The SOLAR QUARTERLY

The Complete Solar Magazine

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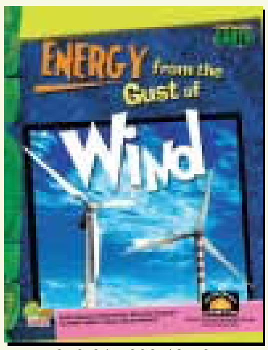

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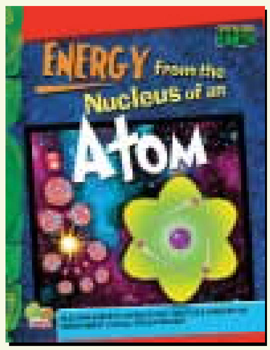

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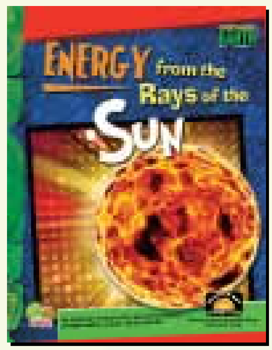

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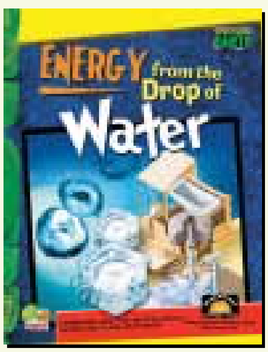

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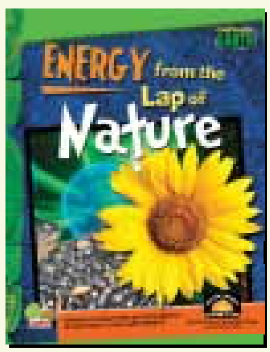

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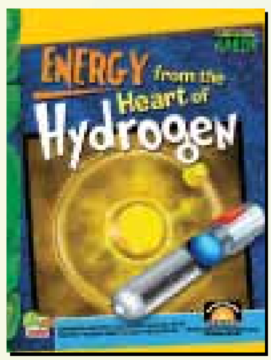

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From the editor's desk...

We have witnessed two significant trends in the recent past; the first one deals with energy access, and the second is the lowering of tariffs in the 2nd phase of JNNSM bidding. While international concern about energy access is growing, the recently released 2011 edition of the World Energy Outlook report mentions that some countries – notably India – have made significant efforts towards improving energy access. According to the report, expenditure on electricity was reported by 67% of the rural population and 94% of the urban population in 2009; up from 56% and 93% respectively when surveyed in 2006. These statistics are indicative of an increased level of access to electricity. A second heartening trend was on display at the 2nd phase of JNNSM bidding. The lowest bid was priced at Rs 7.49 per unit; presumably due to falling module prices, rapid advancements in solar technology, and lacklustre demand in the European market. These two trends have had a significant bearing on achieving the targets of JNNSM, both in the grid as well as in the off-grid sector.

Solar technology has the potential to cater to all three incremental levels of energy access, i.e., basic human needs such as lighting; productive applications; and modern societal needs. Solar lighting systems and domestic systems are well suited to address basic human needs, and mini-grids and power plants can take care of domestic, as well as productive, applications of a sizeable community for its several applications. Megawatt scale power plants, on the other hand, cater to the energy security of the country, and attempt to target the third level of energy access. While we have been innovative in providing technology solutions in all the above categories and have provided a lead for other countries to follow, there is tremendous scope to facilitate innovations in other aspects of solar programmes, ones which are critical for their overall sustainability. For instance, an efficient and effective network for operations and maintenance of these systems, strong supply chains for availability of spares, skilled manpower to provide the after-sales service, customized financing to cater to different strata of society, etc., are some of the examples where we need to improve and can probably learn from other countries.

The integration of innovative approaches in the entire value chain from technology to service should be the emphasis while implementing the programmes of the JNNSM. This will not only enhance the overall statistics of energy access, but will contribute to the advancement of the global agenda of sustainable energy for all.

Akanksha Chaurey
Director, TERI

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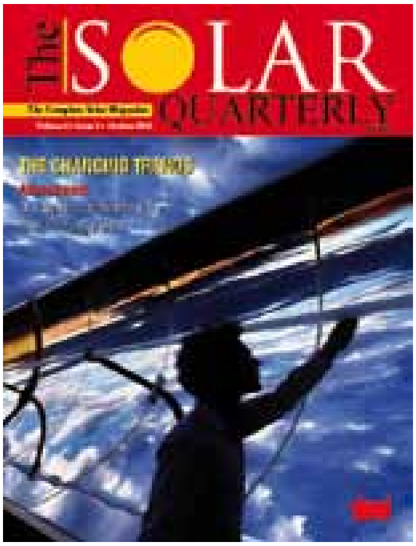

I am a regular reader of *The Solar Quarterly*. I find the material published very relevant and up to date. At a time of depleting resources, it is refreshing to learn what all one can achieve and develop with the largest renewable energy source available, which is the sun. Looking forward to reading more such articles.

Pradeep Kumar
Delhi

I am thoroughly enjoying reading the Indianized issue of *The Solar Quarterly*. It is interesting to know and learn about India's contribution in the field of solar energy. I am a research scholar in the field of renewable energy and the magazine is of immense help especially when it comes to comparing and analysing RE statistics.

Shiv Pandey
Gujarat

The feature on the status of the JNNSM, launched by the government, made an interesting read in the issue. We all have read about the mission but are not properly apprised of the current status of the same. The other articles were also well researched and very well written.

Solar energy is the future and we need to use this energy very prudently for a sustainable future. *The Solar Quarterly* successfully spreads the message among one and all.

Shraddha Nair
Coimbatore

I must say that *The Solar Quarterly* is perhaps the best trade magazine around in the solar energy sector. The magazine's focus on the latest news, technologies, and projects in the solar energy sector allows me to remain at the forefront of the industry. What perhaps separates TSQ from, say, reading news online, is the depth of each essay. The article in the October 2011 issue on Concentrating Solar Power was an example of the depth one looks for in a TSQ article. It succinctly and accurately stated the figures of a growing industry, which for someone looking to enter the sector is priceless. Congratulations on all the good work and I encourage you to go further.

Nitesh Kapur
Delhi

I have been an avid reader of *The Solar Quarterly* since its inception, and would like to say that reading about providing the poor and downtrodden of rural Indian villages with solar-powered appliances and cooking was an adept heart-warming article. I think TSQ's best way forward is by focusing on all renewable energy rather than just solar energy.

Malavika
Mumbai

I thoroughly enjoyed reading the October 2011 edition of The Solar Quarterly, specifically the article on the Education Park in Madhya Pradesh. India is the second-fastest growing economy and has the largest number of young people in the world. Without proper education, this pool of talent can go to waste. I think that the Education Park is a step in the right direction as it is not only fulfilling one of the country's greatest needs, it is also doing so in a manner that does not harm the environment and does not result in a mindless excessive usage of resources. If this model were replicated in 100 more places in India, I think the future talent in this country will be able to grow.

Hashim Khan
Ambala

I think one of the biggest problems faced by the Indian solar energy industry is a lack of indigenous manufacturing technology. When we start making our own PV cells and plants using equipment and panels, we can start moving towards solar energy.

Ram Charitra
Rajasthan

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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India's first solar thermal power plant completed by Abengoa

India's first concentrating solar thermal power plant has been completed by Abengoa. Located in Gual Pahari, Haryana, this plant can generate three megawatts of electrical energy.

The plant utilizes parabolic trough technology, where long rows of curved mirrors concentrate sunlight onto a fluid carried in a central receiver. The heat from the fluid is then used to produce steam, which drives a turbine to produce electricity. The plant is supported by a programme of the Ministry of New and Renewable Energy (MNRE) to boost research and development towards making solar power cost-competitive with conventional electricity.

Abengoa is an international company that provides modern technology solutions for an expanded development in the energy sector. This project was completed with an investment of approximately 4 million US dollars. The design of this power plant and engineering requirements were provided by Abengoa. The best thing about these power plants is that they are eco-friendly and do not release any $C0_2$ gas to the atmosphere.

Source *Solar Server*

Sunborne Energy mulls ₹600 cr solar thermal plant in South India

Sunborne Energy, a Haryana-based solar power producer backed by General Catalyst Partners and Khosla Ventures, is contemplating setting up a 50 MW solar thermal power project in Andhra Pradesh for an investment in the range of ₹500 crore and ₹600 crore (including the land cost).

The company has already acquired 200 acres in Andhra Pradesh and is now trying to work it out with the state government to set up the plant. Sunborne has so far raised US $25 million in a two-round funding from General Catalyst Partners, which recently signed a power purchase agreement with the Gujarat government for a 50-MW solar thermal power plant. The project is expected to be commissioned soon.

Source *Business Standard*

Karnataka Renewable Energy receives 22 bids for setting up solar projects

Karnataka Renewable Energy Development Ltd (KREDL) has received 22 bids for setting up solar power projects under the 'Karnataka solar policy'. As a part of its 350 MW programme, KREDL had floated a tender inviting bids for setting up projects that total to 80 MW. The projects would be allocated under 'reverse bidding' process. They will be allocated to bidders who have quoted the steepest discounts to the tariff fixed by KREDL (₹14.50). "We cannot check the technical details of the bids till the RFP (request for proposals) for bidders under the Phase I Batch II of the National Solar Mission. The allocation of projects with respect to these tenders would start soon. The government has identified land to set up the 80 MW of solar plants, which would be allotted for a period of 30 years of lease. However, it is learnt from sources that only two bids, totalling 20 MW, have been received for 'solar thermal' projects. KREDL had invited bids for 30 MW of solar thermal and 50 MW of photovoltaic. While the 'thermal' part of it has been under-bid, the PV portion has received bids for substantially more than 50 MW. Apart from the projects under the solar policy, projects with a total capacity of 200 MW would

Courtesy: Abengoa.com

be taken up under the REC scheme of the Ministry of New and Renewable Energy (MNRE). "Some companies have already applied for projects under REC mechanism and we will allot the 'REC mechanism projects' very shortly", a source from the ministry said. For these, however, there is no deadline as it is a "continuous process".

Source *Hindu Business Line*

Turbo mode for solar modules: second and third-generation front glasses

Competition in the premium sector is becoming more and more fierce, forcing PV module manufacturers to differentiate themselves through product benefits and better performance in terms of efficiency. While attention has previously been focused on cell technology, it is likely that, in the future, all module components will become part of this competition– a competition in which premium front glasses present a promising element. Anti-reflective coating (ARC) is only the beginning of this evolution. Not only do deeply textured front glasses promise significant increases in output – up to 7% – but their specific product characteristics also make them suitable for niche applications, such as airplane entry lanes and airport buildings.

Source *Photovoltaic International*

Renewable energy ministry of India seeks 10-fold increase in fund outlay

According to some reports, the renewable energy ministry has sought a 10-fold increase in fund outlay for the next five years. The ministry estimates requirement of ₹40,000 crore to ramp up its capacity to 30,000 MW by 2017. An outlay of ₹4,000 crore was earmarked for development of renewable energy in the 11th plan period of 2007-12. India's present renewable energy capacity is over 20,000 MW of which wind farms alone generate 14,000 MW, while the rest is shared between biomass, small hydro and urban-industrial waste. Solar energy capacity currently stands at 35 MW. "The progress in the renewable energy sector is happening at a fast pace but it's not so impressive. Road-map for the next five years is very crucial for its growth," renewable secretary G B Pradhan said at the 11th Sustainable Energy Summit. The ministry also has plans to achieve grid parity in the solar energy sector by 2017, which means that electricity generated by solar plants would be sold at the same rate as conventional electricity. Along side, it will also increase the quantum of grid connected solar power aiming at 20,000 MW. "To achieve it, we need a strong domestic manufacturing base which can absorb technology advancement," said Pradhan. In just two years, capacity of grid connected solar power has increased from 2 MW to 35 MW in 2011. By the end of 11th plan, ministry hopes it will reach 300 MW. The government is also encouraging solar power with its Jawaharlal Nehru National Solar Mission (JNNSM), which aims to tap solar power in India, estimated to be around 5,000 trillion kWh per year.

Source *Panchbuta*

Mahindra arm to develop solar technology for Reva

Mahindra Solar One, the solar business arm of the country's largest utility vehicle maker Mahindra & Mahindra's cleantech ventures division, is in the process of developing solar technology for use in the electric car Reva, according to Vish Palekar, business head (cleantech ventures) of Mahindra Partners. Mahindra Partners is an over $500-million division of M&M that manages the group's new and non-automotive businesses such as retail, logistics, engineering, chemical products, media and entertainment, and energy."We are working on options of how solar can be deployed in automotives. It is in an early stage but we see

that as something that will clearly evolve in the future. We look at this (solar) as a potential for hybridization of cars like Reva. Mahindra & Mahindra had bought a majority stake of over 55 per cent in electric car company, Reva, in 2010. Mahindra Solar One is currently evaluating two options – solar-and-electric and diesel-and-electric – for deployment in Reva. Palekar said Reva was interested in driving standards on green energy automotives. "They (Reva) had done that in batteries and they had done that in the Reva car. I am sure they are going to look at these options as a potential option for hybridization," he said. Stating that if successful, the solar energy subsidiary would offer the technology to the Mahindra Group's automotive division for use in its vehicles like Xylo and Bolero, to start with. "We see solar as a technology that will be deployed for sure.

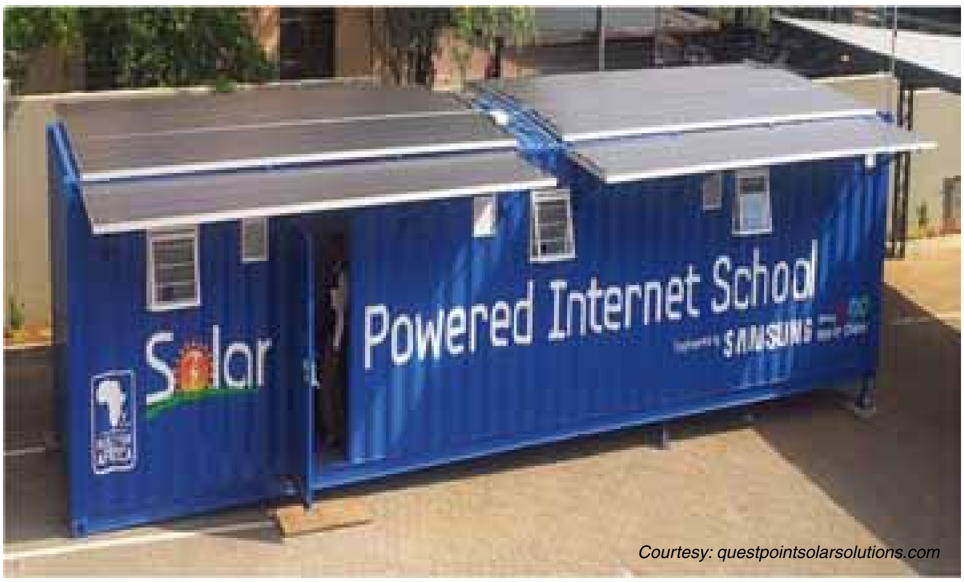
Source *Business Standard*

Solar-powered internet school set to benefit children in rural Africa

The solar-powered classroom has space for 21 pupils and a teacher, and includes a built-in ventilation system. Their days of sitting in a ramshackle, sweltering school building, or taking lessons under the shade of a tree, could be about to change. Children in the farthest corners of rural Africa are the target of a mobile, solar-powered classroom that was launched in Johannesburg this week. The classroom, built inside a 12-metre-long shipping container by electronics firm Samsung, has an array of gadgets including laptops, a video camera and a 50-inch e-board in place of a blackboard. According to the manufacturers, the "solar powered internet school" can easily be carried by truck to remote areas, survive harsh weather conditions and, crucially, operate where there is no electricity supply. Foldaway solar panels provide enough energy to power the classroom's equipment for up to nine hours a day, and for one and a half days without any sunlight at all.

Electricity remains Africa's largest economic challenge with the level of penetration lower than 25% in most of the rural areas."This lack of power isolates communities, and limits their access to education and information, both of which are key to fast-tracking a nation's development". The classroom is fitted with a variety of computers including solar-powered laptops and tablets. It also has an energy-efficient fridge, a file server loaded with educational content, a router, a video camera, and a "world first" Wi-Fi camera, all of which communicate via 3G. This allows a central location, such as the department of education, to monitor classes and deliver curriculum-based content directly to the laptops of both pupils and staff. If, the best-laid plans are struck by a computer glitch, teachers can still use a regular built-in whiteboard and chalkboard. The prototype is being piloted at the Samsung Electronics Engineering Academy in Boksburg, east of Johannesburg. It will then be sent to Qunu in the Eastern Cape to undergo further testing.

Source *Guardian*



Courtesy: questpointsolarsolutions.com

'Green Leaf Mark' certification for Moser Baer Solar for the first time

Moser Baer Solar (MBSL), a subsidiary of Moser Baer India has been awarded the 'Green leaf' Mark by Intertek AB Semco, Germany, for its latest Max Series 'Lead free' solar PV modules. Intertek's Green Leaf Mark certifies that this product

has been independently tested and found to conform to the multiple existing environmental regulations. With this, MBSL has been accorded the rights to display the prestigious 'Green Leaf' mark on product packaging, at point of purchase in displays, product advertising, and literature to highlight its superior environmental credentials.

Source *Panchbuta*

The Hydron Solar Concept by Varun Varshney

For those who are nature lovers and appreciators of natural resource conservation efforts, here is something unique. It has been the outcome of an intensive research and creative thoughtfulness of the Indian designer Varun Varshney. The designer presents an exclusive solution that could bring sustainability in people's lives. This unique product is Hydron, which has come to receive a very special mention in the Fifth Jindal Stainless Steel Innovation Award. Hydron is such a kind of a system that not only generates solar energy by tapping the natural sunlight far better than some such similar equipment or devices, but also supports the harvesting of water. Hydron system is designed in a way that it is able to generate around twice the solar energy as another regular solar panel would do. The system's design also helps it to act like a utility product for individuals. It appears like a beautiful and stylish umbrella on top of a table. The system keeps working while you relax under the shed or use the table for a night party on a terrace. The system would work in an ideal manner on terraces, in gardens, or at open-air restaurants. This would also provide the surrounding environment a very different look and feel, and is refreshing to be utilized on a sunny day.

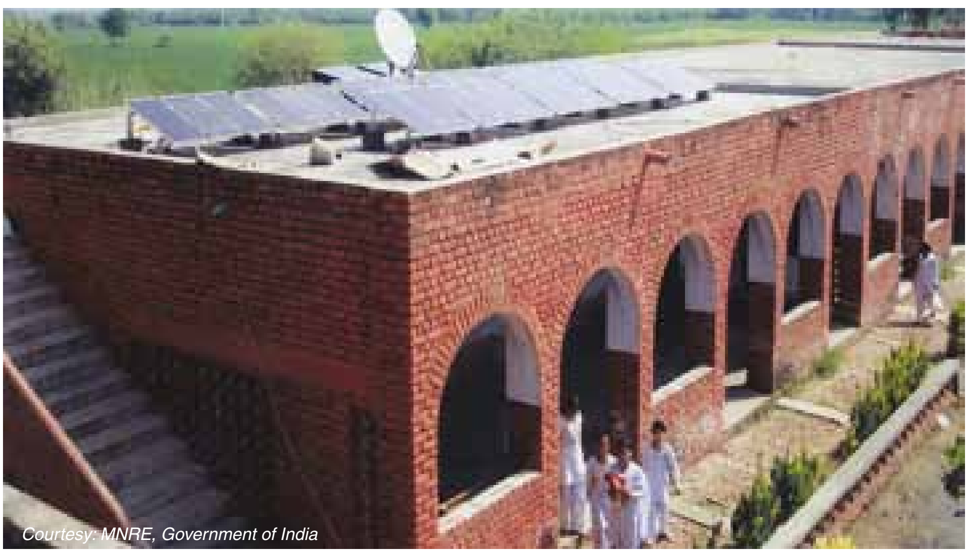
The fact that makes Hydron different from any other solar panel system is its triple-junction silicon solar cells with a thin film. These solar cells are placed on the outer side of the system structure, thus making this structure somewhat lighter than any other conventional solar panel. If, the combined thickness for the solar cell's layers in Hydron is considered, it would be around one hundredth of a typical paper sheet's thickness! This is what helps the system get more efficient in generating a large amount of energy. Structurally, Hydron's solar panels are able to fold inward, while the supporting member turns inside. Its structural design is created in such a way so that it can collect the rainwater, as well as remain exposed to sunlight the whole day in a 360-degree manner. The solar panel structure is connected to the drinking water container or junction to the reservoir. The connecting unit is involved in the water filtration process. That is how the reservoir receives distilled and purified water. Additionally, when you may need the table at night time, its leaf-like panels can easily be restructured and flattened into the shape of a table. The bright and shining top and base of the table turns it into an aesthetic beauty at night.

The system acts like a perfect utility for public places like beaches and hotel swimming pools. Hydron acts as a modular system that enhances its own value. Such efficient and environmentally friendly designs are assets to the possessions of any country or facility. Hydron not only captures renewable resources but also converts them into a useful form so they can be utilized in a wide range of applications at different places.

Source *Solar feeds*

Approval to Solar Cities by MNRE

The Government has given in-principle approval to 48 cities to be developed as 'Solar Cities', based on proposals received from various States, the Minister of New and Renewable Energy, Dr Farooq Abdullah, said in a written reply to a question in Lok Sabha . The Government proposes to develop 60 solar cities. Out of these 48 cities, sanctions have been given


Courtesy: MNRE, Government of India

to 37 that have engaged consultants for preparation of Master Plans. These include Vijayawada in Andhra Pradesh, Guwahati and Jorhat in Assam, Itanagar in Arunachal Pradesh, Chandigarh, Bilaspur and Raipur in Chhattisgarh, Rajkot, Gandhinagar, Surat in Gujarat, Gurgaon and Faridabad in Haryana, Nagpur, Thane, Shirdi in Maharahstra, Agra, Moradabad in Uttar Pradesh, Howrah in West Bengal, Dehradun in Uttarakhand, Gwalior in Madhya Pradesh, Bhubaneswar in Odisha, Amritsar, Ludhiana in Punjab, Jodhpur in Rajasthan, Thiruvananthapurm, Kochi in Kerala among others. The criteria set by the Ministry include a city population between 50,000 to 50 lakh (with relaxation for Special Category States, including the North-East), initiatives and regulatory measures already taken along with a high level of commitment in promoting energy efficiency and renewable energy. So far, an amount of ₹17.23 crore has been sanctioned for 37 cities, of which ₹2.75 crore has been released for utilization by the nodal agencies and municipal corporations concerned.

Source *The Hindu*

Suniva modules power 1.2 MW PV canopy system at Georgia bus facility

Suniva delivers 1.2 MW solar canopy at Decatur, Georgia bus facility. The company has supplied its make in the US solar panels for the recently completed 1.2MW solar canopy at Decatur, Georgia's Laredo Bus Facility. The project, said to be the second largest in the country at a US transit system, was celebrated with a ribbon cutting ceremony held by the Metropolitan Atlanta Rapid Transit Authority (MARTA). We're proud of the fact that Suniva's cells and modules, created here in Georgia, are being used to power the solar canopy at the Laredo Bus Facility," said Bryan Ashley, chief marketing officer for Suniva. "The solar canopy is the biggest project of its nature in Georgia, and will generate enough electricity to offset the majority of the facility's annual electricity consumption."The solar array sports 4,888 PV panels manufactured by Suniva at its Georgia plant. MARTA acknowledged that the solar project was realized with help from the US$10.8 million federal grant it received in 2009 under the American Recovery and Reinvestment Act's Transit Investments for Greenhouse Gas and Energy Reduction Program.

Source *PV-Tech*

Asia-Pacific set to install 4.8 GW in 2011

Moser Baer's 30 MW Gunthawada system is one of a number of installations contributing to the end-of-year surge in PV capacity. An end-of-year surge in the number of utility-scale PV installation in China and India will result in installed capacity for 2011 in the Asia-Pacific region reaching 4.8GW, according to the new Asia Pacific Major PV Markets Quarterly report from NPD Solarbuzz. Total installations in the region for the final quarter of the year amounted to 2GW – a 39% quarter-to-quarter and 130% year-on-year capacity rise. Driving this growth was China, which accounted for nearly half of regional demand in Q4 and by the year's end will have connected close to 2GW. Not only is this total the largest in Asia, but it will also top the 1.6GW figure forecasted for the US. And Solarbuzz is forecasting this regional growth to carry on into 2012, with ambitious installation targets from national governments – China's National

Energy Administration recently revised its cumulative solar installation target by 2015 up from 10GW to 15GW – and rising internal rates of return (IRRs) set to inspire a 45% expansion in market size. Outside of China, demand is being driven by already existing or planned national

incentive programmes in countries such as India, Japan, Thailand, and Malaysia, with the latter two expected to account for an additional 700 MW of demand in 2012. Non-residential, ground-mounted systems will comprise the majority of new installs over the coming 12 months; by Q4 2012, the percentage of such systems will have risen from 16% in Q1 2011 to 64%. This growth will come at the expense of the residential sector, which will fall from 58% in Q1 2011 to 20% in Q4 2012. Despite all this success, market constraints and downstream access issues still exist in most countries in the region, presenting a headache to potential project developers. In China and India, financing, land use and regulatory complications present a significant barrier to entry, while over in Australia, policy disruptions have already forced many downstream companies into Liquidation "As the European markets no longer present certain growth, the Asia Pacific markets are increasingly the focus of international companies looking to expand. Companies seeking to take a share of this growth still face significant hurdles to define strategies to successfully access the downstream value chain," Solarbuzz analyst Christopher Sunsong said. "These challenges, though, are unlikely to deter their determination to participate given the potential of this new regional market opportunity."

Source *PV-TECH*

China's feed-in tariff policy stimulates 14 GW photovoltaic project pipeline

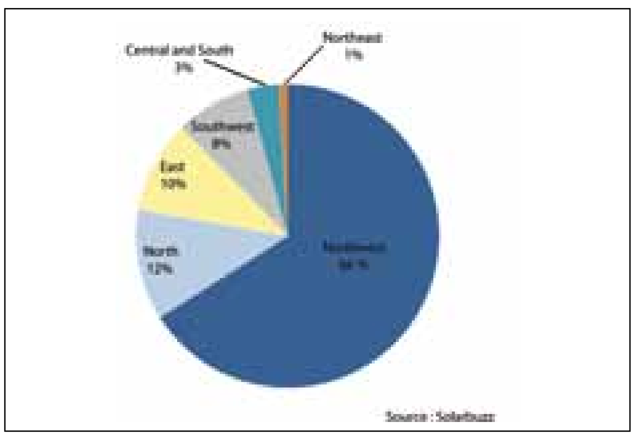
The release of a national photovoltaic (PV) Feed-in Tariff (FiT) policy in early 2011 has resulted in a significant increase in PV project development activity in China. According to the first edition of the Solarbuzz China Deal Tracker, as of the end of September, the non-residential PV project pipeline in China stands at 14 GW. Solarbuzz has identified 1,007 non-residential projects in China that are installed, being installed or in the development phase. Development-phase projects include tender-awarded, going through tender process, or planned without tender.

The Northwest region, where both intense solar radiation and vast amounts of land are available for utility-scale projects, currently accounts for 66% of the total China project pipeline. The top five province pipelines in megawatt terms are Qinghai, Gansu, Ningxia, Inner Mongolia and Sichuan. Non-residential PV project activity, characterized by large project sizes, is now evident across 29 Chinese provinces. Projects above 1 MW are the major segment of the market in MW terms, accounting for 707 of the projects being monitored. The fast-developing non-residential segment has created an important and growing opportunity for project developers, as well as engineering, procurement and construction (EPC) companies. Most leading project developer groups are state-owned enterprises (SOEs), with the top 10 companies accounting for 9.7 GW of the total pipeline.

The collapse in factory-gate module prices in 2011 has enabled projects to provide reasonable internal rates of return (IRR), considering the CNY1.15 (~$0.18)/kWh tariff. Installed system prices of ground-mount projects above 10 MW are now below CNY15 (~$2.4) per watt and decreasing. "The earlier-than-expected release of the national PV FiT policy has opened the door to explosive growth in project development activities in China," said Ray Lian, Analyst at Solarbuzz. "The result is more tenders and an acceleration of PV orders. It is projected that by the end of 2011, the PV market in China will exceed 1.6 GW, representing over 230% growth from 2010."

Strong growth in domestic demand provides great opportunity to Chinese module suppliers. For those projects that have selected their module suppliers, the top four suppliers in MW terms are Suntech, Yingli, GD Solar and Shanghai Aerospace Automobile Electromechanical. The leading inverter supplier is Sungrow Power Supply.

Source Solarbuzz



RE: THE CHANGING TRENDS

THE STATUS OF SOLAR RADIATION DATABASES IN INDIA

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Before India can realistically look at building an energy economy on solar power, it is necessary to collect extensive data on all the factors that affect energy production; none of which are more crucial than sunlight. This article looks at the work being done to create databases on solar radiation across India, and highlights the importance of resource assessment.

Introduction

Resource assessment is one of the most important exercises towards realising large-scale renewable energy projects; mainly due to the intermittent nature of solar and wind energy resources. The Government of India is currently promoting large scale solar energy power projects through several key initiatives like the Jawaharlal Nehru National Solar Mission (JNNSM) and various state policies (currently active in Gujarat, Rajasthan, Karnataka, and others). These projects are working towards achieving a target of generating more than 20,000 MW of power using solar energy by 2022. As of December 2011, a large number of projects have already been implemented across the country, and several other are under different stages of construction. The underlying principle of putting up such projects rests on the availability of solar radiation in varying measures though.

Solar radiation and meteorological data collected by the Indian Meteorological Department (IMD) covers potential locations to implement solar power projects in India across both rural and urban India. An accurate knowledge of site-specific solar radiation data is essential in the accurate design of any solar energy system. There are several other databases available from organizations such as NASA, NREL, METEONORM, 3TIER, SolarGIS, ISHRAE, and WEDCO, which are also widely referred to by project developers for energy estimation purposes. Barring the IMD database, other databases are either based on satellite data or on information obtained from interpolation techniques; this results in large variations between theoretical and observed values. Consequentially, these do not present realistic energy estimates of solar energy projects.

Recently, the Ministry of New and Renewable Energy (MNRE) published a solar radiation data book for India using IMD data. It covers 23 locations across the country, and is based on long-term measurements. The present article is an attempt at estimating mutual uncertainty of various meteorological databases; specifically NASA, NREL, and METEONORM, from the point of view of solar radiation availability. The exercise is expected to present a common platform of comparative databases to aid the bankability of solar energy projects.

Prior to delving into the various aspects associated with this study, it would be prudent to highlight a few basic attributes of the fundamental nature of solar energy.

The Sun

The Sun consists of hot plasma interwoven with magnetic fields. The Sun has a diameter of about 1.5×10^8 m, and it's mass of about 2×10^{30} kg accounts for about 99.86% of the total mass of the Solar System. Chemically, about three quarters of the Sun's mass consists of Hydrogen, while the rest is mostly Helium; however less than 2% consists of heavier elements, including oxygen, carbon, neon, iron, etc.

Solar energy is created deep within its core where the temperature (15,000,000°C) and pressure (*340 billion times Earth's air pressure at sea level*) is so intense that nuclear reactions take place. This reaction causes four protons or hydrogen nuclei to fuse together so as to form one alpha particle or helium nucleus $({}_1H^1 + {}_1H^1 + {}_1H^1 + {}_1H^1 = {}_2He^4 + 26.7\text{MeV})$. The alpha particle is about 0.7 per cent less massive than the four protons.

The energy released from the nuclear process is carried to the surface of the Sun through convection, where it is released as light and heat. Energy generated in the Sun's core takes around a million years to reach its surface. Every second, around 700 million tons of Hydrogen is converted into Helium, and around 5 million tons of pure energy is released. The sun has an effective black body temperature 5760 Kelvin (9900°F), and its cumulative energy output is 3.8×10^{20} MW, which is equivalent to an energy output of 63 MW per square meter of the Sun's surface. The sun disk forms an angle of 32 min of a degree. The earth receives only a tiny fraction of total radiation emitted equal to 1.7×10^{14} kW; however, it has been estimated that around 85 minutes of solar irradiance falling on the earth is equivalent to the world's annual energy demand (about 900 EJ).

The **solar cycle/solar magnetic activity cycle**, is a periodic change in the amount of irradiation from the Sun that is experienced on Earth. It has a period of about 11 years, and is one component of solar variation, the other being a periodic fluctuation. Solar variation causes changes in space weather and to some degree weather and climate on Earth. The cycle is observed by counting the frequency and placement of sunspots visible on the Sun.

Types of solar radiation

All substances (solids, liquids, and gases) which have a temperature above absolute zero emit energy in the form of electromagnetic waves. Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy.

The solar radiation emitted by the sun which is relevant for application

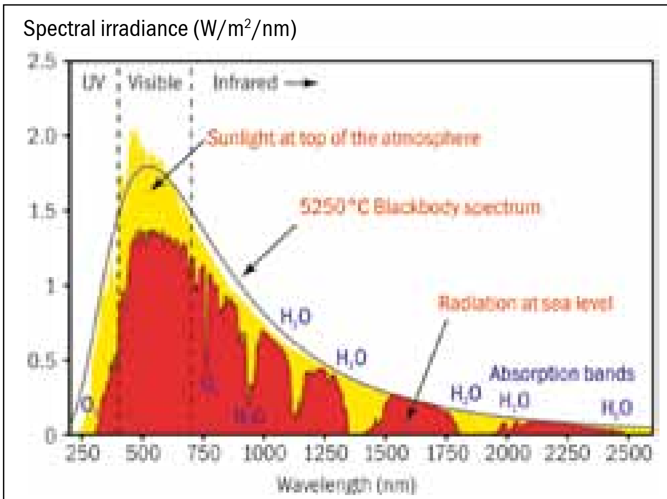

Figure 1: Solar Radiation Spectrum

in the solar power industry lies within the ultraviolet, visible, and infrared regions. Therefore, the wavelengths important to solar power applications are between 0.15 mm and 0.30 mm; and as the wavelengths in the visible region lie between 0.38 mm and 0.72 mm, this means that the wavelengths necessary for solar power applications lie in the ultraviolet range. Solar radiation with wavelengths between 0.1 microns to 100 microns strike the Earth; the components of this radiation and approximate wavelength ranges are given below (Figure 1).

- Ultraviolet: 0.20 - 0.39 µm
- Visible: 0.39 - 0.78 µm
- Near-Infrared: 0.78 - 4.00 µm
- Infrared: 4.00 - 100.00 µm

The maximum spectral intensity occurs at about 0.48 mm wavelength (λ) in the green portion of the visible spectrum. About 8.5% of the cumulative energy is contained in Ultraviolet Region (λ<0.40 mm); next 38.5 % is contained in visible region (0.40 mm < λ < 0.70 mm) approximately and the remaining 53% is contained within the Infrared region (λ >0.70 mm).

As solar radiation passes through the earth's atmosphere, some of it is absorbed or scattered by air molecules, water vapour, aerosols, and clouds. The range of wavelength emitted from the sun varies due to the weakening of its amplitude during propagation from sun to the earth atmosphere (a process known as attenuation). Hence, from the point of view of terrestrial applications of solar energy, only the radiation falling in the wavelength range of 0.29 mm to 2.3 mm is sufficient.

Understanding solar radiation terms

I. Solar Constant

The Solar Constant is the quantum of solar energy per unit time at the mean distance of the earth from the sun, received on a unit area of a surface normal to the sun outside the atmosphere. The World Meteorological Organization has fixed the value of Solar Constant at 1367 W/m^2.

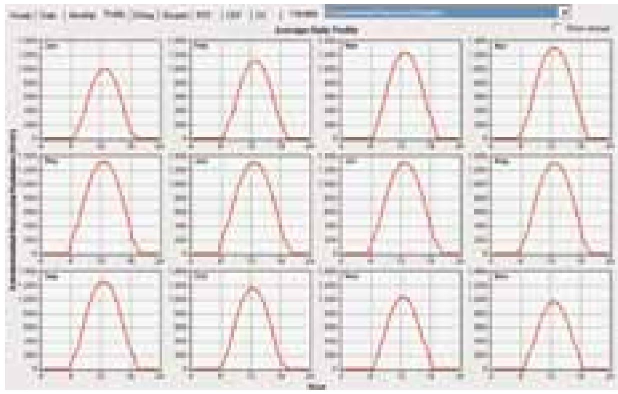

Figure 2: Monthly pattern of extraterrestrial solar radiation

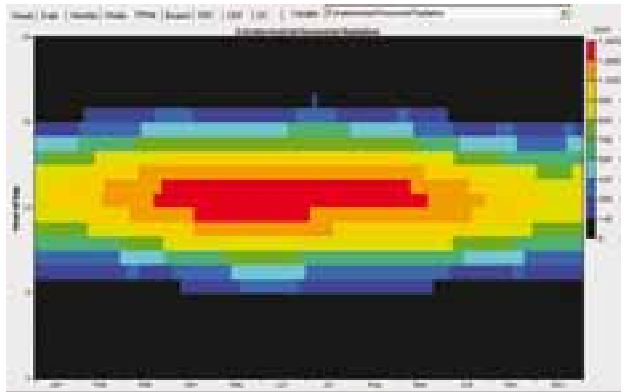

Figure 3: Intensity distribution pattern of annual extraterrestrial solar radiation

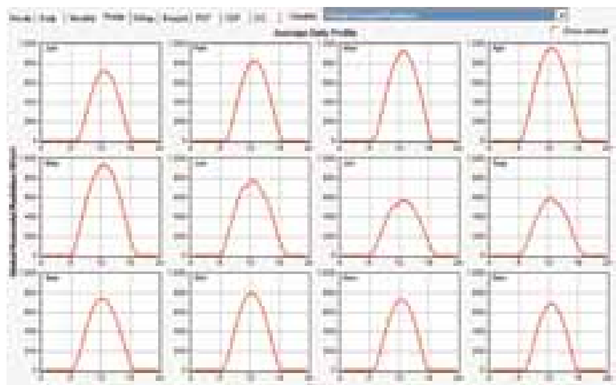

Figure 4: Monthly pattern of global solar radiation

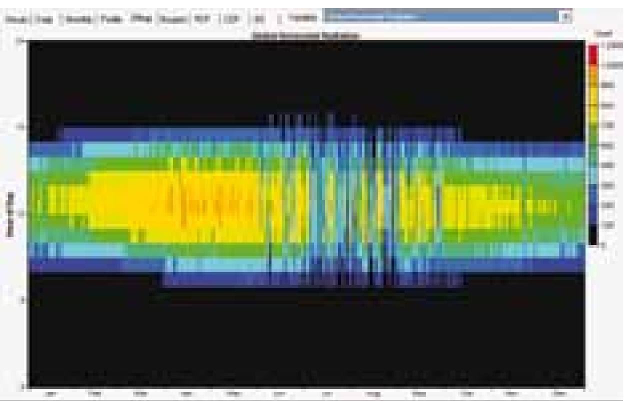

Figure 5: Intensity distribution pattern of annual global solar radiation

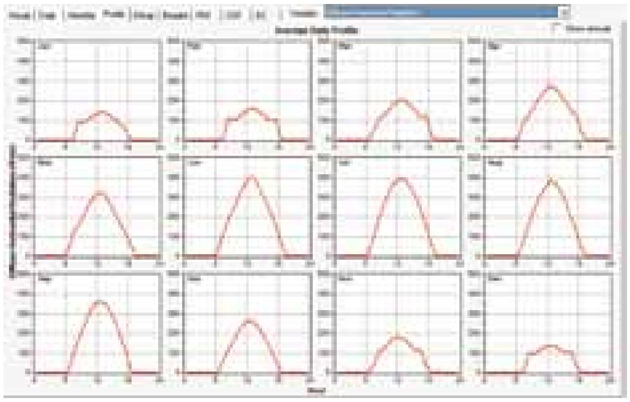

Figure 6: Monthly pattern of diffused solar radiation

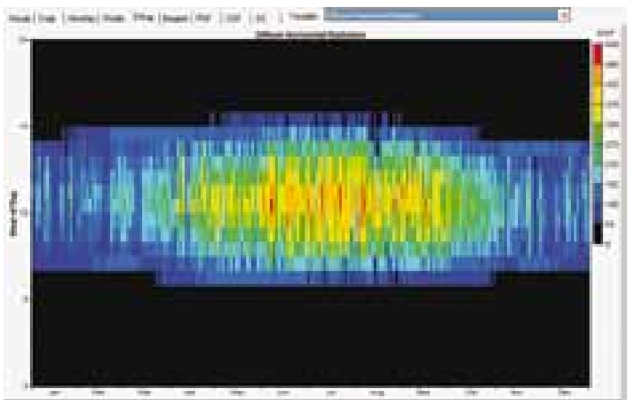

Figure 7: Intensity distribution pattern of annual diffused solar radiation

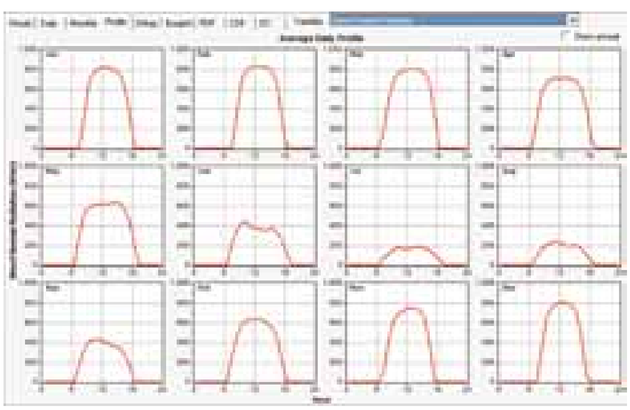

Figure 8: Monthly pattern of direct normal irradiance (DNI)

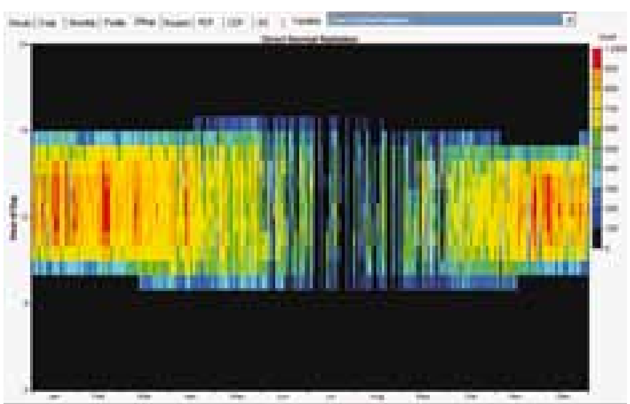

Figure 9: Intensity distribution pattern of annual direct normal irradiance (DNI)

II. Extra-terrestrial solar radiation

Solar radiation incident outside the earth's atmosphere is called Extra-Terrestrial Radiation (Figure 2 and 3).

III. Global solar radiation

The direct component of sunlight and the diffuse component of skylight falling together on a horizontal surface make up Global (or total) Solar Radiation. It is essentially the total amount of solar radiation received by a surface horizontal to the ground (Figure 4 and 5).

IV. Diffuse solar radiation

The radiation that has been scattered out of the direct beam is called Diffuse Solar Radiation. It is the amount of radiation received that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions (Figure 6 and 7).

V. Direct solar radiation

The solar radiation that passes through directly to the earth's surface is called Direct (or beam) Solar Radiation. It is the total amount of electromagnetic radiation that is received directly from the sun at a given location on Earth, excluding diffuse radiation (*the solar radiation that is scattered or reflected by atmospheric components*). Direct solar radiation is equal to the solar constant minus losses due to atmospheric absorption and scattering.

VI. Direct Normal Irradiance (DNI)

DNI is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays coming in a straight line from the direction of the sun at its current position in the sky. It is the amount of sunlight annually received by a surface by keeping it normal to incoming radiation (Figure 8 and 9).

Solar radiation measurement

Various radiation parameters are essential for the design, sizing, testing, performance evaluation, and research and development of solar energy applications. These include global solar radiation, beam radiation, diffuse solar radiation, and sunshine duration. Various types of equipment measure the instantaneous and long-term integrated values of global, beam, and diffuse radiation on a surface. There are basically two types of solar radiation measuring instruments, namely the Pyranometer and Pyrheliometer along the following few considerations mainly:

- A Pyranometer is used to measure broadband solar irradiance on a planar surface. It is a sensor that is designed to measure the solar radiation flux density (in W/m^2) from a field of view of 180 degrees. The Global (total) solar radiation is measured by Pyranometer.
- Diffuse radiation can either be derived from direct and global radiation, or measured by shading a Pyranometer from direct sunlight using a Shadow Band Stand so that the thermopile only receives diffuse radiation.
- Direct radiation is best measured by use of a Pyrheliometer; which measures radiation at a normal incidence. The normal incidence pyrheliometer consists of a wire wound thermopile at the base of a tube, the aperture of which bears a ratio to its length of 1 to 10, subtending an angle of 5°43'30". This limits the radiation that the thermopile receives to direct solar radiation only.
- Sunshine duration (hours) is required for an estimation of global solar radiation. Sunshine duration is defined as the time during which sunshine is intense enough to cast a shadow. The World Meteorological Organization has defined the duration of sunshine as the time during which the direct solar irradiance exceeds the level of 120 W/m^2. The sunshine duration is measured by two type of recorders; the focusing type, and type based on photoelectric effect.

The International Standards Organization (ISO) has published a series on international standards specifying methods and instrumentation for precise and reliable measurements of solar radiation:

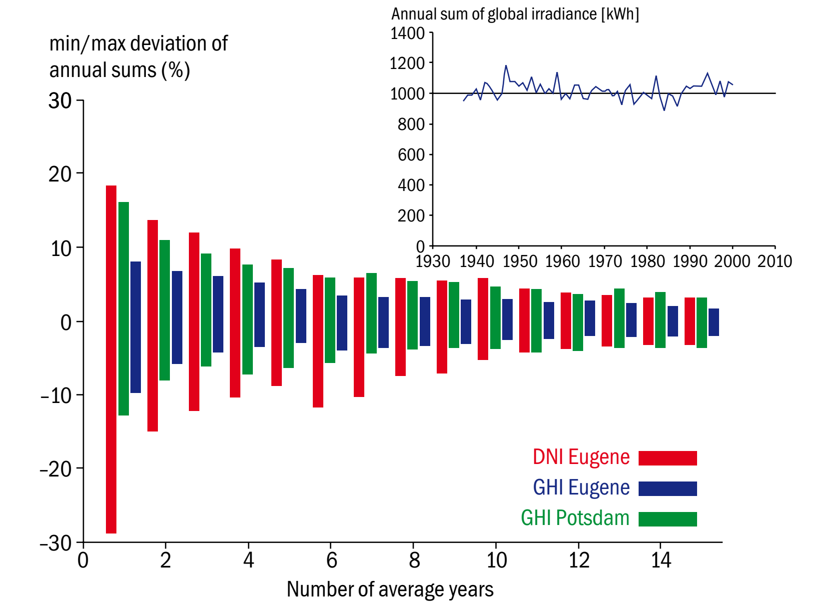

Figure 10: Annual variability of solar radiation

- ISO 9059 (1990) – Calibration of field pyranometers by comparison to a reference pyrheliometer
- ISO 9060 (1990) – Specification and classification of instrumentation for measurement of hemispherical solar and direct solar radiation
- ISO 9846 (1993) – Calibration of a pyranometer using pyrheliometer
- ISO 9847 (1992) – Calibration of field pyranometers by comparison to a reference pyrenometer

The operation and overall performance of any solar thermal/PV system depends on the solar radiation input and ambient temperature along with their sequences. For a local climate, meteorological data over the course of a typical meteorological year is usually required; which is defined as a year that sums up all the climatic information characterizing a period as long as the mean life of a solar system.

I. Typical Meteorological Year (TMY)

The representative database of weather data for one year duration is known as a test reference year (TRY) or typical meteorological year (TMY). A TMY is essentially a data-set of hourly values of solar radiation and meteorological elements; such as solar radiation (global, diffuse and direct), ambient temperature, relative humidity, wind speed, and wind direction, for all 8,760 hours of the year. TMY weather data files are used by all solar energy computer applications like TRNSYS, Energy Plus, and PVSYST, Solar Advisor Model for system sizing and designing.

Solar radiation is highly variable in time and space. The annual sum of incoming solar radiation can change significantly from year to year due to natural weather variations. Thus, at least 10 years of observations are necessary to stay within the limit of ±5% of the long term average (Figure 10).

Status of solar radiation measurements in India

The Indian Meteorological Department (IMD)[1] is a Government of India organisation that is responsible for meteorological observations, and weather forecasts. IMD maintains a nationwide network of radiation stations which

[1] The IMD, New Delhi is also one of six Regional Specialized Meteorological Centres within the World Weather Watch programme of the World Meteorological Organization (WMO), responsible for forecasting tropical cyclone activity in the Indian Ocean north of the equator, including the Arabian Sea and the Bay of Bengal.

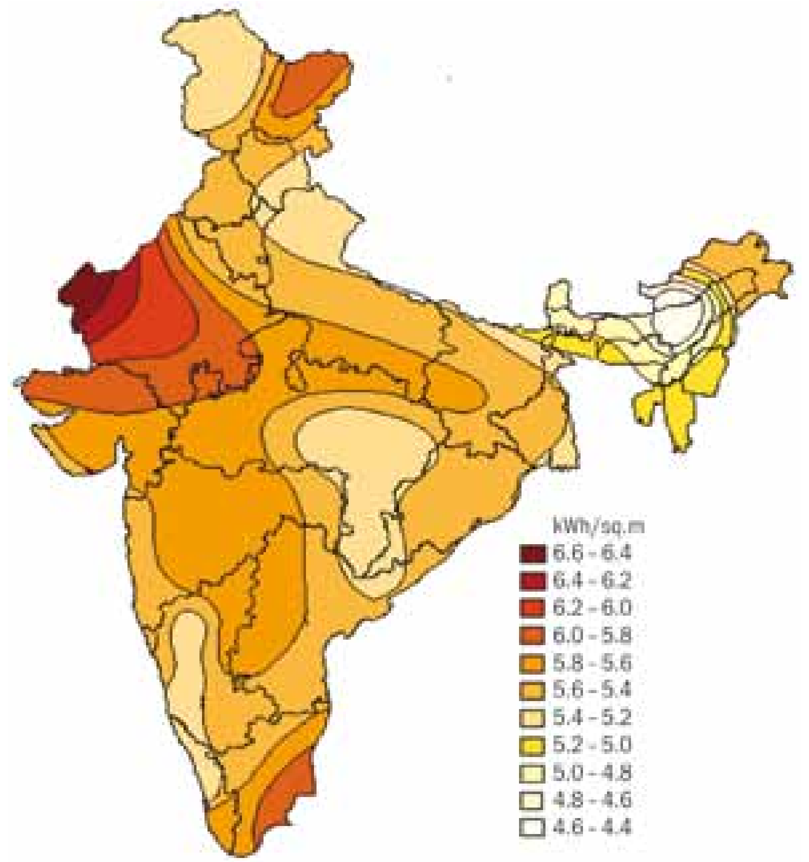

Figure 11: Global solar radiation map of India

Source Indian Meteorological Department

measure solar radiation and also the daily duration of sunshine. In India, systematic long-term measurements of solar and terrestrial radiation, using calibrated and maintained instruments at a network of stations, started in 1957-58. The radiation laboratory of the IMD at Pune serves as the National Radiation Centre for India as well as the WMO Regional Radiation Centre. At present, there are around 45 radiation observatories recording a range of solar radiation parameters. The stations in the radiation network are classified as principal or ordinary stations based on the type of instruments installed and the observational programme being followed. At the principal radiation stations, continuous records of global and diffuse solar radiation are obtained using thermoelectric Pyranometers and direct solar radiation is measured at fixed intervals in addition to the recording of sunshine.

IMD has estimated that in the most parts of India, clear sunny weather is experienced for 250 to 300 days in a year; however, annual global radiation varies from 1600 to 2200 kWh/m^2 across the country. The daily average global radiation is around 5.0 kWh/m^2 in the north-east and hilly areas, to about 7.0 kWh/m^2 in western regions and desert areas with the sunshine hours ranging between 2,300 and 3200 per year (Figure 11).

The solar data collected for various locations of India is available in the "**Solar Radiation Handbook 2008**", published by the Ministry of New and Renewable Energy (MNRE). The database contains global and diffuse solar radiation for several locations of India.

Following databases are available for several Indian locations based on the IMD data:

- **Solar Radiation over India**, (1980), A Mani, Allied Publishers, New Delhi
- **Handbook of Solar Radiation**, (1982), A Mani and S. Rangrajan, Allied Publishers, New Delhi
- **Solar Radiation Handbook**, (2008), Ministry of New and Renewable Energy, Government of India
- **Solar Handbook of Solar Radiant Energy Over India**, (2009), Ministry of New and Renewable Energy, Government of India

MNRE recently initiated a major project on solar radiation resource assessment across the nation so as to assess and quantify solar radiation availability along with weather parameters. The ultimate objective is to develop a Solar Atlas. The Centre for Wind Energy Technology (C-WET) in Chennai is implementing this project by installing a network of 51 Automatic Solar Radiation Monitoring Stations (ASRMS) in the first phase within different states using a mix of high quality, high resolution/instruments. The online solar radiation data for few locations can be explored through the MNRE website (www.mnre.gov.in)

Solar mapping using satellite data

Mapping solar radiation resources using satellite images lowers costs because of reduced dependence on ground-based weather stations, and ensures fewer uncertainties than what would be the case when interpolating data from distantly located measuring stations.

I. Artificial satellites

Applicability of physical models is a major obstacle towards collecting atmospheric data with precision and reliability; however, the development of remote sensing technology (RST) through artificial satellites eventually led to substantial progress towards this goal. Satellite images are tools of great value in obtaining cloud coverage and other atmospheric parameters required for modelling radiative processes in the atmosphere.

Stationary satellites started being utilized at the beginning of the 1980s. Cloud cover evaluation was hitherto very inaccurate due to their small time resolution; however, data obtained with good time and space resolution allowed a better evaluation of atmospheric parameters, and consequently a more accurate estimate of solar radiation. Various polar and geostationary satellites orbiting the earth are used for different purposes.

II. Polar satellites

Polar orbit satellites are located in a limited orbit (about 800 km) around the planet and survey the earth's surface from one pole to the other. Each satellite passes through the same observation point over the earth's surface every 12 hours (*once during the day and again during the night*). Polar satellites make use of visible light and infrared radiations to make measurements of temperature and humidity in the earth's atmosphere.

These satellites aid recording ground water and sea water temperatures, and monitor cloud cover and water/ice boundaries. They are also able to receive, measure, process, and re-transmit data from balloons, buoys, and remote automatic stations distributed around the globe. These satellites make Antarctic ozone level measurements, and long-term environmental measurements used to support global climate change studies. These can view only the poles or a limited area on the earth at the same time. The first polar satellite was launched in 1996 by National Aeronautic and Space Administration (NASA), USA.

III. Geostationary satellites

These satellites are positioned at a height of approximately 36,000 km above the earth, and rotate around the planet at the same speed at which the earth rotates about its axis, thus remaining stationary over a fixed point on the earth (normally over the equator). These satellites are very useful because they are able to observe almost one half of the planet from the same vantage point. A single geostationary satellite is on a line of sight with about 40 per cent of the earth's surface. Three such satellites, each separated by 120 degrees of longitude, can provide coverage of the entire planet, with the exception of small circular regions cantered at the north and south geographic poles. These satellites have sensors at various wave lengths (channels) allowing them to detect different characteristics of the atmosphere and the surface of the earth. The field of view of a sensor is narrow to be able to observe the surface at a resolution better than 1 km.

Relevance of solar radiation resource

Solar radiation varies across the year due to periodic change of Earth-Sun angles. The tropical belt of earth receives the maximum amount of solar radiation. Solar radiation in non-uniformly distributed across the globe and varies with the months.

The energy delivered by any solar energy system is dependent on the incident solar radiation. Outside the Earth's atmosphere, on a surface normal to the solar beam, the power density is 1,367W/m^2 which is known as 'Solar Constant'.[2] As the solar radiation passes through the atmosphere, depending on the length of the atmospheric path traversed by the solar radiation and the quantity of dust, water vapour, ozone, CO_2 and other aerosols present in the atmosphere, some amount of it is scattered and absorbed. The diffused radiation plus the direct irradiance from the sun are together termed as Global (or Total) Irradiance. The diffused sunlight can vary from about 20% on a clear day to 100% in heavily overcast conditions. The peak irradiance of 1,000 W/m^2 has been taken as the standard value by which PV modules are rated.[3] However, the total solar energy received in a day over a specific area, called daily solar irradiance or insolation, is more important than the instantaneous solar irradiance. Solar resource is not equally available in all regions of the world. On a clear day in the tropics, when the sun is overhead, the global irradiance can exceed 1000 W/m^2 but in high latitude it rarely exceeds 850W/m^2. Similarly, daily solar insolation may be 5-7 kWh/m^2/day in the tropics, but could be less than 0.5kWh/m^2/day in high latitudes.

The pattern of intensity (quality of solar radiation) also varies from one location to the other depending on the fraction of diffuse solar radiation. The relative effectiveness of any solar technology (mainly solar PV) is governed by quality of solar radiation, i.e., utilizable portion from the solar radiation spectrum. The locations containing high amount of direct solar radiation also possess high direct normal irradiance (DNI), which can be utilized for Concentrating Solar Power (CSP) technologies.

Historically, climatological profiles of insolation and meteorology parameters, which were calculated from ground measurements, have been used for determining the viability of Renewable Energy projects. These climatological profiles are often used for designing systems that have low failure rates. Although ground measurement data has been used successfully in the past for implementing RETs, there are inherent problems in using them for resource assessment. Ground measurement stations are located throughout the world, but they are situated mainly in the populated regions; whereas in remote areas (where many RETs are implemented) measurement stations are normally limited.

Solar radiation data - Indian context

India, as a largely tropical country, is blessed with good sunshine over most regions; and the number of clear sunny days in a year is also quite high. The country receives solar energy equivalent to more than 5,000 trillion kWh per year. India's equivalent solar energy potential is about 6,000 million GWh of energy per year.

Long-term measured values of solar radiation and meteorological parameters are essential in order to implement large scale solar energy projects. In the present scenario, the Government of India is

[2] The solar constant is defined as the quantity of solar energy (W/m^2) at normal incidence outside the atmosphere (extra-terrestrial) at the mean sun-earth distance. Its mean value is 1367.7 W/m^2.

[3] 1MW PV Power plant will generate 1MW of electricity in an irradiance of 1000W/m^2 with a cell temperature of 25 °C and Air Mass of 1.5.

promoting solar energy technology use through various schemes, fiscal and financial incentives, and regulations. The Jawaharlal Nehru National Solar Mission (JNNSM) recently announced a National Action Plan on Climate Change (NAPCC) which aims to promote the development and use of solar energy for power generation and other uses with the ultimate objective of making solar a competitive energy option with fossil-fuels. The plan includes specific goals towards:

- Create an enabling policy framework for the deployment of 20,000 MW of solar power by 2022
- Create favourable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership
- Promote programmes for off-grid applications, reaching 1,000 MW by 2017 and 2000 MW by 2022
- Achieve 15 million m^2 solar thermal collector area by 2017 and 20 million by 2022, and
- Deploy 20 million solar lighting systems for rural areas by 2022

The First Phase of JNNSM is underway with more than 1000 MW capacity projects en route to being implemented. In addition to JNNSM, various state governments (Gujarat, Karnataka, Rajasthan, and Punjab) have also come up with specific solar specific policies. They are supporting the solar energy sector by implementing innovative measures like Renewable Purchase Obligation (RPO) and Renewable Energy Certificate (REC) as well. The projected solar power market in India has been estimated at more than 60,000 MW by 2022.

It is a well-known fact that the solar power segment is still a capital cost-intensive sector; hence project developers are by and large dependent on the mechanisms of financial institutions. Further, it has been noticed that in the context of financial closure of the projects with the bank, the guaranteed parameters required by financial institutes are either energy generation guaranteed or the plant load factor (PLF). Both these parameters are governed by the availability of solar radiation at the selected project location. As there is no information about long term solar radiation available at most Indian locations where solar energy projects are under implementation, the project implementation flow is affected strongly. Unrealistic solar radiation data and other climate parameters are creating energy generation risk in the overall project evaluation exercise, which is difficult to be addressed without a realistic meteorological database. The uncertainty associated with the meteorological parameters creates maximum impact on the overall Probability of Exceedance of the project.

Satellite solar radiation data

There are few meteorological databases available for India which contains daily or hourly values of global solar radiation and other climatic parameters which are based on realistic ground measurements, satellite measurements, interpolation of ground and satellite measurements, statistically processed, and which use parametric or decomposition models based on empirical relations. Following databases are in use for sizing of solar energy systems.

NASA Satellite Data

Moreover, at any particular station, data recording can be sporadic, leading to

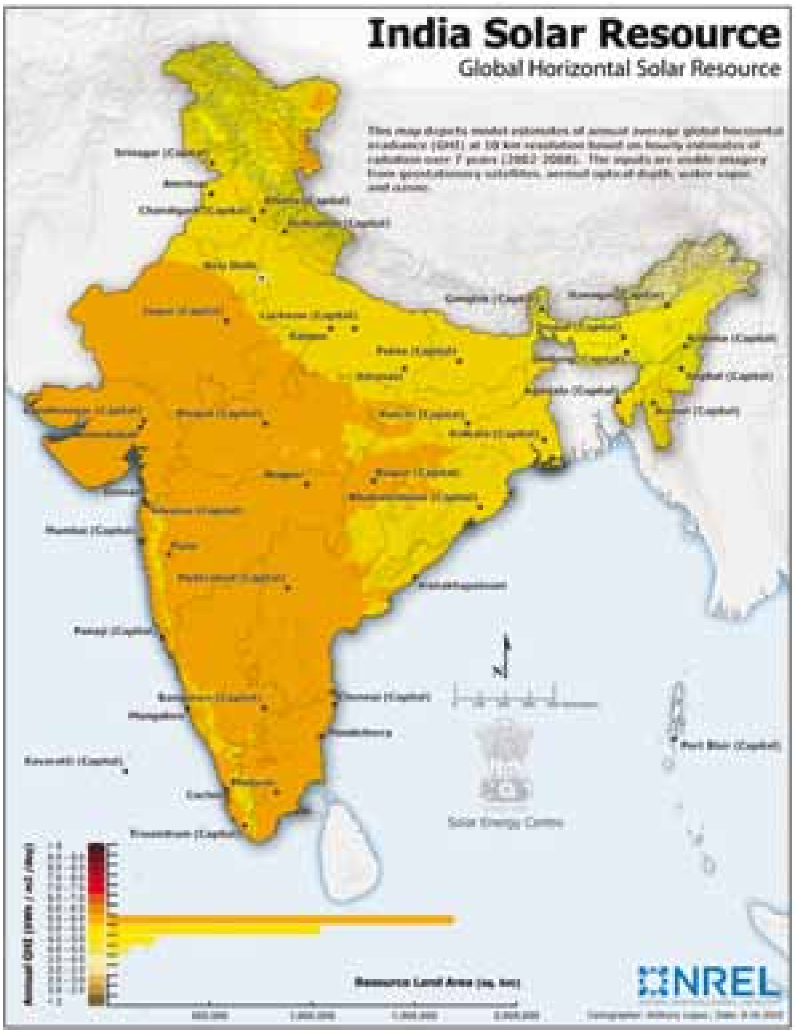

Figure 12: Global solar radiation map of India

Source NREL

incomplete climatic profiles and data inconsistencies, which can occur within a station and from one station to another. In contrast to the ground measurements, the Surface Meteorology and Solar Energy (SMSE) data set from NASA is continuous and consistent with 22 years of global climatology of insolation and meteorology data on a 1° by 1° grid system. By utilizing the SMSE data set, an estimate of the renewable energy resource potential can be determined for any location on the globe, which is considered to be accurate enough for feasibility studies of new renewable energy projects.

NREL Data

Solar radiation data for SSE Release 6.0 was obtained from the NASA Science Mission Directorate's satellite and re-analysis research programs. Parameters based on solar data were derived and validated based on recommendations from partners in the energy industry. Release 6.0 extends the temporal coverage of solar data from 10 years to more than 22 years (e.g., July 1983 through June 2005) with improved NASA data. The spatial resolution is 110 km × 110 km.

The solar maps developed by National Renewable Energy Laboratory (NREL) concern monthly and annual Global Horizontal Irradiance (GHI) data using the hourly satellite data spanning from January 2002 to December 2008. This was generated through the application of the SUNNY satellite to irradiance model (1, 2). Due to their strong impact on solar radiation a deep investigation on AOD (Aerosol Optical Depth) data and their inter-annual variations was carried out. The Monthly gridded AOD values were developed for each month of the SUNNY model run for India. This approach is applied because of the variation in concentration of aerosols over India. The maps cover the entire country at 10 km x10km spatial resolution.

Solar mapping of the entire country based on satellite imagery and duly validated by ground data will provide information of Global Horizontal Irradiance (GHI) on a continuous basis with an approximate accuracy of 15%. It is possible to identify the areas with higher solar radiation and set up ground stations for more accurate measurement of solar radiation and other meteorological parameters. It can thus avoid setting up a large number of ground stations throughout the country, which is an expensive proposition (Figure 12).

METEONORM data

METEONORM is a comprehensive global climatological database for solar energy applications and comprises the following few features:

- A computer program for climatological calculations.
- A data source for engineering design programs related to the passive, active, and photovoltaic application of solar energy with comprehensive data interfaces.
- A standardization tool permitting access to a comprehensive, uniform data base to developers and users of engineering design programs.
- Meteorological reference for environmental research, agriculture, forestry, and for members of the public interested in meteorology and solar energy.

METEONORM contains numerous databases from all parts of the world, and has developed a large number of computational models in international research programs. It is primarily a method for the calculation of solar radiation on arbitrarily orientated surfaces at any desired location. The method is based on databases and algorithms coupled according to a pre-determined scheme. It commences with the user specifying a particular location for which meteorological data is required, and terminates with the delivery of data of the desired structure and in the required format. In addition to the monthly values, METEONORM provides the maximum radiation values under clear sky conditions.

METEONORM data is available in hourly/daily and monthly forms for all locations and could be converted into any desired format like TMY specific for various solar energy applications like TRNSYS, Energy Plus, and PVSYST etc.

In addition, there are other databases available viz. SWERA, NREL, ISHRAE (WEDCO database), and 3TIER – which is based on satellite data and statistically processed ground data. A few of these databases are region-specific, and a few are paid satellite databases. Above databases have been selected for comparative analysis from the point of view of their acceptability and use in solar energy system design capability.

Inter-comparability of solar radiation over India using various databases

In order to check the closeness and adequacy of the satellite databases with measured data, a comparative analysis has been made. The long-term measured daily values of global solar radiation are compared with three databases; namely NASA, NREL, and METEONORM, for 23 locations across India. There is a comprehensive weather measurement facility of the IMD at all the 23 selected locations of which the long-term hourly and daily global solar radiation data is available. The annual global solar radiation over such locations through IMD measurements, NREL, NASA, and METEONORM databases is presented in Table 1.

Table 2 presents the Mean Percentage Error (MPE) of the above three selected databases with respect to the measured data of IMD. The error has been estimated for each daily value of all months for all the locations. It shows that the pattern of deviation of the databases with the IMD data is non-uniform across the months. In a few months, the mutual deflection if, obtained varied by more than 25 per cent for various locations. However the deviation of the databases from measurements is changing with locations.

It has been noticed that all the satellite databases show significant variation with the measured value of annual solar radiation. As the MPE is a statistical tool, it critically depends upon the number of measurements. Hence it could be understood that the mutual scattering will be the highest in hourly data followed by daily and monthly data. The smoothness of the solar radiation databases could be explored graphically (Figures 13, 14, and 15). The

Table 1 Annual solar radiation over selected locations of India

S. No.	Stations	Lat.	Long.	Elev. (m)	GHI_IMD (kWh/m²)	GHI_NREL (kWh/m²)	GHI_NASA (kWh/m²)	GHI_METM (kWh/m²)
1	Minicoy	08 °18'	73 °09'	1	1980	2133	1870	2045
2	Thiruvananthapuram	08 °29'	76 °57'	60	2077	2077	1909	2070
3	Port Blair	11 °40'	92 °43'	13	1908	2049	1854	1980
4	Bangalore	12 °58'	77 °35'	921	1960	2083	1910	2009
5	Chennai	13 °00'	80 °11'	10	1952	2099	1907	2024
6	Goa	15 °29'	73 °49'	58	2001	2112	2114	1990
7	Hyderabad	17 °27'	78 °28'	530	2046	2106	1891	2021
8	Visakhapatnam	17 °41'	83 °18'	7	1964	2065	1841	2081
9	Pune	18 °32'	73 °51'	555	1988	2116	1901	1970
10	Mumbai	19 °07'	72 °51'	8	1644	1851	1705	1764
11	Nagpur	21 °06'	79 °03'	308	1834	2063	2155	1882
12	Bhavnagar	21 °45'	72 °11'	5	1864	2055	1858	1923
13	Kolkata	22 °39'	88 °27'	5	1867	1905	1845	1962
14	Ahmedabad	23 °04'	72 °38'	55	1769	1902	1905	1808
15	Bhopal	23 °17'	77 °21'	523	1726	1902	1935	1853
16	Ranchi	23 °19'	85 °19'	652	1969	2099	1870	2037
17	Varanasi	25 °18'	83 °01'	90	1671	1974	1744	1885
18	Shillong	25 °34'	91 °53'	1,598	1659	1625	1608	1636
19	Patna	25 °36'	85 °10'	51	1534	1811	1689	2006
20	Jodhpur	26 °18'	73 °01'	217	1976	2153	2042	2010
21	Jaipur	26 °49'	75 °48'	390	1764	1938	1840	1831
22	New Delhi	28 °29'	77 °08'	273	1871	2000	1851	1957
23	Srinagar	34 °05'	74 °50'	1,585	1845	2160	2083	2146

GHI_IMD – global solar radiation through IMD (ground measurements)
GHI_NREL – global solar radiation through NREL Satellite
GHI_NASA – global solar radiation through NASA Satellite
GHI_METM– global solar radiation through METEONORM database

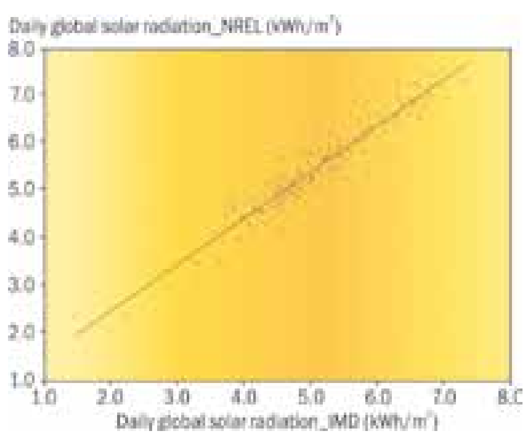

Figure 13: IMD data vs NREL data

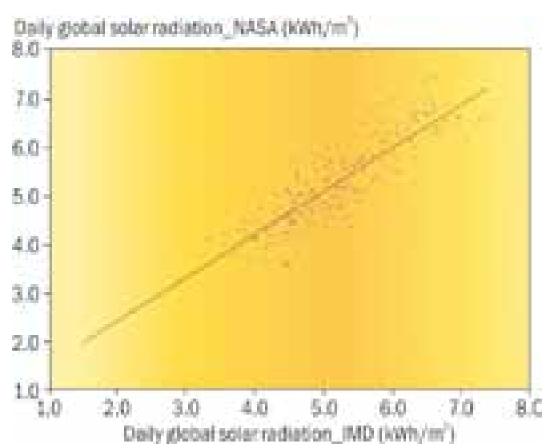

Figure 14: IMD data vs NASA data

pattern of mutual deviation could be explored according to the climatic zones. As there are several climatic zones in the country the accuracy or deviation of databases varies with the locations.

Conclusion

Potential investments in the area of solar energy and its large scale applications require reliable information about the availability of solar resources. It is very critical for technology promoters, project developers, stakeholders, and consultants to carry out realistic annual energy generation, considering the allowable uncertainties of the databases in the technical and financial models towards successful financial closure of the projects. The impact of uncertainty associated with energy yield estimation, and the effectiveness of inter-annual variation needs to be incorporated in the uncertainty analysis of the project over the useful life of a project. ■

Table 2 Percentage Error of Global Solar Radiation for selected locations

Location	GHI_NREL (kWh/m²)	GHI_NASA (kWh/m²)	GHI_METE (kWh/m²)
Bangalore	-7.73	5.55	-3.27
Bhavnagar	-0.01	8.07	0.34
Bhopal	-7.36	2.87	-3.78
Chennai	-6.29	2.55	-2.53
Ahmedabad	-7.50	2.34	-3.65
Goa	-5.53	-5.64	0.59
Hyderabad	-2.94	7.57	1.20
Jaipur	-5.17	6.27	-5.99
Jodhpur	-6.46	4.39	0.92
Kolkata	-12.60	-3.74	-7.33
Mumbai	-12.52	-17.52	-2.65
Nagpur	-10.28	0.31	-3.18
New Delhi	-2.05	1.16	-5.07
Patna	-7.51	-7.68	-2.18
Port Blair	-10.17	-12.12	-7.37
Pune	-6.58	5.04	-3.44
Ranchi	-18.11	-4.37	-12.80
Shillong	2.04	3.04	1.38
Srinagar	-18.04	-10.07	-30.77
Thiruvananthapuram	-8.91	-3.29	-1.68
Varanasi	-9.88	-4.33	-3.83
Visakhapatnam	-6.89	1.06	-4.60
Minicoy	-17.10	-12.91	-16.31

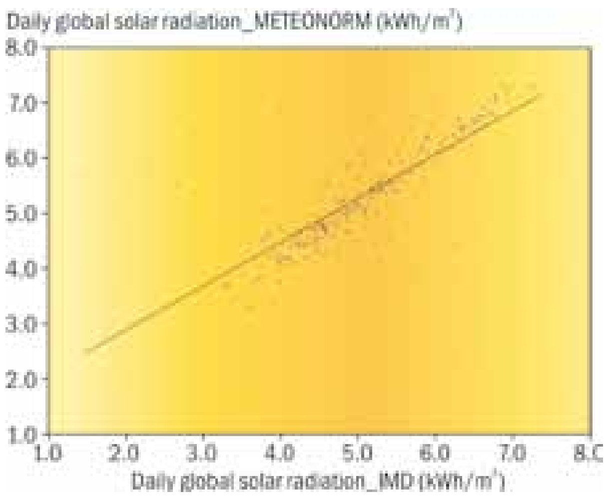

Figure 15: IMD data vs METEONORM data

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Emerging Thrust for Measuring Solar Radiation Accurately

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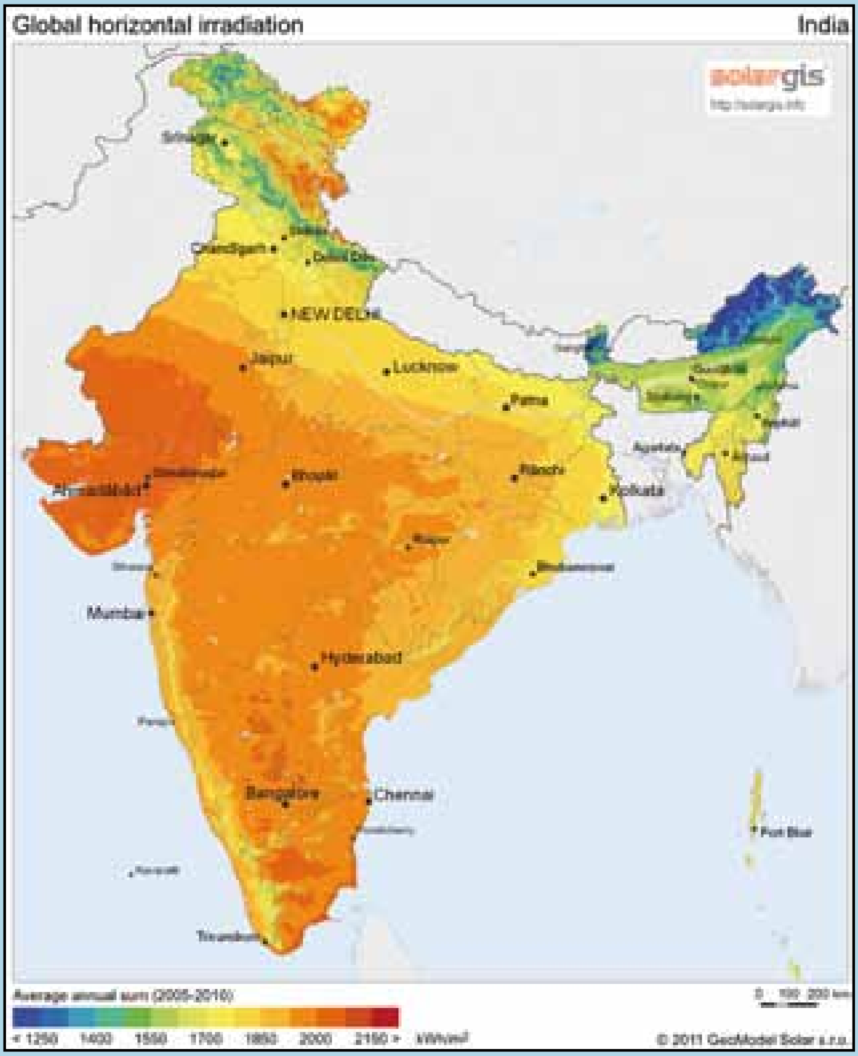

Background

India has an average energy shortfall of around 7%. And, in contrast, the peak demand shortfall touches 12%. We need in excess of 90,000 MW equivalent of new generation capacity within the next five years or so. The clear onus is on policy planners and programme implementation agencies alike to put a heightened focus on the deployment of various renewable energy (RE) technologies, more so solar energy.

The RE sources have emerged as a viable choice to attain the much needed socio-economic development. Along this path, environmental protection too has been ensured to a sizeable extent. Several initiatives have been launched from time to time by the Ministry of New and Renewable Energy (MNRE) to expand the frontiers of solar energy use. The recently launched Jawaharlal Nehru National Solar Mission (JNNSM) stands out for more reasons than one. The pivotal success of the mission depends on a large extent in putting out accurate designs of the solar energy-based systems across diverse geographical locations of the country. For this objective to be realized, the knowledge of real time solar radiation data is of prime importance. Well measured values of solar radiation are expected to lead to much improved system designs and hence a favourable economic viability of the installed projects too. From the energy security perspective, solar is the most secure of all resources – abundantly and locally available. Most parts of India receive 4-7 kWh/m2/day of solar radiation. JNNSM is one of the major global initiatives to promote the solar energy technologies. This article takes a close look at some of the newly evolved initiatives undertaken on the solar radiation availability/ measurement front.

Why seek a solar solution at all

The sun shines bright in most parts of our country. The almost regular hikes in the prices of conventional power make us think hard about utilizing the abundant solar energy to a much extended use. After all, it is one of the most powerful form of renewable energy and also


Courtesy: MNRE, Government of India

because of the following few advantages:

- Solar PV is an ideal choice to meet the peak time energy requirement as energy is produced the most during the day time.
- Short gestation periods of less than 9 months are alluring for meeting the immediate power needs.
- Solar PV may be used both for the grid connected and off-grid solutions with possible realization of much lower transmission and distribution (T&D) costs.
- Solar PV can readily adapt to adding of any new capacities even for sectoral uses.
- Solar is deemed to be the most environment-friendly of all renewable resources. Additionally, it possesses the maximum potential amongst all the renewable sources.

The cost of generation is expected to get even lower paving the way for the much needed fall in the next decade; grid parity is expected to be achieved much earlier than 2018.

The underlying rationale clearly lies in knowing the exact availability of solar energy resource at a given geographical location. The moot question is if, there are any expectations from solar resource which cannot be met readily. Take for example the fact that solar energy is a dilute source of energy and not available on a ready demand as such. Barring these selective few unmet considerations, solar energy is all pervading thus seeking quick attention of one and all. The following section takes a close look at a few other newer initiatives undertaken.

Addressing the concerns

The opening of request for proposals (RFP) related to JNNSM, Phase I, Batch II has just taken place under the curious eyes of a few hundred intending solar project developers and investors, etc. But what is the real issue at hand? There is a school of thought which says that some developers may be putting up projects without a clear knowledge of the sunshine availability on the exposed solar panels. They feel that this trend may be fine for those just beginning their solar ventures. However, the same should change in the presence of some established techniques now available to measure and estimate correctly the solar irradiance. The much talked about JNNSM came into being in 2009 with a clearly spelt out target of adding 20 GW of power generating capacity through solar power projects by the year 2022. It is quite desirable to have a ready access to reliable solar radiation data for designing and optimizing the performance of any solar power plant. The vexing issue is if precise data is available for a sizeable number of interesting locations for the wholesome use of a growing tribe of the project developers? In the absence of which, it sounds tricky to work out the output and economic risks involved in their solar power projects.

The measuring practices

As of now, a good number of solar project developers look at the freely flowing satellite generated data. This is used as a basis for positioning a solar farm despite the satellite data being error-prone. Experts feel that satellite data has been found to be at a clear variance by as much as 10% against the backdrop of actual data measurement. There are selective few companies like 3-Tier which take actual measurements of the solar radiation over a period of time. It is then followed by taking the satellite data for the corresponding period. This is done with a clear-cut purpose of estimating the extent of adjustment that may be ultimately needed in the perceived scheme of things. The same is further followed by taking the satellite data for several back years with an eye on adjustment of errors. This is being regarded as a far more scientific practice of evaluating the irradiance values. Amongst a case specific example is a collaborative activity between 3-Tier and Emergent Ventures India Ltd. This activity involves the measurement of solar radiation values in the sun soaked state of Rajasthan. It is genuinely felt that solar radiation measuring instruments should be installed at majority of the potential sites. In this way, following few parameters could well be positively impacted for a better project outcome:

- electricity generation
- cost of financing
- bankability

New solar mapping initiatives

Seemingly, with due realization to the above mentioned concerns, MNRE has finally kick-started a countrywide solar resource assessment project in a big way. Significant objective is to obtain reliable data on solar radiation so as to fast pace the planning and implementation