would translate into a cradle to grave analysis of a product's environmental impacts (starting from the raw material extraction till the end of life treatment — waste disposal). Learning from this, a solar lantern can be a carbon-neutral product only when the carbon emissions offset (resulting from substituted kerosene) are equal to or more than the carbon emissions related to raw material production, distribution, usage as well as its ultimate disposal.

Life cycle analysis is based on the selection of a reasonable functional unit which can act as a common denominator for more than one technology to be compared. Solar lanterns generally replace kerosene lanterns (hurricane lamps) on a near equivalent consideration of size and weight. Comparison on the basis of kerosene consumption, and an accompanying light output or the number of lamps/ lanterns can be envisaged in a LCA for solar lantern.

The long lasting approach

Many variants of life cycle assessment are in use. Two of the multiple variants have been discussed here.

Cradle to grave LCA

This is a material flow approach wherein, full life cycle analysis is carried out from the raw material extraction (cradle) till the end of use treatment or disposal (grave). The process consists of material inflow and outflow considerations. For example, a normal 80Wp solar panel comprises of solar cells, aluminium module frame, terminal boxes, and so on. The cradle to grave analysis would consider all the above mentioned steps for each of the inventoried components and calculate the environmental impacts such as the following.

- Global warming potential
- Ozone depletion potential
- Acidification
- Various other toxicity indices for the same.

Typical system boundary while conducting a cradle to grave analysis for a crystalline solar module is presented in the following figure.

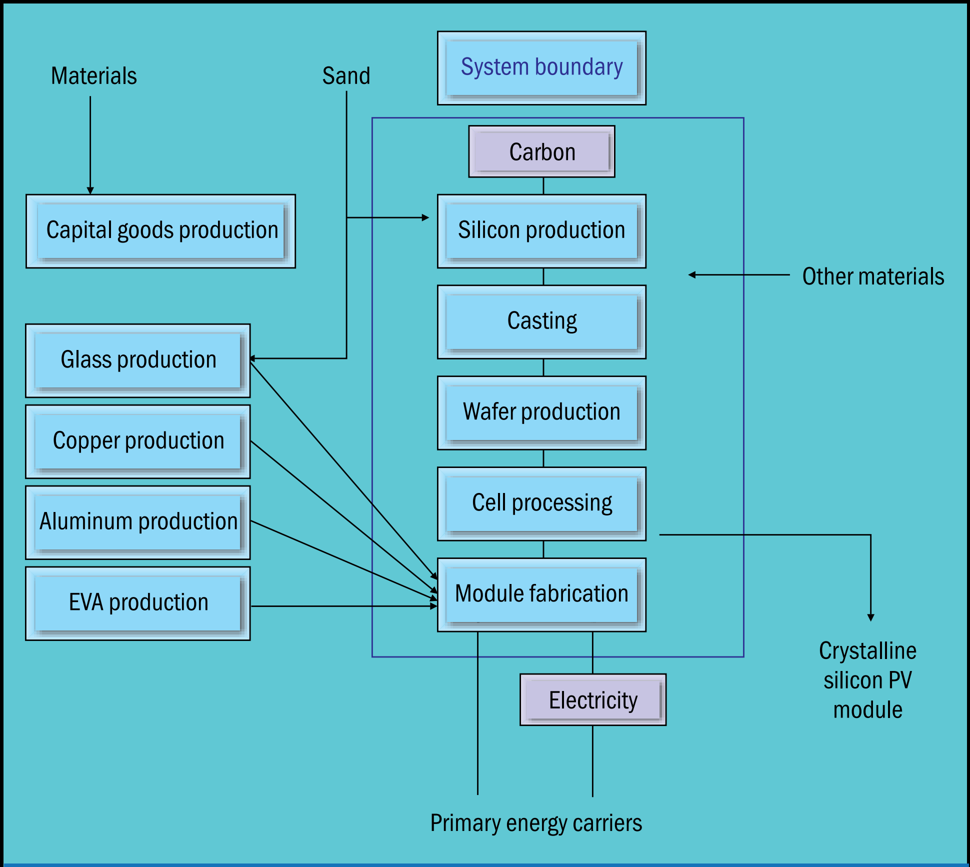


Figure 1 System boundary and material flow analysis (G J M Phylipsen and EA Alsema, 1995)

Economic input output LCA

EIO (economic input output) uses an aggregate sector level data in order to proportion the quantum of environmental impact of a particular product to different sectors. Since many of these sectors are interlinked, it draws relations between sectors and uses the sector-level average for analysis. For example, manufacture of a solar module would usually require equipment like laminators, ovens, simulators, and so on which in turn need electricity to operate. This electricity can in turn be generated by a solar power plant or other conventional sources. To delimit the boundary of linkages between different processes and sectors, scope definition of the LCA is dealt with an EIO approach.

Since these are sector level averaged out data, it might not be the best in order to determine environmental impacts of a product. To elaborate this, let us take an example of the battery sector. EIO would simply assign value of environmental impact (lets say CO_2 emissions) for a unit (in terms of money) consumed by a battery. This would be irrespective of the type of battery. A NiMH battery might have less toxicity indices as compared to a lead acid one but these nuances remains untraced while using the EIO approach.

Baseline

LaBL targets only those households that are using kerosene for lighting purposes. The baseline scenario can be addressed only when the total kerosene consumed by different types of lamps has

Image credit: TERI

been ascertained. There are different varieties of kerosene lamps available in the market including the normal wick lamp (*dhibri*), chimney, and the most sophisticated one called the Hurricane lantern. It has been found that most of the households have at least one hurricane lantern in use for a few major activities like reading, cooking, and so on. The amount of kerosene consumed and the light output from each lamp varies. Studies report that the effective light output from most of these lamps ranges from 20–90 lumens which not even half of the illumination is provided by a super-bright high efficiency — a 3W LED solar lantern. This provides an interesting clue towards defining the functional unit for such kind of an assessment. The common denominator over here is the light output produced by each of the lamps. This means that the concept of confronting one hurricane lantern against one solar lantern would not lead to a fair comparison since a single solar lantern provides many more times light output than the former. In other words, if one solar lantern is providing 250 lumens of light output every day, we would have to consider the number of kerosene lanterns that would have to be lit simultaneously to get the same amount of illumination. Over here, we are discounting the fact that for any productive use like reading and writing, the light intensity per unit area is a much more ideal characteristic to be measured. This is just to ensure conservativeness in the LCA approach by virtue of the fact that the kerosene lanterns can never make up to the equivalent lumens per unit area as compared to a solar lantern.

An ideal functional unit to analyse life cycle emissions from both these products seems to be kL (Kilo-lumen). In other words, life cycle emissions from one solar lantern producing 0.25 kL, at any given instant of time, can be compared with the life cycle emissions from the number of kerosene lanterns used to produce the same amount of light output at any given time.

Solar lantern — an anatomical perspective

Even the most sophisticated kerosene lantern would like to be a simple device compared to the solar lantern assembly. Majority of the emissions from its life cycle are from the kerosene it consumes during its life span of say 'n' number of years. On the contrary, a solar lantern is an assembly of complex sub-assemblies including the solar panel, battery, light source (LED/ CFL), a PCB (Printed Circuit Board), chimney, luminary, handle, body, and various other parts like switches, screws, cables, and so on. A better idea could be gauged from the figure.

Identification and listing of all the components (inventorization) in a solar lantern is the first and very crucial step towards analysing the life cycle impacts. One can, with a little effort, complete the inventorization process. However, the substantive amount of analysis has to be done after that using standard datasets.

As far as component wise results are concerned, it is likely that the most significant contributors to the life cycle costs or the global warming potential would be the solar panel and the lead acid battery. This can be attributed to the fact that the manufacturing process of solar cells is one of the most energy-intensive processes while the battery rates high on lead contamination as well as global warming potential.

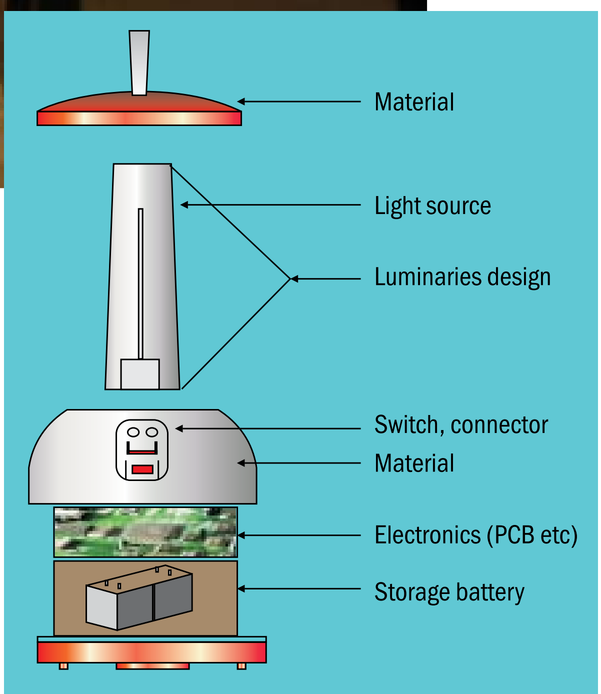


Figure 2 A prototype figure

The analysis so far

Based on the preliminary analysis conducted by TERI in collaboration with researchers from KEIO University, Japan and Yale University, United States of America, it is estimated that even an individual solar lantern scores much better as compared to a general kerosene lantern. These estimates are conservative since they have been calculated based on the number of lanterns and not the effective light output. Further analysis should ensure that solar counterparts of rural lighting devices are really carbon neutral and environmentally benign.

However, LaBL intends to reach rural areas with two service delivery models. These would be the already existing SLCS model while at the same time provisioning of individual solar lanterns through the SLCS entrepreneurs. Although a centralized SLCS (solar lantern charging station) model stands following life cycle benefits against an individual solar lantern.

Performance warranty

The SLCS model allows bigger panels (30 – 80Wp) to be used which generally have a performance warranty of at least 10 years. On the contrary, smaller 3Wp modules are non-standard and the performance is also not warranted.

Material use

It has been observed that in solar modules, aluminium frame is one of the major contributors to the life cycle emissions. Understandably, a larger panel of 30Wp would use lesser quantity of aluminium as compared to 10 3Wp panels so as to get a cumulative equivalent capacity.

Transportation

In the LaBL campaign, bulk orders are placed for installation and commissioning of SLCS in a cluster of villages. Thus, the transportation frequency is reduced and so are the life cycle emissions.

Buy back system

While giving out solar lanterns for rent, the SLCS model would allow an operator/entrepreneur to deposit a certain amount as a security deposit. This deposit does not necessarily have to be in monetary terms. It can be ensured that each household which rents a solar lantern deposits its hurricane lantern to the charging station. This is possible only when the single point accountability rests with the entrepreneur.

Image credit: TERI

End of life treatment

It is inherent in LaBL that the current and future charging stations act as TRCs (technology resource centres) and undertake all the related maintenance work in the future. TERI shall ensure that the TRCs are well equipped to replace all the old batteries in time and send the same to recycling. This can have a massive impact given the magnitude of the campaign.

Discussion

Quality as well as expanse of the database is a key determinant for any product's authentic life cycle assessment. The Indian scenario is a bit grim on this front since no standard database exists to undertake this kind of exercise. Since, solar cell and module manufacturing process is standardized throughout the world, arranging proxy values for the Indian scenario is not difficult. The other side deals with other components of the solar lantern like the battery, PCB, body, and so on. For these processes are not standardized and differ from one country to the other. Henceforth, usage of these datasets (available in most of the LCA softwares like SimaPro™ and GaBi™) for an Indian case study would not be ideal. This might lead to other aggregated approaches like the EIO technique that has been described earlier.

LCA does a kind of an Environmental Cost Benefit Analysis wherein environmental costs are weighed in terms of certain indicators. But, is it feasible to quantify all environmental benefits in terms of screws nuts and bolts?

Drawing from the experience of the LaBL campaign, it can be said that a solar lantern is downing much more than simply replacing kerosene. It is indeed replacing a grim sorrow with a lasting smile! There have been instances where kerosene has caused massive harm at a personal as well as at the village level. Instances of burn injuries and fire are quite common at places where kerosene is predominantly used as a lighting fuel.

The lighting from solar lanterns can be classified as a productive light output since it facilitates livelihood activities like basket making, cultivation, weed removal, and so on. Various case studies have documented the economic benefit that betel leaf cultivators are accruing from introduction of the campaign in their village. This could never ever have happened through the traditional kerosene lighting. Such vital benefits cannot be captured by a purely positivist approach that a LCA inherently follows.

Every watt counts: a market perspective for solar consumers

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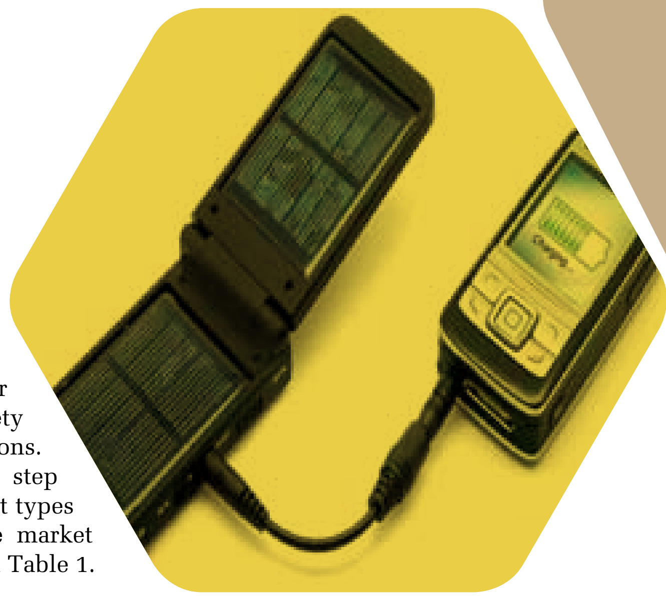


Background

Small is beautiful may not be true in each and every situation. Solar PV (photovoltaic) is not a notable exception for that matter. Use of solar power in a very low capacity may not be an instant priority anymore. A qualitative shift in the way urban people are live marks a sound reason for this renewed line of thought. However, there are still quite a few niche areas where utilization of even a very small amount of solar power can bring about significant changes. There is a real need for sensitizing people about the availability of various need-based consumer products relying on the freely available sunlight. The rationale for doing so lies in a sizable number of people making use of secondary cells. These are becoming costlier by the day and their safe disposal is often given a go by risking our immediate environment to the associated perils. Solar products in contrast last much longer and thus, may avoid or eliminate the use of such batteries. It is of an absorbing interest to talk about the different facets of very low power consumer product from various end-use considerations in the following few sections.

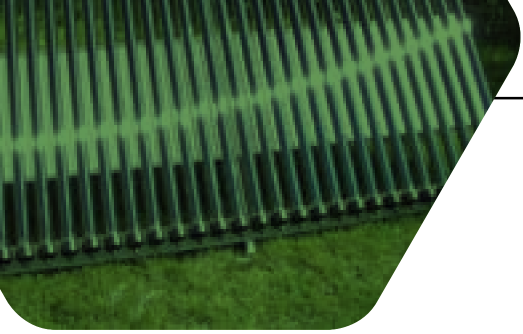
Breaking the market

It is relevant to deal with the market acceptability of very low power consumer products from a variety of end-use considerations. Perhaps, a well guarded step would be to know different types of commercially available market segments as represented in Table 1.

Table 1 Different types of commercially available market segments

Market segment	PV capacity	Major applications
Consumer products	< 1 Wp	Calculators, watches, automobile products
Remote industrial	(1 Wp–10 kWp)	Telecom, Telemetry, signalization, environment
Remote villages	(100 Wp–10 kWp)	Lighting, refrigeration, pumping, and irrigation
Grid connected	1kWp–10 kWp	Solar facades, private solar roofs
Central power plants	< 50 kWp	Utilities

It is clear from above table that first category of products—the very low power consumer products comprising of calculators, and so on consume the least amount of power in direct comparison to other categories. Let us now try to run through a series of efforts made within different organizations in developing/popularizing the use of very low power consumer market.



The early efforts

CEL (Central Electronics Limited) was the first Indian company to design, develop, and market a range of solar PV products. It developed a special module for an exclusive use of radio and tape recorder out of nearly 10 types of crystalline silicon cut cells. The module yielded a power output of around 3W at 8 volts. Early product demonstration of such an application was perceived to be successful. However, as the customary PV product range expanded, mini products like these were accorded little or no priority. Suryamapi was yet another product, which had attracted attention mainly from the academic and research organizations. It used a silicon solar cell as a photo sensor to record the value of incident solar radiation in milliwatts/cm2. A hand held tool like this was deemed to be ready option for a much more sophisticated range of pyranometers whether of an analogue or a digital type. Seemingly, both these products are now available only against customized demand.

Displaying it here and there

It was a treat to watch a wide range of low power consumer products being displayed at the renewable energy exhibitions at a popular venue—Pragati Maidan in the early nineties. Such products included solar caps, torch lites, and fountains thus, generating fair amount of curiosity amongst the visitors. However, for one reason or the other, these are used to represent the imported items making them expensive for an average buyer. The indigenous manufacturing activity was by and large seen to be absent in this case. Consequently, any noticeable volumes of these products were quite hard to come by.

Survey of solar consumer products

World Bank supported a major project for SPV market development at IREDA (Indian Renewable Energy Development Agency) from 1993 to 1998. Significant objective of this project was to stimulate the creation of a local market for products as diverse as lantern to power packs. It comprised of several key segments with one of those to ascertain the market worthiness of very low power consumer products like those mentioned above. The outcome of this large scale market survey carried out by Delhi based Admar Marketing Services pointed to a sizeable demand for various consumer products. However, any concrete strategy to gain ground on this specific front was not visible later.

The first hand account

Majority of Indian solar PV manufacturers usually display the conventional product range much sought after by the state nodal agencies under various socially oriented schemes/ programmes of MNRE (Ministry of New and Renewable Energy). However, a company with significant investment/ interest in the thin-film technology route had decided to focus on very low power consumer products too. The author had an opportunity to be associated with such an effort from the very beginning and thus, was witness to the subsequent market response as well. A multi-pronged approach was developed for the purpose in a phased manner as given below.

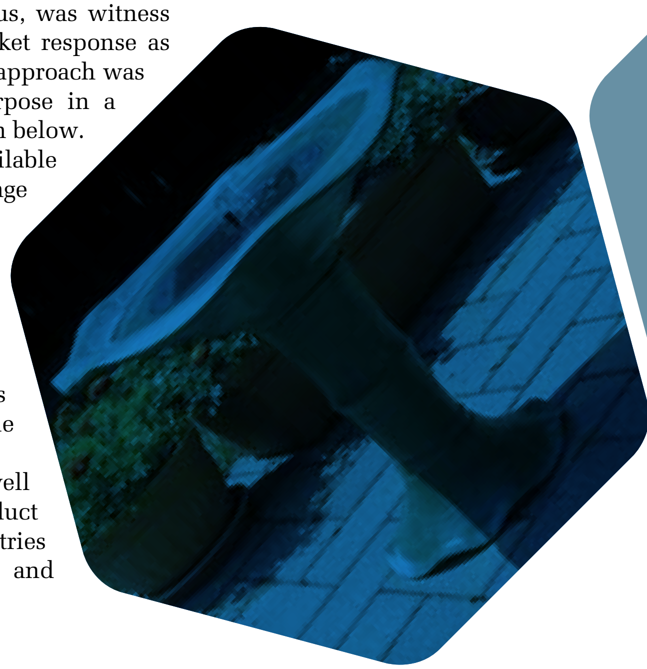
- Investigation of available product range (imported make) in terms of technology, end-use, cost, import duty structure, and so on.
- Selection of products deemed to be suitable at the local level
- Identification of well recognized product suppliers (in countries like Hongkong and Taiwan).
- Procurement of sampling lots for testing-cum-evaluation (in-house)

Subsequent to it, following few products were imported in small quantity.

- Solar cap (2 different models)
- Solar car ventilator
- Solar window ventilator
- Solar mosquito repellent (ultrasonic based)
- Solar garden fountain
- Solar charger

Products received were put to limited performance evaluation phase. Following which, it was decided to test the actual market response. Product exhibition venues like Chandigarh, Ludhiana, and Patiala were initially chosen for the purpose. Following points of significance were observed during such product demonstrations.

- A large cross-section of people visited the exhibition put up for the purpose
- Curious and quite interesting queries ranging from product operation and from use to selling prices were recorded.
- About 25% of the customers showed their instant willingness to make on-the-spot purchases of these products (that is cash purchases).



However, the decision to not sell but just gauge the customer responses did put off nearly all the intended buyers. A clear sign of dejection was noticed on their part as they seemed to be keen to buy the solar products. A well marked response gave a further fillip to the company's objectives to think of large scale production of selective few products like caps. Casting of dies and moulds being critical to this scheme came in for discussion stage with those adept at it. However, it did not turn into a favourable business proposition mainly in view of a strong dependence on the availability of off-specification cut cells. Thus, a well intended move to create a very low power consumer market had to be kept in abeyance. Perhaps, following few issues added relevance in this context.

- A solar company having its own cell/module manufacturing facility does not feel inclined to set up a dedicated unit just for scrap cells (to put these to product development use).
- Products/systems with much higher capacities make up enough business volume for them.
- Cost of marketing such consumer products is often seen to be prohibitive and time consuming.
- Attaining economies of scale is often seen to be an impediment for making such products readily affordable for a common man.

Consumer products — international outlook

Japan has been widely regarded as the bulk producer-cum-user of very low power consumer products. Amorphous silicon based products were found to have huge market demand with companies like Sanyo gaining an early lead. That is not all, as Matsushita continued to market products like solar calculators based on thin-film CdTe (Cadmium Telluride) technology. It made an annual shipment of about 1 MW on a continuous basis despite non-availability of CdTe modules to run any higher capacity products/ systems. Table 2 shows application based global cell use in megawatts.

It is quite clear from above that the consumer product has exceeded the market demand for off-grid commercial market year after year. However, it is quite less than that witnessed for the off-grid rural market, not to talk of grid-connected market for the residential and commercial sectors. The consumer segment has registered a steady growth during 1996–2006 with a slight dip observed during 2005–06. However, with new products like solar powered phones and laptop screens coming to the fore, consumer market is bound to register good market sales. That is not all, as the growing consumer electronic market segment may surge the demand for PV component further in the times ahead.

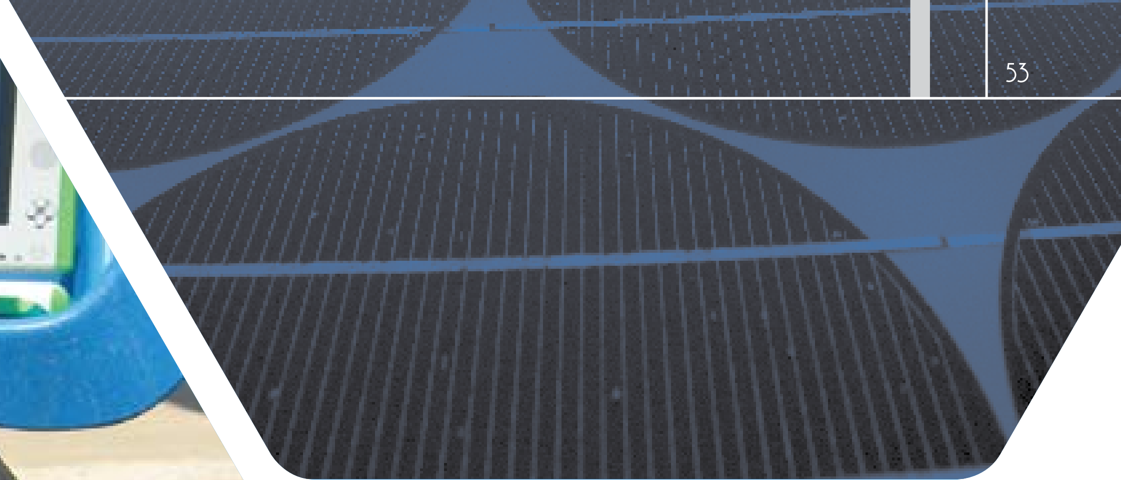
Solar consumer products worth the try

Mobile telephony is making huge inroads into the country more so since the last few years or so. Such a phenomenal growth is expected to continue in future too. The moot question is, can any of the solar consumer products today replicate such a remarkable feat in some way or the other. Perhaps yes, if, PV cell is made an in-built component of the mobile phones. There is a huge rural market waiting to be tapped

Table 2 Application based global cell use (in megawatts)

Market Sector	1996	1998	2000	2002	2004	2005	2006
Consumer products	22	30	40	60	75	80	90
World off-grid rural	23	34	53	85	110	125	140
Communications/signal	23	31	40	60	80	90	100
Off-grid commercial	12	20	30	45	55	60	70
Grid connected (residential/ commercial)	7	35	120	270	700	1375	1600
Large (> 500 kWp)	2	2	5	5	20	30	100
Actual MW/year	89	152	288	525	1040	1550	2200
Actual average module price (US$/Wp)	4	4	3.5	3.25	3.25	3.5	3.75

Source PV News, July 2007



and solar may play a pivotal role in its realization. Using a conventional charger is in no way problematic. However, if the ease of convenience is increased via solar, numbers may swell up. Another product with a high market potential for in-built solar can be a laptop computer. Solar operated screen can come more alive in this age of fast rising battery prices. The average use for these appliances is constantly increasing, which means use of battery is running out faster. Solar power is quite capable of serving this market segment in a clean and manner.

The changing dimensions

Micheal Gretel is widely credited with the invention of a new type of solar cell based on Titanium material. These types of cells are capable of changing the available sunlight directly into electricity. The process utilized for the purpose is akin to photosynthesis and thus, the product can be used even under low light and shade. That is not all as the dye cells function smoothly over a wide range of temperatures. Besides, such cells can be made both in transparent and opaque forms. As per available estimates, dye based cells can revolutionize the development of novel type of consumer product range including that based on the very low power requirements. The semiconductor devices laboratory at IIT (Indian Institute of Technology) Kanpur has been working on organic type solar cells for quite some time. It has been able to fabricate a basic configuration of the polymer solar cell. Small prototypes of modules and consumer electronic products like calculators and digital watches have been fabricated.

Consumer products with a big impact

There is a long list of very low power consumer products which are readily available in the international marketplace. While some of these are for sheer novelty, few chosen products can offer a big value for the little money spent. Following section takes a quick look at about six such products that can lead to sizable market volumes based on the actual need served.

Solar radio

Radio is still counted amongst a cheap and reliable source of both information and entertainment. Rural areas without any conventional power often go without this luxury due to lack of power supply. Even the cheap availability of dry cells may be an issue in such remote areas. Solar power in a small measure can meet this need quite easily and at no running cost at all. Also, any professional on a countryside visit may find refuge in the company of a solar operated laptop.

Solar car ventilator

It is also known as solar-auto-ventilator or solar-auto-fan. This sleek product keeps the car cool with the solar operated ventilation. The covered parking space is becoming more and more scare in the urban areas thus leaving the cars exposed to the hot summer sun. A few hours of exposure makes it quite hot. Use of a solar ventilator in the car helps to keep it cool. The device is usually placed on the car door glass with solar part facing the sun. Do not use this device while driving. Some very important features of this environment-friendly product are the following.

- Takes out hot and stuffy air inside your car with its unique method of ventilation
- Blows hot air out of parked car
- Uses no battery or wiring
- Keeps valuable items safe from quite hot conditions
- Brings down the use of air conditioning
- Less fuel consumption

Potential use of solar radio is in cars.

Solar window ventilators

A good number of people travel to other places on one pretext or the other. This way, their houses are left locked which also means switching off all electrical appliances, including

an exhaust fan in the bathroom. With occupant returning to its fold after a few days of outing usually finds the bathroom environment not so pleasing. This is where a solar window ventilator can keep the interiors always fresh and clean.

Potential use in residences and hostels.

Solar cap

It is a wonderful product with a comfortable positioning of both the solar cell and fan. The solar cooling fan is capable of absorbing the energy to drive a tiny fan mounted atop. It provides a whiff of cool air-via-solar energy use. Brighter the sun, faster the fan will rotate. It is normally available in different shades of colours and sizes.

Potential use for sports persons and those assigned with field activities like surveys, and so on.

Solar car air purifier

It is of a small size and sits pretty on the car's dash board. The intention is to purify the air inside the car. This solar electronic air purifier can produce ozone, which can deodorize and sterilize the car. It is very convenient to use and can work effectively. The device is easy to fix with a dual-adhesive plaster and can supply fresh air in the car. The working principle is that it can ionize oxygen into ozone. Ozone is considered as a strong oxidizer and is capable of decomposing the organic substance and the chemical material in the air. Take care to install this device in the path of sun.

Potential use in cars.

Solar mosquito killer lamp

This device is also known as a solar pest killer light and serves the purpose of a solar garden light too. It uses a super bright LED (light emitting diode) and is capable of working round the clock under the pest killer mode after a full day's charge. This device can be used both indoors and outdoors. Lights can be operated for as long as eight hours on a full day charging. Use of rechargeable batteries is made for the purpose. Just turn on the lamp and the iron net around the bulb has a specific voltage to kill the mosquitoes. The purple UV light attracts the insects while the white light is simply for illumination. It is a wonderful product to suit the convenience of many.

Potential use in residences, gardens, and camp sites.

Solar-powered address number light

Are you left wondering about the location of a house number in a residential colony during pitch dark conditions? Solar-powered address number light can solve the problem. It is made of durable ABS plastic and is fully resistant to the weather conditions. This device can clearly identify any address up to five digits. Such numbers can become visible from about 400–500 feet. Even if the sun shines for two hours, the device will operate throughout the night. What is more that it will switch 'on' and 'off' automatically via a light sensor.

Potential use in residences and cottages.

The ministry initiative

The MNRE took a bold initiative to set up a 1 MW amorphous silicon module manufacturing facility at Gual Pahari in Haryana. In fact, this plant was dedicated to the nation in August 1992 and was supposed to produce thin-film

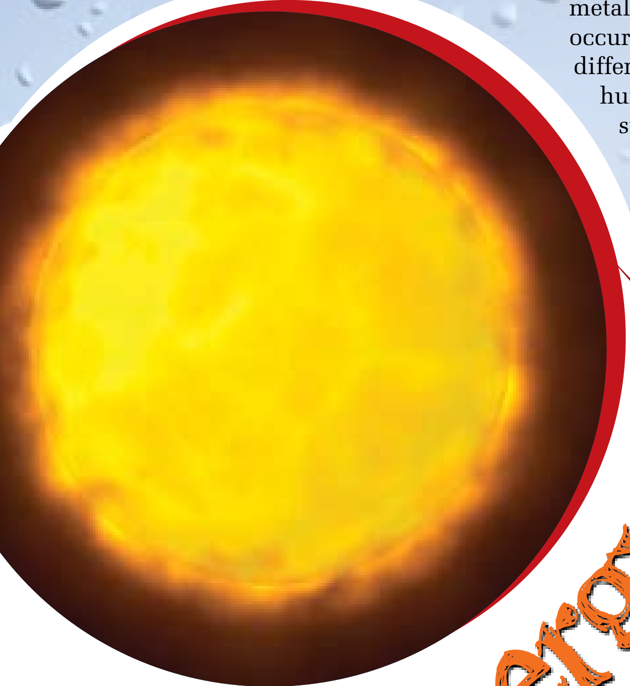
modules besides an accompanying range of low power consumer products. It passed through several stages of operational issues with BHEL (Bharat Heavy Electricals Limited) taking the lead role. Prototypes of selective few consumer products like wall clocks were fabricated and put up for field testing-cum-evaluation. However, commercial versions are still to see the light of the day for one reason or the other. The ministry programme has no special thrust on the very low power consumer product development. Perhaps it is so because large number of people in far off villages is still waiting for their turn to own a solar lighting system or even a solar lantern. In a way, one can say that solar lantern using LED (light emitting diodes) and using module capacity of just 3 Wp or so is the foremost consumer product to be promoted lately. However, it crosses the customary mark of less than a watt of power consumption to qualify under the consumer market category as such.

Issues meriting consideration

A large number of towns and cities are still reeling under severe power cuts. Standby options like inverters in the residential sector are being deployed in increasing numbers. The most affluent of the lot are taking refuge in an un-interrupted power supply via the use of diesel generators put up in a captive mode. However, those using inverters are left high and dry the moment AC mains are not available to charge a depleted battery. The option left around then is the use of age old candles—a clear source of risk filled and low quality light. Such a situation leaves open the choice of solar powered torch lites. However, products like these are not readily known and visible unlike other conventional products. Perhaps, use of such products may very well stimulate a need for another solar product like a solar garden light or even a home lighting system for that matter. After all, an urban user benefitting through the conventional power since long cannot be expected to make a transition to solar systems in one go. The process may very well begin with the introduction of low power consumer products to gain confidence of a user being exposed to solar use for the very first time.

The final consumption

Selective few corporate entities and other organizations had taken recourse to distribution of very low power solar consumer products as small tokens of appreciation. Perhaps it needs to be revitalized on a much bigger scale now so as to take the message of PV use far and wide. Like we often say that every small drop of water counts, same thing may be true for this type of solar market. That is not however to belittle the effort actually needed to encourage the use of a wide range of need based solar products amongst the most potential customer segments. These days different type of sports events are organized day in and day out. How about the real idea of at least some of the participants being given to wear tee-shirts fitted with solar powered fans at the back? Something may then work for sure in the direction of taking the rather subdued Indian PV consumer market to its rightful place.



Sun energy to purify drinking water

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Background

Drinking water with any type of physical, chemical or biological contamination has a harmful effect on human beings. The types of pollutants that occur on the surface water and used for drinking purpose differ in their very nature. Disease-causing organisms such as, bacteria, viruses, protozoa, parasitic worms, and so on are normally found in surface water, with less presence of dissolved salts. In contrast, ground water generally contains many water-soluble inorganic salts and toxic metals. These contaminations can occur in many ways and from many different sources, both natural and human-induced. As per the available standards, the recommended maximum limit of TDS (total dissolved solids) in drinking water is 500 mg/L (milligram per litre). Similarly, special attention is required to disinfect the surface water, as most of the diseases are caused by biological contamination. Though chlorination is the most widely used technique for disinfection, it reacts with natural organic matter to form harmful by-products like trihalomethanes. Currently, membrane based UF (Ultra-filtration) has been found to be a better option for removing biological and other colloidal species in a single step. Another membrane process, RO (reverse osmosis) is best suited for removing all types of dissolved salts from the contaminated water.

Energy: a prime mover

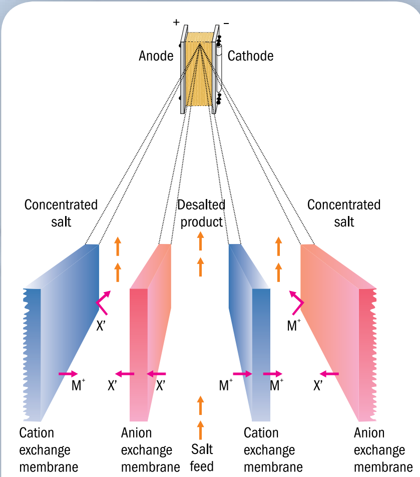
Membrane based desalination or water purification systems require considerable amount of energy in the form of electricity so as to achieve separation of the contaminants. With the greenhouse effect and the importance of carbon dioxide levels in the atmosphere, environmental pollution caused by burning fossil fuels for power production is a major concern. In addition, for remote locations, production, and supply of pure water from centrally located large desalination plants or extension of a national electricity grid to provide power for desalination is often not practical or economically viable. Therefore, these communities are often seen using drinking water of a sub-standard quality, as they do not possess the facilities to purify water. Using diesel generators in such situations constitutes a lower capital investment, but fuel transportation logistics and its maintenance costs make their operational cost high. On the other hand, renewable energy is a locally available and non-polluting alternative. It becomes more competitive for remote and rural areas where, small quantities of water for human consumption are needed. The renewable energies most suitable for combination with desalination or water purification systems are wind and solar energies.

Desalinating for a purpose

Solar desalination is used by nature to produce rain which is the main source of fresh water on earth. Solar energy can also be converted to electrical power using PV (photovoltaic) panels in order to operate power-driven desalination processes such as RO, ED (electro-dialysis) or VC (vapour compression).

PV-RO (Photovoltaic powered reverse osmosis) systems are a proven technology due to the low specific energy consumption, relatively low maintenance requirements, and the economic viability for desalting small amounts of water.

However, selection of an appropriate



Electro-dialysis

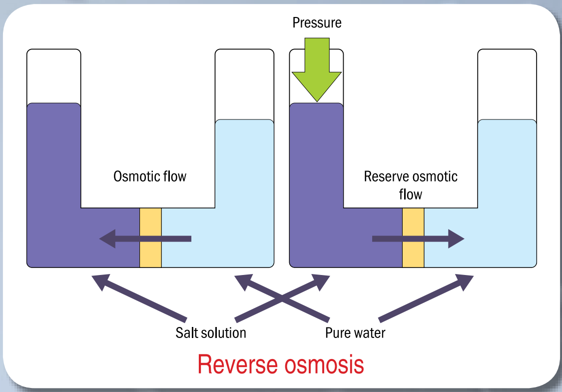


Table 1 Typical performance data of the bench scale RO and UF units

RO		UF	
Power Input (W)	10–15	Power Input (W)	10
Pressure (bar)	4–5	Pressure (bar)	1–2
Feed Salinity (ppm)	1000–2500	Feed Turbidity(NTU)	10–20
Product Salinity (ppm)	100–200	Product Turbidity (NTU)	0.5–1
Product Flow (lph) (litres per hour)	10	Product Flow (lph)	12 (candle) 100 (capillary)

solar desalination technology depends on a number of factors like, plant size, feed water salinity, infrastructural availability, and so on. The main challenge of solar based desalination is in interfacing the two technologies, as desalination processes are designed for a continuous steady state operation and solar energy by nature is intermittent and with variable intensity.

Membrane based water purification systems using solar energy

Bench scale RO unit

RO is a pressure driven process, where pure water from salty water is continuously drawn through a semi-permeable membrane. The pressure requirement varies with the amount of dissolved salts. The normally reported brackishness in India is in the range of 1000–3000 mg/L. On an average, a family of five uses 25 litres of water for drinking and cooking purposes in a day at the rate of 5 lpcd (litres per capita per day)

In the RO unit (Figure 1), the feed water is passed through the membrane with the help of a DC pump directly connected to the PV panels, without any batteries. The unit can normally be operated for 8–9 hrs on sunny days, which can cater to the drinking and cooking requirements for 3–4 families. This unit contains a cartridge pre-filtre and a spirally wound RO membrane element of 1812 (1.8 in diameter and 12 in length) size.

Figure 1 Bench scale solar RO unit

Bench scale UF units

Surface or well water containing only filterable contamination such as, biological matter, colloids/ turbidity, and so on. Without any salinity problem it can be made fit for drinking through UF. It can be used as a pre-cursor to RO also. The pressure requirement is of the order of 1–2 bars. In this unit (Figure 2), the feed water is passed through the membrane with the help of a DC pump directly connected to the PV panels, without any batteries. The UF unit consists of candle and capillary (1812 size) type filtres in parallel. The candle filtre is suited for 3-4 families for their drinking and cooking needs and the 1 m3 /day water from the capillary filtre is sufficient for 40–50 families.

Drawing a clear comparison

The typical performance data of these units are given in Table1. No significant variation in the rate of power production from the PV panels has been observed during the effective operation period.

Figure 2 Bench scale solar UF unit

In villages, to keep the water cost low for the people, facilities such as, piped or door-to-door distribution of water should be avoided. Thus, a number of localized small capacity plants are better suited than big plants, considering the ease of accessibility of drinking water within walkable distances. Thus, typical production capacities ranging from 200–500 lph will be the optimum so as to take care of small communities. In this regard a pilot scale demonstration plant is under construction in BARC (Bhaba Atomic Research Centre).

The main linkage

Integrating desalination units with renewable energy sources is quite important for addressing the climate change issues. Perhaps, solar energy may well turn out to be an exciting option for tackling the twin issues of power scarcity and poor water quality as witnessed in the remote rural areas. Importantly, sustainability of water production can be achieved only through a proper selection and integration of power production and water purification technologies.

SUMMARY OF SOLAR CELL PRODUCTION SURVEY 2008

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Global Production of PV cells in 2008, including thin-film modules, was way up — an incredible 85 % to more than 7.9 GW. This beats out the 69% increase in PHOTON International's last survey on 2007 production when 4.3 GW was manufactured — itself a record-breaking result over all of the previous years. However the recent economic crisis and rampant rumours of factory closures has led to several layoffs being announced in the PV industry. This has created a fear of oversupply of modules and a corresponding decrease in prices all along the value chain. This scenario though good for consumers is scary for manufacturers, integrators, and installers given the shrinking profit margins. 2008 also witnessed ups and downs in the performance of a number of manufacturers and companies. Amongst the top 20, all of the Japanese companies lost ranking positions, all the Chinese companies either moved up or matched their standing. China not only kept its spot as the leading cell-producing country, it more than doubled its numbers as compared to the last survey.

However, for the second year running, Q-Cells SE, the German company, has held on its lead as the biggest cell manufacturer in the world. Though, Q-Cells did not exactly blow the competition away, still its 2008 production of 581.6 MW works out to a very respectable production increase of 49% over the 389.2 MW in 2007. This year its core crystalline-based business expects to produce between 800 MW and 1 GW. Though promising, this figure is actually a climbdown to the earlier statements of producing at least 1 GW. While the Q-Cells 2008 story may seem huge, an even bigger one concerns CdTe (cadmium-telluride) manufacturer First Solar Inc.

After making a splash by becoming the first pure thin-film producer to find a home among the top ten in 2007, when it was catapulted from 13th to 5th spot. Then in 2008 it rose to the second place by producing 503 MW, thus marking an impressive 152% gain for the year. China's largest PV Company, Suntech Power Co. Ltd. retained its third-place in relative ranking. This puts Suntech ahead of Sharp Corp. for the first time. Suntech's market share also dropped, of which 60% was multicrystalline and 40% monocrystalline. However, the company has put a hold on adding to its capacity and is leaving it at 1GW for 2009. Sharp Corp. is now in the fourth place, having slipped two rungs from its second-place ranking last year. In 2007, Sharp produced just 363MW for a 16% decrease over 2006. But in 2008 its increase in production is slowly bringing back the lost glory for the company. There is a big gap between Sharp and the next manufacturer—JA Solar. According to the survey, the company grew 127% over the previous year for a 3.8% market share on a year-end capacity of 750MW. For this year, the company is forecasting a production of 500MW, which would be a 67% increase over 2008. Other than Sharp, the only other Japanese solar producer in the

AFRICA AND MIDDLE EAST

	Production plans 2009	Capacity end-2009	Production 2008	Capacity end-2008	Production 2007
United Arab Emirates					
Microsol International	25.0	50.0	14.0	50.0	–
AMERICA					
Canada					
Centennial Solar	1.3	–	0.4	–	0.4
USA					
Advent Solar[*5]	NA	NA	25.0	25.0	2.7
Amonix	–	–	–	–	1.0[*1]
Ascent solar	–	–	0.5[*1]	1.5[*1]	NA
AVA solar	–	200.0	–	–	NA
BP solar	–	–	30.0[*1]	–	27.7
Emcore	–	–	0.5[*1,*3]	0.6[*1,*3]	0.4[*3]
EPV	25.0	25.0	10.0	10.0	5.0
Evergreen	130.0	160.0	26.5	58.5	16.4
First solar	147.0[*2]	147.0	145.0[*1]	147.0	119.0[*2]
Global solar	25.0	40.0	5.0	20.0	3.0
Heliovolt	–	–	–	20.0[*1]	NA
Miasole	–	–	–	50.0[*1]	0.0[*1]
Nanosolar	–	–	–	430.0	0.0
Prime star solar	3.0	–	–	–	NA
Schott solar	NA	0.0	11.0	15.0	10.0
Power Industries	60.0	100.0	25.0	50.0	3.5
Solar world	120.0[*1]	250.0	30.0[*1]	100.0	35.0[*1]
Solopower	–	–	–	20.0	NA
Solyndra	50.0	110.0	–	110.0	NA
Spectrolab	–	–	–	–	–
United solar ovonic	–	200.0[*1]	112.6	178.0[*1]	48.0[*1]

NA-Not applicable, – No information
[*1] estimated, [*2] geographical split estimated
[*3] assuming a concentration of 520
[*4] formerly brilliant 234, [*5] end of production
[*6] started production in Feb. 2009
[*7] will start production in 2009, [*8] formerly ever Q

ASIA

	Production plans 2009	Capacity end-2009	Production 2008	Capacity end-2008	Production 2007
China					
Beijing Hope	35.0 – 38.0	50.0	–	–	NA
Canadian Solar (CSI)	300.0	570.0	102.8	270.0	40.0
Changzhou EGing	150.0	200.0	106.0	200.0	10.0
China Sunergy	180 – 210.0	320.0	100 – 120.0	320.0	78.0 – 83.0
Chinalight Solar	75.0	75.0	22.0	75.0	13.0
Chint Solar (ZheJiang)	90.0	120.0	50.0	100.0	25.0
CSG PVTech	–	75.0	10.0	25.0	NA
Energias Alternativas	20.0	25.0	14.0	25.0	NA
Galaxy Energy	40.0	40.0	0.0	0.0	NA
JA Solar	500.0	800.0 – 1000.0	300.0	750.0	132.4
Jetion	–	–	65.3	100	35.0
Jiangsu ShunFeng	100.0	100.0	50.0	50.0[*1]	25.0
Jiawei Solar	5.0	25.0	–	–	NA
Motech	55.0	120.0	2.0	60.0	NA
Nantong Oiangsheng (QS solar)	40.0 – 50.0	100 – 140.0	4.0	25.0	–
Ningho Shanshan Ulica	45.0 – 50.0	50.0	30.0	30.0	30.0
Ningbo Solar Electric	–	300.0	175.0[*1]	250.0 – 270.0	100.0
Ninghai Risen Electric	–	100.0	70.0	70.0	15.0
Perfectenergy	40.0	50.0	15.0	45.0	NA
Polar Photovoltaics	25.0	100.0	6.0	12.0	1.0
Shandong Linuo Photovoltaics	70.0	100.0	15.0	50.0	NA
Shanghai Chaori Solar	>36	175.0	25.0	50.0	50.0
Shanghai Solar Energy	–	–	20.0[*1]	20.0 – 30.0	25.0
Shanghai Topdolar	150.0	200.0	48.0	100.0	–
Shenzhen Topray	100.0	100.0	–	–	–
SMIC	30.0	30.0	8.0	8.0	–
Solarfun	–	360.0	160.0 – 180.0	360.0	–

top ten is Kyocera Corp. This company dropped two rungs in the cell-manufacturing hierarchy. Kyocera's end-of-year capacity was 360MW in 2008 at its Shiga prefecture factory and has given no details of this year in the survey. After Kyocera is the third Chinese cell manufacturer in the top ten, Yingli Green Energy Holding Co. Ltd. This company has produced 281.5 MW of multicrystalline cells in 2008.

This impressive 93% increase in production over 2007 was enough to lift it two rungs in the ranking. Taiwan's biggest PV manufacturer, Motech Industries is in the eighth position. Though this company saw a 54% increase in production over the last year, it still fell two rungs. Making its debut in the top ten is high-efficiency leader SunPower Corp. With its headquarter in California, this company manufactured 237MW of monocrystalline cells in 2008 as it

	Production plans 2009	Capacity end-2009	Production 2008	Capacity end-2008	Production 2007
Sutech Power	800.0	1000.0	497.5[*1]	1000.0	336.0
Suzhou Shengiong PV-Tech	75.0 – 80.0	75.0 – 80.0	15.0	17.0	12.0
Tranjin Jinneng Solar	15.0	25.0	3.5	8.0	2.5
Trina Solar Energy	350.0 – 450.0	350.0 – 550.0	210.0	350.0	29.0
Trony	75.0	105.0	27.0	35.0	25.0
Wanxiang Solar	20.0	25.0	0.0	0.0	NA
Wuxi Shangpin Solar	60.0	60.0	30.0	50.0	-
Yingli	550.0 – 600.0	600.0	281.5	400.0	145.5
Yunnan Tianda	50.0	100.0	21.0	60.0	10.0
Yunnan Zhoye Energy	5.0	10.0	0.4	3.0	0.2
Zhejiand Leye Photovoltaic	100.0	100.0	–	50.0	NA
Zhejiang Shuqimeng Energy	–	35.0	25.0	35.0	20.0
Zhejiang Sun Valley	80.0	100.0	35.0 – 40.0	50.0	6.0
India					
Bharat Electronics	3.0	7.0	3.0	7.0	–
BP Solar	–	–	35.0[*1]	–	23.2
Central Electronics	5.0	15.0	2.0	15.0	3.0
Euro Multivision	20.0	20.0	–	–	NA
KL Soalr	–	0.0	–	0.0	–
Moser Baer	190.0	225.0	30.2	80.0	35.0[*1]
Shurjo Energy	1.5	7.0	0.5	2.0	0.8
Titan Enegy	16.0	–	5.0	5.0[*1]	NA
USL Photovoltaics	2.0	4.0	0.0	4.0	0.8
Webel	24.0	42.0	10.0	12.0	–
XL Telecom	–	–	0.0	–	NA
Japan					
Clean Venture 21	34.0	34.0	1.0	15.0	NA
Fuji Electric	–	–	10.0[*1]	20.0	12.0

rose from a tie for the 13th position. The tenth rank is taken by the Japanese electronics firm Sanyo Electric Co. Ltd. It produced 215 MW, including 5 MW of amorphous silicon thin-film modules, in 2008.

According to the survey, the largest percentage of production was multicrystalline based, with a 4.7% slice of the cell pie, up from 45.2% in 2007. Monocrystalline cells dropped nearly 4% points to 38.3%. There are a number of companies pursuing the dream of thin-film modules. Compared to 2007, thin-film production was up just 2% points to 125%. However, the thin-film sector often seems more adept at producing press releases rather than the real thing. Also, the real commercial success of many a thin-film technologies still needs to be proven, except CdTe modules.

	Production plans 2009	Capacity end-2009	Production 2008	Capacity end-2008	Production 2007
Honda Motor	–	–	20.0[*1]	27.5[*1]	0.0
Kaneka	60.0	70.0	57.0	70.0	45.0
Kyocera	400.0	–	290.0	360.0	207.0
Mitsubishi Electric	–	–	148.0	220.0	121.0
Mitsubishi Heavy	–	68.0	40.0[*1]	42.0	14.0
Sanyo	300.0[*1]	–	215.0	345.0	165.0
Sharp	600.0[*1]	–	473.0	710.0	363.0
Showa Shell	50.0	80.0	15.0	20.0	NA
Malaysia					
First Solar	657.0[*1]	784.0	167.0[*2]	392.0	0.2
Q-Cells	120.0[*1]	520.0	NA	NA	NA
Philippines					
Sun Power	450.0	574.0	237.0	414.0	100.0
Singapore					
SEP	–	–	–	10.0[*1]	–
South Korea					
Hyundai Heavy	100.0	330.0	20.0	60.0	NA
Kyungdong Photovoltaic	55.0	100.0	25.0	90.0	25.0
Millinet Solar	30.0	150.0	5.0	30.0	NA
Shinsung	130.0	150.0	70.0	100.0	NA
Taiwan					
Auria Solar	30.0	60.0	–	–	NA
Big Sun	50.0	90.0	13.0	90.0	NA
Delsolar	–	–	83.0	120.0	54.0
E-Ton Dynamics	–	–	97.0	320.0	62.0
Formosun Solar	6.0	6.0	2.0	6.0	NA
Gintech	360.0 – 460.0	560.0	180.0	310.0	60.2
Green Energy Technology	30.0	50.0	0.0	0.0	NA
Kenmos Photovoltaic[*6]	10.0 – 15.0	30.0	NA	NA	NA

	Production plans 2009	Capacity end-2009	Production 2008	Capacity end-2008	Production 2007
Mosel Vitelic	90.0	160.0	40.0	60.0	18.0
Motech	360.0	435.0	270.0	350.0	176.4
Neo Solar	210.0 – 600.0	210.0 – 600.0	135.0[*1]	210.0	36.0
Sinonar	–	–	5.0[*1]	30.0[*1]	15.0
Solartech Energy	117.0	170.0	59.0	60.0	30.0
Sun Well Solar	45.0	45.0	8.5	8.5	NA
Sunner Solar	18.5	25.0	0.0	25.0	NA
Sunrise Global	–	40.0	NA	NA	NA
Tainergy Tech	70.0	120.0	12.0	60.0	NA
Top Green Energy	20.0	30.0	15.0	30.0	10.0
Thailand					
Bangkok Solar	44.0	50.0	11.0	–	11.1
Ekarat Solar	15.0	25.0	4.0	25.0	NA
AUSTRALIA					
BP Solar	0.0	0.0	40.0[*1]	–	35.4
EUROPE					
Belgium					
Photovoltech	80.0	80.0	80.0	80.0	29.1
Cyprus					
Enfoton	–	80.0	NA	NA	NA
France					
Free Energy	0.8	1.2	0.7	1.2	0.5
Photowatt	75.0	75.0	58.0	60.0	38.5
Germany					
Arise Technologies	60.0	80.0	13.0	40.0	NA
Avancis	10.0	20.0	3.0[*1]	20.0	NA
Calyxo (Q-Cells)	15.0[*1]	60.0	3.0[*1]	25.0	1.0[*1]
Centrosolar	12.0	12.0	3.0	3.0	6.0
CIS-Solartechnik	0.0	0.0	0.0	0.0	–

There were a few a-Si success stories amongst the pure thin-film manufacturers in 2008. The biggest one was United Solar, one of the pioneers for the technology. It more than doubled its production of the triple-junction a-Si modules to 112.6 MW.

There are several companies currently producing CIS modules, this technology seems to be making some headway, as is evident by the PV equipment maker Centrotherm Photovoltaics AG. Centrotherm has moved into the CIGS sphere, offering a 50 MW CIGS production line. Thus, there are many companies that are trying to enter the solar thin-film production. However, according to Photon International's estimates about 200 companies working on setting up a thin-film production are at a risk of not surviving through the end of 2009.

As per the survey, China again was the main hub for cell manufacturing. By more than doubling its production to 2.6 GW, this means that every third cell to greet the world in 2008 was born in China. Also, all Chinese companies in the top 20 list remained and retained their position from the last year. After China, Germany was the second largest cell manufacturer. Japan dropped a place and positioned itself in the third position. Japan was responsible for manufacturing 1.3 GW, up by over 300 MW as compared to 2007. Taiwan took the fourth place for the second consecutive year. Its production was well over 900 MW. In other words, it doubled its cell output over 2007 to nearly 12%of global cell production. Like Taiwan, even America retained its position in the fifth place, as its cell production rose 58% to over 432 MW.

The survey says that though Europe could improve from 2 GW in 2008 to 3 GW this year, it seems to be left behind by Asia. Asia has clearly doubled its production to 5.4 GW in 2008 and has the potential to rise further. As far as 2009 is concerned, if, all companies are able to realize their plans then it is possible that production in 2009 could come close to doubling the 7.9 GW achieved in 2008.

Courtesy: This is a summarized version of the Cell Production 2008 survey that appeared in Photon International, March 2009. Research Assistant for this survey was Marie Faidas, Anne Laura Finis, Yilin Jin, Beate Knoll, Ran Li.; Text: William P Hirshman

	Production plans 2009	Capacity end-2009	Production 2008	Capacity end-2008	Production 2007
Coenergy	120.0*1	200.0*1	50.0*1	100.0*1	0.0*1
CSG Solar	0.0*1	0.0*1	6.0	10.0	1.0*1
CTF Solar	0.0	0.0	0.0	0.0	NA
Deustsche Cell (Solar World)	170.0*1	200.0	160.0*1	160.0	135.0*1
EPV	30.0	30.0	5.0*1	–	NA
Ersol	210.0	320.0	143.0	260.0	55.0
First Solar	196.0*2	196.0	192.0*2	196.0	81.0*2
Global Solar	10.0	30.0	2.0	10.0	NA
Intico Solar*7	10.0*1	30.0*1	0.0	0.0	NA
Inventux	5.0*1	30.0	1.0*1	30.0	NA
Johanna Solar	35.0	40.0	0.0	0.0	NA
Malibu	6.0	50.0	0.0	0.0	NA
Masdar PV	0.0*1	0.0*1	0.0*1	0.0*1	NA
Nanosolar	1.0*1	35.0	1.0*1	5.0	1.0*1
Odersun	0.0*1	0.0*1	0.0	0.0	NA
PVflex Solar	780.0*1	800.0	570.0	760.0	389.2
Q-Cells	20.0	35.0	20.0	35.0	18.0
Scheuten Solar	295.0*1	355.0	138.0	205.0	74.0
Schott Solar	35.0	45.0	2.0	20.0	NA
Signet Solar	0.5	2.0	0.0	0.1	0.0
Solarion	17.0	20.0	13.0	16.0	10.0
Solarwatt	55.0*1	90.0	5.0	30.0	NA
Solibro (Q-Cells)*4	20.0*1	145.0	3.6	25.0	1.0*1
Sovello*8	100.0*1	180.0	80.0*1	100.0	NA
Sulfurcell	3.0	35.0	2.0	3.0	0.6
Sunfilm	50.0	60.0	NA	50.0	NA
Sunways	82.0	116.0	33.0	76.0	38.0
Wurth Solar	30.0	30.0	20.0	30.0	15.0

	Production plans 2009	Capacity end-2009	Production 2008	Capacity end-2008	Production 2007
Greece					
Solar Cells Hellas	15.0	60.0	0.0	30.0	0.0
Italy					
EniPower	7.5	30.0	1.9	10.0	3.0
Helios	55.0	60.0	16.0	60.0	–
Omniasolar	12.0	15.0	1.0	10.0	NA
Solsonica	–	30.0	–	30.0	NA
X Group	25.0	85.0	9.0	25.0	2.0
Netherlands					
Solland	150.0	170.0	60.0	170.0	36.0
Norway					
REC Scancell	225.0	–	135.0	192.0*1	46.0
Russia					
PCMP	1.0	2.0	1.5	2.0	1.7*1
Solar Wind	–	7–	6.2*1	12.0*1	4.3
Spain					
BP Solar	55.0*1	55.0*1	40.0*1	–	15.3
Gadir Solar	10.0	40.0	NA	NA	NA
Groupo Unisolar	10.0	10.0	0.7	2.0	NA
Instalationes Pevafersa	6.0	60.0	–	–	30.0
Isofoton	130.0	180.0	130.0	180.0	87.0
MX Group (Solarcell)	20.0	30.0	–	–	NA
Solaria Engergia	80.0*1	350.0	20.0*1	250.0	NA
T-Solar Global	–	40.0*1	NA	NA	NA
Pramac	12.0	30.0	NA	NA	NA

MOVING TOWARDS A SUSTAINABLE FUTURE

ANKUSH GARG, Graduate Student, Haas School of Business, UC Berkeley

Background

The world is currently undergoing a sea change. The global financial meltdown coupled with an increasing awareness of the adverse impact of climate change has brought the concept of sustainability to the forefront. Sustainability has emerged as a global movement – a movement that will manifest itself into all walks of life. The Sustainability Network is an initiative that engages students and prepares them to face the grim realities of this emerging scenario. By enabling students to lead sustainability movements and bring about real on-the-ground change on campuses of educational institutes, the Sustainability Network will help the future leaders of the country to develop a holistic awareness of the multi-dimensional nature of sustainability issues.

Campuses as life-size laboratories

Educational institutions are microcosms of our society. College campuses are effectively life-size laboratories for testing cutting-edge technical, social and behavioural solutions to sustainability problems. If, students can lead successful sustainability initiatives on campuses, they will be well on their way to developing a sustainability consciousness. They will ultimately ingrain it into their professional lives as well. Like a new born child normally adapts the traits and characteristics of the family. Similarly, a campus community which embraces sustainable practices infuses a spirit of sustainable living, as a way of life amongst citizens of tomorrow.

Students today, have a strong level of awareness about sustainability issues. In fact, as we went to various campuses across the country, we realized that students had already formed a number of groups and were considerable amount of effort into pursuing various sustainability issues. Yet in the entire eco-system of a campus, the efforts of these groups were not focused on delivering positive outcomes in terms of making campuses sustainable. These initiatives which focused on organizing events to create a general awareness were really commendable. However, the real understanding of the practical social, economic, and technical difficulties of transforming a campus 'green' would not have been possible through this approach.

IIT Kanpur campus

Reasons galore

Some of the key factors which hinder the development of a comprehensive green campus initiative are as follows.

Lack of administrative support and involvement

Any initiative, unless acknowledged and supported by administration of the institution never gets institutionalized. We observed that a key reason for poor administrative support was their lack of confidence in the commitment and seriousness of the students. In fact most of the administrative units in the colleges want to create a green campus, but are hesitant to allow the leadership of this initiative to rest with the students.

Reinventing the wheel syndrome

Lot of synergy is possible among different groups. For example, few students had done a campus audit on one campus and it served as a good precedent for groups elsewhere. However, due to lack of collaborative culture, these synergies have not been explored and leveraged.

No alumni involvement

Student groups needed mentoring for various issues from alumni and faculty. The involvement of alumni with experience in the relevant area vastly improves the effectiveness of any result-oriented initiative.

Weaving together a Sustainable Network

In the process of conceptualizing 'Sustainability Network', all the above limitations were considered.

After which, a model driven by the students and mentored by alumni and supported by the administration was developed. In this model, a student team, with the help of alumni mentors are involved in the conceptualization and actual implementation of the solutions to sustainability problems on the campus. This not only gives a well-rounded awareness to the students on all aspects of sustainability issues, but also helps build green campuses that act as examples for corporate entities to emulate. The alumni mentor, trained by the Sustainability Network plays the key role of linking students with the administration and arrives at the ideal model for the green campus initiatives specific to each campus. The Sustainability Network portal helps the groups from different educational institutes to collaborate and share their experiences. The idea is to create campuses that operate on near zero dependence on external energy sources via the following few practices.

- Recycle and re-use their waste within campus community
- Develop a mechanism for self perpetual replenishment of its water sources
- Build intelligent infrastructure with minimum environmental impact and maximum natural synergy
- Create citizens of tomorrow who committed to the ethos of sustainability.

Networking along a well defined agenda

The Sustainability Network is in the process of preparing a sustainability agenda. It will be a policy-cum-strategy document to be developed jointly by students, faculty, and professionals drawn from diverse educational, professional, and geographical background. The agenda is a baseline document which sets out the blueprint for the creation of a vibrant student-led sustainability movement encompassing all key aspects of the sustainability of campus community. These mainly include energy, water, waste, and buildings.

Students and alumni are encouraged to form a sustainability chapter in their campus and lobby for adopting the agenda as part of campus development plans. Once the resources for the same are allocated, students can then involve in the actual implementation of the agenda. Through this model, Sustainability Network ensures that the initiatives go beyond the stage of propaganda and into actual implementation. A key aspect here is that it also creates a channel for alumni to get involved both in mentoring and funding specific initiatives on campus.

Putting the network to trial

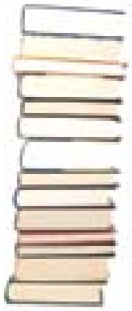
In 2009, the Sustainability Network undertook a pilot project of ECEE (Energy Conservation and Energy Efficiency) initiative at the IIT (Indian Institute of Technology) Chennai campus. With the support of the Dean of Students Welfare, Maintenance Department and an enthusiastic student-team of volunteers, the foundation for building a successful campus energy-saving initiative was laid. IIT-Chennai Alumni from the 2005 batch is mentoring the students and providing them with relevant industry experience. It is mainly to ensure that the initiative remains result-oriented and does not veer towards a theoretical study. The ECEE initiative will be launched as a campus-wide initiative during the upcoming academic year, including a campus energy-conservation award.

Another key role of the Sustainability Network is to facilitate the students from the various Sustainability Network chapters to undertake internships with both non-profit institutions and corporate sectors. We call this as The Sustainability Network Experience. Students are encouraged to work with non-profit institutions that work on sustainability solutions at the grass-root level. In order to prepare them better for their future careers, the students are also given opportunities to work on sustainability initiatives within professional set up.

As a pilot initiative in the summer of 2009, Sustainability Network facilitated student participation in Lighting a Billion Lives an initiative by TERI (The Energy and Resources Institute). Students and alumni from IIT Kanpur travelled to different villages and tribal regions of Jharkhand and Orissa. Thereafter, they took up a few projects to strengthen the campaign. A team of students did internship under the GRIHA (Green Rating for Integrated Habitat Assessment) group at TERI.

Lead the change on your campus...

We believe that the time is ripe for educational institutes in India to rise to the occasion. They are expected to play their part in securing a sustainable future for the country. We also strongly believe that this movement will necessarily have to comprise of student-led and hands-on-initiatives so as to bring about a transformation of our campuses. By tapping the intellectual horsepower of educational institutions, we can emerge as a country in sync with our leadership role in the fight against climate change. Hopefully, leaders from every college will step forward to begin Sustainability Network chapters and contribute to this massive transformation. So, it is time for students to take up the gauntlet and bring about a green transformation in every single educational institution in the country. This is, in essence, the vision and belief of the Sustainability Network and ready to go places in near future.



Solar Energy Vol 27, No 2 , pp 103-107,1981 0038-92X/81/080103
Printed in Great Britain.

DESIGN OF A PHOTOVOLTAIC ELECTRIC POWER SYSTEM FOR AN INDIAN VILLAGE

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(Received 1 July 1980; accepted 17 February 1981)

Abstract—Photovoltaic generation and electrochemical storage of electrical power offer an attractive possibility for the electrification of a village that is normally considered “uneconomic” for electrification by the conventional REP. The modular nature of both solar cells and storage batteries make it possible to use either a centralised or a decentralised system within a village. A critical analysis or the electrical energy requirements of the village including its domestic, agricultural, community, and street lighting needs and its technoeconomic aspects is therefore to be made for the most cost effective and maximum beneficial choice between (a) the centralised village energy centre or (b) highly decentralised roof top units within the village. A methodology is first developed this paper to investigate this problem on the basis of balance of systems (BOS) cost per peak walt and IS then applied to a typical village in West Bengal, India. The analysis indicates that the centralised village energy centre approach IS about five times more cost-effective than the roof top approach under the assumed conditions.

1. INTRODUCTION

Rural development in countries like India is closely linked up with the availability of electrical energy in villages. Conventional methods of carrying electricity to villages through long distance high voltage transmission/distribution network is not always economically viable if the villages are located far away from the central transmission grid [l].

Direct conversion and storage of solar energy to electricity through the use of solar cell panels and electrochemical storage batteries offers an alternative and attractive method for providing electrical energy to such remote villages. Recently a number of experiments have been started to study the feasibility of the Photovoltaic Electric Power System (PEPS) in villages [2].

Apart from the solar cell panels the PEPS is composed of a number of other components such as array structure, mounting frames, control circuits, wiring and interconnections, storage batteries, and accessories. Costs are also incurred for the system sizing and design, installation and checkout, testing and maintenance, etc. All these can be lumped together as balance of system (BOS) costs [3J.

The design of a PEPS for a village needs careful considerations of both solar cell panels and the BOS components. Because of the highly modular nature of solar cells and the storage batteries, two alternative approaches are theoretically feasible viz.: (a) village energy centre with centralised generation and distribution within the village and

(b) decentralised roof-top generation for meeting on-site load. The purpose of the present paper is to examine critically the relative technoeconomic aspects of these two approaches. A methodology is developed in Section 2 to analyse different categories of daily electrical energy needs and load pattern in the village. The right sizes of solar cell panels and storage batteries are then determined from the energy balance considerations of Section 3. The BOS costs are estimated in Section 4 for the above two approaches and the results finally summed up in Section 5, The PEPS has been assumed as a stand-alone type having no back-up supply of power.

2. DAILY ELECTRICAL ENERGY NEEDS AND LOAD PATTERN

The daily electrical energy needs of a village can be broadly divided into five categories, viz. (a) agricultural, (b) industrial, (c) domestic, (d) community and (e) street lighting. Of these, agricultural and industrial needs usually constitute the daytime loads and the remaining three constitute the night time load.

2.1 Daytime load

Electrical energy is needed for agricultural purpose in order to meet (a) irrigation requirements and (b) mechanical operations like land tillage, puddling, sowing, spraying, etc. The energy requirements for mechanical operations are not considered here.

The basic energy need for perennial irrigation is strongly dependent on the planning of intensive crop pattern and the soil conditions. Consequently it varies from place to place and crop mix selection. However, a crude estimate of the energy required for perennial irrigation can be obtained by determining the energy required (EA) to provide water in the cultivable land which is sufficient to compensate the evaporation and