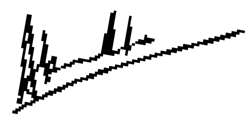
India has a rich experience of using solar, both PV (photovoltaic) and thermal, for over 30 years. Our national programme for promoting renewables is driven both by energy security issues as well as by climate concerns. We have many *first-of-its-kind* models and initiatives to our credit. Our innovations can be found in all aspects of promoting solar; policy and regulatory framework, fiscal and financial incentives, system designs and applications, standardization and quality control, testing and certification, support to the industry, user awareness, information dissemination, and much more. While rest-of-the world is, generally, promoting a few applications of solar (solar home systems, roof-top PV, solar hot water systems), several of Indian programmes have been trend-setters in their own ways. Solar water pumping, voltage-support to tail-end rural grid network, solar minigrids, roof-top PV for saving of diesel, solar cities, solar thermal for air heating are some of the apt examples.

However, in the past few years, we have lost some grounds due to slackening production on our part and a growing competition with countries within the region. Apart from this, there is no reason why we should not regain our leadership position among developing countries for designing and managing one of the largest solar programmes in the world in terms of its geographical spread, numbers, and types of systems and applications that have benefited communities over the past three decades. We have an edge over others in having gone through the entire learning curve of concept-to-commissioning of various systems and applications and this puts us in an advantageous position to initiate south-south cooperation of knowledge and technology transfer. At the on-set of the formal announcement of the National Solar Mission, the commitment to south-south cooperation would be a true tribute to our 30 years of solarized thinking and practice.



Akanksha Chaurey
Director, TERI

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Letters to editor

I have just received the July 2009 issue of *The Solar Quarterly* and read your editorial. We are happy that the world production of SPV is making fast progress. I wish the editorial included the information on India's contribution to PV production in 2007. You must be aware that in the next six years China plans to increase its share in global PV production to about 67%. India's share is likely to be below 1%. We seem to be happy to approve (some times even own) the progress made by others. Once in a while we also need to draw attention to the factual state of our own renewable energy programmes.

B S Pathak
Gujarat

The article 'Towards smart mini-grid' in the July issue of *The Solar Quarterly* was very informative. It gave a detailed analysis and understanding of the system. The boxes in the article were very good and informative. The article helped me clarify my doubts in the area of mini grids.
Keep up the good work and keep publishing such informative articles, which can clarify our understanding of various concepts in the field of solar energy.

Wishing your endeavour a success!

Ravi Kumar
Bangalore

I am an avid reader of *The Solar Quarterly* magazine. I am an academician and I generally read lot of articles and papers in the field of solar energy. This magazine is one of the best in this area. Earlier, we use to refer to only international magazines for academic purposes in this area. Thanks to *The Solar Quarterly*. This is not the case now. This magazine gives an Indian perspective and articles which are India specific, something that is not available in many international journals.

All the best for the forthcoming issues.

Rohan Pandey
Delhi

I am a regular subscriber of *The Solar Quarterly* magazine. As far as the content of the magazine is concerned, the editorial team is doing a great job. However, I fully agree with one of the letters that appeared in the last issue, that the number and size of the pictures need to reduce in the magazine. Hope the editorial team will work in this direction.

Suneet Rao
Patna

The Solar Quarterly gives us extensive information in the area of solar energy.
In the July issue of the magazine, I was specially happy with Dr Suneel Deambi's article titled 'Building pathways with the sun'. The article was written in a very simple language and even very complex concepts were made easy by the author.

I hope more such articles are published in the forthcoming issue of the magazine.

Shreya Gupta
Jamshedpur

TSQ provides me with a broad overview of the solar scenario in the country. There is valuable information on the products, markets, and technologies. New trends and ideas are given due coverage. As a student, I especially appreciate University Focus, and would like to see a section on jobs in the sector.

Rajeev Yadav
Muzaffarpur

I am a student of environment science and my main interest is solar energy. And TSQ is the best resource for all information in this field.

Pooja Mehta
Chandigarh

Thank you very much for your encouragement. The editorial team of *The Solar Quarterly* will make every effort to make this magazine highly informative and useful to all our readers. We welcome your suggestions and valuable comments to make further improvement in terms of content and presentation.

Editor
The Solar Quarterly

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VOLUME 2 • ISSUE 1 • October 2009

Sharp becoming sharper under the sun

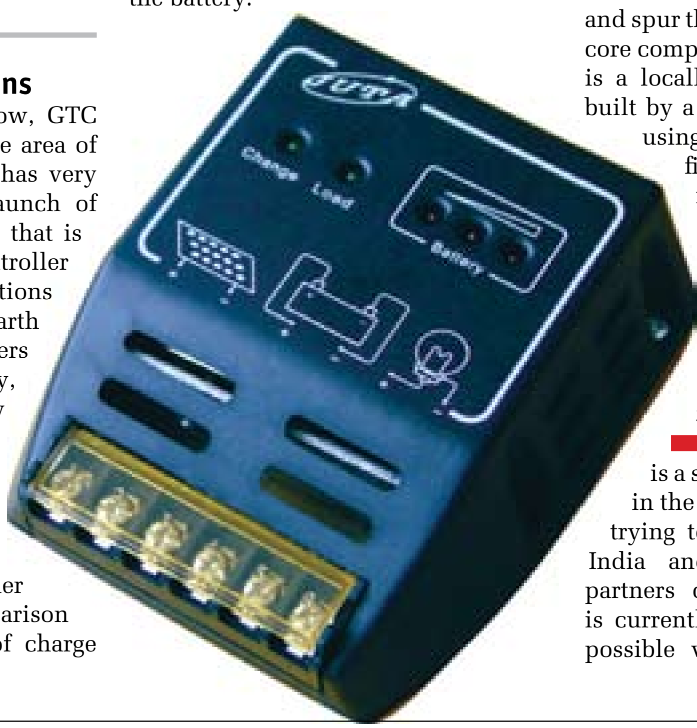
Thin film amorphous silicon has often been mired in the controversy of losing power here and there. Sharp (Japan) is now set to produce tandem a-Si thin cells with solar to electric conversion efficiencies of 10%. It is on the verge of completing a 1000 MW (megawatts) manufacturing facility in Sakai City, Osaka Prefecture, Japan. From an existing thin-film module efficiency of 8.5%, it is going to be a steady gain of 1.5%. It is expected to take Sharp into a leadership role almost coinciding with the 11% figure marked up for cadmium telluride modules by First Solar. In contrast, majority of the a-Si thin film producers are able to produce cells with modest efficiency levels of just 6%–7%. Sharp then will make room for a triple junction cell technology promising 12% efficiency by 2011. It is worth mentioning here that this Japanese company relies on a proprietary low temperature process and tools unlike many thin-film producers. After all, sharp developed its thin-film technology nearly 35 years back, that is in 1975.

Controlling for more gains

For quite some time now, GTC Almere has been active in the area of components and systems. It has very recently made public the launch of a novel device GTC-Solar 80 that is a solar battery charge controller exclusively for solar applications by early 2010. There is no dearth of good quality charge controllers available in the market today, but GTC-Solar 80 has few unique features. This device makes the best possible use of leading IC technologies and offers the following few advantages.

- Provides about 30% higher power output in comparison to the traditional range of charge controllers, basically, it enables applications to make use of smaller solar panels
- It is quite cost effective and a viable competing option
- Has a very low power consumption
- Offers quite simple user interface
- Ensures high level of configurability

It accepts an input voltage range of 10–27 V (volt) from the solar panel. Further, it supplies maximum charging current of 6A to the battery and load current of 12.5 A (ampere) at 12 V from the battery.



Nano making it big

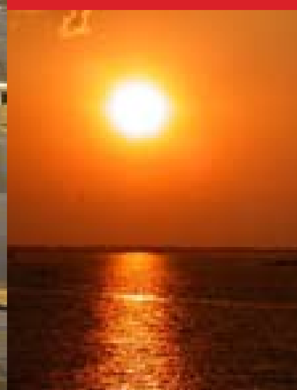
Here we are not talking about India's small car. Well, it is all about Nano Solar, which has just completed its new thin film panel-assembly production facility in Luckenwalde, Germany. The propriety technology in use is copper indium gallium di-selenide cells. The factory of Nano Solar produces one solar panel every 10 seconds for an annual capacity of 640 MW, if, operated 24×7. The company derives satisfaction out of the fact that its cells have been verified to bear a conversion efficiency of about 16.4% by none other than the prestigious NREL (National Renewable Energy Laboratory).

Modelling of a different kind

Applied Materials Inc. is a well known name in the PV industry. It has recently given a good thought to churning out a successful business model for PV development under the name of fab2farm model. The company is upbeat about terming it as a complete regional ecosystem model bringing within its fold communities, solar panel manufacturers, and the utilities. The wholesome intention is to bring down the cost of electricity that would in turn lead to green jobs and spur the local economic activity. A core component of the fab2farm model is a locally sited solar panel factory built by a solar module manufacturer using Applied's SunFab thin-film production line. A solar farm can be quickly put up without a need for extensive and costly transmission lines.

Partnering with a sunny purpose

Bright Source Energy Inc is a solar thermal company based in the United States. It is currently trying to woo the companies from India and China as its business partners outside US. The company is currently busy to rope in the best possible ventures of a collaborative



nature in the area of solar thermal power generation. Incidentally, this announcement came at a time when First Solar made public its big time intentions to enter China. Incidentally, it will now be the world's largest solar plant. China obviously seems to be playing a big time affair and surprising its rivals in the process. The thermal plants are typically much larger than those made up of Photovoltaic or simply PV power plants.

Modules—choices galore

Mitsubishi has very recently introduced 10 new models of Solar PV modules in tune with their utilization within different market segments. Out of these, five models are for the European market, while the remaining five would cater to the markets in North America and Asia. The new line up is made of modules with power outputs of 210, 220, 225, 230, and 235 W (watt). The expected shipments are scheduled for early next year. It feature unique to these modules is that these use lead-free solder and incorporate PV cells with four bus bars. It has been possible to obtain a high power output of 235 W by using an effective combination of new cell designs in tandem with an increased module size. This way fewer modules are needed to put up a system, which also helps to bring down the total system cost. These modules are expected to make their first public appearance at the 24th European Photovoltaic Solar Energy Conference and Exhibition beginning on 21 September 2009 at Hamburg, in Germany.

Laying a solar foundation

Sun Power is a highly acclaimed name in the Indian PV industry. It has just shaped up the Sunpower foundation–a non profit organization. The clear intention is to lay a framework for creating a new breed of solar leaders in communities across the globe. It is a laudable initiative also for the fact that it is fully funded by a major solar company. To begin with, the SunPower foundation has partnered with the 100 People Foundation to create 100 people under the Sun. It is basically a programme which offers classroom lesson plans to guide the students in identifying energy use besides investigating solar energy usage. A total of 140 schools spread over 39 countries are taking part in this programme. So far, a series of 12 videos have been prepared for information dissemination.

PV manufacturing support from distant land gases

Inox Air Products Ltd. is a company specializing in the supply of gases for use in the PV manufacturing plants. It has recently signed two new contracts with a leading Indian PV company for the company's Sun Source (TM) solutions gases and materials to support the growing PV industry. The company has inked a long-term gas supply contract to HHV Solar Technologies Pvt Ltd at its new thin-film PV factory in Bangalore. Under the contract, gases such as hydrogen, nitrogen, oxygen, and argon as well as gases including silane, methane, and dopant mixtures. Near total supplies of these gases will also be made to a new PV facility at Baddi in the state of Himachal Pradesh set up by Jupiter Solar Systems-a subsidiary of Jupiter International.

Solar energy market—poised for a quantum leap

The distributed energy generation using a variety of renewable power technologies is deemed as one of the most important tools for addressing the challenge of meeting the growing global electricity demands. Within the renewable distributed energy generation market, the sub-utility SPV systems are the most important segment so far. As per the recent findings of Pike Research, the distributed solar energy market is slated for a dramatic growth over next few years that will witness the global installed capacity touching around 2.5 GW by 2012. This is expected to garner an annual revenue crossing $55 billion. Presently, the residential and commercial solar energy segments remain a subsidy driven market. However, the economies of scale will to be realized that may finally see the withdrawal of any utility supported incentives. Perhaps, the dependence on feed-in-tariffs and other incentives will be much lower in Europe within the next 3–5 years in Europe. It may take a little longer say about 5–10 years for a similar change to occur in the US. The distributed solar PV growth has been spearheaded in the last few years by markets such as Germany, Japan, Spain, and the US. Pike is optimistic about US becoming the largest market for small solar installations by 2011 leaving behind Germany, China, and India, which are also expected to carve out a respectable role for themselves in the long term.

Rann of Kutch in Gujarat is the project site for solar farming

Solar farming in Gujarat

It is not a typical kind of farming using some free electricity. Instead, sun will produce the electricity under a line of agreement between the state of Gujarat and Clinton Foundation. Plans are afoot to put up a total combined capacity of 3MW worth solar farm capacity for this $10 billion project wooing the overseas investors presently. In fact, the long-term plan is to build four or five solar farms with a tentative installed capacity of 700–800 MW. Thus, electricity generated from these facilities is going to be sold to the state power companies. It will create about 20 000 jobs of both direct and indirect nature. These PV farms may derive incentives as announced under the Gujarat government's solar power policy launched in January 2009. This policy exempts the solar energy plant operators from paying any electricity duty and also binds the grid operators to buy power from them for a long period of 25 years at a fixed tariff. The feed-in-tariff for projects commissioned prior to December 2013 is about Rs 13 per unit during the first 12 years of power generation. Thereafter, a much reduced tariff of Rs 3 per unit will be payable to them for the remaining period of 13 years. Land is not going to be an issue, as vast stretches of land that is about 1500 hectares in the Rann of Kutch has been allocated by the concerned state government to the project developers.

Solar Trust—the company dedicated to thermal energy development

Solar Trust is a company devoted to the solar thermal energy development. It recently had received an opportunity to build up to 726 MW worth of solar power plants under a recently signed power purchase agreement. The California Public Utilities Commission is to approve

the setting up of two or three 242 MW power plants. Such plants will be operational only by 2013 or 2014. Solar Trust is basically a joint venture of two German companies making their way to the US market. Solar Millennium AG is a company with specialized skills in parabolic trough solar thermal power plants while MAN Ferrostaal, (which has an Ohio-based subsidiary) is an engineering and construction company. It is believed that the parabolic trough solar thermal technology will be a next generation technology. The parabolic troughs used in these solar thermal power plants reflect the sunlight to heat liquid, which in turn makes steam to generate electricity.

Solar water heating—the Chinese way

Solar water is not merely another solar device. It has become a symbol of the country's standard of living. For example, in the seaside city of 2.8 million, about 99% of the households make use of solar water heating systems. China has committed itself to be a leading practitioner of green technologies, which may ultimately help to combat the growing menace of climate change. Amazingly, China has now become a leading producer of the solar panels and wind turbines.

China seems to have written a great environmental success story as more than 30 million homes use the power of sun today. This accounts for nearly 66% of the world's solar water heating systems in use today. As per the available studies, water heating accounts for as much as 25% of a building's energy usage. The Chinese solar water is estimated to have prevented the emission of nearly 20 million tonnes of carbon dioxide with the help of the solar water heaters. A unique point is that solar water heating systems are priced same as that of the electric heaters in this country. That is why, a 3-fold increase of solar heater capacity by 2020 is being contemplated with a fair amount of hope. A record number of 5000 solar manufacturers have grown up in the last decade. It has obviously led to lower costs but a widening range of product quality too. Now Chinese villages are slowly bracing themselves to adopt this novel mode of technology use often banking on the age old techniques of wooing the customers by arranging stage shows for singing and dancing. Is this not a rich blend of a tradition in league with a modern day technology like solar water heaters?

Increasing maturity of solar thermal plants

Solar thermal power generation has often been seen as a cost effective way to produce solar power. However, it is still to make noticeable impact more so in the developing countries

Photo credit: Larry D Moore

where it is needed the most. Anyway, concentrated solar thermal power plants with thermal energy storage are fast gaining a foothold in Spain. As of now, it has about 30 such power plants under various stages of construction. The concerned companies are busy seeking project approvals for a capacity addition of almost 3400 MW aggregating to an investment outlay of $24.5 billion. There are quite a few distinctive advantages of utilizing solar thermal power, which mainly include the following.

- Availability of a mature technology based largely on steam power cycles
- Can be conveniently integrated with the existing steam based power plants
- Large power output with thermal energy storage thus ensuring 24-hour operation
- Cost less to build at $ 5700/kw in direct comparison to the nuclear power plant
- Can be easily built within a short span of 2–3 years

Of late, a few Spanish renewable power companies like Acciona has marginalized their wind power investments taking an obvious favour for building solar thermal power plants instead.

(A clear change of heart indeed with a clear tussle between the mighty sun and freely flowing wind)

Marching the organic way

Solar PV market is steadily gaining ground. However, it could march even faster but for the expensive and fragile silicon. The moot question is, if there is a cheaper and light-weight and quite reliable technology option at hand? Well, the answer may come from the OPV (organic photovoltaics) in the time ahead. The fact of the matter is that OPV market is just at the takeoff stage. Experts believe that OPV and hybrid OPV sales may touch almost $600 million by 2016. There are a wide variety of applications possible with the OPV technology use. For example, Building Integrated Photovoltaics is expected to account for $470 million in revenues by 2015 (Nan markets). A bigger surprise in the offing may be an integration of OPV into a wide range of textile products, including outdoor equipment like tents. That may be an ideal combination of living along with the mighty sun in breathtaking locations.

Clearing the mistaken belief

Solar systems have often been a subject of intense debate in terms of their actual performance reliability more so in the rural environs. Now, there is much to cheer about going by the field monitoring and evaluation study undertaken by independent agencies like the NCAER (National Council of Applied Economic Research), NPC (National Productivity Council) and IRADe (Integrated Research and Action for Development). The study pertains to the following few solar energy systems installed in the rural areas of the country.

- Home lighting systems
- Streetlights
- Solar lanterns
- Water pumping systems
- Solar cookers
- Solar power plants

Dr Farooq Abdullah, Minister of New and Renewable Energy, has recently revealed that about 70% of these systems have indicated satisfactory field performance so far. In addition, several measures have now been put forth to improve the field performance rate of the solar systems further. These include the following.

- Allowing the authorized centres to prescribe specifications of the systems accompanied by their type testing
- Provision of a minimum of two years warranty for the complete solar system (includes the batteries)
- Minimum of 10 years warranty for PV modules

- Provision of a comprehensive AMC (annual maintenance contracts) for five years in case of systems (including the warranty period)
- Additional facilities of after sales service and maintenance through the akshay urja shops, service networks of the manufacturers and local level offices of the state renewable energy development agencies.

Sun and wind likely to pay you more

The Energy Saving Trust has just released some interesting results of its poll on whether inclusion of any renewable energy source yielded a better resale value for the residential property. Yes, over 35% of those polled showed their willingness to pay a little more for the house that had a solar PV rooftop system. It clearly means that buyers are ready to invest for a cleaner tomorrow. Perhaps time is ripe to start buying in these systems even for the standby power needs in cities and towns marred by high power interruptions. It is clearly a logical approach to gauge the public opinion on the use of green energy technologies, before these come landing in an average household.

Sunny days ahead for the solar entrepreneurs

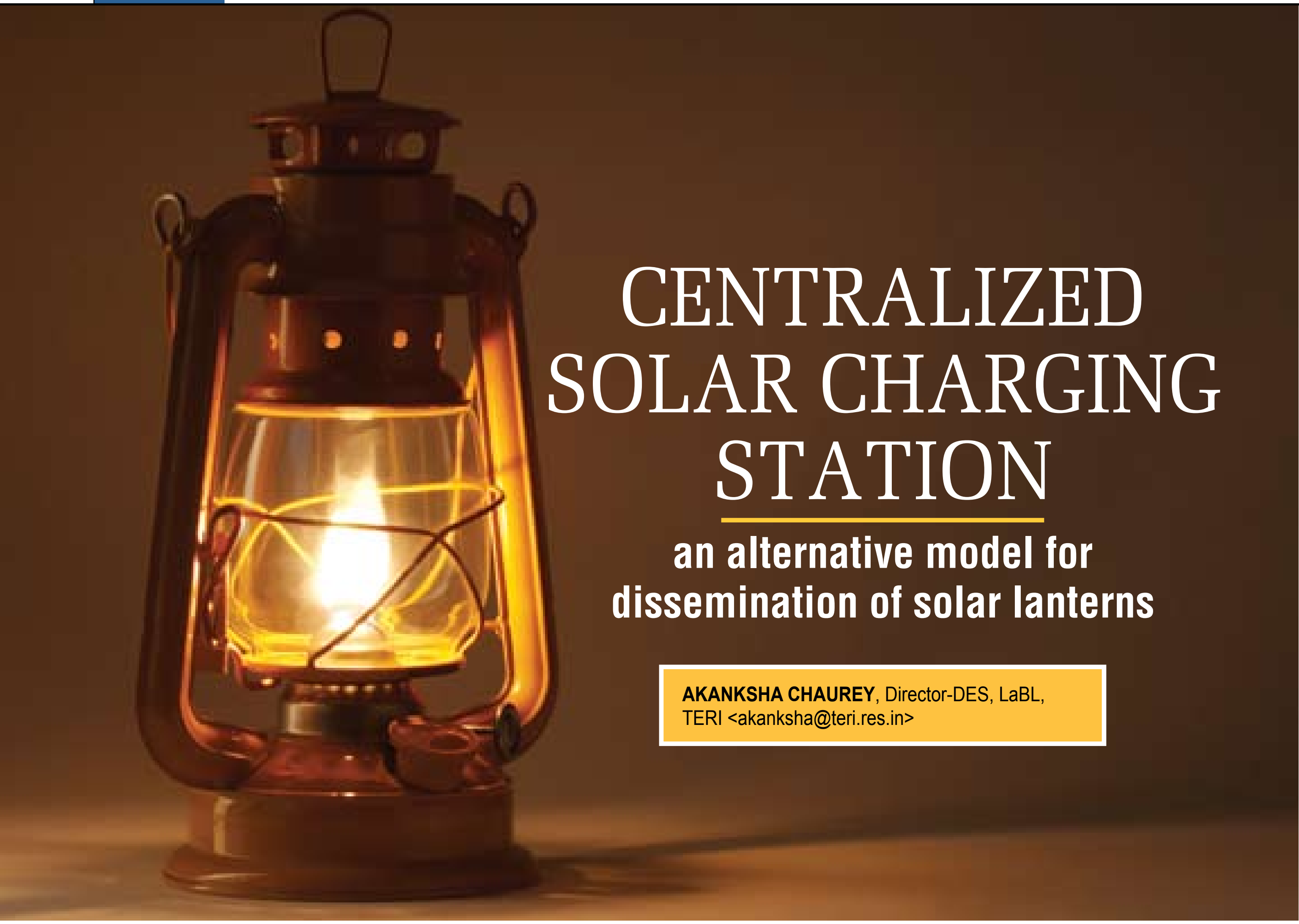
MNRE (Ministry of New and Renewable Energy) is brimming with an enthusiasm to declare a new solar policy on the forthcoming birth anniversary of Pandit Jawaharlal Nehru. As a part of this initiative, a wide range of benefits will be available to those involved in the power generation equipment activity. It was disclosed by none other than Dr Farooq Abdullah, Union Minister for New and Renewable Energy during the release of a brochure related to SolarCon India 2009 at Hyderabad. He further pointed out the need for bringing down the custom duties and other levies on the manufacturing of solar power devices. The ready intention is to popularize the use of solar and other RE technologies at well known places of holy pilgrimage.

Connecting fast with the sun

Solar PV applications are becoming quite widespread by the day. This means a search for all possible ways and means to bring down both the component costs and installation costs. The device in question is a new grounding connector from Tyco Electronics. It minimizes the installation time of a ground wire to a solar panel frame. The threaded connector inserts via a hole in the frame and makes use of two hex nuts to ensure a reliable connection. Such a connector is capable of handling six and eight AWG (13.3 and 8.4 mm^2) solid un-insulated copper wire. An interesting thing to note is that this procedure is quite simple and fast to realize.

Packing more power despite being thin

European Photovoltaic Solar Energy Conference is taking place in the third week of September 2009 in Hamburg, Germany. Here, Q-Cell is most likely to display the most powerful thin-film module based on CIGS technology. It is expected to have solar to electric efficiency of about 12% duly verified. The company is keen to move this technology into the volume production taking full advantage of the brand equity enjoyed by Q-Cells so far. Those who believe in thick film crystalline silicon technology need not despair a bit. Q-Cells would be putting for a public view a new fully square six-inch cell module. The important gain is by way of a boost in the module efficiency by up to 5%.



CENTRALIZED SOLAR CHARGING STATION

an alternative model for dissemination of solar lanterns

AKANKSHA CHAUREY, Director-DES, LaBL, TERI <akanksha@teri.res.in>

Energy is at the pivot of socio-economic development of communities. It is also needed to meet the developmental needs of more than 1.2 billion people worldwide living under extreme poverty conditions. By 2015, MDGs (Millennium Development Goals) targets to reduce the population of people, with income less than $1, by 50%. There are numerous other dimensions of poverty linked to deprivation such as one billion people without access to safe drinking water. Even though energy is not included as one of the MDGs, it is widely accepted that access to clean, affordable, and appropriate energy services will be a crucial factor in achieving the target of most of the MDGs. Electricity, for instance, is an indispensable input for productive and economic activities, as well as for overall health and well-being of communities. For vulnerable rural population, the positive impacts of electricity for activities such as pumping water for drinking and irrigation, lighting for extending working and learning hours, and powering small-scale rural industry are quite significant. Literature also points to the fact that the positive contribution of electricity to the HDI (Human Development Index) is strongest for first kilo-watt hour. This means that the poor are likely to benefit from even minimum electricity inputs to meet their basic needs. The HDI values for electrified households in Bangladesh were found to be substantially higher (0.642) as compared to non-electrified households in electrified villages (0.440) and for households in non-electrified villages (0.436). This study also reported the overall literacy rate in the electrified households to be higher than in non-electrified households.

In 2002, India's National Human Development Report has recognized electricity as the basic amenity for its socio-economic development. National Electricity Policy has set upon itself ambitious targets of extending electricity to all households by 2012. However, much needs to be done for providing access to country's vast rural population. According to the National Sample Survey Organization's most recent reports, about 67 million rural households in India rely upon kerosene as a lighting fuel. Kerosene is not only inefficient in terms of cost per useful energy but also has adverse implications on the national economy due to the huge subsidy burden. Besides, there are hazardous incidents of fire due to spillage of kerosene from wick lamps, accidental drinking of kerosene by children, indoor smoke related problems, and so on. This is reported not only in India, but also in other developing countries such as South Africa, Argentina, Senegal, and Kenya where a large population uses kerosene for domestic lighting. The most common type of kerosene based lighting device is the bottle or wick lamp wherein cotton wick is inserted into a small bottle or other container of kerosene and is burnt like a candle. There is no glass cover on the wick. The hurricane lantern is an improved lighting device having a glass cover or the chimney over the wick, a handle (or a stand) and an option to lower or raise the wick for dimming or brightening the illumination. Its luminous flux is about 70 lumens and specific fuel consumption is 0.04 litre/hour. The most advanced version of kerosene lamps is the kerosene mantle lamp, known as Petromax giving flux of 1300 lumens.

Solar lantern, due to its portability and versatility of use, is a good option for replacing kerosene hurricane lantern and wick lamps for domestic lighting applications and of course petromax, wherever applicable. According to the statistics given by the Ministry of New and Renewable Energy, as on July 2009, 0.73 million solar lanterns were disseminated across the country. Considering the total number of households that use kerosene for lighting (67 million), the figure of 0.73 million solar lanterns disseminated so far is miniscule. If at all these households were to switch over to solar lanterns, about two billion litres of kerosene can be saved annually, estimated at an average monthly consumption of 2.5 litres per household. Besides, each solar lantern has a potential to mitigate about 143 kg CO_2 annually by replacing the use of kerosene. If the total 67 million households switch to solar lanterns, 9.5 MT of CO_2 can be abated annually.

Despite the above advantages, the dissemination of solar lanterns faces operational, financial, and marketing problems. Unlike solar home systems that have been in use for more than three decades, the experience related to the above aspects of solar lantern dissemination is limited. The recent trends, both nationally and internationally, indicate a growing interest in this market not only for rural but also for urban applications such as camping, expeditions, and so on.

Image credit: TERI

Marketing and dissemination models for solar lanterns

Under the national programme on SPV demonstration, design and development of solar lanterns was initiated in 1991. Considering the high cost of the systems, capital subsidy of up to 100% was provided to the users in the initial years of the programmes, which subsequently reduced to about 50% in 1995. The subsidy pattern has been changing frequently and this may have had some impact on the dissemination of solar lanterns. However, lack of awareness among prospective users, limited outlets for procurement as well as unavailability of different models catering to varying needs were some of the other reasons cited for the poor dissemination. In a recent survey conducted on the availability of solar lanterns in the country, the market for solar lantern appears to be changing (Reference: The Solar Quarterly, October 2008). There are more than 100 suppliers/ manufacturers of solar lanterns present in the country as per the survey results, some of them existing since 1990. Further, there are about 30 models of solar lanterns with varying configurations that are currently available in the market.

The dissemination model adopted so far in India is the ownership model where the solar lanterns along with PV module are sold directly to the user either at full cost or at subsidized cost. The multiple drivers for purchase of solar lanterns by the users appear to be power cuts, ease of outdoor use, no electricity, saving on electricity cost, environment-friendly operation, convenience, and safety. High price and limited hours of usage, on the other hand, are generally perceived as the barriers by the users. While the LED (light emitting diode) lanterns address these barriers to an extent, they face challenge vis-à-vis kerosene lanterns within the cost vs benefit framework, from a user's perspective. For instance, the upfront cost of LED lantern is almost ten times that of the kerosene lantern for benefits that are less than five times in terms of lumen output, even though the cost per kilolumen-hr of LED lantern calculated over its life time is much less than that of kerosene lantern. The cost vs benefit analysis is worth considering for the marketing and dissemination of solar lanterns. At the same time, it may also be worthwhile to consider a shift from ownership to fee-for-service or renting model that might facilitate a wider reach of solar lanterns among prospective users.

The fee-for-service or the rental model for dissemination of solar lanterns was piloted in early 1990s in a remote village in the Sunderbans region of West Bengal. Here a centralized charging station for 40 solar lanterns was set up by a NGO (non-government organization). It was further demonstrated by the same NGO in two more villages in the same region. However, in the second initiative, emphasis was more on developing and training entrepreneurs to operate and manage such charging stations. In a similar experience in Senegal, West Africa, a central solar charging station was set up under the French foreign assistance programme wherein users could either bring their lanterns for recharging or could also hire recharged lanterns if they were either unwilling or unable to own them. Recently, this model for dissemination of solar lanterns has been adopted for a global programme called LaBL (Lighting a Billion Lives) in which such stations are already set up in 100 villages across various states in India. More information on this is available on http://labl.teriin.org/.

Even though the ownership model is prevailing in the country for the dissemination of lanterns, there are both advantages and disadvantages of this model as compared to fee-for-service or rental model. While the owner of the lantern has the freedom to use it as and when and wherever desired, the user of the charging service has to confine the lantern usage within the rented duration and location. The user may also run the risk of not getting the lantern on rent when required as the charging station may have run out on them. The discomforts of walking up to and from the charging station, carrying the lantern, could also pose a problem. However, one of the most significant points in favour of fee-for-service is the third party maintenance. Another advantage of fee-for-service model is the flexibility to rent or recharge the lantern and therefore pay for the services only when required. The user is not burdened either with the upfront cost of purchasing the lantern or for maintaining it throughout its useful life. This might be more acceptable to a large population of rural households who purchase kerosene in small quantities as and when required, depending on their affordability.

Lighting Africa—A World Bank Group initiative is using alternative energy to light up Africa villages

Centralized charging station for solar lanterns

Centralized charging station works on the model of fee-for-service or renting where the user either owns the solar lantern and recharges its battery by paying a fee or does not own the lantern but hires a charged lantern, as and when required, from the charging station. In both the cases, the user does not own the PV module as in the case of ownership model. Solar PV modules, adequately sized for the number and configuration of lanterns to be charged, are installed at a central location in the village where it is convenient for the users to come on a daily basis. The charging station is operated and managed by an individual or a group of individuals who would either sell the charge for a fee or rent the charged lantern for a rental amount.

Technically, the charging station would incorporate PV modules installed in a specific voltage and current configuration to charge a number of lanterns either in a series or in parallel. A combined charge controller for all the lanterns would ensure that each lantern is adequately and properly charged. The charge controller would be housed inside a junction box that will also have sockets to plug-in the leads for individual solar lanterns. The charging station design would necessarily have to ensure the following.

- It should be able to accept and charge any number of lanterns (optimum utility to its design) at any time without damaging the lanterns already connected to the junction box.
- It should protect each individual lantern battery from overcharge irrespective of the number of lanterns already connected.
- It should be able to charge all connected lanterns irrespective of the state of charge of their respective batteries.
- It should be able to indicate clearly and individually the charging status of each connected lantern.

A few advantages of centralized charging station designs vis-a-vis individually used PV modules are the following.

- The fixed installation of PV modules in a charging station design ensures their proper orientation and tilt to maximize the solar gain. However, it may not be ensured in individually

Image credit: TERI

owned and used small capacity PV modules which are required to be kept out in the sun everyday by the user and taken indoors after the sunset.

- Large capacity PV modules (37–100 Wp) typically used in the PV array required for the charging station offer better unit costs in terms of Rs/Wp and usually better efficiencies as compared to small capacity modules (3–10 Wp) that are used with individual lanterns.
- In case of a central charging station, excess energy from PV modules, when the lanterns are not available for charging, can be utilized for some other purpose such as charging of batteries. This flexibility might not be available in individually used small capacity PV modules.
- Monitoring of performance and usage of solar lanterns, in case required for techno-economic evaluation, carbon financing, and so on would be easier in centralized charging station model as compared to individually owned and used solar lanterns
- The risk of theft of modules is minimized in central charging station.

A centralized charging station operates like an infrastructure facility or a service centre in a village that sells several types of services to a variety of users depending upon their requirements and willingness to pay. It is an entrepreneurial set up which offers opportunities for livelihoods for those who would like to own, operate, and manage such facilities through several institutional models. The charging station can be owned by an individual or a group of individuals by paying full cost of setting it up. The owner(s) would be responsible for the operation and management of the charging station and would keep all the revenues from recharging the batteries or from renting out the lanterns. They may or may not employ operators for managing the charging station. Alternatively, the charging station could be owned by an NGO, state or the district level authority, corporate entity or even an individual. However, the facility could be leased out to a third party at an agreement. The third party will operate and maintain the facility on behalf of the owner. The financial viability of charging station models for disseminating solar lanterns needs to be analysed from the perspective of the user as well as from that of the owner of the charging station. The user will compare the annual costs of owning vs renting and/or charging the lanterns and the owner will evaluate the viability on the basis of net revenue from selling the services. The experiences and user feed-back on the ownership, rental, and fee-for-service models are worth considering.

Feed back and experiences from selected case-studies

Recharging fee for lanterns in Uganda, Africa and in Laos, South East Asia

In Laos, in a private sector driven initiative, a company rents out solar lighting devices, home lighting systems as well as lanterns, to rural households. The company has recently proposed to extend this model to Uganda with an understanding that the rural households in Uganda can afford electric lighting with the small incremental payments that they make to purchase kerosene bottles.

In Laos, instead of renting the equipment directly to the user, the company rents them to the VEC (Village Energy Committee), whose members are selected by the entire village. The VEC in turn leases the equipment to individual households. This puts the community in control of setting prices, collecting rents, and performing basic maintenance. Payments are usually made by women, who generally manage household finances. The rental programme runs on a commercial basis, such that the rent covers all capital and maintenance costs. While larger PV systems provide power for community services such as health systems and water pumping, portable solar lanterns are popular for use when villagers have to work away for two or three days at a time in their distant family lands. Apparently, about 1870 solar home systems (including 20 larger ones for community use) and 500 solar lanterns are rented to families in 73 different villages in Laos. The business model adopted by the company involves a selected and trained network of franchisees to install and maintain the solar PV equipment, and each franchisee trains technicians in the villages to perform day-to-day maintenance.

Solar lanterns are financed with the help of a recharging fee. The household makes a deposit for the first fully charged lantern. From then on the household brings discharged lantern and takes home fully charged one, paying only the charging fee. One charge that provides light for 15 hours costs around $0.4. Users are reported to be keen on the solar lantern rental, as they pay a fixed price and get 15 hours of light, allowing them to plan their usage and spending accordingly.

The replacement of kerosene lamps with solar PV lighting in homes has reportedly brought a range of benefits, including a reduced risk of burns and fires, improved air quality, and better quality light. The improved light is useful for children doing their homework. A Lao government study of the rural electrification indicated that children with electric light at home performed better in exams than those without. The solar lanterns are sometimes rented to supplement a solar-home-system, as and when extra light is needed, but they mainly have outdoor use. The programme has created seven full time jobs within the company, and full-time or part-time work for 34 franchisees and over 80 village technicians.

Solar battery charging stations in the Philippines

This is an initiative of the Government of Philippines under the rural electrification programme where solar battery charging stations are set up in remote villages. Hamlets and households are provided with the batteries which they can charge at the charging station by paying a nominal amount. As a part of providing basic electricity services to remote villages without electricity, The Department of Energy, Government of Philippines, has provided small capacity (typically 300 Wp) solar battery charging stations to charge up to two numbers of 100 Ah batteries daily. About 20 batteries are given to the households on a first-cum-first served basis. The charging station is managed by a village power association and is operated by an operator who is appointed by this association. The rental charges for the battery were kept at $0.5 per charge.

While the charging station have provided facility for the village residents to use basic electricity services such as lighting and entertainment, some initial problems were reported on account of two aspects—non-payment of rentals by the villagers and inadequate technical support for O&M (operation and management) related issues rendering most of the charging stations in-operational. These problems were addressed by selecting and training village women to operate the charging station on incentive basis and by engaging technically qualified local institutions to provide O&M support. The solar battery charging station model adopted by the Government of Philippines under its remote village electrification programme has reportedly helped villages and hamlets across the country in meeting the objectives of providing basic amenities to its population as well as in facilitating small livelihoods to villagers.

Key lessons from the case-studies

1. The solar lanterns (and battery charging) can become popular among users if they are made available at prices equivalent to the household's current expenditure on kerosene and candles.
2. The rental model could be a viable business model for local companies as well as a good entrepreneurship and socio-economic developmental model for the NGO sector.
3. The upfront contribution from the user in the form of security deposit ensures the safety of the lanterns.

The above case-studies have highlighted the popularity of rental and fee-for-service model through the centralized charging station facility in the village and have substantiated the techno-economic viability of the centralized charging station for

Image credit: TERI

Image credit: TERI

their potential in enhancing the dissemination of solar lanterns.

Way forward

While the efforts of the local government, industry, NGOs, and other institutions are noteworthy in promoting the solar lanterns, it would be worthwhile studying the international developments in similar and related fields that will impact the dissemination of solar lanterns in India. Specifically, the current R&D (research and development) in lighting and storage devices; innovative approaches in system designs; opportunities for NGOs and communities in active participatory and mutually beneficial mode; global initiatives and approaches for providing lighting to 1.6 billion people and changing perspective of corporate social responsibility within private and public sector to promote such initiatives. A few of these are presented here.

Global initiatives for providing domestic lighting

One of the most significant programmes for providing improved lighting is the recent World Bank Group initiative—Lighting Africa. It is aimed at providing access to non-fossil fuel based, low cost, safe, and reliable lighting products with associated basic energy services to 250 million people in Sub-Saharan Africa by the year 2030. Jointly managed by the World Bank and the International Finance Corporation, this programme addresses the lighting needs of predominantly low-income households and businesses which currently depend on costly, inefficient, poor quality, and often hazardous fuel based products, such as kerosene lamps and candles.

Two important activities that have helped Lighting Africa move forward are the (i) DM (Development Marketplace) competition which is a competitive grant based programme to support private enterprises in developing and delivering a wide selection of modern lighting products and services to poor households and businesses, and (ii) market research consultation for providing insights into consumer demographics and characteristics, current lighting habits, preferences, needs, willingness and capacity to pay for lighting. Although Lighting Africa is technology neutral, 16 projects that were awarded the DM grant in May 2008, 12 of these use LED based lighting products powered by solar PV. Further, these products and services are proposed to be made accessible to the poor communities through renting/fee-for-service model or micro-finance aided purchase model. The recently released market research reports on Ethiopia, Ghana, Tanzania, Kenya, and Zambia on qualitative and quantitative usage and attitude study has provided significant insights into the African market for solar lighting devices. For instance, the report characterizes the Tanzanian consumer to be living every day with only enough money to fulfil basic needs such as food, lighting, children's education, and so on. Majority of the households (60% of the surveyed sample of 1000 households) use paraffin lamps with glass cover as their main source of lighting and spend $5 on an average to purchase the lamp and a similar amount on fuel per month. In such a scenario, although modern lighting products are looked at positively, they are still considered to be expensive, not easily available and many consumers see them as

Solar lantern charging station

being out of their reach. Interestingly, 32% of the sample of 400 surveyed consumers found solar lanterns to be their preferred lighting option, but the maximum amount that they are willing to spend on any type of modern lighting device is about $7.50.

The Lighting Africa has already highlighted the importance of understanding the rural lighting market and offering lighting products customized to the user needs and willingness to pay. It has also helped in engaging international and local industry to work towards a common goal for providing modern lighting to global poor population.

Opportunities in expansion of charging stations

The design of the charging station being modular, offers the advantage of expanding the capacity of the charging station, if required. The capacity can be added using PV module and other renewable energy technologies such as wind-electric-generator, biomass gasifier, and others. Thus, the charging station can function like a mini-utility in the village that can offer battery charging facilities for a multitude of applications such as mobile telephone charging, water purification and selling, powering computer, television, and so on. Besides, there are opportunities for introducing newer designs in the solar lantern charging station itself such as having a buffer battery bank that is charged first from the PV modules. Solar lanterns in turn are charged from this buffer battery. The advantage of such a design is that it offers the flexibility to the user to bring his/her lantern anytime of the day for recharge. This additional convenience to the user might improve the business prospects of the charging station operator. Further, it is possible to add a manually driven charger such as the paddle charger that keeps the buffer battery bank topped up in days of low sunshine.

Improved institutional support for assembling, servicing, operating, and maintaining the charging stations

The charging station model has the potential to build and strengthen many institutions at the local and national level. To elaborate, setting up of charging station would require identifying, selecting, and training entrepreneurs to operate and manage a charging station, while at the same time, undertaking servicing of solar lanterns in terms of minor repairs and replacements of parts. So far, this activity is usually undertaken at the project level where entrepreneurs are selected and trained within the project boundary itself. However, if a national level programme is launched to develop the institution of charging station entrepreneurs, initiatives such as Lighting a Billion Lives and Lighting Africa would provide ample livelihood opportunities to such trained entrepreneurs.

Similarly, the charging station model offers a platform for linking and synergizing the initiatives and commitments of the NGOs, CBOs (Community Based Organizations), local governments, private sector, and donor agencies towards socio-economic development of the communities using lighting as a means for facilitating and advancing their initiatives. Health services, information and communication technology based educational services, water purification services, and so on, can be provided to the communities by expanding the capacity of the solar lantern charging stations in future. It also provides a market for financing and micro-financing institutions to help the potential buyer of solar lantern, while at the same time, enabling the entrepreneurs and service providers to initiate and expand businesses of providing lighting products and services.

There could be a national level initiative for identifying potential entrepreneurs among local youth, grass-roots level organizations, local businesses and support them to set-up centralized charging station at villages all over the country. Incentives in the form of part or full capital subsidy support would ease the burden of having to pay the high initial investment while at the same time, enhancing the business prospects for the entrepreneur. Option of providing micro-finance to such prospective entrepreneurs to set up the charging stations is worth a consideration.

SOLAR COOLING

REMOVING HEAT FOR GAINFUL PURPOSES

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Low temperature enables several applications such as preservation of various food and pharmaceutical products. Air conditioning is a well known low temperature use for a better occupant comfort. Processes like these rely on the traditional refrigeration cycles and are in turn driven by the electricity on an increasing scale. The IIR (International Institute of Refrigeration) has estimated a global electricity usage to the tune of about 15% on refrigeration and air-conditioning processes alone. Incidentally, regions with moderate climatic condition are witnessing an increased demand for cooling. Obvious enough is a dramatic rise in electricity demand during the summer days. This is indicating increased fossil fuel consumption too. That is not all, as it also puts an extra demand on the not so stable power grids in a developing country scenario like India. Even our country spends a sizeable amount of energy for residential cooling apart from refrigeration

What is cooling?

Simply put, cooling is essentially a process of becoming cooler that is attaining low temperature. It is characterized by the transfer of thermal energy from a region of low temperature to a region of high temperature. The essential distinction between refrigeration and air conditioning lies mainly in their application of different temperature ranges. The air conditioning/cold storage requires cooling temperatures in an approximate range 5–20 °C, while refrigeration takes place in the temperature range of -20–5 °C.

The sun is basically a giant fusion machine supplying the earth with 'free' heat and light. The amount of energy being produced every second by the sun is staggering. There is an unmistaken belief in all the applications being energized by the mighty sun. Taking a strong cue from it, many techniques have been established to harness this abundant energy. The plain intention is to minimize the use of polluting sources of energy as far as possible.

Ancient approach

Rome invented the cooling concept followed by the wind catcher. It came to be known as the first air cooling system in Persia (Iran). In this system, hot air passed through water and shafts fixed on roof blow the cool air. Natural example of cooling is 'evaporation of sweat'. The cooling rate depends on the rate of evaporation which basically varies with humidity and temperature. Latent heat of evaporation transfers from air to coolant or refrigerant [water] and depends on the surface area and temperature. It is a common method of dissipating heat from the system. Evaporative cooling includes direct, indirect, and two stage cooling [direct-indirect] designs. In the first design, shot air evaporates the water and becomes moist (open circuit). Cooling is accomplished by heat exchangers as an indirect approach. In the second stage, indirect cooling followed by direct step controls level of humidity of the cool air.

In the good old days, cooling was normally achieved by employing thick layer or bundle of wool, aspen wood fibers, melamine sheets, and so on. These could hold large amount of water so as to cool the hot air by absorbing its heat when passed through it. A

thickness of eight inch cooler pad with a higher surface area is more effective than just a one inch pad, providing more contact time.

Modern approach

Technology sustains with possible adaptation of a few improved designs. The need for comfort and luxury has stepped cooling concept into use of refrigerants. Here electricity is supplied to power devices like compressors, heat pumps, and evaporators. This results in a highly sophisticated circuit to obtain a desired cooling temperature along with humidity control. Most of us are aware of the functioning of a domestic refrigerator.

How it works?

A basic design consists of coils and pipes through which the refrigerant gas enters compressor as warm, low pressure gas and exits as a hot gas at a high pressure. It loses heat to the outdoors when itenters condenser and gets converted into warm liquid. The warm refrigerant now expands in the expansion valve, temperature drops and partly converts into gas. The refrigerant is now ready to take up the heat from the indoor and cool air is blown back to indoor as the moisture trickles down on the cooling coil.

Staying cool for a purpose

The conventional cooling and space conditioning devices need electricity—fossil fuels. Solar cooling is emerging as one of the most important aspects of such energy utilization. A solar cooling system necessarily needs solar collection and storage with a cooling device for its continuous solar operation. Sunshine in abundance has more often than not pointed towards its sustainable use for a variety of end-use considerations. A combined heating and cooling system with few important benefits of energy conservation and ultimately sustainable development.

Typically, solar energy has been used in the cooling cycles for the following two related purposes.

- Comfort cooling
- Refrigeration for food preservation.

Cooling is important in space conditioning of the buildings in hot and dry, composite, warm and humid climates zones.

The cooling load and solar radiation availability are approximately in phase. An effective combination of solar thermal and cooling possesses a high potential to replace the traditional cooling machines keeping in view the coincident availability of solar radiation.

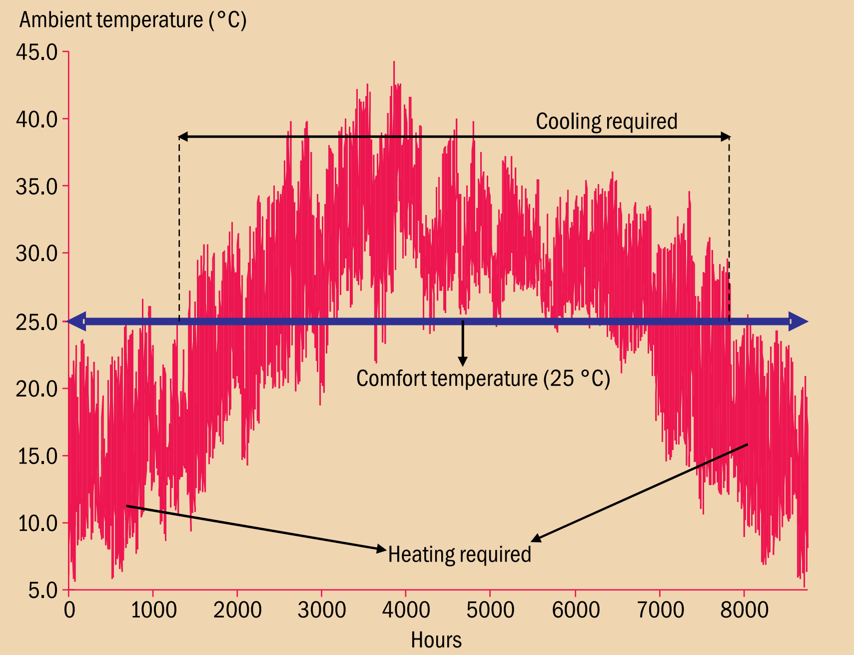

Figure 2 Cooling requirements as a function of ambient temperature

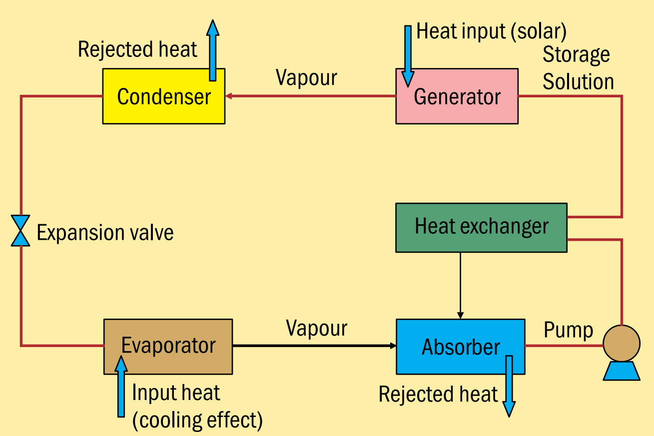

Figure 1 Schematics of a solar cooling process

Case specifics–India

India being a tropical country is blessed with good sunshine, and the number of clear sunny days in a year is quite high. India is in the sunny belt of the world. The country receives solar energy equivalent to more than 5 000 trillion kWh per year, which is far more than its total annual energy consumption. The daily average global radiation is about 5 .0 kWh/m2 in north-eastern and hilly areas to about 7.0 kWh/m2 in western regions and cold desert areas with the sunshine hours ranging between 2300 and 3200 per year. There are various application has been developed which is energized by solar energy. As per the application point of view, solar energy has two divisions, SPV (solar photovoltaic) and solar thermal. Solar photovoltaic include electricity generation in which through SPV cells, solar radiation gets converted into DC electricity directly. This electricity can either be used as it is or can be stored in the battery. On the other side solar thermal devices use the heat energy of the sun for running varied applications of the following nature.

- Cooking
- Space heating
- Drying, desalination
- Greenhouse process heat

Photo courtesy:DOE/NREL

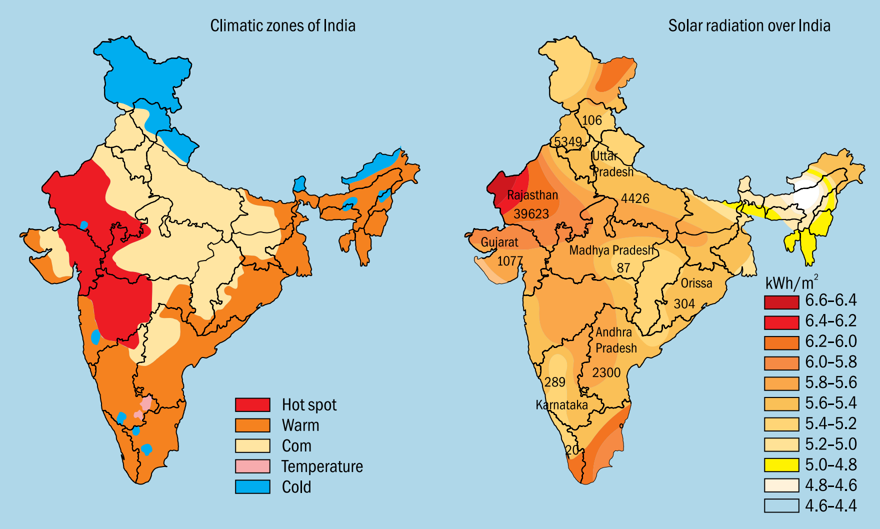

Figure 3 Distribution of solar radiation over India

- Power generation
- Detoxification space cooling
- Refrigeration
- Cold storage

Solar cooling is one of the recent concepts relying on the advancements made in the area of solar energy technology.

Solar cooling—still a challenge to deal with

There are a number of solar thermal applications; out of which the cooling technology is very complex. It is so in terms of conceptualization and construction. This is why such a technology is still awaiting commercialization.

It is essential that the energy collected through solar collectors must be converted to cold through a suitable device. It should be capable for absorbing heat at a low temperature from the conditioned space and rejecting it into an intermediate temperature heat reservoir.

Solar cooling system

A solar cooling system makes use of a heat transfer fluid, which is heated in solar collectors up to a temperature well above the ambient. The power thus available runs a cooling device. The heat transfer fluid may include any one of the following.

- Water
- Air phase change material
- Any other liquid

The purpose is to store it during no-sunshine period. The heat taken from the conditioned space as well as from the solar energy source is released into the environment. It is done by using a cooling tower or an air-cooled condenser. The cooling device may produce a desired cooling effect in a number of different ways. For example, it can generate chilled water which may be distributed through the fan coils, or use to cool air. Following which, it is distributed through the air ducts. A major part of the every solar cooling system is the solar collectors. These convert incident solar radiation into utilizable heat as a temperature suitable for powering the cooling device. A brief overview of solar collectors is presented under the following section.

Solar cooling techniques

Solar thermal cooling can be achieved via various given technologies followed by a brief treatment of each of the following.

- Absorption chillers
- Adsorption chillers
- Desiccant cooling system
- Solar-mechanical processes

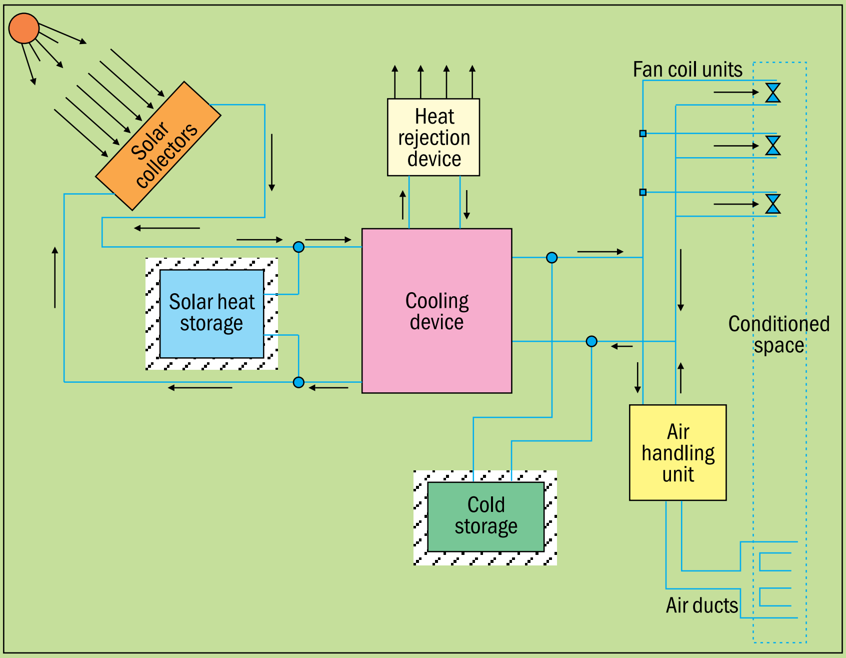

Figure 4 Schematics of a solar refrigeration process

Absorption chillers

Amongst the cooling technologies, absorption cooling seems to offer a promising market potential. Major work in solar air conditioning has so far been based on continuous absorption cycles and is adapted to operation from solar collectors. Absorption heat pumps are essentially air-source heat pumps driven not by electricity, but by a heat source such as natural gas, propane, solar-heated water, or geothermal-heated water. The absorption system uses a 'thermal' compressor (consisting of the generator, absorber, pump, and heat exchanger) to boil water vapour (refrigerant) out of an absorber/absorbent solution and then compress the refrigerant vapour to a higher pressure. Increasing the refrigerant pressure also increases its condensing temperature. The refrigerant vapour condenses to a liquid at this higher pressure and temperature. Because this condensing temperature is hotter than the ambient temperature, heat moves from the condenser to the ambient air and is rejected. The high-pressure liquid then passes through a throttling valve that reduces its pressure. Reducing its pressure also reduces its boiling point temperature. The low-pressure liquid then passes into the evaporator and is boiled at this lower temperature and pressure. Because the boiling temperature is now lower than the temperature of the conditioned air, heat moves from the conditioned air stream into the evaporator and causes this liquid to boil. Removing heat from the air in this manner causes the air to be cooled. For chilled water above 0 °C, as it is used in air conditioning, typically a liquid H_2O/LiBr solution is applied with water as refrigerant and operates at temperature range 70–95 °C. Other liquid solutions can be used like H_2O/LiCl or NH_3/H_2O, which permit to produce chilled water at temperatures below 0 °C and operate at temperature range 125–170 °C. In the market two types of chillers are available.

- Single effect
- Double effect

Single effect chillers

The single effect absorption chiller is mainly used for building cooling loads, where chilled water is required at 6–7 °C. The COP will vary to a small extent with the heat source and the cooling water temperatures. Single effect chillers can operate with hot water temperature ranging from about 80–150 °C when water is pressurized.

Double effect chillers

The double effect absorption chiller has two stages of generation to separate the refrigerant from the absorbent. Thus, the temperature of the heat source needed to drive the high-stage generator is essentially higher than that needed for the single-effect machine and is in the range of 155–205 °C. Double effect chillers have a higher COP of about 0.9–1.2.

Adsorption system

Adsorption chillers use solid sorption materials instead of liquid solutions. Much like in a vapour compression system, the adsorption refrigeration system also consists of a compressor, a condenser, a throttle valve, and an evaporator. However, in this system the compressor is replaced by a thermal compressor which is operated by heat instead of mechanical energy. The vapourized refrigerant is adsorbed in the pores of the adsorbent within the reaction chamber. Thus, the operation of adsorption cooling system depends on adsorption/desorption characteristics of the particular adsorbent/refrigerant pair. Market worthy systems use water as a refrigerant and silica gel as sorbent, but recently some manufacturers have developed an alternative to silica gel as zeolith. So two such technologies now availables are: Silicagel/H_2O and Zeolith/H_2O.

Absorption cooling technology is a form of heat pump technology. Absorption systems typically use ammonia, hydrogen gas, and water. At room temperature ammonia is normally a gas that has a boiling point of -33 °C. However, the absorption cooling system is pressurized to the point that the ammonia is held in a liquid state at room temperature.

Desiccant cooling system

It is a relatively new and potentially clean technology that can be used to condition the internal environment of buildings without the use of harmful refrigerants. Desiccant type cooling systems appear to represent a potentially promising alternative to other methods of open-cycle solar-powered air conditioning. In these systems, water is employed as a refrigerant and a desiccant (sorbent) material is used to facilitate the exchange of sensible and latent heat of the conditioned air stream. The term 'open' is used to indicate that the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is supplied in its place in an open-ended loop. In an open system there is no separation between the air being cooled and the refrigerant with the two being in direct contact with each other.

Solar cooling–summing up the perspective

Solar cooling is still in an experimental stage. Relatively few experiments have yielded information on the following key aspects

- Solar operation of absorption coolers
- Use of night sky radiation in locations with clear skies
- Combination of a solar-operated Rankine engine and a compression cooler
- Open cycle, humidification-dehumidification systems

Many more possibilities for an insightful outlook still exist. Seemingly, solar cooling may benefit from the collector developments that permit energy delivery at higher temperatures and thus solar operation of additional kinds of cycles. Improved solar cooling capability can open up new applications of solar energy, particularly for larger buildings, and can result in a market demand for retrofitting of the existing buildings. In addition, mechanical ventilation replaces conditioned air from within a home or building with unconditioned air from the outside, which is hot during the summer and cold during the winter months, ERVs recapture some of this energy and thus increase the mechanical ventilation's efficiency.

Solar collectors

A solar collector is a device for extracting the energy of the sun directly into a more usable or storable form. These collectors are a special kind of heat exchangers that transform solar radiation energy to internal energy of a transport medium. Solar collectors are a major component of any solar system. Collectors absorbs the incoming solar radiation, retain its heat, and transfer this heat to a fluid (Heat Transfer Fluid) flowing through the collector. Thus, the collected solar energy is carried from the circulating fluid either directly to the hot water or space conditioning equipment or to a thermal energy storage tank from which it can be drawn for use at night and/or for cloudy days. There are basically two types of solar collectors:

- Non concentrating or stationary
- Sun tracking and concentrating collectors

A non concentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux.

Non-concentrating or stationary collectors

These collectors are permanently in a fixed position and do not track the sun. Three types of collectors fall in the following few categories.

- Flat plate collectors
- Stationary compound parabolic collectors
- Evacuated tube collectors

FPC (Flat plate collectors)

In the flat plate collectors solar radiation passes through a transparent sheet

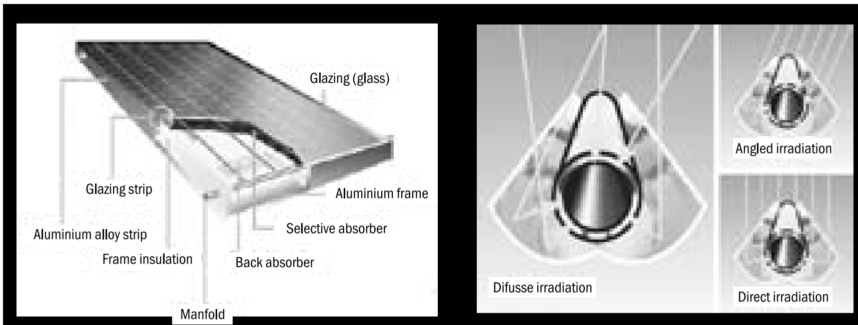

Figure 5 Schematic diagrams of flat plate and compound parabolic collectors

and impinges on the dark absorber surface of high absorptivity. Thus, a large portion of energy is absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for storage or use. The concentration ratio for FPC is one and its indicative temperature range is 30–80 °C.

CPC (Compound parabolic collector)

Compound parabolic concentrators can accept incoming radiation over a relatively wide range of angles. By using multiple internal reflections, any radiation that is entering the aperture, within the collector acceptance angle, finds its way to the absorber surface located at the bottom of the collector. The absorber can take a variety of configurations and the concentration ratio for CPC is one to five and its indicative temperature range is 60–200 °C. The schematic diagrams of FPC and CPC collectors are presented below.

ETC (Evacuated tube collectors)

Evacuated tube solar collectors or simply ETC consist of a heat pipe inside a vacuum-sealed tube. ETC has demonstrated that a right combination of a selective surface and an effective convection suppressor can ensure a good performance at high temperatures. This type of collector consists of rows of parallel transparent glass tubes with special light-modulating coating, each of which contains an absorber tube. The absorber can either consist of copper (glass-metal) or specially-coated glass tubing (glass-glass). The concentration ratio for ETCs is one and its indicative temperature range is 50–250 °C.

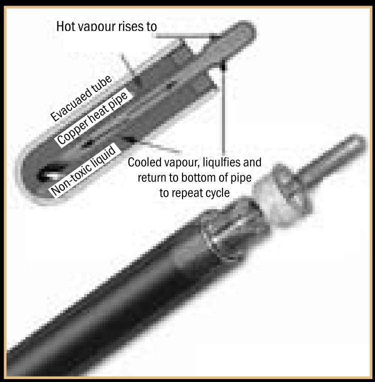

Figure 6 Evacuated tube collector

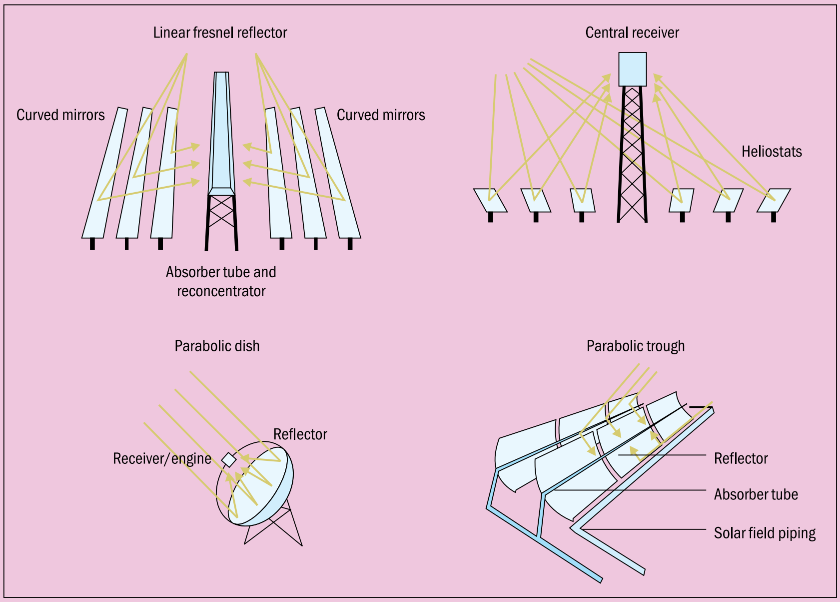

Figure 7 Solar concentration techniques

Concentrating collectors

In the concentrating type collectors, solar energy is optically concentrated before being transferred into heat. Concentration can be obtained either by reflection or refraction of solar radiation via use of mirrors or lenses. The reflected or refracted light is concentrated in a focal zone, thus increasing the energy flux in the receiving target. Sun tracking refers to the concept of movement of collector reflector surface along with the movement of sun by any auxiliary tracker device. Tracking is of two type single axis tracking and double axis tracking. The collectors falling in this specific category are following.

- Parabolic trough collector
- Linear Fresnel reflector
- Parabolic dish
- Heliostat field reflectors

PTC (Parabolic trough collector)

Parabolic trough-shaped mirror reflectors are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough's focal line. A heat transfer fluid, such as synthetic thermal oil, is circulated in these tubes to attain the heat from tube. The trough is usually aligned on a north-south axis, and rotated to track the sun as it moves across the sky each day. Basically single axis tracking is used in PTCs. The concentration ratio for PTC is 15–45 and its indicative temperature range is 60–300 °C.

LFR (Linear fresnel reflector)

A linear fresnel reflector array is a line focus system similar to parabolic troughs in which solar radiation is concentrated on an elevated inverted linear absorber using an array of nearly flat reflectors. CLER (compact linear fresnel reflector) uses many thin mirror strips instead of parabolic troughs to concentrate sunlight from a large field onto just two tubes of working fluid. This has a unique advantage in that the flat mirrors are much cheaper to produce than the parabolic mirrors. Further, it also allows for a greater density of reflectors in the array, allowing more of the sunlight to be used. The concentration ratio for LFR is 10–40 and its indicative temperature range is 60–250 °C.

PDC (Parabolic dish collectors)

Dish systems use parabolic reflectors in the shape of a dish to focus the solar radiation on to a dish mounted receiver at the focal point. The parabolic dish system uses a parabolic dish shaped mirror or a modular mirror system that approximates a parabola and incorporates two-axis tracking to focus the sunlight onto receivers located at its focal point. The concentration ratio for PDC is 100–1000 and its indicative temperature range is 100 to 500 °C. In India, PDC are being used for quite varied purposes such as:

- Steam generation for industrial process heat
- Solar cooking
- Distributed power generation

Table 1 Solar cooling technologies in tune with suitable solar collectors

Solar cooling technology	Temperature (heat source)	CoP	Type of solar collector used
Single stage absorption chillier	> 115 °C	~ 0.7	ETC (heat pipe), CPC, PTC, PDR
Two stage absorption chillier	> 150 °C	~ 1.2	ETC (heat pipe), CPC, PTC, PDR
Adsorption Chillier	>100 °C	~ 0.5	ETC (heat pipe), CPC, PTC, PDR
Desiccant Cooling	> 60 °C	~ 0.4	FPC, ETC (all glass), ETC (heat pipe), CPC
Ammonia Water Absorption Chillier	> 115 °C	~ 0.5	ETC (all glass), ETC (heat pipe), CPC, PTC, PDR

Scheffler dishes, ARUN-Solar dishes are few commercialized versions of PDCs in India.

HFR (Heliostats field reflectors)

Heliostat is a device that, in general, tracks the movement of sun. This device typically utilizes a reflector, which can be oriented throughout the day to redirect sunlight along a fixed axis toward a stationary target or a receiver. A heat-transfer medium in this central receiver absorbs the highly concentrated radiation reflected by the heliostats. The concentration ratio for power tower is 100 to 1500 and its indicative temperature range is 150–2000 °C. A schematic diagram of the concentrating solar collectors is shown. Table 1 sums up the solar cooling technologies in tune with the suitable solar collector types.

Cooling requirements of various edible products

India has a huge resource of edible products; but which needs to be preserved due to its perishable nature. It is still a huge challenge to make available cold storage facilities for such items mainly due to energy intensive nature of the preservation process. Under such a situation, there is a significant scope for solar cooling in various climatic zones of India.. As agriculture is a major contributor to the Indian economy (GDP); preservation of agro product is all the more crucial. Livestock maintenance and agriculture are two parallel activities and people with small land holdings rely more on livestock for meat and dairy product for their livelihood. Our country is the largest milk producing country in the world and the share of exported milk products is rising. It requires advance technology for a proper storage at a huge cost. . It is quite difficult to ensure healthy shelf life of agro, meat and diary products without a reliable and sustainable cold storage facility. India ranks second in the world production of vegetables after China. The estimated production is of the order of 101.4335 million tonnes grown over about 0.67556 million hectare. The estimated production of fruits in the country is estimated at 4.92948 million tons or equivalent to 8.0% of the world production. It, therefore, ranks second after Brazil in the production of fresh fruits. The total area under fruit cultivation is 3.3 million hectares. Similarly the meat and meat processing industry

Evacuated tube collector-based solar collector array of the solar cooling system

Photo courtesy: www.mamtaenergy.com

Table 2 Preservation temperature, storage duration, and relative humidity for fruits and vegetables

Preservation temperature								
-1 to 1.5 oC			5 to 10 °C			10 to 15 °C		
Vegetables/ fruits	Relative humidity (%)	Storage duration (months)[1]	Vegetables/ fruits	Relative humidity (%)	Storage duration (months)	Vegetables/ fruits	Relative humidity	Storage duration (months)[1]
Cabbage	95 to 100	3 to 4	Melons	85 to 95	0.5 to 1	Tomatoes	85 to 90	0.25to 0.5
Carrots	98 to 100	5 to 9	Lady finger	90 to 95	0.1to 0.25	Sweet potatoes	85 to 90	4 to 7
Cauliflower	90 to 95	0.5 to 1.5	Potatoes	90 to 92	2 to 3	Pumpkin	70 to 75	5 to 8
Cucumbers	90 to 95	0.5	—	—	—	Cucumbers	90 to 95	0.25to 0.5
Garlic	65 to 70	6 to 7	—	—	—	Lemon	86 to 88	—
Beets	95 to 100	0.25to 0.5	—	—	—	Banana	—	—
Beans	90 to 95	0.1to 0.25	—	—	—	—	—	—
Onions	65 to 70	6 to 8	—	—	—	—	—	—
Peas	90 to 95	0.1to 0.25	—	—	—	—	—	—
Spinach	90 to 95	0.1to 0.25	—	—	—	—	—	—
Apples	—	3 to 6	—	—	—	—	—	—
Pears	90 to 95	2 to 7	—	—	—	—	—	—
Grapes	85	1 to 5	—	—	—	—	—	—
Plums	90 to 95	1	—	—	—	—	—	—
Cherries	—	½	—	—	—	—	—	—
Peaches	90	1 to ½	—	—	—	—	—	—
Apricots	90 to 95	1 to ½	—	—	—	—	—	—
Oranges	85 to 90	2 to 3	—	—	—	—	—	—

[1] differs from variety to variety

Table 3 Storage life of food products

Food Product	Average useful storage life (days)		
	0°C	>20°C	> 35°C
Meat	6 – 10	1	< 1
Fish	2 – 7	1	< 1
Poultry	5 – 18	1	< 1
Dry meats and fish	> 1000	> 350 & < 1000	> 100 & < 350
Fruits	2 – 180	1 – 20	1 – 7
Dry fruits	> 1000	> 350 & < 1000	> 100 & < 350
Leafy vegetables	3 – 20	1 – 7	1 – 3
Root crops	90 – 300	7 – 50	2 – 20
Dry seeds	> 1000	> 350 & < 1000	> 100 & < 350

of India is growing quite sharply and we need to produce about 450 million boilers and 30 billion eggs annually. It essentially requires an availability of cold temperatures for preservation. In India, the total milk production in year 2006–07 was over 94.6 million tonnes with a per capita availability of 229 grams per day. It recorded an annual growth of 4% during the period 1993–2005, which is three times the average growth rate of the dairy industry in the world. Tables 2 and 3 show vegetable and fruit varieties on the basis of associated operating temperatures required for preservation, relative humidity, and storage duration as well.

The opportunities galore

Solar cooling may provide a suitable energy alternative for the fastest growing component of conventional energy use. Solar cooling technology is maturing further and a number of such projects are functional in different parts of the world. In India, solar cooling may exert a significant influence to bring down the exponentially rising need for cooling needs in the residential sector with agro product segment seeking a similar technology choice.

Budgetary allocation for the solar photovoltaic industry

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Background

Today, solar PV (photovoltaic) industry is a multi-billion dollar enterprise. It has not happened overnight but has taken years of research and investment support though mainly from the government sources. Developed nations led from the front by Europe, US, and Japan has taken recourse to PV technologies in a real big way. Substantial investments on research and development activities are now reaping good dividends. The Indian solar PV program is not lagging behind with investment being rated as quite positive now. MNRE (Ministry of New and Renewable Energy) is the pivotal organization, whose close affinity to promote PV programme in the country is well known. However, there are a few issues which still merit attention such as turning the large number of investment proposals into actual projects. The national solar mission has just laid out a highly ambitious roadmap for India's quest in putting solar energy into maximum possible use.

Major central government investments in PV

PV power is not cheap, but it takes around Rs 18–20 crores to produce 1 MW of power via a solar plant. Under the ambit of National Solar Mission, the government aims to install solar generation capacity of 20 000 MW (megawatts) by 2020, 100 000 MW by 2030 and 200 000 MW by 2050. Funding requirements, as envisaged for the purpose, have been worked out to be in the range of Rs 85 000 crores–Rs 105 000 crores. Under the Twelfth Five-year Plan scheduled to begin in 2013, about Rs 12000–15000 crores is expected to be raised.

Photo courtesy:DOE/NREL

State government initiates for PV investments

The state government of Gujarat has recently approved a total of 34 projects at an estimated outlay of Rs 12 000 crores over the next few years. Out of these, 24 projects with an aggregated capacity of 365 MW will be based on solar PV technology and the remaining will make use of solar thermal technology. These projects are expected to make a cumulative addition of nearly 716 MW to the state electricity grid. It is nearly equivalent to 2%–3% of the power requirement within the state. A unique feature of these investments will be a distinct possibility of manufacturing various components of solar power plants here. As per the available estimates, these proposals if, implemented in full will lead to power generation of about 12.50 million units of energy every year and avoid the use of about 875 000 tonnes of coal on an annual basis besides an associated emission of 1.25 million tonnes of carbon dioxide. Likewise, the Government of Punjab has envisaging the possibility of putting up solar power projects of an aggregated capacity of 25 MW by 2020. Few other state governments like Haryana are also eyeing large scale PV related investments in the near future.

Major private investments in PV

A total investment of Rs 66 394 crores is expected to come through under the auspices of national semiconductor policy announced by MICT (Ministry of Communications and Information Technology) in 2007. Table 1 shows the company-wise investments mainly for manufacturing initiatives.

Table 1 Company-wise investment for manufacturing initiatives

S.No.	Company	Proposed investment	Remarks
1.	Lanco Solar	12938.00	There are market speculations of a few companies like Reliance Industries having put on hold its solar energy related investments
2.	PV Technologies India	6000.00	
3.	KSK Surya	3211.00	
4.	Pheonix Solar India	200.00	
5.	Reliance Industries	11631.00	
6.	Signet Solar Inc.	9672.00	
7.	Solar Semiconductors	11821.00	
8.	TF Solar Power	2348.00	
9.	Tata BP solar	692.08	
10.	Titan Energy Systems	588.58	

However, if, implemented properly, such an investment will go a long way in completing the still incomplete supply chain say, in the area of wafer manufacturing.

Solar PV specific financial allocations

MNRE has been supporting R&D (research and development) activities in the PV technology area since 1976. In all, a total of 68 research projects were sanctioned by the ministry with an approved outlay of Rs 13.5 crores. In addition, the ministry supported a five year project entitled, NASPED (National Solar Photovoltaic Energy Development Programme) at CEL (Central Electronics Limited) during the period 1980–85. The approved allocation for this purpose was equivalent to Rs 11.97 crores. MNRE supported yet another major project (during the Seventh Five-year Plan) on setting up of a pilot plant for the fabrication of amorphous silicon solar cells at the Solar Energy Centre. BHEL (Bharat Heavy Electricals Limited) is taking care of this project, which has involved an outlay of Rs 16.35 crores. About nine projects were approved with a total funding support of Rs 3.15 crores during 1993–1994. Table 2 gives a breakup of the financial support provided to various activities of the following nature.

Summary outlook related to activity specific investments

a. PV materials

Metkem Silicon Limited, a subsidiary unit of Chemplast India was given a financial grant of Rs 10 million to upgrade its poly silicon technology. Significant objective of the project was to bring down the energy consumption in the production of polysilicon besides introducing a new process step of hydrocholorination. The energy consumption level of 120 kWh/kg was finally achieved. Importantly, an additional capacity of 10 tonnes per annum of polysilicon at the above unit was realized. In addition, a project related to the development of multi-crystalline silicon ingots was funded at the NPL (National Physical Laboratory), with an approved outlay of Rs 4.3 million. This project helped to develop a laboratory scale novel method of multi-crystalline silicon ingot fabrication by lowering of the crucible. This enabled NPL to design a machine based on this technique ultimately leading to a growth of large size (40 kgs) multi-crystalline silicon ingots.

Further, IISc (Indian Institute of Sciences), Bangalore was granted a project on development of silane gas with an approved outlay of Rs 6.243 million. Silane gas is an important input material for the production of thin-film amorphous silicon solar cells.

b. Development of crystalline silicon solar cells and modules

NASPED project has often been termed as a turning point of the Indian PV program for quite a few reasons. CEL was awarded this five year project (1980–85), which resulted in development of an indigenous base for crystalline silicon based cells and modules. Subsequently, CEL transferred this know-how on module assembly to a state public enterprise unit—REIL (Rajasthan Electronics and Instruments Limited) in 1985–1986. Further, BHEL was assigned the task to upgrade the module technology during 1990–1993 at a cost of Rs 5.275 million. Specific objective of this project was to develop modules of 38–40 Wp using circular cells. Later on, this target was revised to develop 48 Wp modules. Solar cells bearing conversion efficiency of 14.2% were developed under this project besides bringing about major improvements in the production yield.

Another major project concerning development of 15% efficient single crystal and multi-crystalline solar cell was funded at the NPL at an outlay of Rs 4.57 million. Major gain of the work accrued in the form of improvement in the contact metallization of solar cells. It helped to achieve reduction in the use of silver paste by as much as 40% on the back surface of a solar cell. Thus, solar cell fabrication

Table 2 Breakup of the financial support provided to various activities

Activity	Amount spent (in Rs crore)	Remarks
Research projects in materials for PV applications	2.09	Thin film amorphous silicon development has received the highest allocation, but has not resulted into a successful commercial ventures
R&D in crystalline silicon solar cell/module technology	13.00	
Amorphous silicon technology	21.00	
Polycrystalline thin films	1.69	
Other type of devices	1.12	
System development and other related activities	2.01	

became somewhat cheaper due to the incorporation of this innovative step.

c. Amorphous silicon solar cell/ module development

MNRE undertook an ambitious R&D programme in the amorphous silicon technology. Under this, a pilot plant for the development of thin-film amorphous silicon modules was set up by BHEL at an approved outlay of Rs 16.35 crores. It used the R&D inputs developed earlier at the IACS (Indian Institute for Cultivation of Science), Kolkata. Solar cells of about 12% efficiency in the laboratory scale were developed at IACS. Further, NPL was awarded yet another major project. It was related to the development of 1ft×1ft size chambers. The purpose was to deposit amorphous silicon layers for use in the above mentioned plant. Financial outlay for the purpose was Rs 4.75 million.

d. Polycrystalline thin-film solar cell

The ministry showed keen interest in the development of polycrystalline thin-film technologies like CdTe (Cadmium Telluride) and CIS (Copper Indium di-selenide). Few selected projects were supported at various universities and IITs. It resulted in solar cell efficiency development of 8%–10% under laboratory conditions. It is of interest to mention here that under the PACER (Programme for Acceleration of Commercial Energy Research), a project on development of CdTe solar cells was sanctioned to ECO-Solar systems—a Pune based organization. This activity incorporated R&D inputs from a consortium based approach comprising of NPL, University of Poona and University of Colorado without any financial grant as such from MNRE.

e. Photovoltaic systems

A wide range of Solar PV systems for various end-use applications like lighting, water pumping, and telecommunication were developed under the ambit of NASPED project. The demonstration programme of ministry involved the promotion of few systems like street lighting system, community based lighting system, and water pumping system. A total of 1520 systems for these end-use applications were delivered under this project. Design modifications were subsequently carried out over the last several years and adapted by a few small scale entities. It was during 1989–92, that a project related to the development of new models of photovoltaic water pumping system was supported at CEL with a financial outlay of Rs 2.15 million. A direct outcome of this effort was the development of two types of water pumping systems using 600 W and 900 W PV arrays. The array was coupled to a permanent magnet DC motor pump set earlier developed at Kirloskar, Pune. This DC motor-pumpset unit was reported to be about 43% efficient. Subsequently, CEL undertook an extensive testing-cum-evaluation exercise of such pumping system used for agriculture and related applications.

The ministry also supported a major project for development of PV systems for rural applications at the Jadavpur University, Kolkata, with an outlay of Rs 1.05 million. Under this project, 2 kWp of lighting systems were installed in a village within Sunderbans. That is not all, solar lanterns were also developed for both the stand-alone and central charging applications. The later concept was already put to a trial use in the north-eastern region of the country.

Five-year Plan period allocations by MNRE

The ministry has been a prime mover of PV activity on diverse fronts of technology development, product availability, and implementation of a nation wide demonstration programme in the country so far. The Seventh Five-year Plan target for the entire RE sector was initially set at Rs 410 crores, but was finally slashed to a meagre Rs 7 crores in view of a massive change in the policy planner's outlook. Fortunately enough, such allocations have been on a steady rise during the subsequent plans.

a. PV expenditure during 1997–2003

It is of a definite interest to know the expenditure incurred on the smooth implementation of PV programme during 1997–2003. Table 3 below shows the corresponding figures for each year.

The financial allocation as approved by the ministry touched a total of Rs 1610 million, a net increase of about 600 million. It showcased the government's commitment to promote and encourage the use of PV amongst all the potential customer segments.

Table 3 PV expenditure for each year

Period	*Amount (Rs in milllion)*	*Remarks*
1997–1998	178.5	The expenditure almost doubled during 2001–02
1998–1999	444.1	
1999–2000	479.1	
2000–2001	491.6	Over the previous year taking it beyond the 1000 million mark in 2002–03
2001–2002	896.8	
2002–2003	1040	

b. Sanctioned outlays for PV programme during the Tenth Five-year Plan

The national solar PV program has been quite active on several front. Major plans allocations have been made with regard to the electrification of remotely located villages and hamlets. Special thrust has also been accorded to the running of demonstration programme (Table 4) with a multi-purpose objective to widen the utilization base of various products and systems developed by the Indian industry so far.

Table 4 Sanctioned outlays for PV programmes

Programme component	*Amount (Rs in billlion)*	*Remarks*
Rural electrification	6.00	Allocation for the rural electrification programme exceeds the rest of programme components by a huge margin thus indicating the governments determination to provide the electricity to all by 2012
Demonstration	3.0	
Water pumps	2.0	
R&D	0.25	
Market development	0.1	

c. Solar PV power plan allocation

A total amount of Rs 75 crores was approved as an outlay for the development of solar power programme. However, far less amount seems to be have been spent in practice for one reason or the other as evident from Table 5.

d. Priority allocation under SPV demonstration and utilization program

The national PV programme took off quite early when viewed alongside similar programmes in other parts of the world. Incidentally, Indian PV programme is widely regarded to be the largest demonstration programme. It has given a thorough insight into various facets—technology development, product design-cum-development, program implementation besides capacity building at various levels. The demonstration program of this type encompassed products like solar lantern, home lighting system, and power packs of various capacities. Let us now take a look at the plan allocations made during the Ninth Five-year Plan period—1997–2002 given in Table 6.

Table 6 Plan allocation during the Ninth Five-year Plan

Allocation head	*Amount (Rs in crore)*	*Remarks*
Plan allocation	219.00	The actual expenditure crossed the revised budgetary estimate thus, indicating implementation of a broad based field demonstration programme
Budget estimate	192.07	
Revised estimate	150.84	
Actual expenditure	157.40	

Allocations under the Tenth Five-year Plan

The Indian PV programme has been showing a definite value addition while moving from one plan period to the other. The market penetration of solar PV products has increased and product range is readily available on a customized basis too. The Tenth plan implemented during 2002–07 (Table 7) was approved at a total financial outlay of 290 crores. The north eastern region was accorded a top priority by being approved Rs 80 crores.

Allocations for solar PV water pumping programme

The ministry evolved a national programme on the development-cum-market dissemination of solar water pumping primarily for agriculture and related needs. Core objective of this programme was to draw people away from an expensive use of the diesel generating units. Under this programme, PV array capacity of 900–1800 Wp was actually utilized with pump capacity ranging between 1–2 h p. A total of 7068 such systems were deployed across various geographical regions of the country. PV subsidy allowed per unit was gradually received to about Rs 30 per peak W

Table 8 Allocation for solar PV water pumping programme

Allocation head	*Amount (Rs in crore)*	*Remarks*
Plan allocation	46.5	Clearly, the actual expenditure fell short by about 20% for a variety of reasons.
Budget estimate	49.0	
Revised estimate	44.3	
Actual expenditure	37.2	

Table 7 Allocations under the Tenth Five-year Plan

Head	*2002–03 (Rs in crores)*	*2003–04 (Rs in crores)*	*2004–05 (Rs in crores)*	*2005–06 (Rs in crores)*	*2006–07 (Rs in crores)*
Budget estimate	53.00	37.00	23.00	25.00	29.50
Revised estimate	41.00	27.00	46.00	20.00	47.70
Actual expenditure	41.24	28.65	12.12	23.55	47.66

Table 5 PV power plan allocation

Head	*2002–03 (Rs in crores)*	*2003–04 (Rs in crores)*	*Remarks*
Budget estimate	8	6	There is still a meager installed power capacity base of just over 2 megawatts. Large scale initiatives like the one based on generation-based incentives need to have a very positive outcome.
Revised estimate	8	2.10	
Actual expenditure	2.60	1.10	

in a phased manner. Table 8 show the Ninth plan budget allocation related to solar PV water pumping programme.

Budget allocation to solar industry

The ministry has been quite forthcoming in supporting the Indian industry through its financial arm—IREDA (Indian Renewable Energy Development Agency) right through 1987. Tenth plan outlay, in terms of interest subsidy on the manufacturing loan to the industry, was about Rs 30 crores. The budgeted estimate during 2003–04 was Rs 2 crores, as the actual expenditure stood at Rs 0.42 crore.

Budget allocation under R&D

R&D activities are an integral part of any major effort to popularize solar energy technology. This is true in case of solar PV, which is in dire need of finding a cost-effective solution on the application front. The ministry has been encouraging the academic and research organizations to carry out goal driven and time bound R&D activities. The Ninth plan allocation for this purpose was Rs 25 crores, while the actual expenditure was little less than a half at Rs 10.15 crores. Table 9 gives a quick insight into the tenth plan budgetary provisions for pursuing research and development activities on the well identified thrust areas. Total allocation was about Rs 30 crores spread over the usual five year-plan period.

Table 9 Allocation of funds for R&D

Head	*2002–03 (Rs in crores)*	*2003–04 (Rs in crores)*	*2004–05 (Rs in crores)*	*2005–06 (Rs in crores)*	*2006–07 (Rs in crores)*
Budget estimate	2	—	2	5	0.50
Revised estimate	2	—	1	0.50	0.10
Actual expenditure	0.96	—	0.31	0.26	0.10

The investment path ahead

Efforts are being carried out to make solar PV more and more affordable. The trick of the trade lies just not with a continued dependence on the government grants and allocation under various heads. Time is quite ripe for the private sector to come forward with massive investments under a public–private partnership mode. That may finally pave the way forward to increase the geographical outreach of the PV programme apart from meeting enhanced power specific requirements of various magnitudes.

OPERATIONAL FEATURES OF A GRID-CONNECTED PHOTOVOLTAIC SYSTEM

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Background

There is a growing global concern to the impending energy crisis, mainly triggered by an ever increasing energy demand and rapid depletion of fossil fuels. The major sources of the electricity production are the fossil fuels such as coal and natural gas. Developing countries in particular are facing frequent power interruptions as a result of an increasing gap between the demand and supply of power. Moreover, electrification of certain remotely located areas, by extending the electrical power grid, is often not techno-economically feasible. Moreover, the release of greenhouse gases and hazardous wastes from power plants has led to global warming. Indeed, nuclear energy is a clean form of energy for bulk electricity production. However, it puts a huge demand on the installation cost and involves several safety issues such as safe disposal of harmful radioactive wastes.

Making room for renewable energy

In view of the above stated facts, renewable energy sources seem to be the best form of sustainable energy sources. Their share in cumulative power generation is being planned in almost all the countries. These are often described as clean and green forms of energy because of their minimal environmental impact as compared to the fossil fuels. As of now, a few renewable energy technologies have already matured, amongst which solar photovoltaic is a potential contender. Internationally, wind energy has already made a mark for itself with India occupying the fifth place.

Adoption of these technologies requires suitably designed controllers for their integration in the grid for enhancing their performance both under grid connected and stand-alone operation. This article deals with the modelling of GCPS (Grid Connected Photovoltaic Systems). An introduction to the photovoltaic system and its different configurations are described in the subsequent sections.

Understanding PV systems

PV systems operate with no moving parts, thus, require very low maintenance. These systems have capacities ranging from a few watts up to several megawatts. A major source of instability in conventional energy sources arises out of the fact that the input energy must be immediately consumed by the load. Unless the energy balance is maintained at that instant, it leads to undesirable situations such as frequency drift in an alternator of a thermal or hydro power plant. However, PV does not require this balance to be maintained, since available energy, in excess of load demand, is not converted into electricity. Hence, a major source of instability, present in the conventional plants, is not present in the PV based

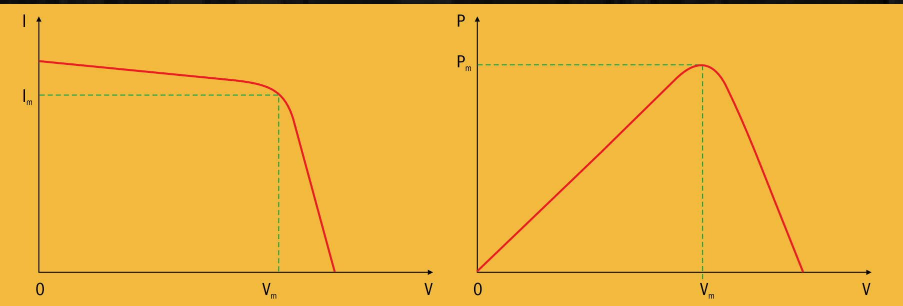

Figure 1 IV (current vs voltage) and PV (power vs voltage) characteristics of PV array

systems. This results in a more reliable operation and requires reduced operational complications.

Characteristics: a diagnostic tool

Characteristics of a typical PV source are shown in Figure 1. From this figure, it is observed that the power output from a PV source depends on the voltage across it. The short circuit current (I_{sc}) of the PV source increases with a corresponding increase in the incident energy from sunlight and open circuit voltage (V_{oc}) decreases with the increase in temperature. In this figure, V_m and I_m are the voltage and current of the PV source at which it can deliver the maximum power. Hence, a power conditioner is needed to operate the PV source at a maximum power point and to convert this voltage to a level, which is more suitable to the load or complying with the electric grid specifications, if the PV source is connected to the grid.

PV: underlying limitations

Few limiting factors, which restrict the usage of PV sources, are given below.

1. PV energy system is expensive
2. It requires large collection area for installation of the panels to get high power output.
3. PV energy is not available at night and is also affected in cloudy weather conditions. This necessitates the use of storage system or an alternative power system during phases of non-availability.

All these disadvantages have been addressed to a great extent with cell and module efficiency improvements over the last 20 years and design of high throughput plant equipment and machinery. The present energy production cost from a PV source ranges between Rs 18–20 per kWh. However, it has been projected that by the year 2020, the PV energy costs may reduce to Rs 4–7 per kWh.

Characteristics of PV array

PV cell/module/array characteristics (voltage and current) depend upon the solar insolation level and cell operating temperature. Short circuit current, I_{ph}, is directly proportional to insolation. As insolation drops, short circuit current also drops, and vice versa. Decreasing insolation also reduces the open circuit voltage, V_{oc}, but it follows a logarithmic relationship that results in relatively small changes in V_{oc}.

As the cell temperature increases, the open-circuit voltage decreases substantially, while as the short circuit current increases only slightly. As such, a photovoltaic system performs better on cold, clear days than when it is hot. For crystalline silicon cells, drops by about 0.37% for each degree Celsius increase in temperature and increases by approximately 0.05% /°C. The net result, when cells heat up, is the MPP (maximum power point) slides slightly upward and towards the left with a decrease in maximum power available of about 0.5%/°C. The characteristics of 160W PV module (BP3160) for various temperature and solar insolations conditions are simulated using PSCAD/EMTDC, industry standard power system simulation software. Specifications of BP3160 PV module are given in Table 1 A 5.6 kWp PV array can be constructed by connecting series-parallel combinations (six 160 W modules in series and six such parallel combinations) of BP3160 PV modules. Specifications of 5.7 kWp PV array are given in Table 2.

Table 1 Specifications of BP3160 PV Module

Maximum power	P_{max}	160 W
Voltage at maximum power	V_{max}	35.1 V
Current at maximum power	I_{max}	4.55A
Short circuit current	I_{ph}	4.8 A
Open circuit voltage	V_{oc}	44.2 V

Table 2 Specifications of 5.7 kWp PV array

Maximum power	P_{max}	5760 W
Voltage at maximum power	V_{max}	210 V
Current at maximum power	I_{max}	26.8 A
Short circuit current	I_{ph}	28.8 A
Open circuit voltage	V_{oc}	264.6 V

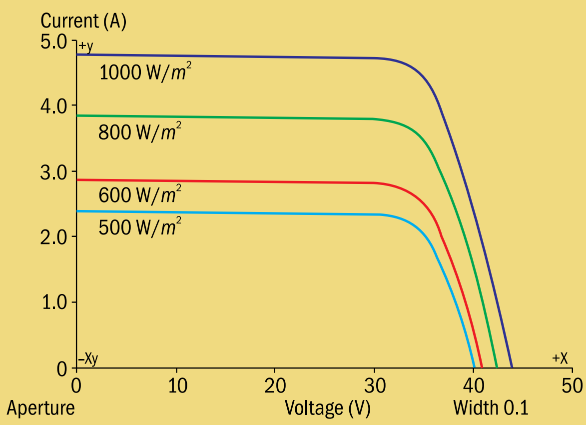

Figure 2 I vs V characteristics of PV module for different insolation (S) levels at T = 25 °C

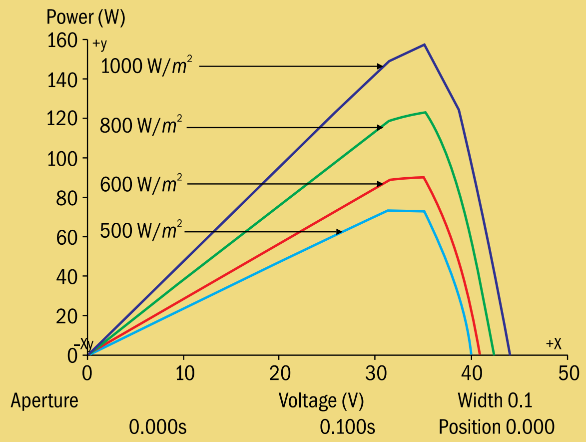

Figure 3 P vs V characteristics of PV module for different insolation (S) levels at T = 25 °C

Effect of insolation on PV module characteristics (BP 3160)

Figures 2 and 3 show the voltage vs current and voltage vs power characteristics, respectively for different solar insolation conditions at constant cell temperature (25 °C) of PV module BP 3160.

Effect of temperature on PV module characteristics (BP 3160)

Figures 4 and 5 show the voltage vs current and voltage vs power characteristics, respectively for different cell operating temperature conditions at constant solar insolation.

Photovoltaic power system

PV modules are easy to transport and install. This enables an easier expansion of generation and installation in remote areas. These can be designed to provide DC and/or AC power output, can operate interconnected with the utility grid or in isolation. PV power systems are generally, classified according to their functional and operational requirements, component configurations, and how these are connected to other power sources and electrical loads. The two principle classifications are stand-alone system and grid-connected or utility-interactive systems.

Stand-alone PV systems

In several countries, the electric grid is largely confined to feed the loads mainly in the urban areas and substantial proportion of the rural population does not have any access to the electricity. In such cases, properly designed stand-alone PV systems find potential application in the rural electrification arena to generate electricity locally, at the site where it is directly consumed. The block diagram of a stand-alone PV system is shown in Figure 6. This kind of power supply is immune to utility blackouts and does not rely on the penetration of long distance transmission lines. As the PV source is not available during the night or cloudy weather

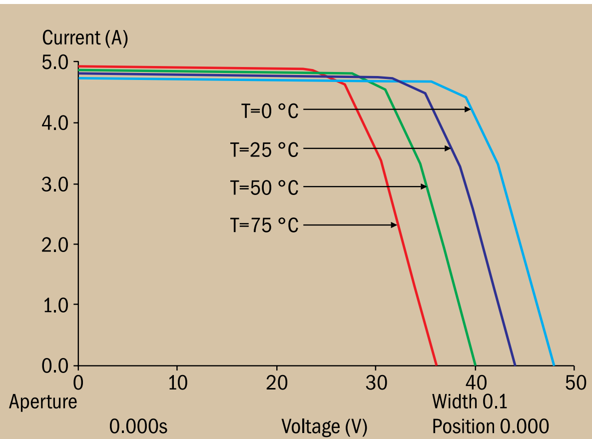

Figure 4 I vs V characteristics of PV module for different temperature levels (T) at S = 1000 W/m²

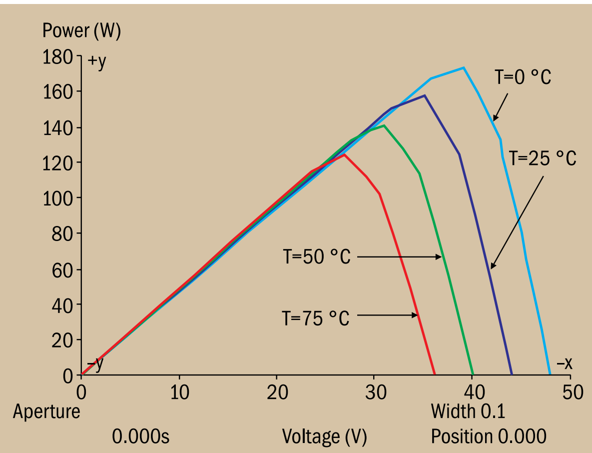

Figure 5 P vs V characteristics of PV module for different temperature levels (T) at S = 1000 W/m