One-Day Seminar on

Solar Photovoltaics

on

25th March 2009

at

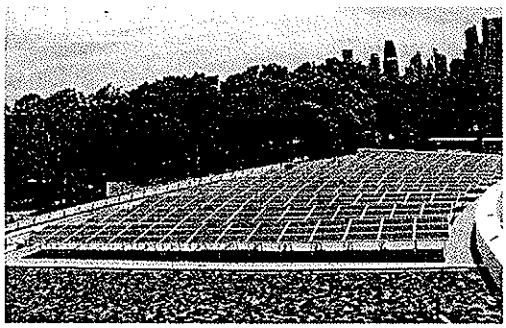
Novotel Clarke Quay, Singapore

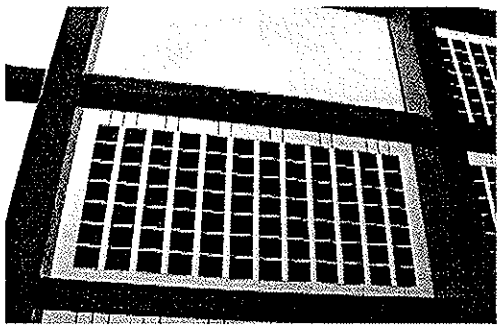
Organized by

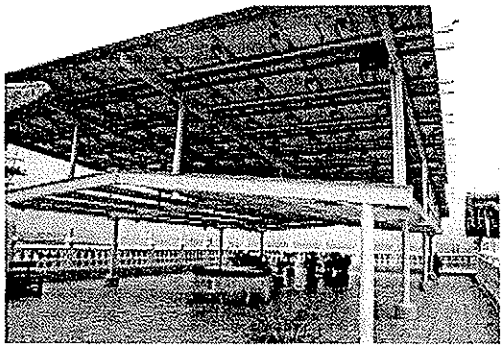
IES Academy

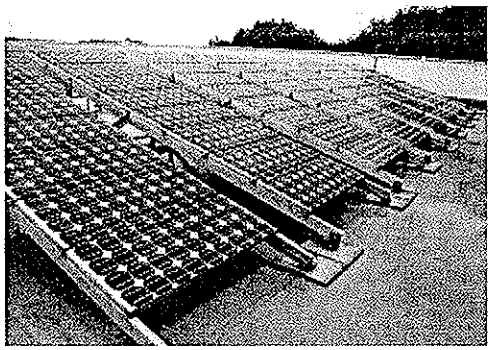
IES M & E Engineering T.C.

IES Clean Energy Interest Group









Summary
of news
on

The solar photovoltaic industry in Singapore

Compiled by
Clean Energy Interest Group
Institution of Engineers, Singapore

March 2009

April 2007

Launch of Clean Energy Programme Office (CEPO)

CEPO is Singapore's key inter-agency workgroup responsible for planning and executing strategies to develop Singapore into a Global Clean Energy Hub, where clean energy products and solutions are developed locally and exported globally.
CEPO leverages upon the strengths of various government agencies: Economic Development Board (EDB); Building & Construction Authority (BCA); Agency for Science, Technology & Research (A*Star); Energy Market Authority (EMA); National Environment Agency (NEA); International Enterprise Singapore (IE Singapore) and Ministry of Trade & Industry (MTI), for a comprehensive approach to develop the clean energy industry.

August 2007

Launch of Clean Energy Research & Test-bedding (CERT) programme

The Clean Energy Research & Test-bedding (CERT) programme was launched by the Clean Energy Programme Office to stimulate research in the application of clean energy in Singapore. Over the next five years, $17 million will be invested in the setting-up of CERT, to offer opportunities for companies to develop applications and solutions to test-bed their clean energy technologies in Singapore. The three key partners involved are R&D organisations, technology providers and implementers.
R&D organisations will lead and conduct test-bedding activities, while technology providers will provide the clean energy equipment and technologies to participate in these activities. The implementers are Government agencies which will provide the test-bedding locations as well as facilitate these projects.
The test-bedding locations for the first phase involve NUS, National Park Board's Gardens by the Bay, PUB's Marina Barrage and Singapore Polytechnic's campus.

(For details, refer to EDB news release, dated 20 August 200 entitled "Launch of $17 mil. Clean Energy research & test-bedding programme").

October 2007

REC ASA – Singapore chosen for new manufacturing complex

Renewable Energy Corporation ASA (REC) announced plans to establish its new global solar manufacturing complex in Singapore and signed an agreement with EDB. The agreement outlines the terms and conditions related to the development of a new production site, the process of establishing a manufacturing complex, as well as operational and commercial conditions.
In addition to the wafer, cell and module production, the manufacturing complex will incorporate infrastructure and support facilities, as well as an on-site supplier park. Sufficient space has also been reserved for future R&D activities. Depending on the final capacity and site development, the total investments in the Singapore site may exceed EUR3 billion within the next five years.

(Refer to REC press release of 25 Oct. 2007 entitled "REC ASA – Singapore chosen for new manufacturing complex" and also REC press conference held in Oslo, Norway on 18 June 2008). REC web-site: www.recgroup.com

November 2007

Launch of $25 million programme for Clean Energy Scholarships

The Clean Energy Scholarships are managed by the Clean Energy Programme Office and funded by the National Research Foundation (NRF), and will be used to develop technology and industry leaders in the Clean Energy industry in Singapore. The scholarships aim to sponsor about 130 students over five years to take-up post-graduate degrees relevant to the sector.

There are two specific scholarships programmes – the NRF(Clean Energy) PhD Scholarships, which is wholly supported by the government, and the NRF(Clean Energy) Company Scholarships, which involves the sharing of the training cost between the industry and the government.

(For details, refer to EDB news release dated 13 November 2007, entitled "Clean Energy manpower development gets S$25 million boost")

June 2008

Pioneer cohort of NRF(Clean Energy) PhD Scholarships awarded

The inaugural National Research Foundation (Clean Energy) PhD Scholarships were conferred on three outstanding students selected from the first cohort of 36 applicants. The three scholars will be engaged in solar energy research. Two will be attending the University of New South Wales, Australia, while the third will be at the University of California, Berkeley, USA. Each overseas scholarship is worth about S$500,000 and covers tuition fees, monthly stipends and annual return airfares.

(For details, refer to EDB news release, dated 19 June 2008, entitled "CEPO awards pioneer cohort of NRF(Clean Energy) PhD Scholarships").

February 2008

Launch of Solar Energy Research Institute of Singapore (SERIS)

The National University of Singapore (NUS), in partnership with the Clean Energy Programme Office (CEPO) managed by the Economic Development Board, established a solar R&D centre to develop critical technological capabilities to drive the solar energy sector.

Established with a total expected investment of S$130 million over five years, SERIS will be Singapore's national research institute in solar energy.

SERIS will leverage on NUS existing capabilities in engineering, architecture and other areas to build up strong capabilities and knowhow in solar technologies.

(Full details in joint EDB - NUS press release, dated 21 February 2008, entitled "New National Solar Research Institute at NUS to conduct world-class R&D and train specialist manpower").

April 2008

Solar Park at Marina Barrage

The solar park at Marina Barrage is a 70.88kWp solar grid-tie system, designed and installed by systems integrator RenewPowers Pte. Ltd. The system uses 405 - 175W mono-crystalline PV modules, supplied by Solar World. The system provides 50kWp of electrical power to the Visitor Centre and 20kWp to the Drainage Pumping station control room.
The Marina Barrage was officially open on 1 Nov. 2008.

May 2008

Launch of Solar Capability Scheme

The Clean Energy Programme Office of EDB launched the Solar Capability Scheme to spur demand and build up expertise for the solar industry.
It has set aside S$20 million for the private sector to offset part of the capital cost involved in installing solar technologies in new energy-efficient buildings. Financial support of up to 40 percent of the capital cost of the solar solution can be granted and is capped at S$1 million per project.
This scheme caters to new building developments in the private sector, which meet a minimum Green Mark Gold standard, a benching marking system administered by the Building & Construction Authority.
Applications for existing buildings undergoing extensive retrofit will be considered on a case-by-case basis.

(For details, refer to EDB news release dated 6 May 2008, entitled "CEPO launches Solar Capability Scheme to boost the use of solar technologies in new buildings".
Also refer to the EDB factsheet on the Solar Capability Scheme, dated 12 May 2008)

October 2008

Solar Photovoltaic Testing & Certification Hub in Singapore

In October 2008, VDE Testing & Certification Institute and the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE), set up a joint venture to meet the needs of solar manufacturers in the region. It is known as the VDE-Fraunhofer ISE Pte. Ltd.
This joint venture is the first Southeast Asia hub for solar photovoltaic testing and certification, which marks a new milestone for the local solar industry, as well as in the region. The new entity will provide support and service to the PV sector. In particular, its expertise is in ensuring that any new product or service introduced by local or Asia-based foreign manufacturers is compatible with international standards. It will work closely with the Solar Energy Institute of Singapore (SERIS).

(For details, refer to EBD news release dated 2 Oct. 2008, entitled "Southeast Asia's First Solar Photovoltaic Testing & Certification Hub opens in Singapore").

October 2008

Singapore's first Zero-Energy Building starts construction

In November 2007, BCA announced that the BCA Academy will retrofit an existing building at its Braddell Road premises into a Zero-Energy Building (ZEB). In Oct. 2008, BCA awarded the main contract worth S$10.47 million to ACP Construction Pte. Ltd. for the above project. BCA also awarded a contract of S$1.7 million to Singapore company Grenzone Pte. Ltd. for installing the solar panels.
The ZEB is part of BCA's plan to raise awareness on sustainability in the built environment and is BCA's flagship R&D project under its Green Building Masterplan.

(Refer to BCA media release dated 2 October 2008, entitled "Singapore's First Zero Energy Building starts construction in October 2008").

October 2008

Phoenix Solar subsidiary to build largest PV roof system in Singapore

Phoenix Solar Pte.Ltd. will be installing PV modules with a peak output of 181kW for the Swiss biotech company Lonza Biologics Tuas Pte. Ltd. This installation will be on the south-west wing of the new Lonza building in Tuas. Phoenix Solar is responsible for the planning and turnkey completion of the project. For the project, Phoenix Solar will use polycrystalline modules supplied by REC, a world leader in the solar energy field.
The system will include real-time performance monitoring, an energy output display unit and remote internet monitoring.

(Refer to media release dated 25 Sept.2008, entitled "Phoenix Solar signs contract with Lonza Biologics using REC modules")..... **www.phoenixsolar.com/sg**

November 2008

Powering Pulau Ubin with Clean and Renewable Energy

The Energy Market Authority (EMA) has embarked on a pioneering project which could potentially transform part of Pulau Ubin into a model "green" island, powered entirely by clean and renewable energy. EMA has called a tender for a consultancy study to develop and implement clean and renewable energy solutions for a cluster of homes and businesses on the island. Depending on the outcome of the study, it could be followed by the development of infrastructure such as a micro-grid system with energy sources like solar, wind and biomass to supply electricity.
The company that is awarded the contract for the consultancy study will help to recommend a plan to develop and implement the various clean and renewable energy options. The study will look into both the technical and commercial viability of the options proposed, while giving due consideration to economic, environmental and social costs and benefits.

(For details, refer to EMA news release dated 7 Nov. 2008, entitled "Powering Pulau Ubin with Clean and Renewable Energy" and an accompanying attachment of the info-graphics).

November 2008

Solar Technology Centre opens at Ngee Ann Polytechnic

The Solar Technology Centre was opened at Ngee Ann Polytechnic on 12 Nov. 2008. The Centre will study the performance of various types of solar modules under tropical conditions. About 90 solar modules have been installed on the roof and at various locations in the centre. The centre will also be used by Ngee Ann Polytechnic students enrolled on the new diploma course in Clean Energy Management which will commence in 2009.

February 2009

Solar PV test-bed project at Singapore's Budget terminal

The Civil Aviation Authority of Singapore (CAAS) is embarking on a solar PV test-bed project, to convert electricity from sunlight, at Singapore's Budget Terminal.
A tender for the project was issued on 11 Feb. 2009 for bidders to submit their proposals.
The project aims to supplement the terminal's main power supply and reduce electricity costs.
The solar PV system will be installed at the BT departure hall's rooftop. It is estimated to generate about 281,000 kWhr of electricity annually, which translates into an estimated electrical cost savings of about S$60,000 per year.
The above project is part of Singapore's Clean Energy Research & Test-bedding (CERT) programme launched in 2007 by the EDB and the Clean Energy Programme Office (CEPO).

(For details, refer to CAAS media release dated 11 Feb. 2009, entitled: "CAAS to embark on Solar Photovoltaic Test-bed project at Singapore's Budget Terminal").

Technology of Thin-Film Solar Cells

Armin Aberle

Solar Energy Research Institute of Singapore (SERIS)
National University of Singapore (NUS)

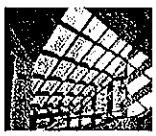
March 2009

The Mission of SERIS



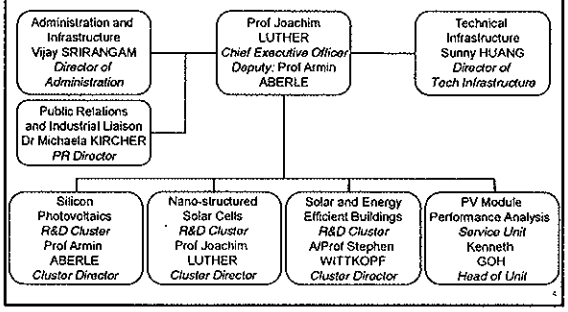
SERIS conducts industry-oriented research and technology development and use-inspired basic research in the field of solar energy conversion, in close collaboration with industrial partners

Main R&D Areas of SERIS



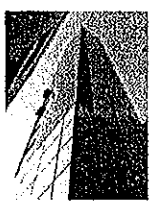
- Silicon solar cells – wafer and thin-film
- Nano-structured solar cells (printable cells on flexible substrates)
- Solar and energy efficient buildings

SERIS, organisational structure



For more details on SERIS, please visit www.seris.sg

Outline of talk



1. Why thin-film photovoltaics?
2. Silicon thin-film solar cells
3. Cadmium telluride solar cells
4. Copper indium diselenide solar cells
5. Summary

1. Why thin-film photovoltaics?

- Thin-film PV has, fundamentally, **huge potential** for lowering the cost of solar electricity:
  - Fabrication of modules requires little energy;
  - Fabrication of modules requires small amounts of semiconductor material;
  - Thin-films can be deposited over very large areas;
  - Thin-film solar cells can be series-connected in a fast & inexpensive way;
  - Efficiencies & long-term stability of modules are improving;
  - Costs per Watt are falling.
- As a result, PV module costs of **well below 1 €/W_p** seem possible with the best thin-film PV technologies, in large-scale production

Why thin-film photovoltaics? (cont'd)

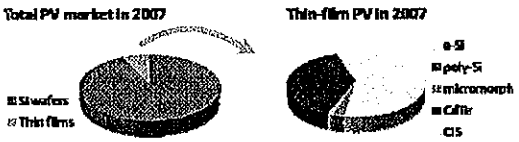
- New PV applications: Green-field plants, building integrated
- Standard substrate: Glass (soda-lime float glass)

Technology	Best Eff in lab	Best Eff in Industry	Remarks
a-Si:H	9.5%	5-6%	p-i-n cell, Si by PECVD
µc-Si:H	~10%	not produced	Strong hydrogen dilution of silane
Poly-Si	10.4%	7-8%	SPC of PECVD a-Si
Micromorph	11.7%	8-10%	Tandem cell
CdTe	16.5%	10-11%	Uses Cd (toxic). Uses Te (scarce)
CIS	19.9%	11-13%	Uses indium (scarce)

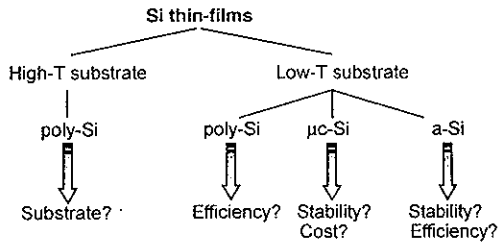
Efficiencies shown are stabilised values.

Why thin-film photovoltaics? (cont'd)

- Thin-film PV production is growing rapidly (> 50% p.a.)
- Market share of thin-film PV is increasing
- Diversification (new market entrants)

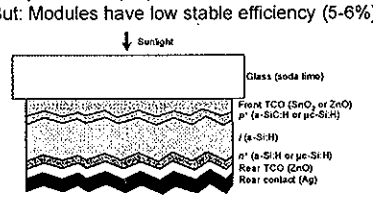


2. Silicon thin-film solar cells



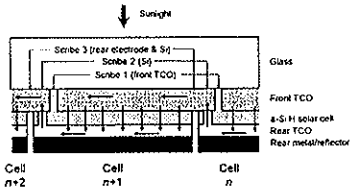
2.1 Amorphous silicon cells

- Invented in 1970s
- Si deposition at low T by PECVD ("glow discharge")
- Si source material: Silane
- Many excellent properties for low-cost PV
- But: Modules have low stable efficiency (5-6%) ?% and all

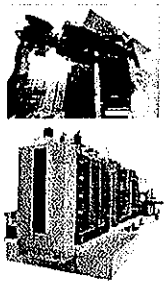


Amorphous silicon cells (cont'd)

- Two TCOs (transparent conductive oxides), front & rear
- TCOs: Good conductance and transparency req'd
- 3 sets of parallel scribes (laser and/or mechanically)
- Width of each scribe approx 100 microns

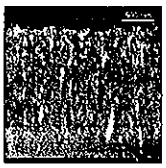


Amorphous silicon cells (cont'd)



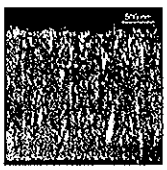
- Turn-key factory lines for a-Si modules now available
- PECVD machines: Batch-type or clustertool or in-line
- Machines developed for LCD industry (*"free ride for solar"*)
- Leading turn-key line suppliers: Oerlikon Solar, Applied Materials, ULVAC, ...
- Good progress with equipment (Si, TCO, lasers) → 7% a-Si modules within reach

2.2 Microcrystalline silicon cells



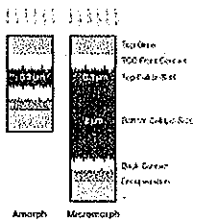
- Motivation: Use same equipment as for a-Si, but achieve higher efficiency
- Pioneered by U Neuchatel, CH in 1990s
- Grown by plasma CVD, using strong dilution of silane with hydrogen
- Approx 6% silane in hydrogen gives best PV efficiency
- μc-Si:H is a mixed-phase material (contains a-Si regions, c-Si regions, and voids). Bandgap ~1.0 eV
- c-Si grains are long & columnar

Microcrystalline silicon cells (cont'd)



- Best cells now ~10% efficient (several groups)
- Low Si deposition rate (< 40 nm/min)
- One approach for higher dep rate: Very high frequency ("VHF PECVD")
- Not commercially viable at present as a stand-alone cell (€/W_p cost too high).
- However: Very interesting material for a tandem cell

2.3 Micromorph tandem silicon cells



- U Neuchatel, 1994: Efficient a-Si/μc-Si tandem cell on a soda-lime glass superstrate
- Voltages of up to 1.36 V, Eff (initial) of up to 13.1% (in 1994!)
- Concept has been taken up by industry (Kaneka, Sharp, ...)
- Turn-key lines for micromorph PV modules now available

Source: Oerlikon Solar

Micromorph tandem silicon cells (cont'd)

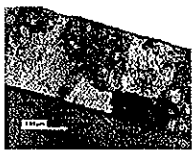
Kaneka Corp:

- 2001: Start of pilot production of "hybrid cell" *("very similar to Neuchatel's micromorph cell")*
- 0.4-m^2 pilot-line modules with Eff (initial) of over 12%
- Thin TCO interlayer to boost the current of a-Si cell
- 2004: Stable Eff of 11.7% indep confirmed for small cell

Market snapshot 2009/10:

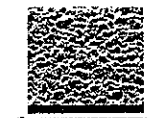
- Kaneka, Brilliant, Moser Baer, Ersol, Malibu, ...
- 10% stable efficiency for large modules within reach
- Main challenge of micromorph technology: Cost/m^2

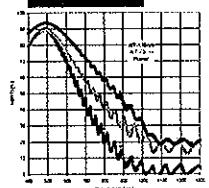
2.4 Polycrystalline silicon cells



- Combines advantages of c-Si with those of thin-film PV
- Standard method: SPC at 600°C of PECVD-deposited a-Si *(pioneered by Sanyo Corp in 1990s)*
- Sanyo: 9.2% in 1996 (on metal)
- SPC method transferred to glass by Pacific Solar Ltd (UNSW spin-off)
- Other methods: SPC of evaporated a-Si, poly-Si growth by IAD, laser crystallisation, ...

Polycrystalline silicon cells (cont'd)



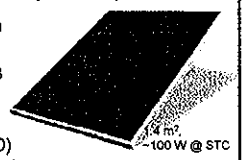


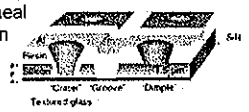
- c-Si is poor absorber for $\lambda > 800$ nm → Need light trapping → need textured glass
- Two glass texturing methods developed in recent years (AIT method and glass bead method)
- The micrograph shows a poly-Si film grown on AIT-textured glass
- If a good BSR is applied: $J_{sc} > 25$ mA/cm² for 2-µm poly-Si films

2µ

Polycrystalline silicon cells (cont'd)

- CSG Solar: Runs a PV factory in GER. Capacity 20 MW_p p.a.
- Glass = borosilicate (Borofloat33 from Schott)
- a-Si diode deposition in batch-type PECVD machines (KAI1200) → SPC at 600°C → Defect anneal → H^+ → Metal → Encapsulation
- Eff of up to 10.4% (94 cm²)
- Factory modules: 6-8%

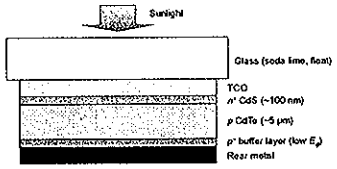




Source: www.csgsolar.com

3. Cadmium telluride cells

- Process: Clean front glass → TCO → Scribe 1 → CdS window layer (heterojunction) → CdTe absorber (~5 µm) → Activation step (annealing at ~450°C in $CdCl_2$) → Scribe 2 → Back contact → Scribe 3 → Rear glass
- Entire process takes less than 3 hours



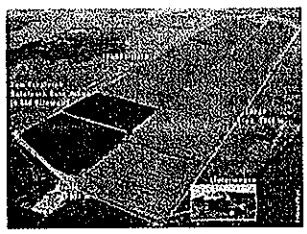
Cadmium telluride cells (cont'd)



Source: First Solar

- Both CdS and CdTe are easy to deposit stoichiometrically at 400-600°C
- Standard method: Close-spaced sublimation
- No doping req'd (both films are automatically doped)
- Best commercial modules now 10-11% efficient
- Rapid expansion (First Solar). Pre-financed collection & recycling program for modules

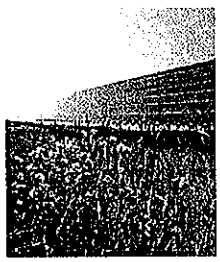
Cadmium telluride cells (cont'd)



Artist's impression (Source: juwi GmbH, GER)

World's biggest PV plant: Solar park *Waldpolenz* in Brandis, GER (40 MW_p, completion in 2009, modules from First Solar).

Cadmium telluride cells (cont'd)



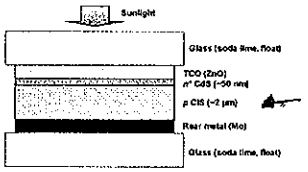
- Main technical issue: Back contact
- Standard solution: p^+ buffer layer with a smaller bandgap
- Main issues of technology:
  a) Toxicity of Cd
  b) Scarcity of Te (limits production to a few GW_p p.a.)

Cadmium - not agreeable by some country ?

SERIS NUS

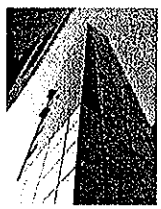
4. Copper indium diselenide cells

- Process (substrate configuration): Clean rear glass → rear electrode (Mo) → Scribe 1 → CIS absorber (~2 μm) → CdS window layer (~50 nm, heterojunction) → Scribe 2 → TCO (ZnO) → Scribe 3 → front glass
- CIS film has complex composition (Cu, In, Ga, Se, S)



SERIS NUS

Copper indium diselenide cells (cont'd)

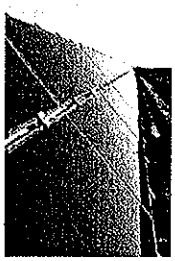


- CIS is a star performer in the laboratory, however, it has proved difficult to commercialise
- Best commercial modules 11-13% ←
- Present production ~10 MW_p p.a.
- Main issues:
  a) Complexity of CIS film (5 elements)
  b) Toxicity of Cd
  c) Scarcity of In (limits total production to ~10 GW_p)

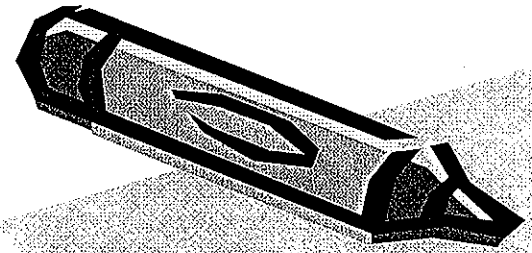
difficult to manufacture.

SERIS NUS

5. Summary

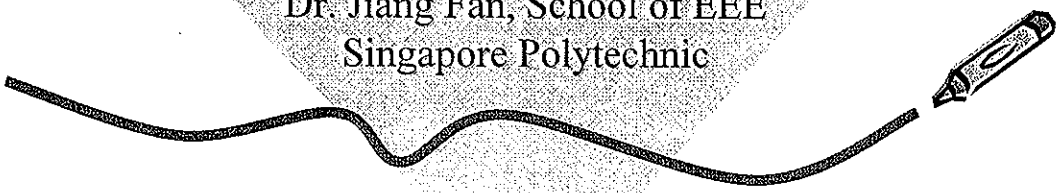


- Thin-film PV is booming (> 50% p.a.)
- Its market share is increasing
- Diversification (new entrants!)
- Five technologies: a-Si, micromorph, poly-Si, CdTe, CIS
- Trend towards higher efficiencies
- CdTe is expanding very rapidly
- *"CdTe and CIS have a window of opportunity, but are not a solution to humanity's long-term energy needs"*
- Si thin-film PV well suited for large-scale production, no bottlenecks *



PV PERFORMANCE IN SINGAPORE

Dr. Jiang Fan, School of EEE
Singapore Polytechnic



OUTLINES



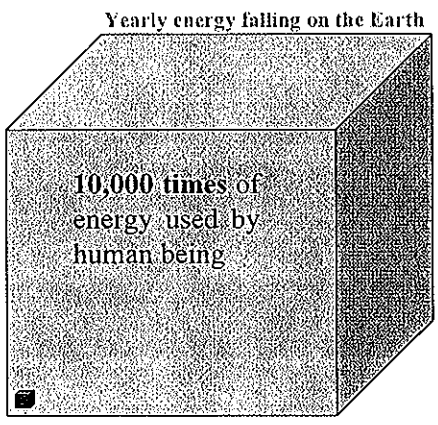
- INTRODUCTION
- ENERGY FROM THE SUN
- PERFORMANCE OF A PV SYSTEM IN SINGAPORE
- CONCLUSION



1. INTRODUCTION

To date, solar energy has been accepted worldwide as a high potential alternative energy for our future. Progressive increase in conversion efficiencies and manufacturing economies of scale are the underlying drivers.

What Potential for Solar Energy ?

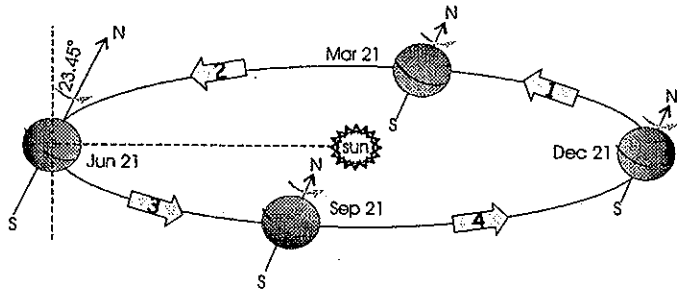


Singapore, as a country on the equator, possesses the solar energy *more than 4 kWh/m^2/day* that is higher than many other countries where solar energy has been strongly accepted as a high potential alternative energy.

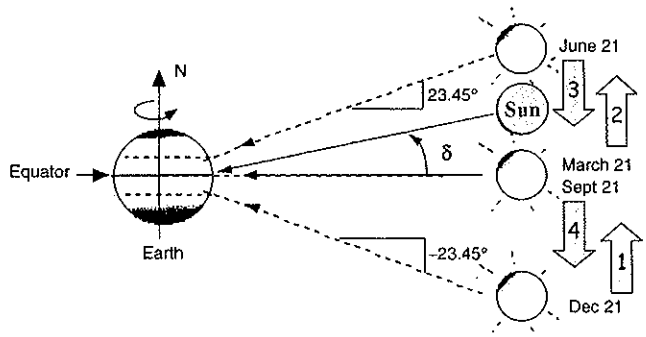
2. ENERGY FROM THE SUN

- On average, the Earth's surface receives about 1.2×10^{11} MW of solar power.
- The solar energy on the Earth in less than one hour is more than enough to satisfy the one-year energy demand of the human being on the Earth.

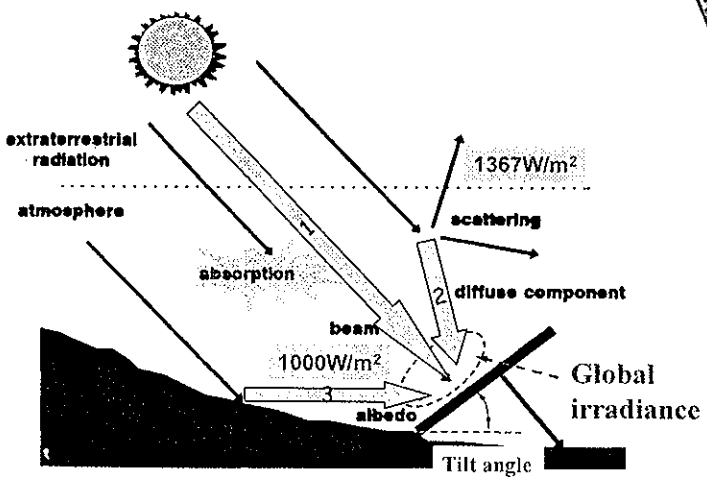
How Solar Energy Reaches The Earth



Another View of Solar Radiation on the Earth in Different Months



The solar radiation reaching a PV module



1000W/m² Max.

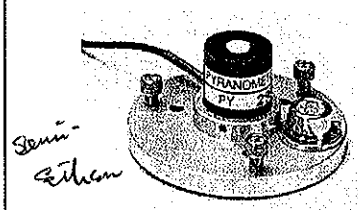
Measurement Of Solar Radiation

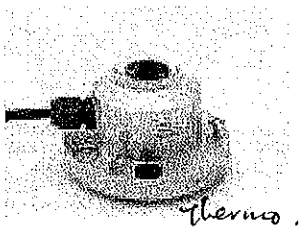
The calculations and approximations in the world cannot yield exact amount of sunlight that will fall on a given surface in a given place. Only on-site measurement can acquire accurate sunlight data for a PV system.

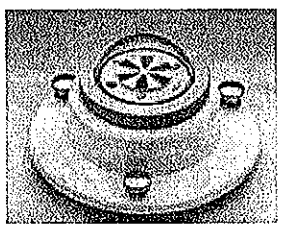
The Instrumentation for Solar Radiation Measurement

- **Pyranometer** is designed to measure ***global irradiance*** that covers ***beam***, ***diffuse*** and ***albedo*** radiations.
- **Pyrheliometer with tracker** is designed to measure ***beam*** radiation.
- **Pyramonmeter on shadow band stand** is used to measure ***diffuse*** radiation.

Pyranometer

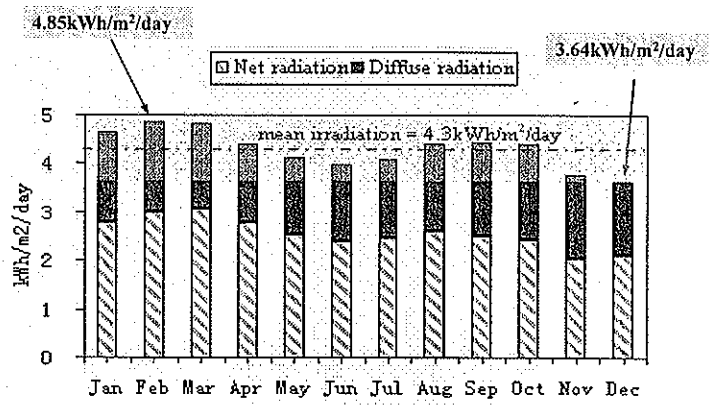




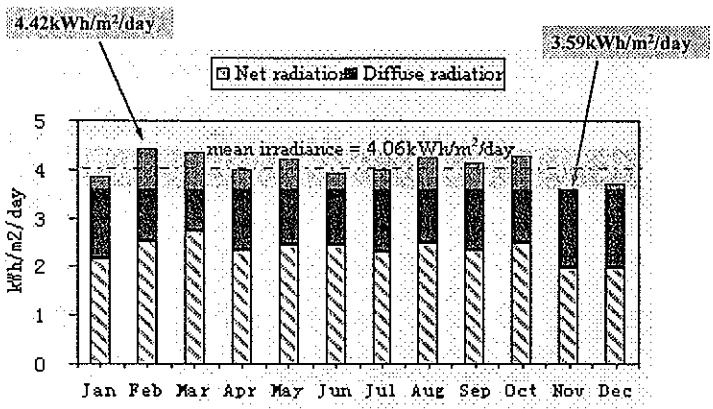


The performance of a PV system depends on many factors such as solar radiation, installation of PV modules, operation temperature, selection of systems and operating conditions. In terms of performance of a PV module, two most important parameters to be considered are **solar radiation** and **operating temperature**.

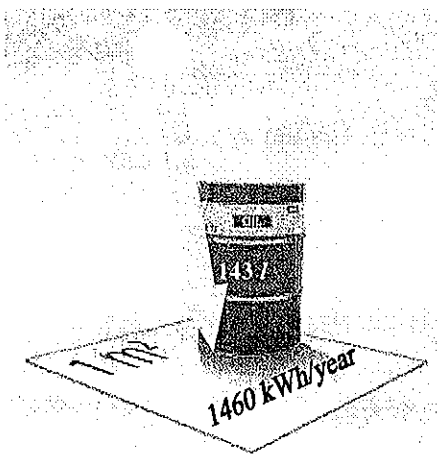
Singapore Solar Radiations in 2002



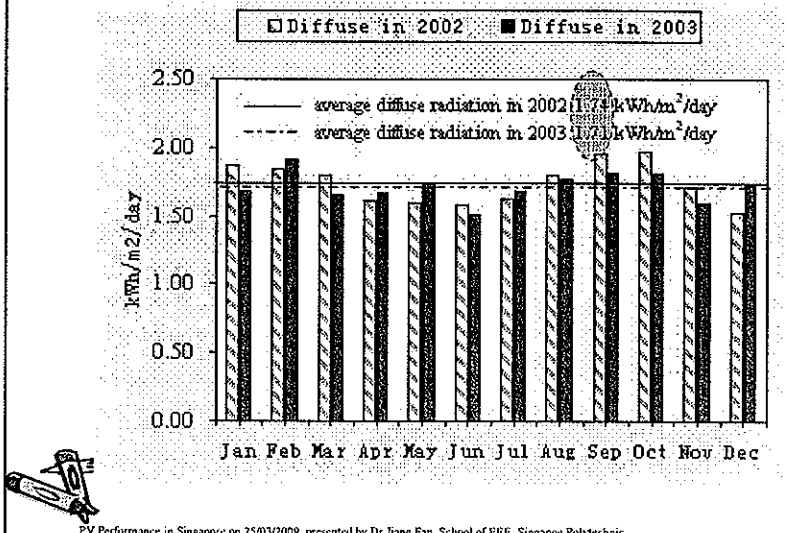
Singapore Solar Radiations in 2003



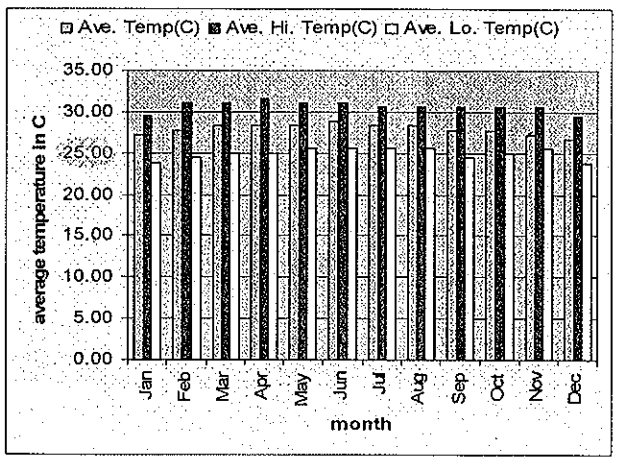
Solar Energy Available in Singapore



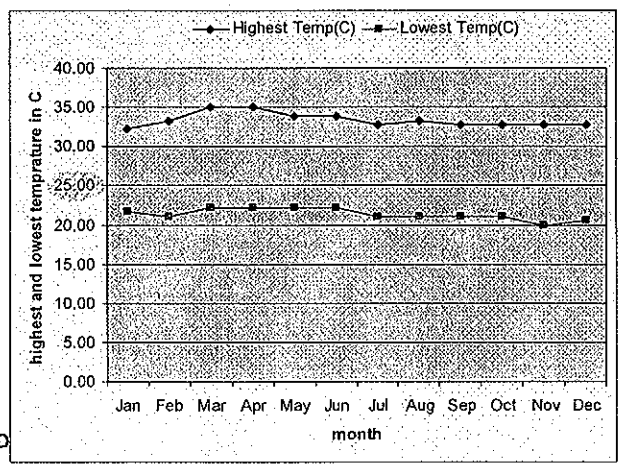
High Diffuse Radiation in Singapore



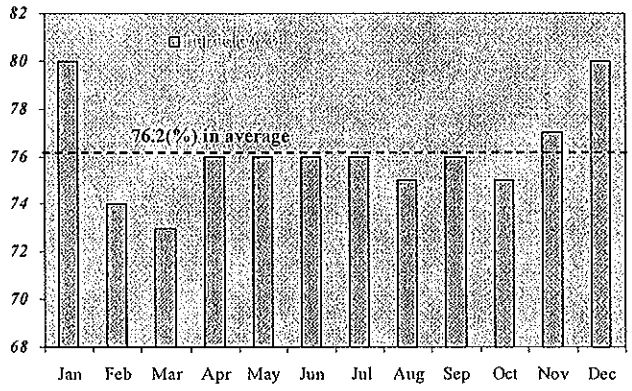
High Temperature



Monthly Highest and Lowest Temperatures



High Humidity



3. PV PERFORMANCE IN S'PORE

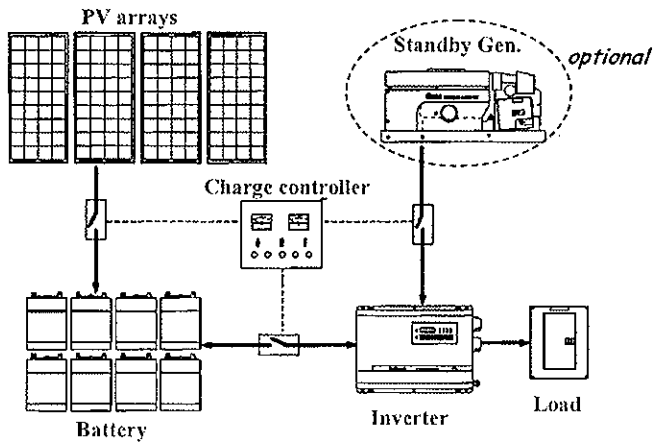
There are two main categories of PV system,

1). stand-alone.

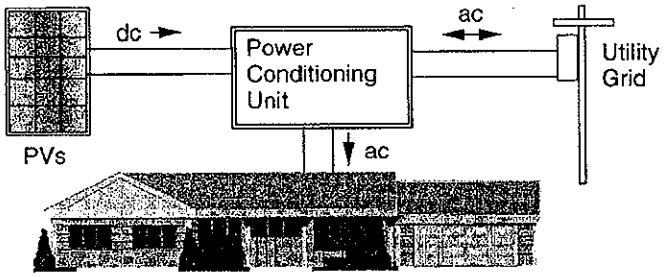
2). grid-connected.

The Energy Market Authority(EMA) has launched PV handbook to encourage the people to install solar photovoltaic systems and integrate them to the utility grid.

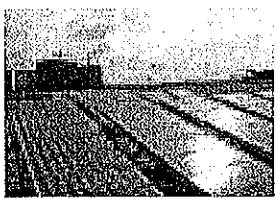
A stand-alone PV system



A grid-connected PV system



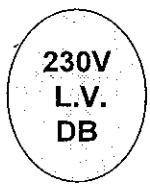
19.2kW$_p$ Grid-tie PV System Installed in Singapore Polytechnic in 1996



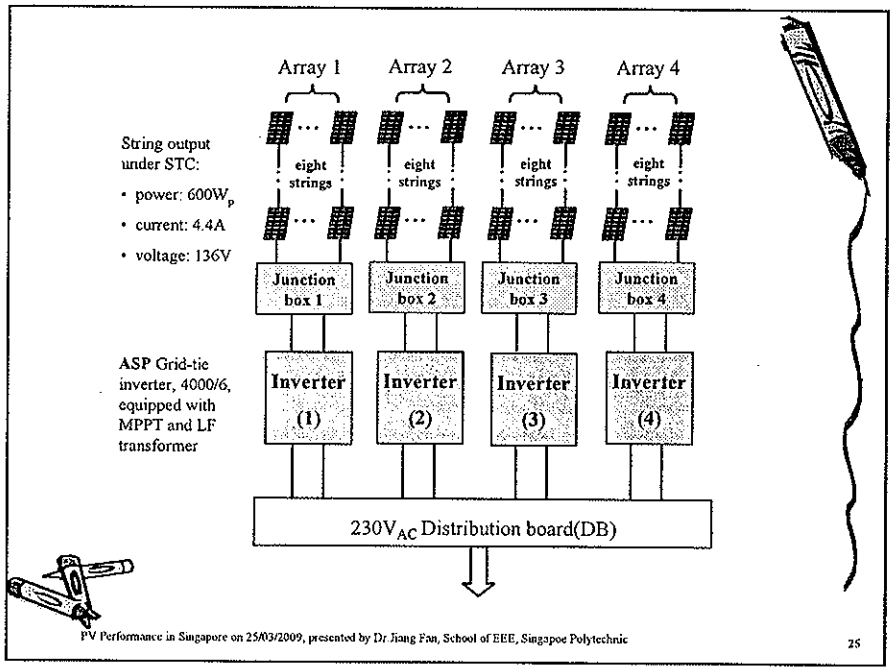
The 19.2kWp PV system consists of 4×4.8kWp solar arrays, facing the South with the tilted angle of 15°.



4×4kW **SPA** POWER-PLUS "GRID III" grid-tied inverter



230V low voltage distribution board


Array 1
Array 2
Array 3
Array 4
String output under STC:
• power: 600W$_p$
• current: 4.4A
• voltage: 136V
eight strings
eight strings
eight strings
eight strings
Junction box 1
Junction box 2
Junction box 3
Junction box 4
ASP Grid-tie inverter, 4000/6, equipped with MPPT and LF transformer
Inverter (1)
Inverter (2)
Inverter (3)
Inverter (4)
230V$_{AC}$ Distribution board(DB)
PV Performance in Singapore on 25/03/2009, presented by Dr Jiang Fan, School of EEE, Singapoe Polytechnic
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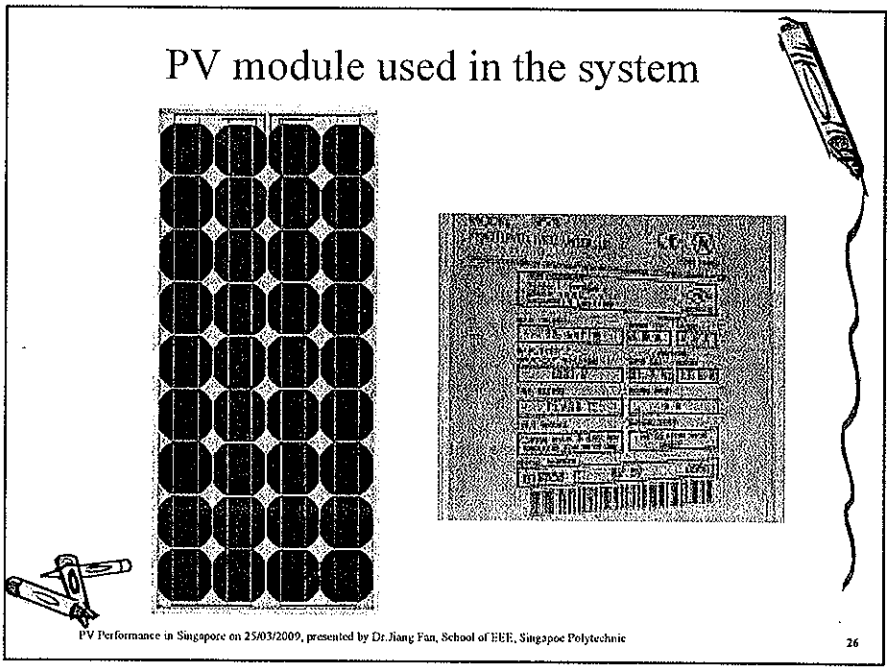
PV module used in the system
PV Performance in Singapore on 25/03/2009, presented by Dr Jiang Fan, School of EEE, Singapoe Polytechnic
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Specifications of PV module

TABLE I. TYPICAL DATA AT STANDARD TEST CONDITIONS(*STC)

Parameters of the module	Value
Nominal peak power(P_{mpp})	73 W
Peak power voltage(V_{mpp})	17.0 V
Peak power current(I_{mpp})	4.3 A
Short circuit current(I_{sc})	4.6 A
Open circuit voltage(V_{oc})	21.4 V
The tolerance on the peak power	± 4%
Voltage temperature coefficient(αV_{mpp})	-78 mV/°C

***STC: 1000W/m² irradiance, AM1.5 and 25° C cell temperature**

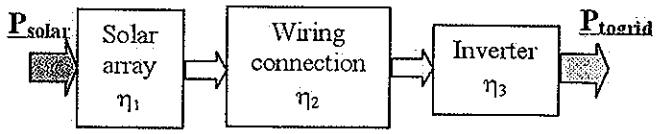
Inverter- how freq preferred.
To discuss with PG

Specifications of grid-tied inverter

TABLE 2. MAIN SPECIFICATIONS OF POWER-PLUS "GRID III" INVERTER

Parameters of the inverter	Value
Rated Input DC Power	4000W
Input Voltage Range	72~145V_{dc}
Max. Power Point Tracker(MPPT) range	82.~120V_{dc}
Max. Conversion efficiency	94%
Rated AC power	3500W
Rated AC voltage	195 ~ 256V_{ac}
Rated AC current	14 A_{ac}
Frequency range	49 ~ 51 Hz
Protection schemes	OV/UV and OF/UF

The Efficiency of Entire PV System

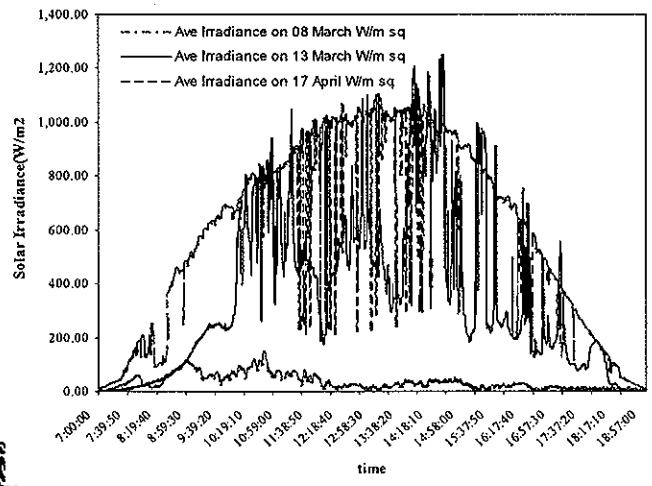


$$\text{The system efficiency, } \eta = \frac{P_{togrid}}{P_{solar}} = \eta_1 \eta_2 \eta_3$$

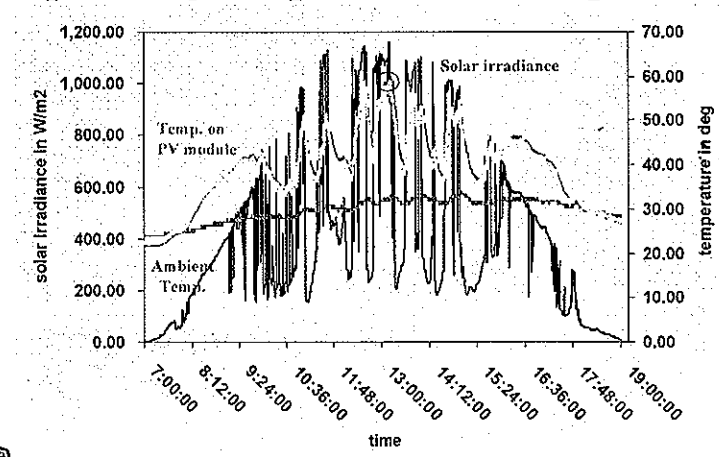
Two Important Factors for PV System Operation

- The efficiency of PV modules is primarily dependent upon
  - the solar radiation and
  - the temperature of solar cells.
- The solar irradiance determines the output current of PV modules, while the cell temperature affects the output voltage of PV modules.

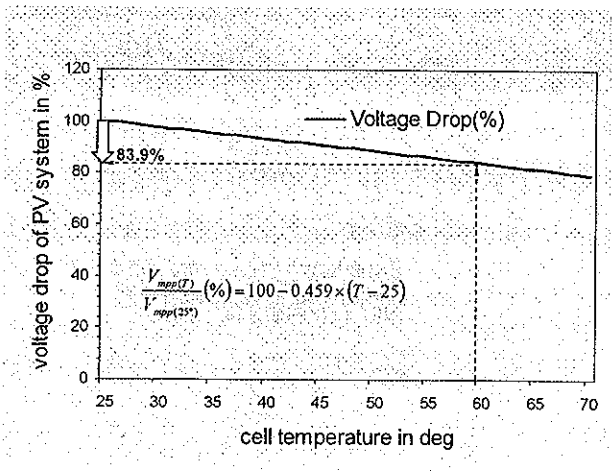
The Irradiances of Three Typical Days



Operating temperature of PV panels



Impact of cell temperature on system voltage



The System Performance

Performance of a PV system is usually investigated by

1). the reference yield, $\mathbf{Y_R}$,

$$Y_R = \frac{\text{the daily in-plane irradiation}}{\text{the STC reference in-plane irradiance}}$$

2). the final yield, $\mathbf{Y}_f$,

$$Y_f = \frac{\text{the daily plant energy ouptut}}{\text{the installed PV array power}}$$

3). the Performance Ratio, ***PR***. $PR = \frac{Y_f}{Y_R}$

Ave : 0.6 ~ 0.8

The Performance Ratio, ***PR***, indicates the overall effect of losses on PV array's rated output due to array temperature, incomplete utilisation of the irradiation, and system component inefficiencies or failures. As discussed previously, ***PR*** of 19.2kWp PV system can be worked out as follows:

$$Y_R = \frac{4.12 kWh/m^2/day}{1kW/m^2} = 4.12\ hrs$$

$$Y_f = \frac{47.1 kWh/day}{19.2 kWp} = 2.45 hrs$$

$$PR = \frac{Y_f}{Y_R} = 59.5\%$$



Improvement of The Performance of PV System

- To capture the maximum solar radiation that can be achieved by
  - optimizing the tilt angle of fixed solar panels by adjusting the title angles in different season.
  - using solar tracker.
- To reduce the operating temperature of solar panels.

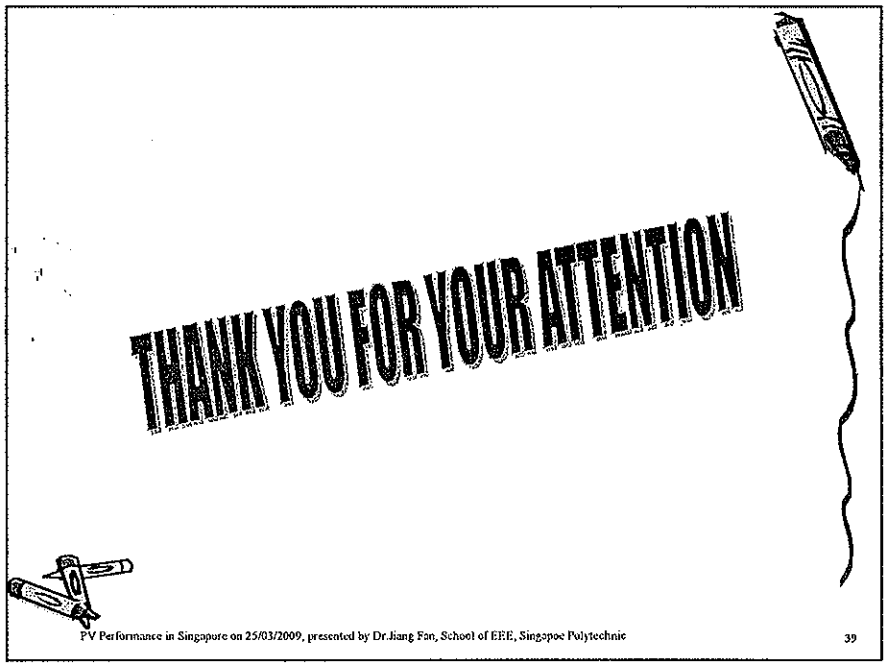


Main Issues Concerned by Local Utility

- Power quality issue caused by integration of PV system with the grid,
- Safety of PV system operation,
- Selection of metering system for grid-tie PV system.

5. CONCLUSION

Singapore that possesses annual average irradiation more than ***4kWh/m²/day*** is a good location to deploy the solar energy. As oil price will stay high and increasing attention is paid to global climate changes, solar energy will be widely accepted in Singapore as an important energy alternative in future.


THANK YOU FOR YOUR ATTENTION
PV Performance in Singapore on 25/03/2009, presented by Dr.Jiang Fan, School of EEE, Singapoe Polytechnic
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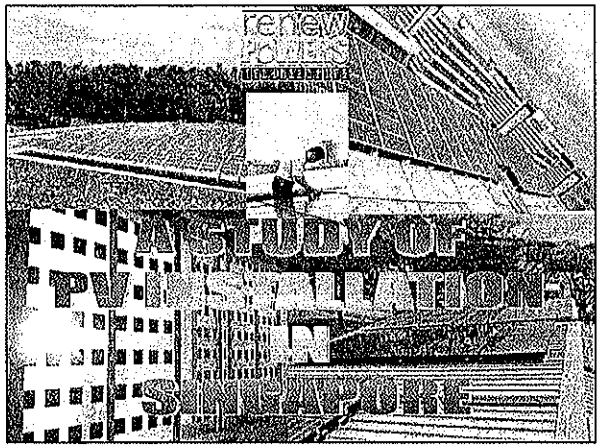
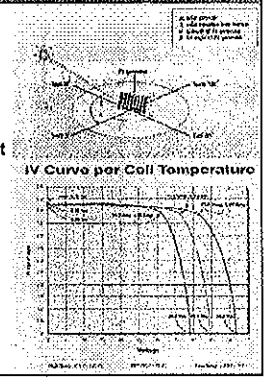


PV System Installation & Commission

- Site Survey & Shading Analysis
- Sizing & Selection of equipment
  - Solar Modules
  - Mounting Structures
  - Grid Tie Inverters
  - Balance of System Components
- Testing & Commissioning
  - I-V Testing
  - Monitoring Operating Data
- Consultation Process to Power Grid
  - Appoint 'Solar' LEW
    - Submission of Application Form to SP Services (SPS)
    - Compliance with CP5, CP33 & Power Quality requirement – SP PowerGrid (SPPG),
    - Arrangement of Turn On Date with SPPG, SPS and Licensing LEW

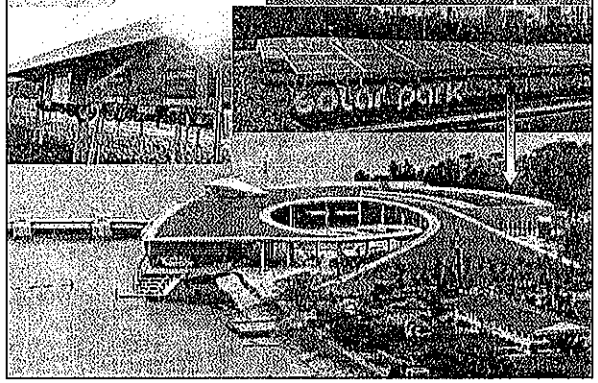
Factors Affecting Solar Output

- Sun Radiation
- Array Orientation
- Shading
- Tilt Angle
- Effect of Temperature on solar output
  - ↑ 25°C , voltage ↓
  - ↓ 25°C , voltage ↑
  - 1000W/m²
  - Air Mass of 1.5
- Mismatch Losses
- Cable Losses
- DC to AC conversion Loss (Inverter Efficiency)
- Dirt & Dust



Marina Barrage Solar Park, 70kWp

Water for All Conserve, Value, Enjoy

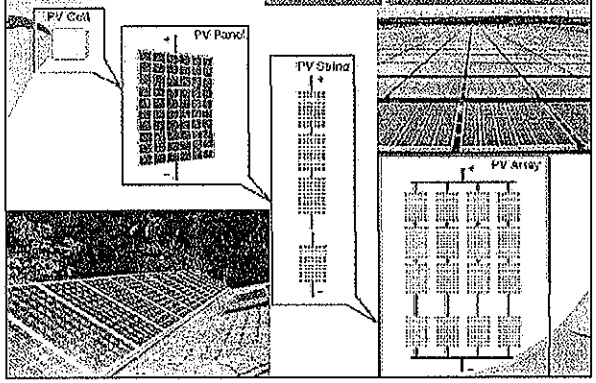


1. Solar Array Layout Design

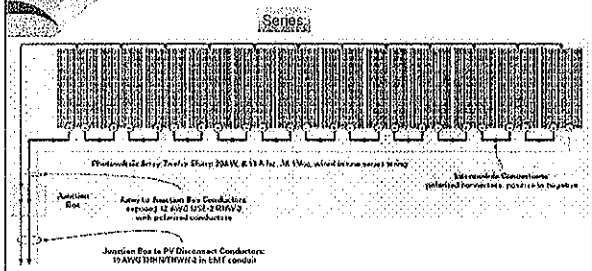
- 70.9kWp
- 175Wp per PV module
- 15 modules per row
- 3 rows per Array – 45 modules
- 9 PV Arrays – 405 modules



PV Array Composition



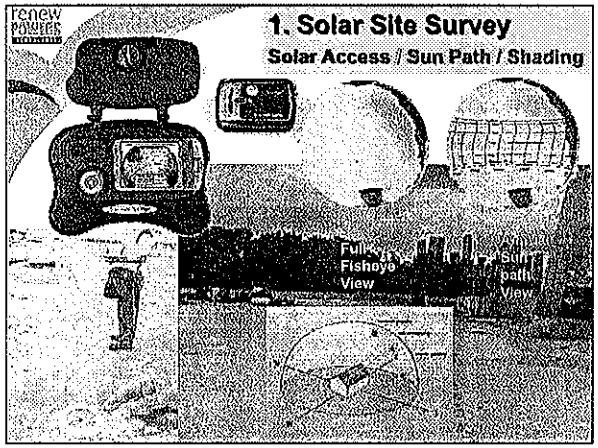
PV String Wiring Diagrams



PV String Voltage : 36.1V x 12 modules = 433.2V

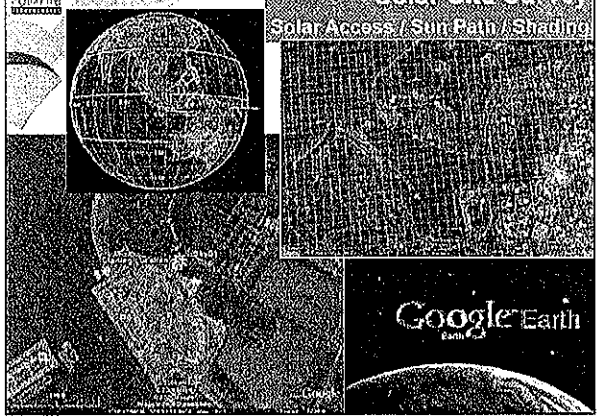
1. Solar Site Survey

Solar Access / Sun Path / Shading

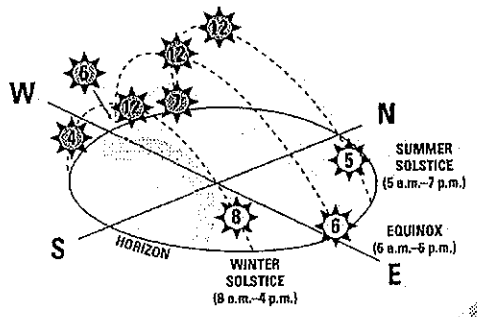


Solar Site Survey

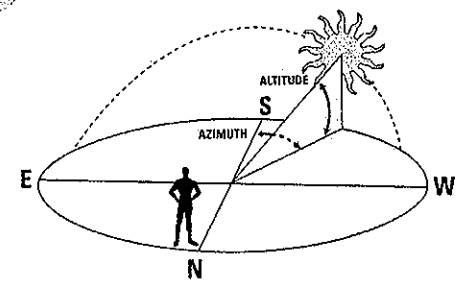
Solar Access / Sun Path / Shading



THE SUN'S PATH THROUGHOUT THE YEAR NORTHERN LATITUDES



Orientation

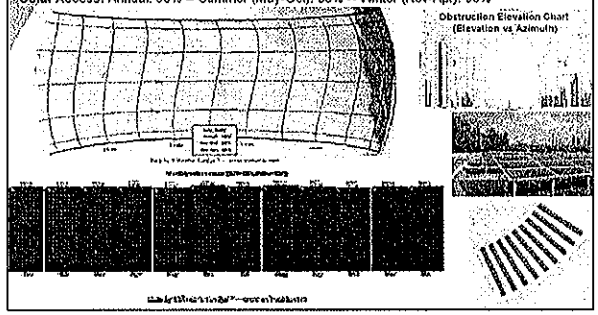


AZIMUTH AND ALTITUDE FOR ALL NORTHERN LATITUDES

Solar Site Survey

Solar Access / Sun Path / Shading

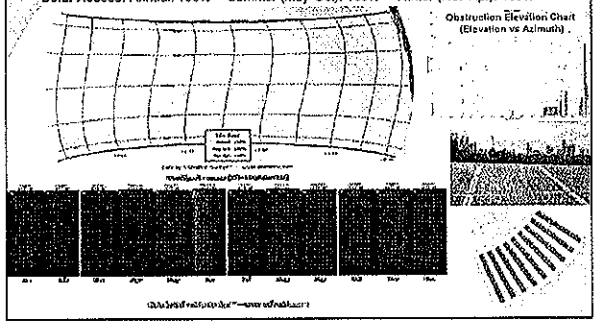
Location: Marina Barrage PV Array 1
PV Orientation: Tilt=10° -- Azimuth=90°
GPS Location: Latitude=1.27986°N -- Longitude=103.87026°E
Solar Access: Annual: 98% -- Summer (May-Oct): 98% -- Winter (Nov-Apr): 98%



Solar Site Survey

Solar Access / Sun Path / Shading

Location: Marina Barrage PV Array 9
Panel Orientation: Tilt=10° -- Azimuth=90°
GPS Location: Latitude=1.27986°N -- Longitude=103.87026°E
Solar Access: Annual: 100% -- Summer (May-Oct): 100% -- Winter (Nov-Apr): 100%

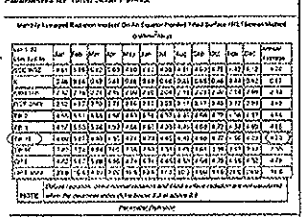


NASA Data

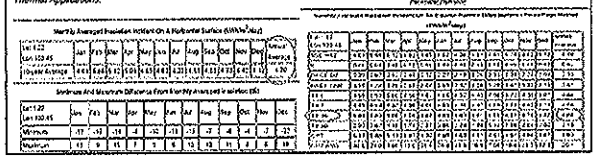
Sun Hour

NASA Surface meteorology and Solar Energy - Available Tables

Parameters for Tilted Solar Panels:



Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:



Effect of Tilt Angle

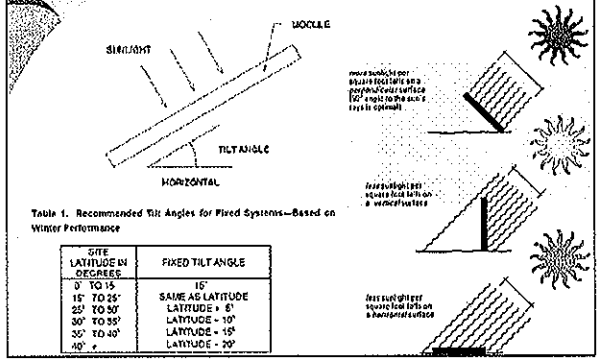
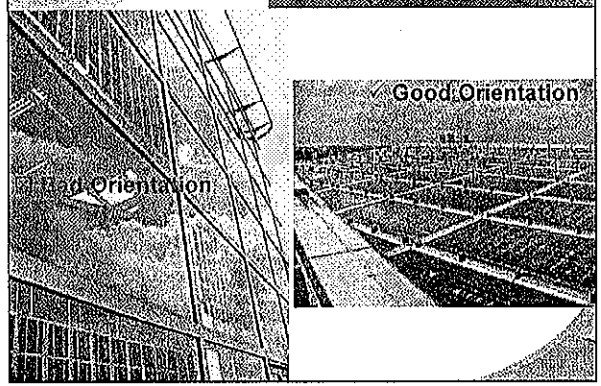
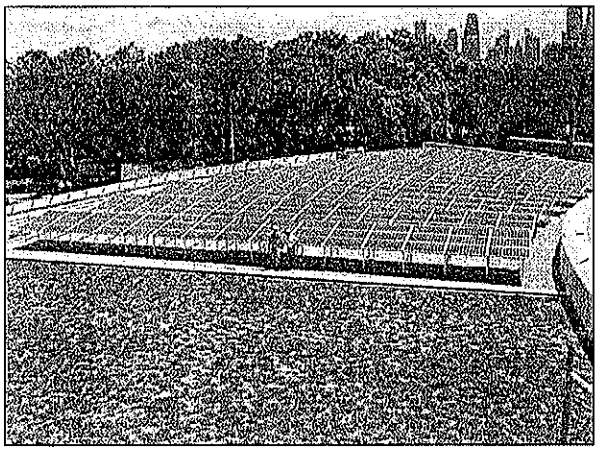


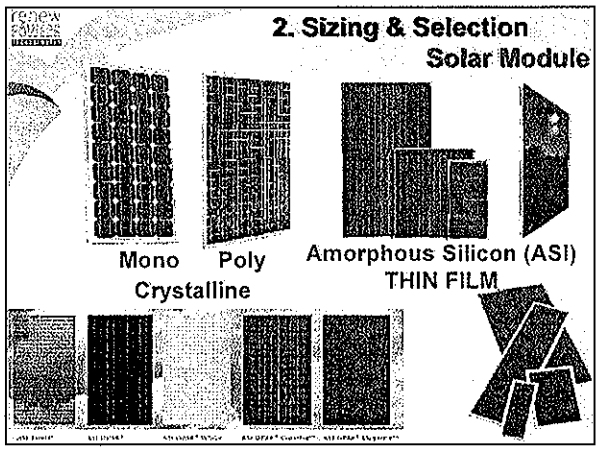
Table 1. Recommended Tilt Angles for Fixed Systems—Based on Winter Performance

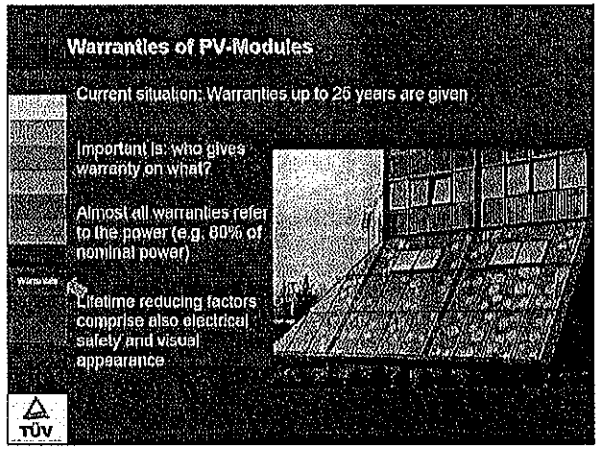
SITE LATITUDE IN DEGREES	FIXED TILT ANGLE
0° TO 15°	15°
15° TO 25°	SAME AS LATITUDE
25° TO 30°	LATITUDE + 5°
30° TO 35°	LATITUDE + 10°
35° TO 40°	LATITUDE + 15°
40° +	LATITUDE + 20°

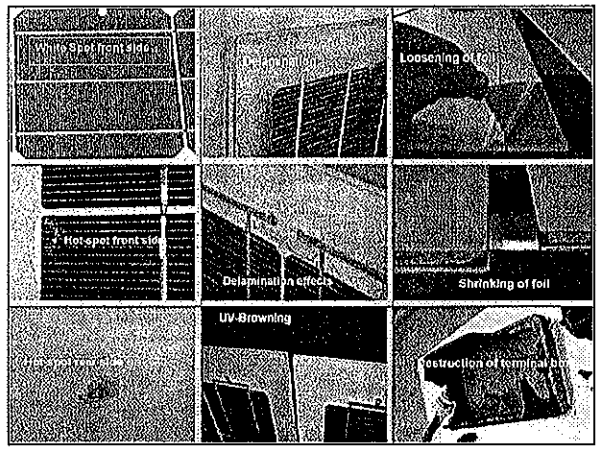
PV Orientation

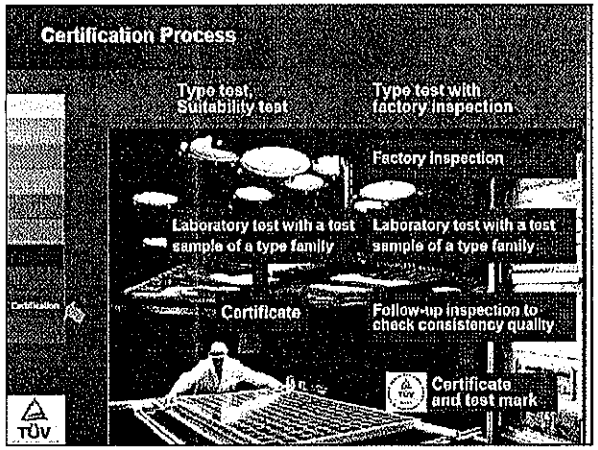


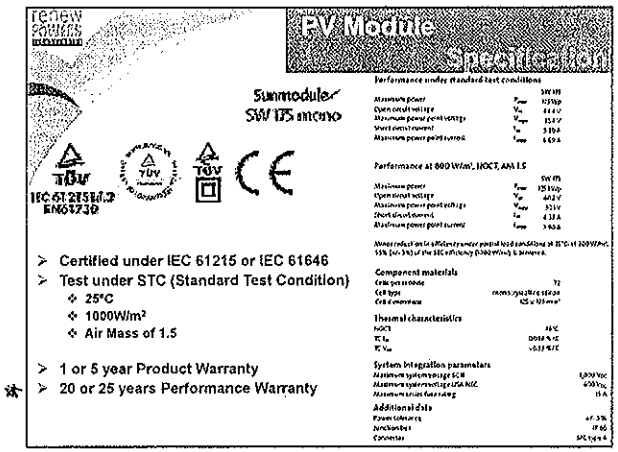


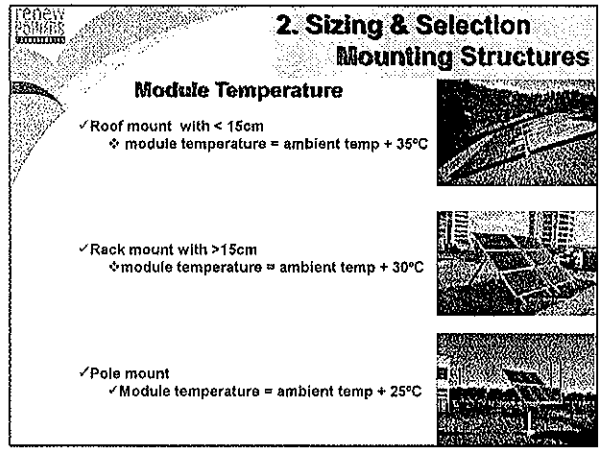

2. Sizing & Selection
Solar Module
Mono Crystalline
Poly
Amorphous Silicon (ASI) THIN FILM

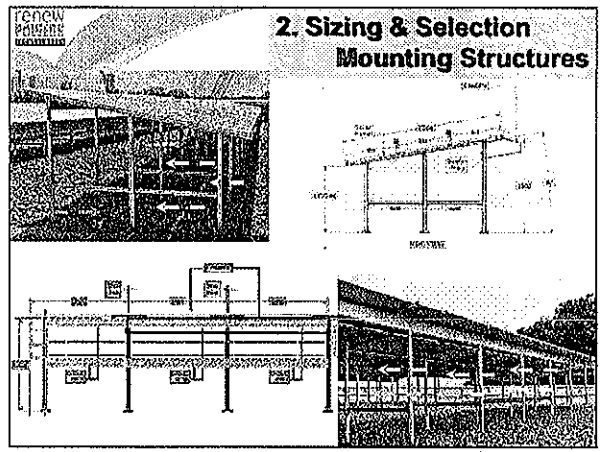

Warranties of PV-Modules
Current situation: Warranties up to 25 years are given
Important is: who gives warranty on what?
Almost all warranties refer to the power (e.g. 80% of nominal power)
Lifetime reducing factors comprise also electrical safety and visual appearance
TÜV

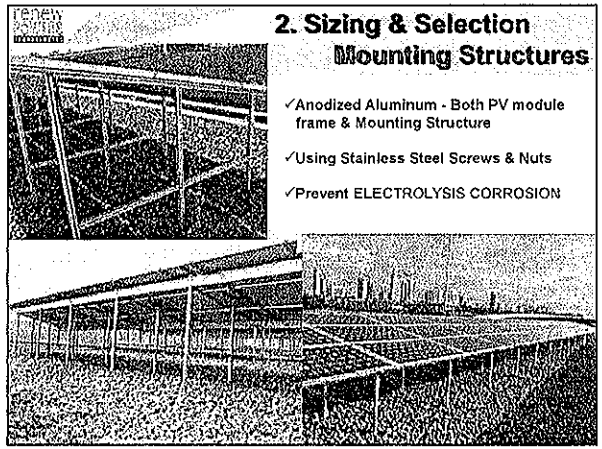

Loosening of foil
Delamination effects
Shrinking of foil
UV-Browning


Certification Process
Type test, Suitability test
Type test with factory inspection
Factory inspection
Laboratory test with a test sample of a type family
Laboratory test with a test sample of a type family
Certificate
Follow-up inspection to check consistency quality
Certificate and test mark
TÜV

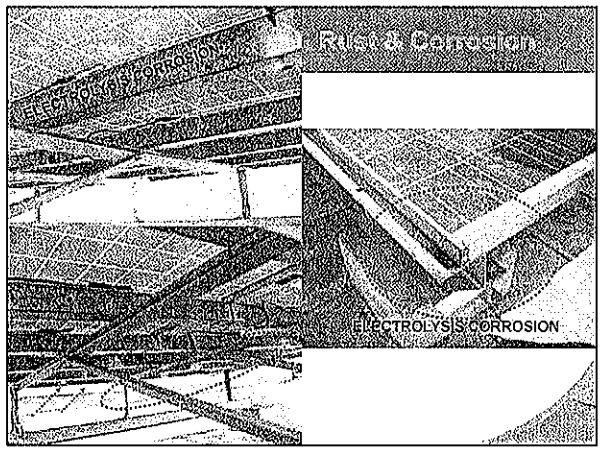

PV Module Specification
Sunmodule SW 175 mono
IEC 61215/61730
EN61730
➢ Certified under IEC 61215 or IEC 61646
➢ Test under STC (Standard Test Condition)
❖ 25°C
❖ 1000W/m²
❖ Air Mass of 1.5
➢ 1 or 5 year Product Warranty
➢ 20 or 25 years Performance Warranty

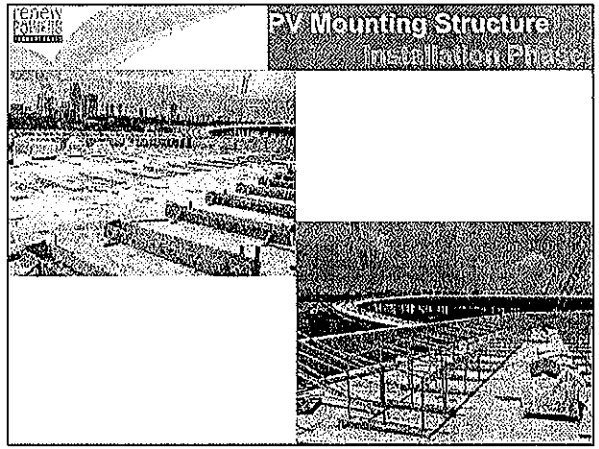

2. Sizing & Selection
Mounting Structures
Module Temperature
✓Roof mount with < 15cm
❖ module temperature = ambient temp + 35°C
✓Rack mount with >15cm
❖module temperature = ambient temp + 30°C
✓Pole mount
✓Module temperature = ambient temp + 25°C

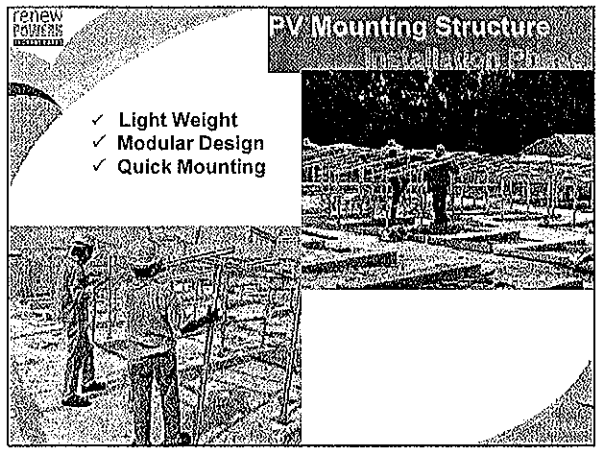

2. Sizing & Selection
Mounting Structures


2. Sizing & Selection
Mounting Structures
✓Anodized Aluminum - Both PV module frame & Mounting Structure
✓Using Stainless Steel Screws & Nuts
✓Prevent ELECTROLYSIS CORROSION

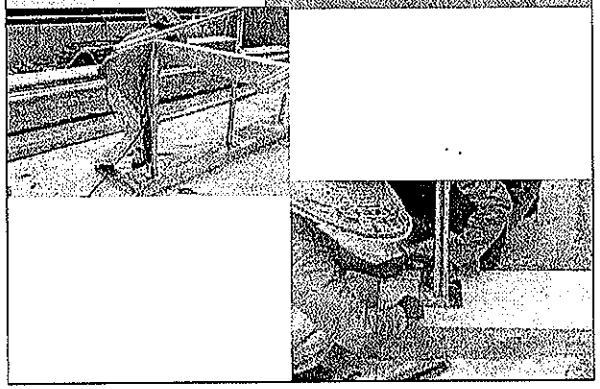
Al.


Rust & Corrosion
ELECTROLYSIS CORROSION

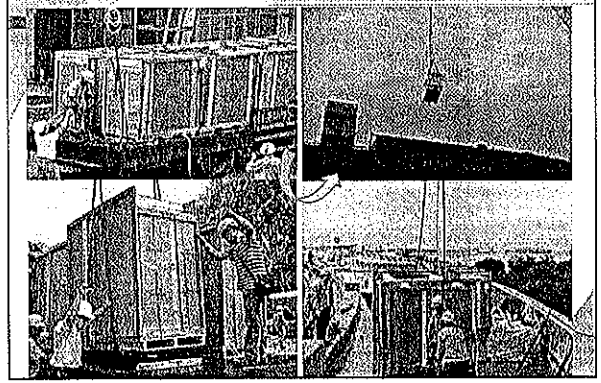

PV Mounting Structure


PV Mounting Structure
✓ Light Weight
✓ Modular Design
✓ Quick Mounting

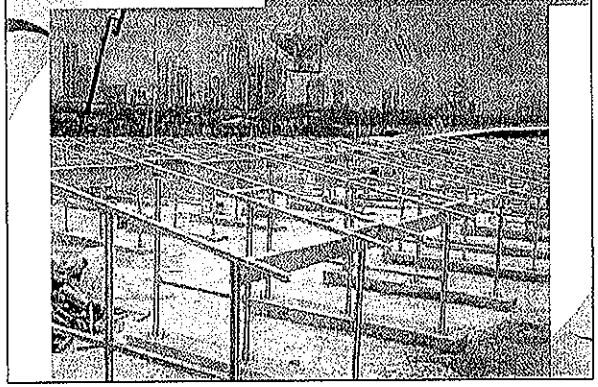
PV Mounting Structure
Installation Phase



Mounting PV Modules
Installation

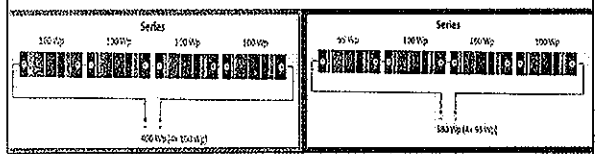


PV Mounting Structure
Installation Phase



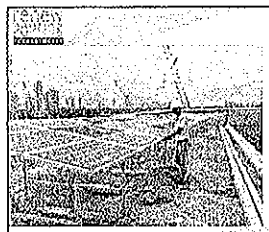
Mounting PV Modules
Mismatch Losses

- The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules.
- This difference is a result of slight inconsistencies in performance from one module to the next and is called **module mismatch**
- at least 2% loss in system power



Variance in PV power.

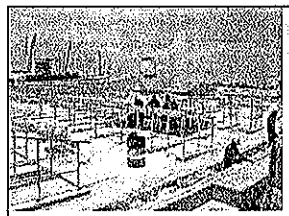
Mounting PV Modules
PV Module Mismatch

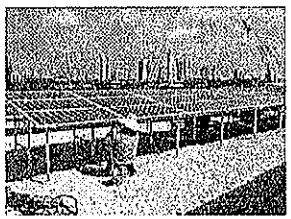


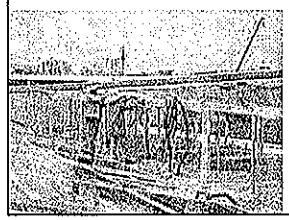
Select PV modules with same powers and match them under same string.

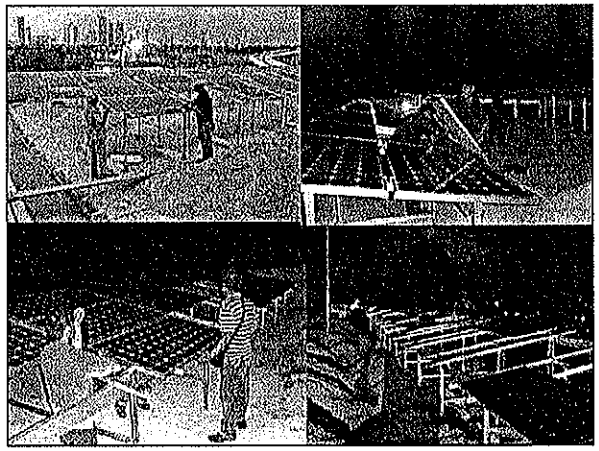


Mounting PV Modules
Installation





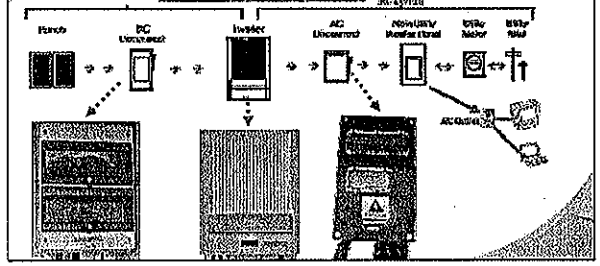


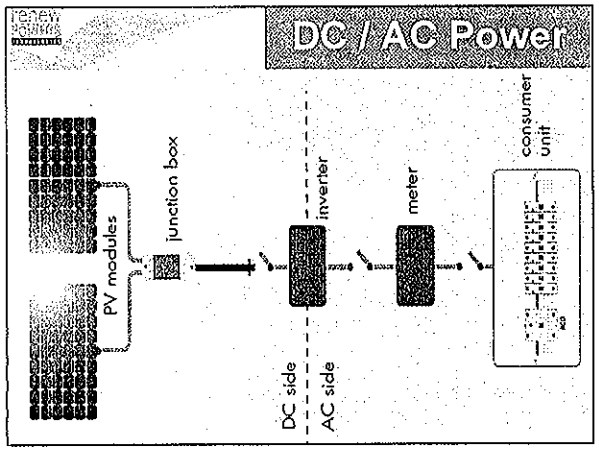


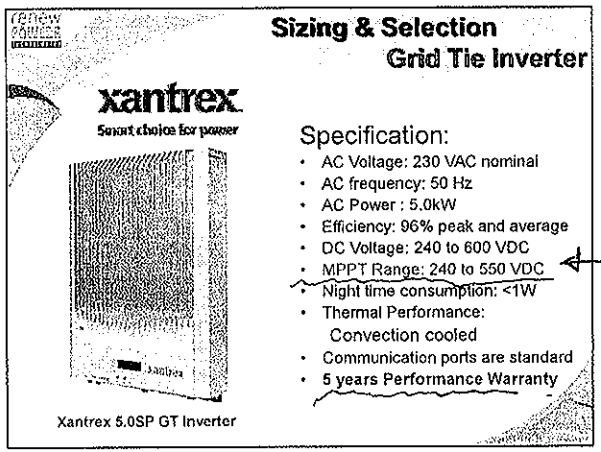
Sizing & Selection
Balance of System

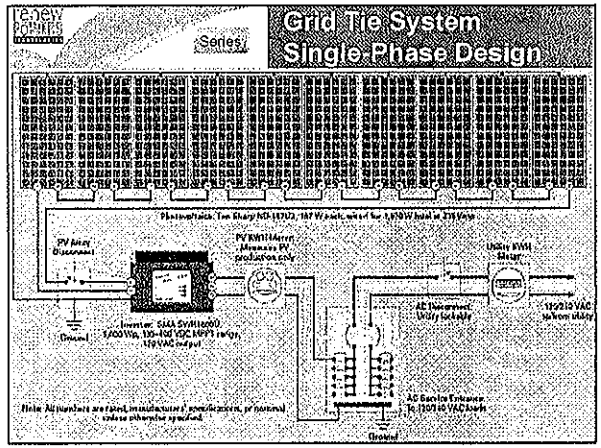


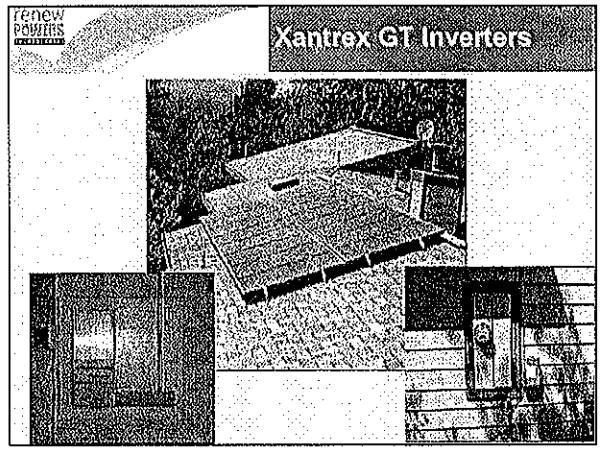
Balance of System components consist of all components of a renewable energy system except for the solar modules and mounting system.
These components include inverters, fuse/breakers, over-current protection, enclosures, batteries, cables, etc.



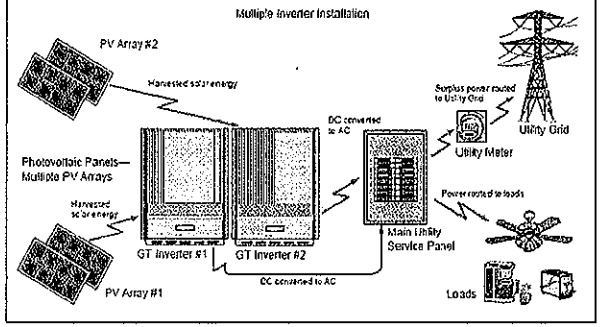

DC / AC Power
PV modules
junction box
inverter
meter
consumer unit
DC side
AC side

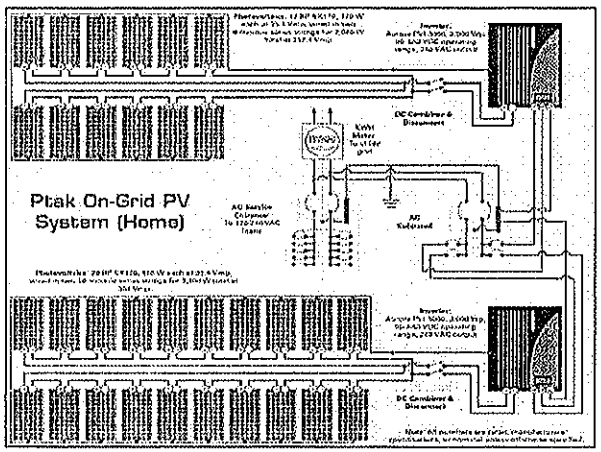

Sizing & Selection
Grid Tie Inverter
xantrex
Smart choice for power
Specification:
• AC Voltage: 230 VAC nominal
• AC frequency: 50 Hz
• AC Power : 5.0kW
• Efficiency: 96% peak and average
• DC Voltage: 240 to 600 VDC
• MPPT Range: 240 to 550 VDC
• Night time consumption: <1W
• Thermal Performance:
Convection cooled
• Communication ports are standard
• 5 years Performance Warranty
Important
Xantrex 5.0SP GT Inverter


Series
Grid Tie System
Single Phase Design

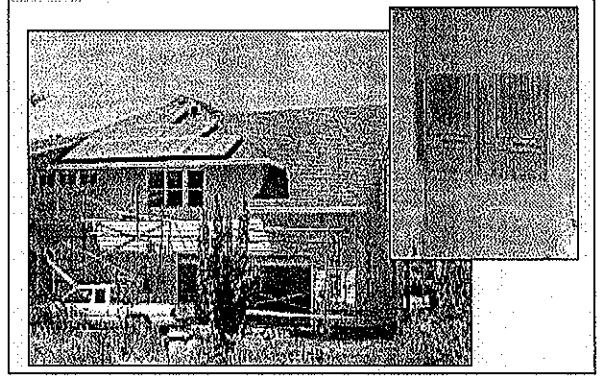

Xantrex GT Inverters

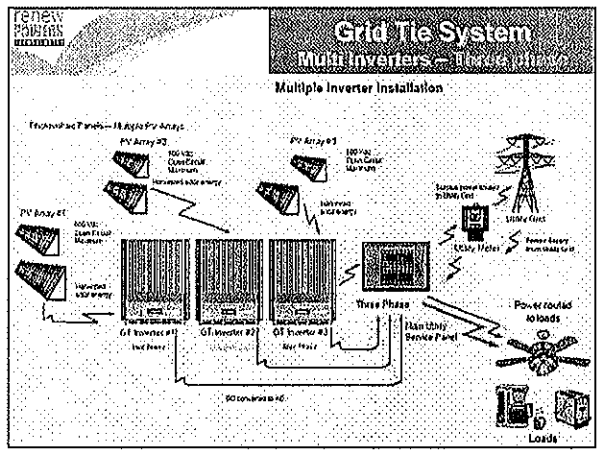
Grid Tie System
Multi Inverters – single phase

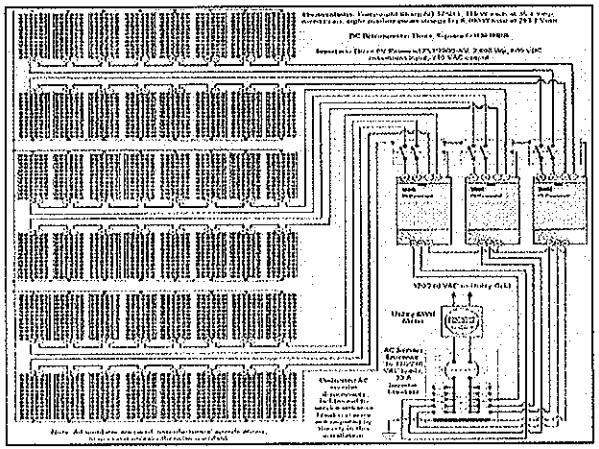


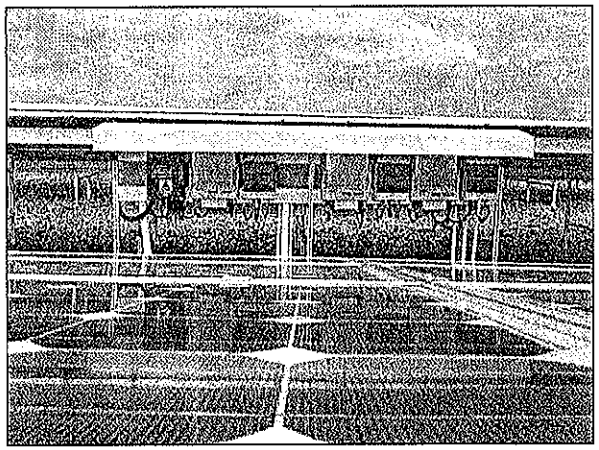


Xantrex GT Inverters





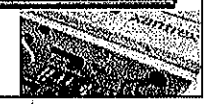




Communications

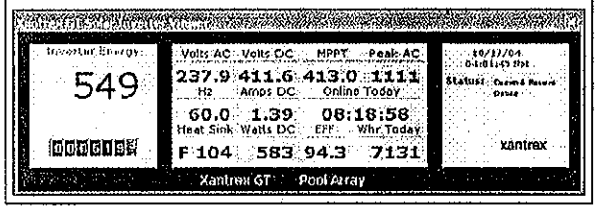
Full featured local display
- Backlit 2 line 16 character
- "Knock sensor" feature
  - Turns backlight on & cycles displays
- 2 custom installer screens available in firmware
- Night time operation with low draw aux power

Included Comm Ports
- Isolated RS232 + 2 RJ45

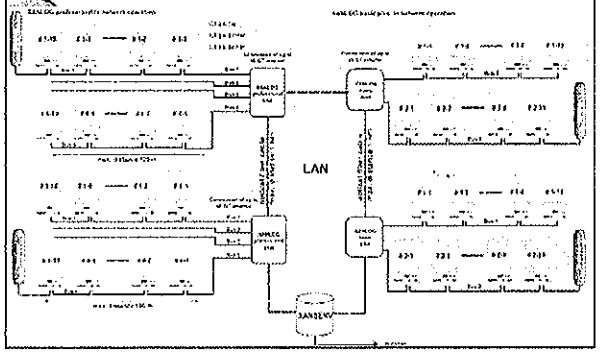


PC Monitoring Software

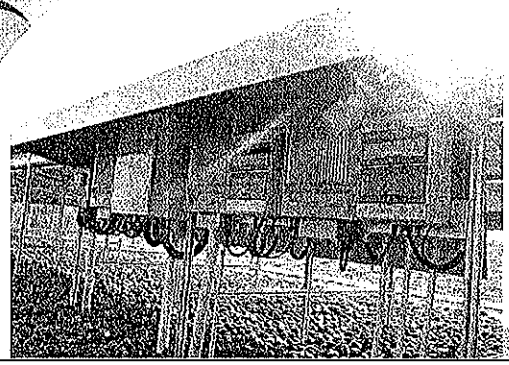
- "GT View" is free to download from www.xantrex.com/gridtie
- RS 232 single inverter monitor
- Web based upload capability
- Multiple instances of application can be run if multiple inverters are used



Network Communication



DC & AC Connection



3. Mounting PV Modules Design Cable Losses



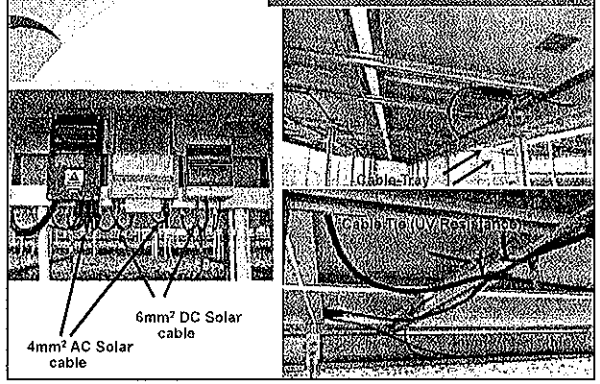
✓Solar Cable
- ➢Double-Insulated
- ➢ Heat Resistance (-15°C to 90°C)
- ➢ UV & Water-Resistant
- ➢ Rated for higher voltage (1000V)
- ➢Flame resistance

The system's careful design should consider proper wire sizing allowing for efficient operation. The most important parameter is the wire section.
- ✲ *Inappropriate wire sizing could result in excessive heating and even fire due to large current.*

➢ Properly connected and sized wiring won't require any maintenance for years.

➢ A simple rule to follow in small systems is 1 mm² wire area per 1A current. Its application will prevent wire overheating and curb loss within required limits.

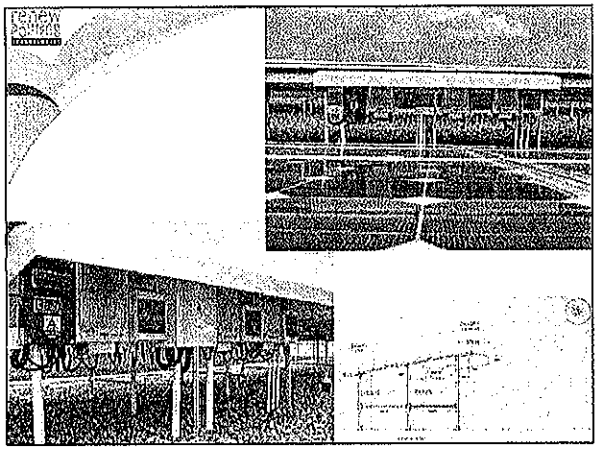
3. PV Mounting Structure

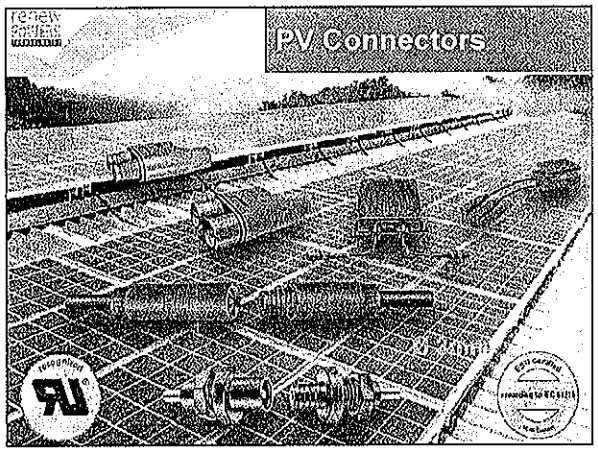


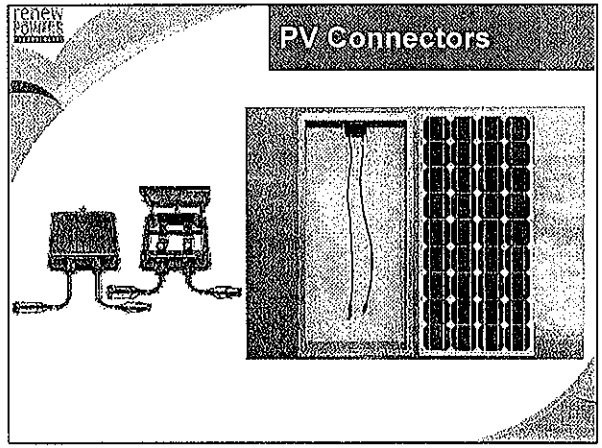
Cable
UV cable tie
Avoid exposure to weather

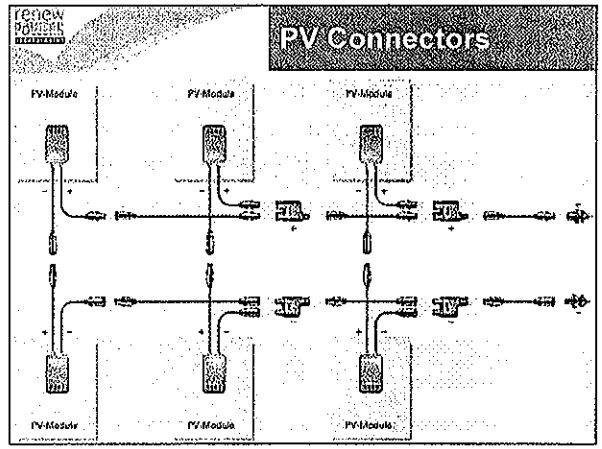
Install shape over inverter
selection of inverter important.

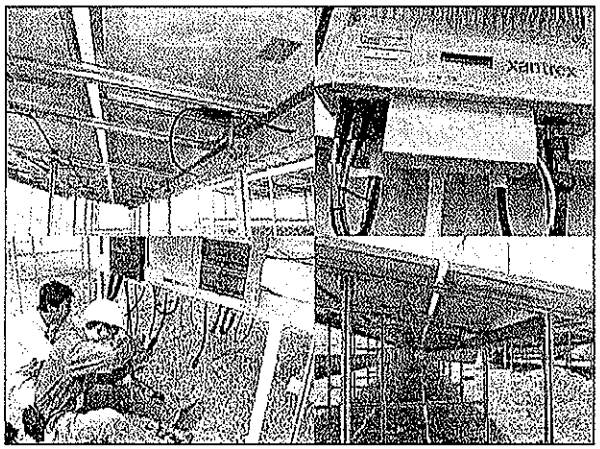
shading to
ensure - no
direct sun.

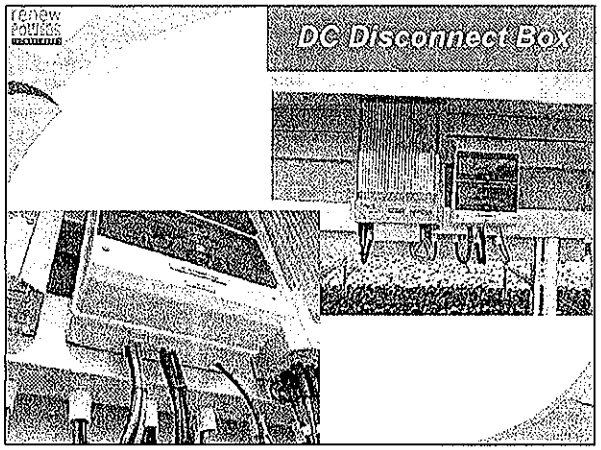


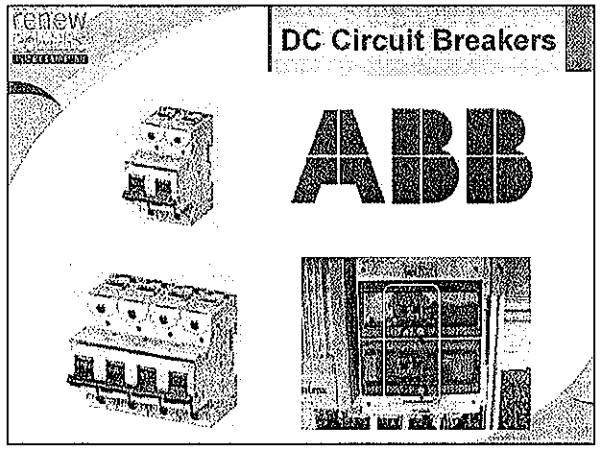




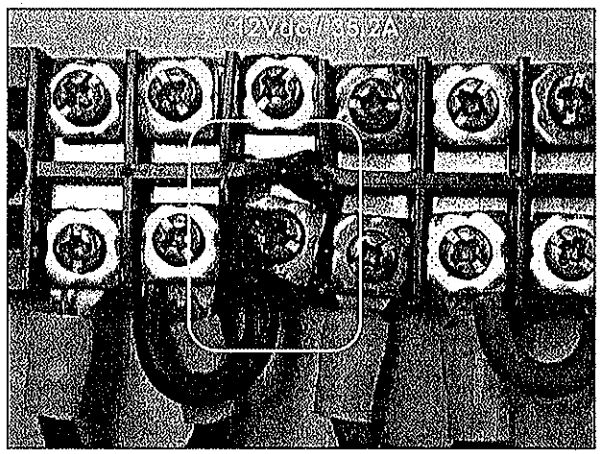


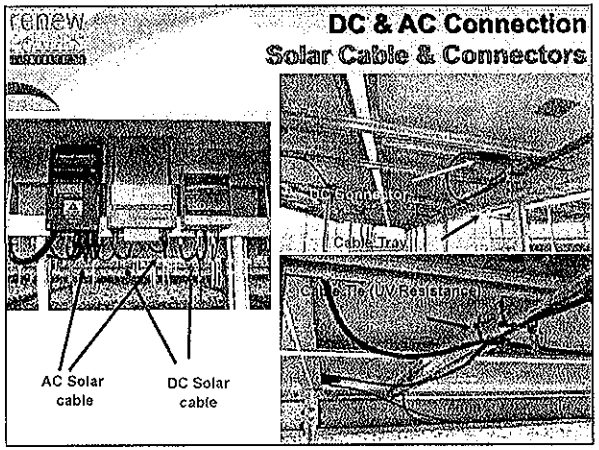


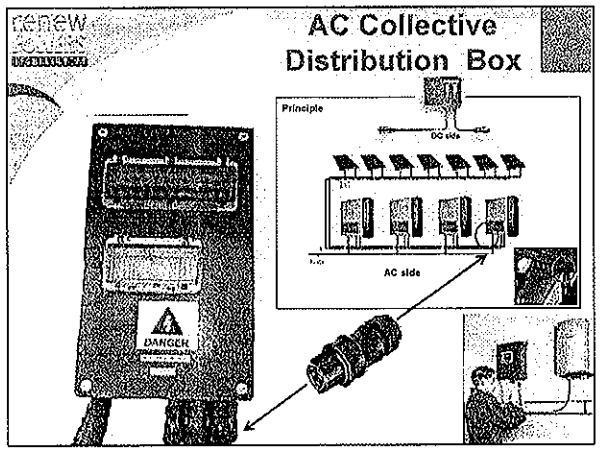


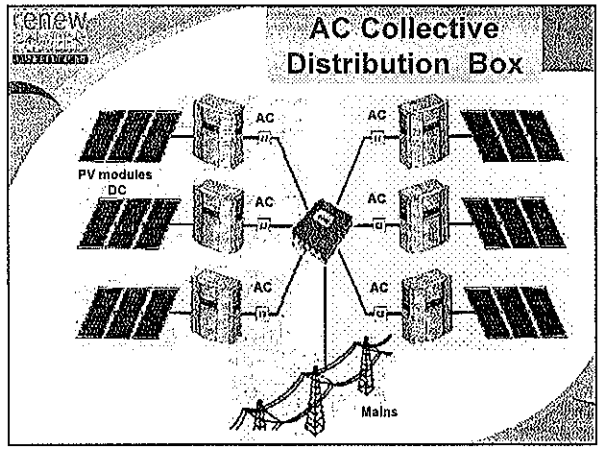


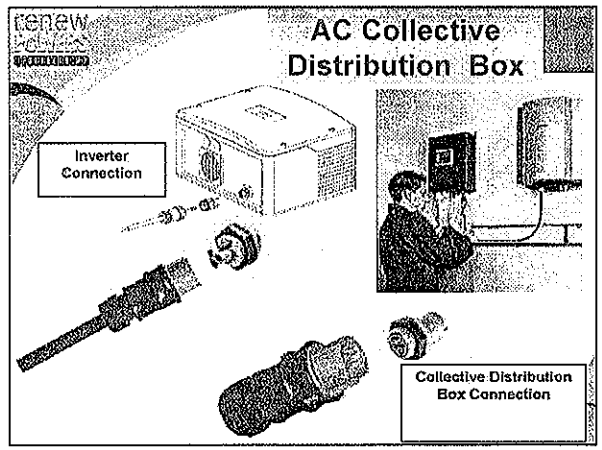
dc-problem — takes time



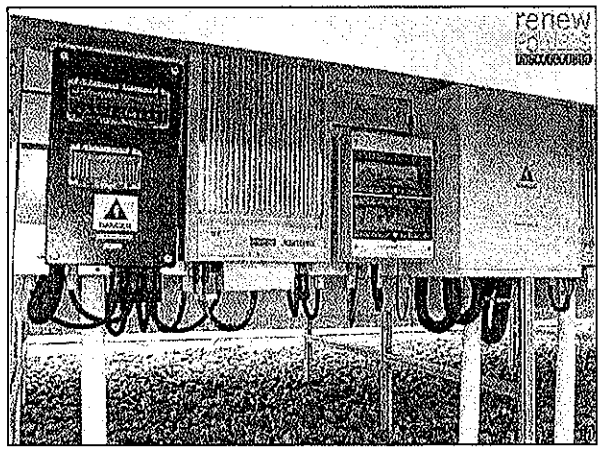

renew
DC & AC Connection
Solar Cable & Connectors
Cable Tray
AC Solar cable
DC Solar cable

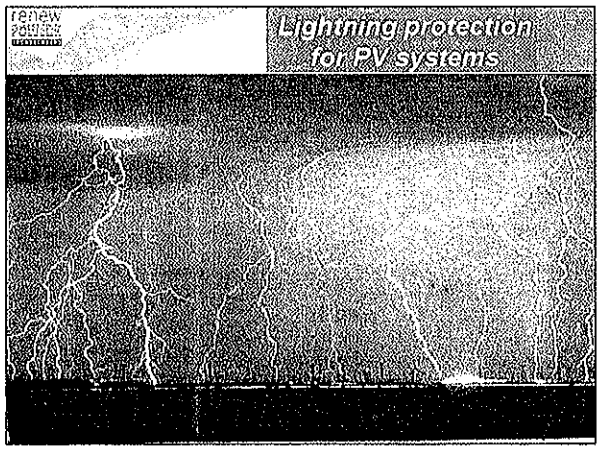

renew
AC Collective Distribution Box
Principle
DC side
AC side
DANGER

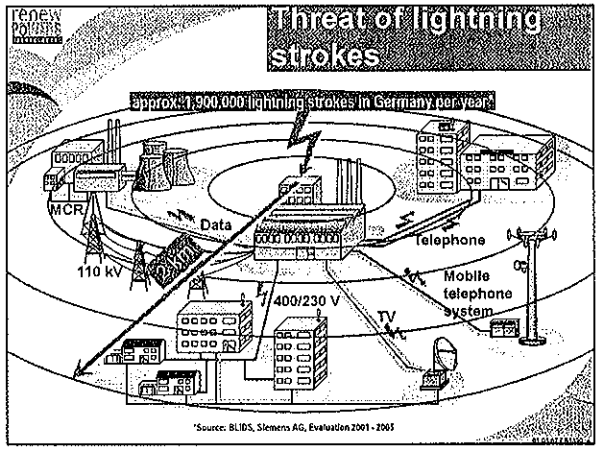

renew
AC Collective Distribution Box
PV modules
DC
AC
Mains

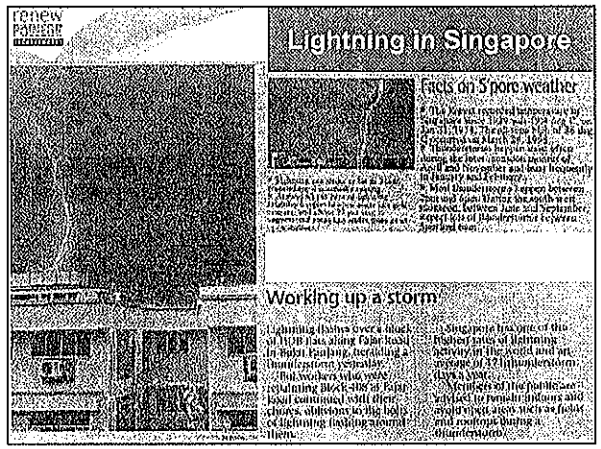

renew
AC Collective Distribution Box
Inverter Connection
Collective Distribution Box Connection

IP65

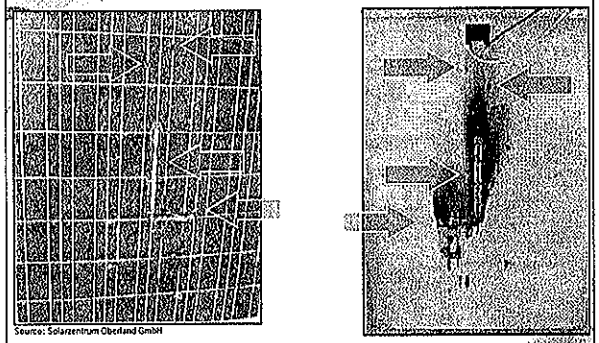



Lightning protection for PV systems

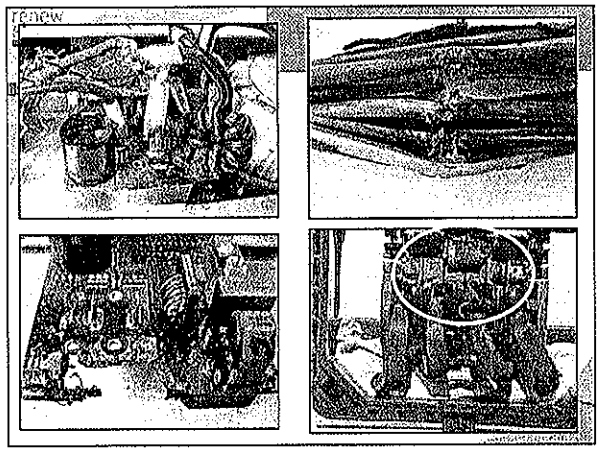

Threat of lightning strokes
approx. 1,900,000 lightning strokes in Germany per year*
MCR
Data
110 kV
400/230 V
telephone
Mobile telephone system
TV
*Source: BLIDS, Siemens AG, Evaluation 2001 - 2005


Lightning in Singapore
Facts on S'pore weather
Working up a storm

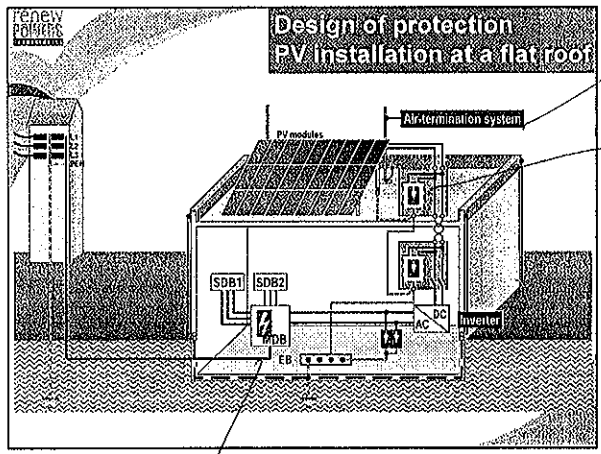
Damaged PV modules due to lightning strike



Source: Solarzentrum Oberland GmbH



Design of protection PV installation at a flat roof



Air Terminal

DC Surge Inverter

AC Surge Diverter

ABB DC Circuit Breakers & Surge Arrestors

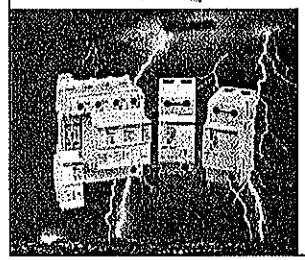
S800PV-S

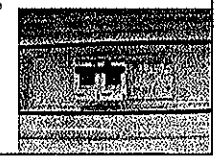
Photovoltaic String Protection

ABB

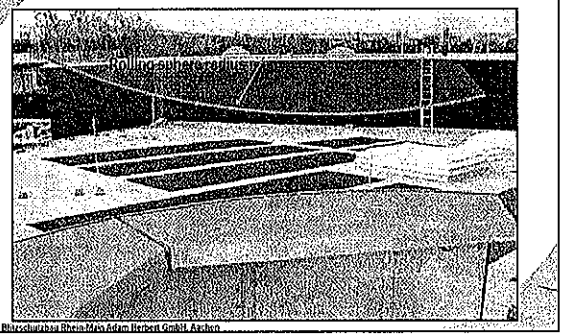
Overvoltage Protection

OVR Range



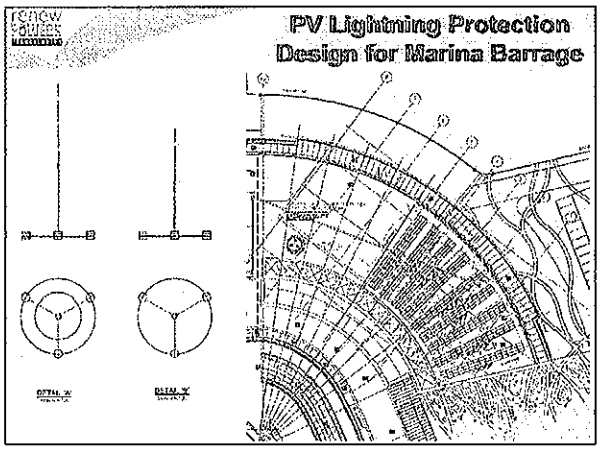


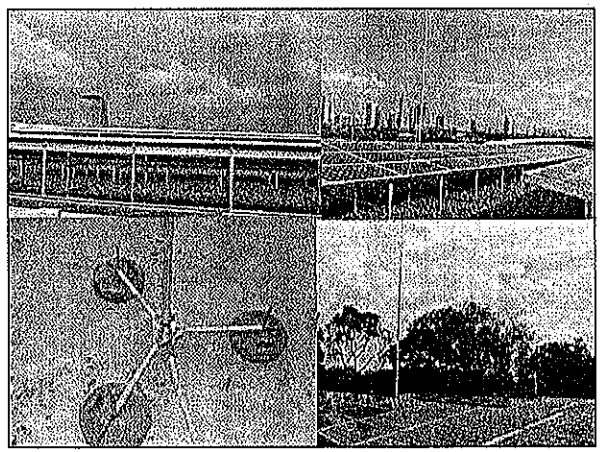
Lightning protection for an Evalon® Solar roofing membranes by means of UNI-SOLAR PV laminates

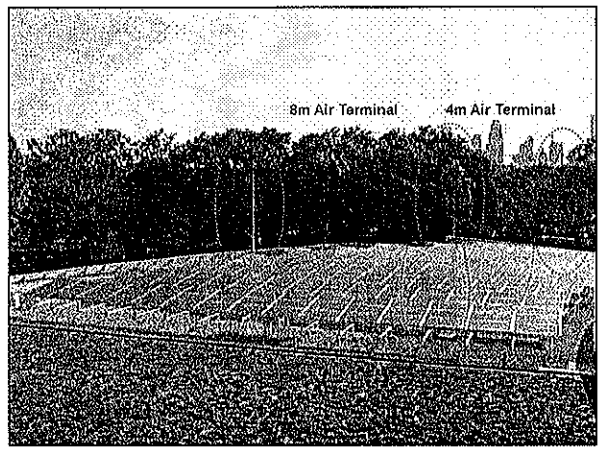


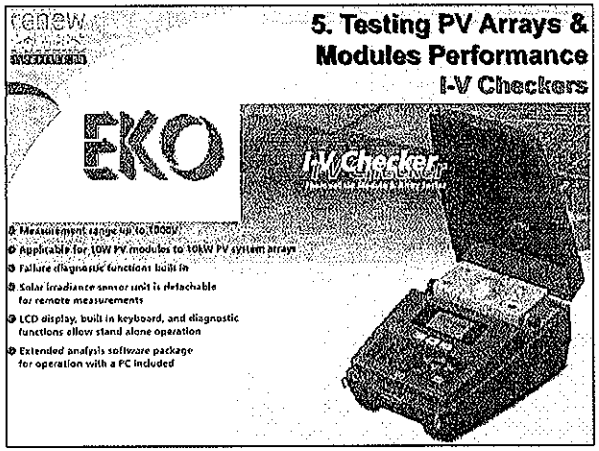
Source: Blitzschutzbau Rhein-Maas Adam Herbert GmbH, Aachen

PV Lightning Protection Design for Marina Barrage

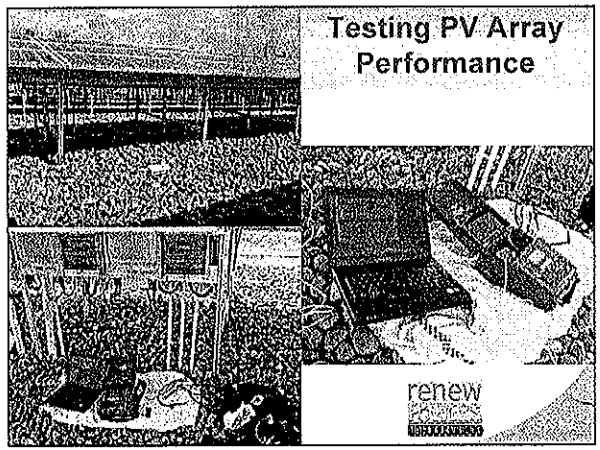




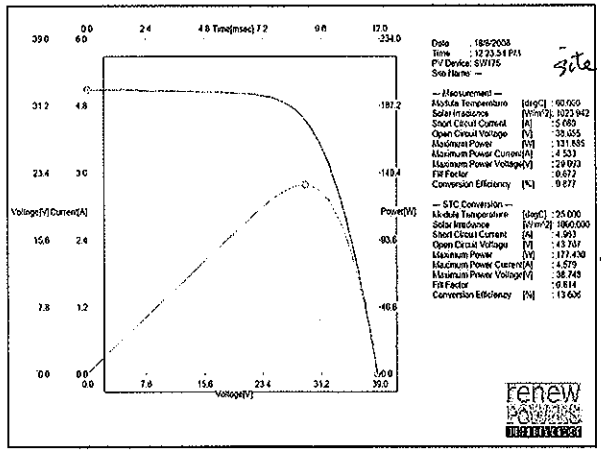




IV Checker



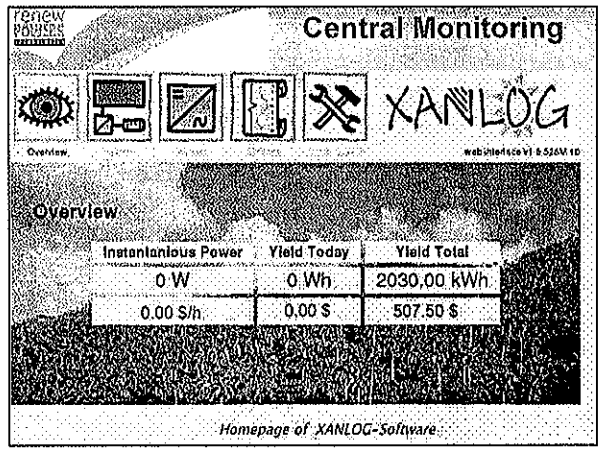
Cell Temp
Ambient Temp.



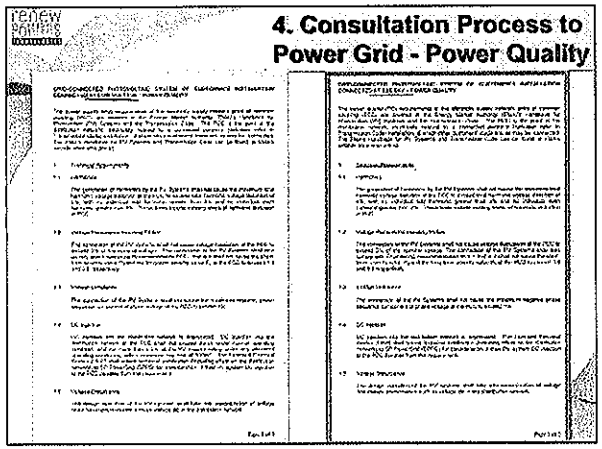
site

131 W (175W)

Ref back to STC

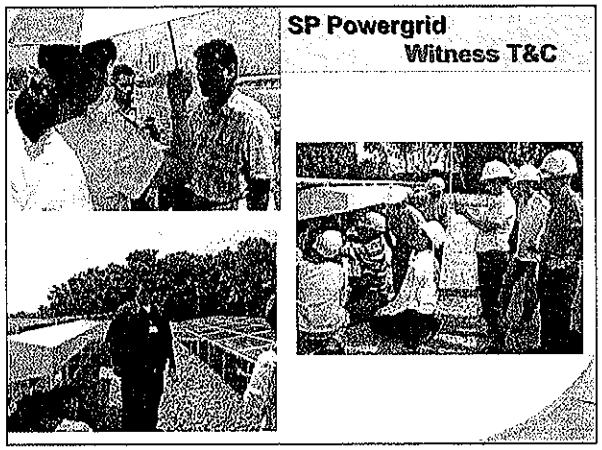


Power Quality — Report.
2 LEWs: Licensing needs to declare.

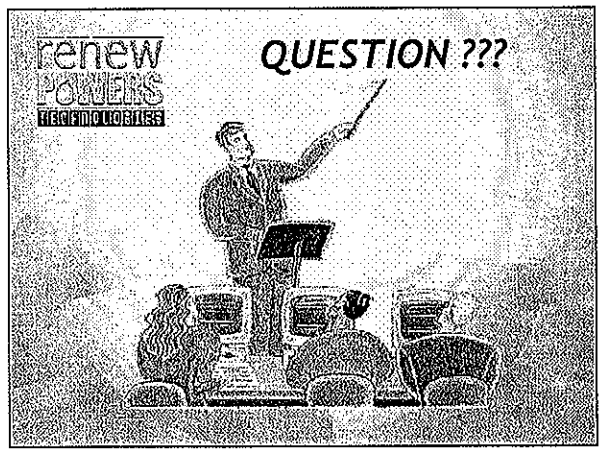


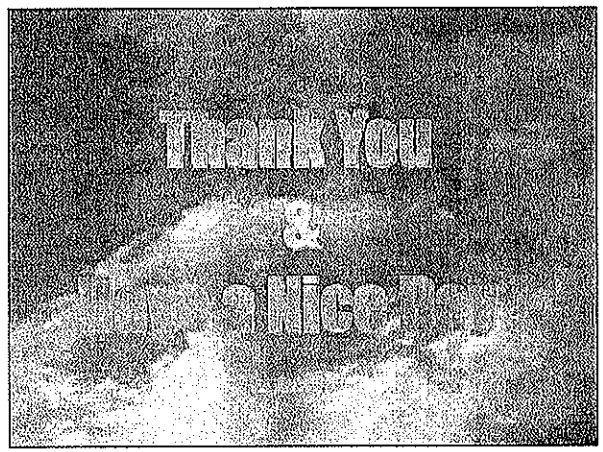
HV — Less problem.

LV
* DC injection problem
$\not>$ 20mA.
* Fluctuation: voltage: 415V or 22kV or 66kV. (Requirements)



Two important tests — turn off safety
— grid on → inverter turn on





BIPV Fundamentals

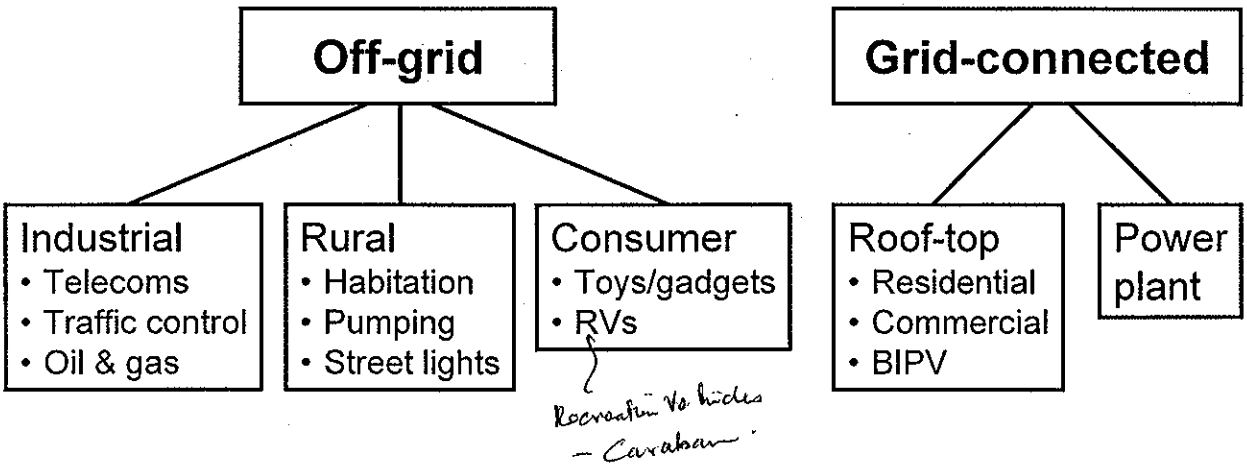
IES, 25 March 2009

Christophe Inglin
Christophe.inglin@PhoenixSolar.sg
Tel +65-6511 9339

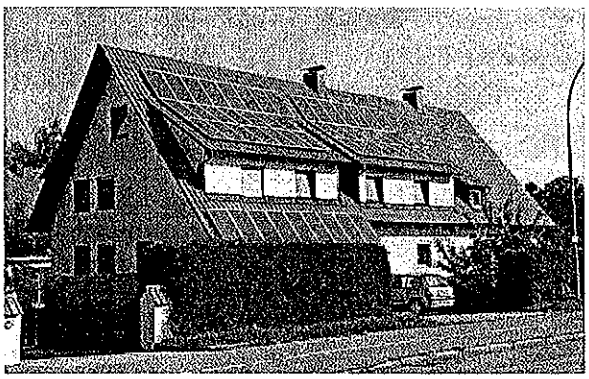
PV fundamentals - contents

- **What is BIPV?**
- **Grid-connected operation**
- **Good and bad locations for BIPV near the Equator**
- Case studies
- Range of technologies
- Energy yield and economics
- Conclusions

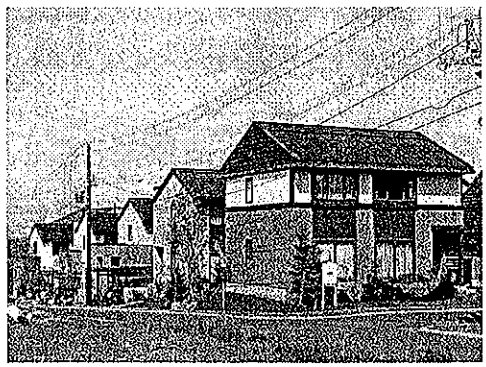
Many applications for Photovoltaics (PV)



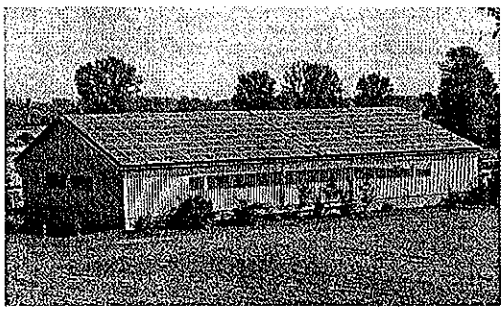
Worldwide, the grid-connected market dominates



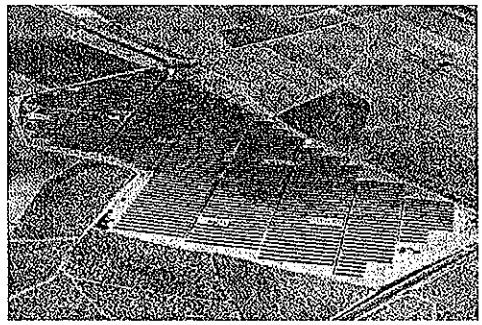
Residential rooftop PV system, Germany



Residential rooftop systems, Japan

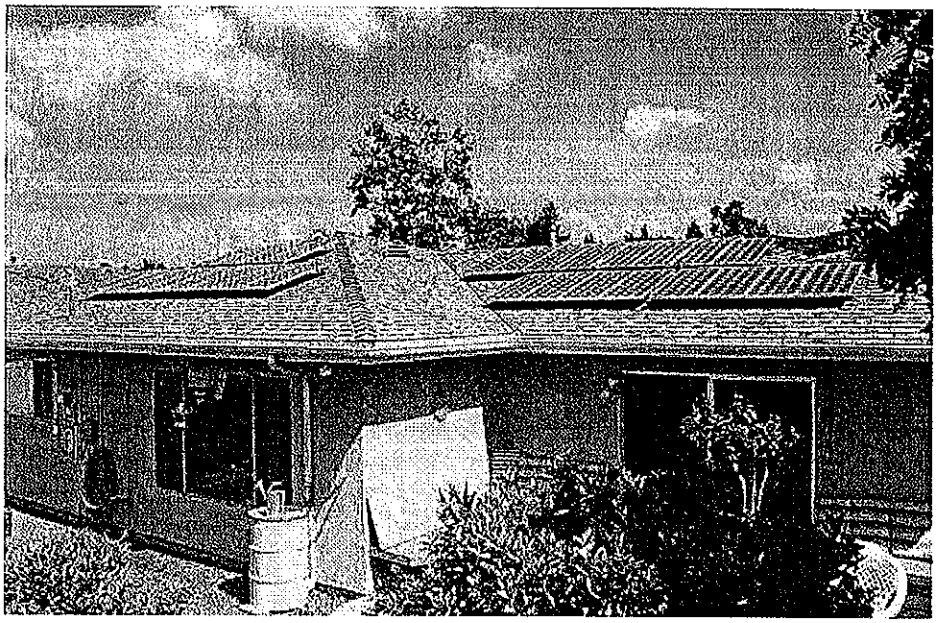


Commercial rooftop PV system, Germany



6.5MW PV power plant, Spain

Retrofit rooftop modules do not really enhance the aesthetics…



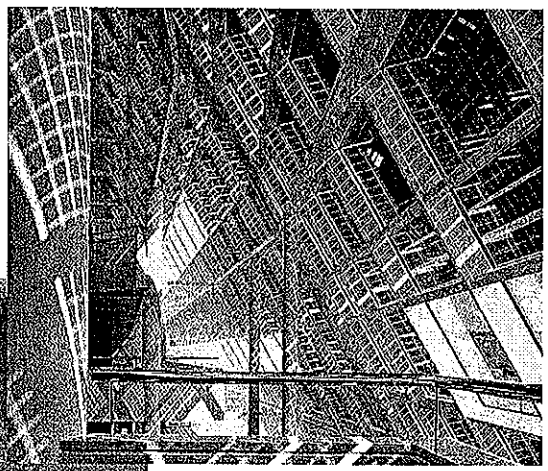
PV system on a California residential rooftop, ca 1998

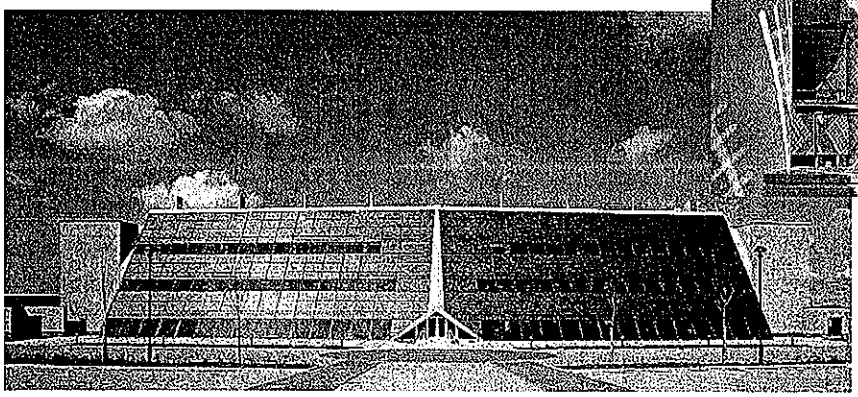
BIPV can make a strong architectural statement

Dramatic façade and lively light play at the Solar Office Doxford International, UK.

Awards:

Eurosolar Award 1999
Design Council Millennium Product Award 1999
Energy Globe Award 2000

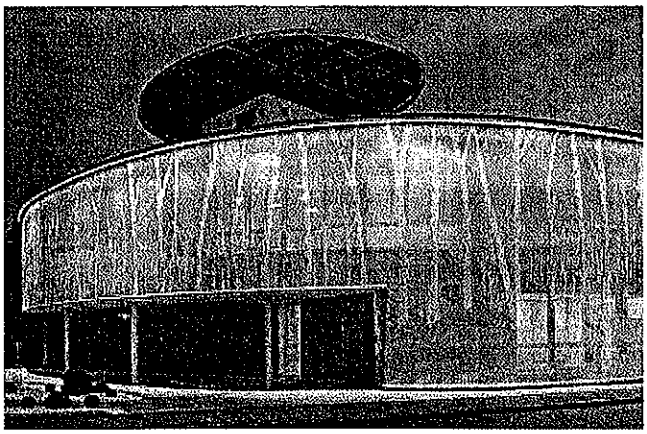




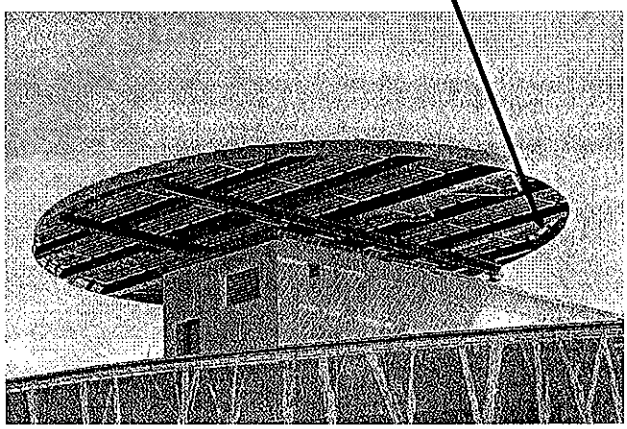
Client: Akeler
Architects: Studio E Architects
Main contractor: Bowmer & Kirkland

Images downloaded from IEA PVPS website: http://www.iea-pvps.org
Photos © Dennis Gilbert

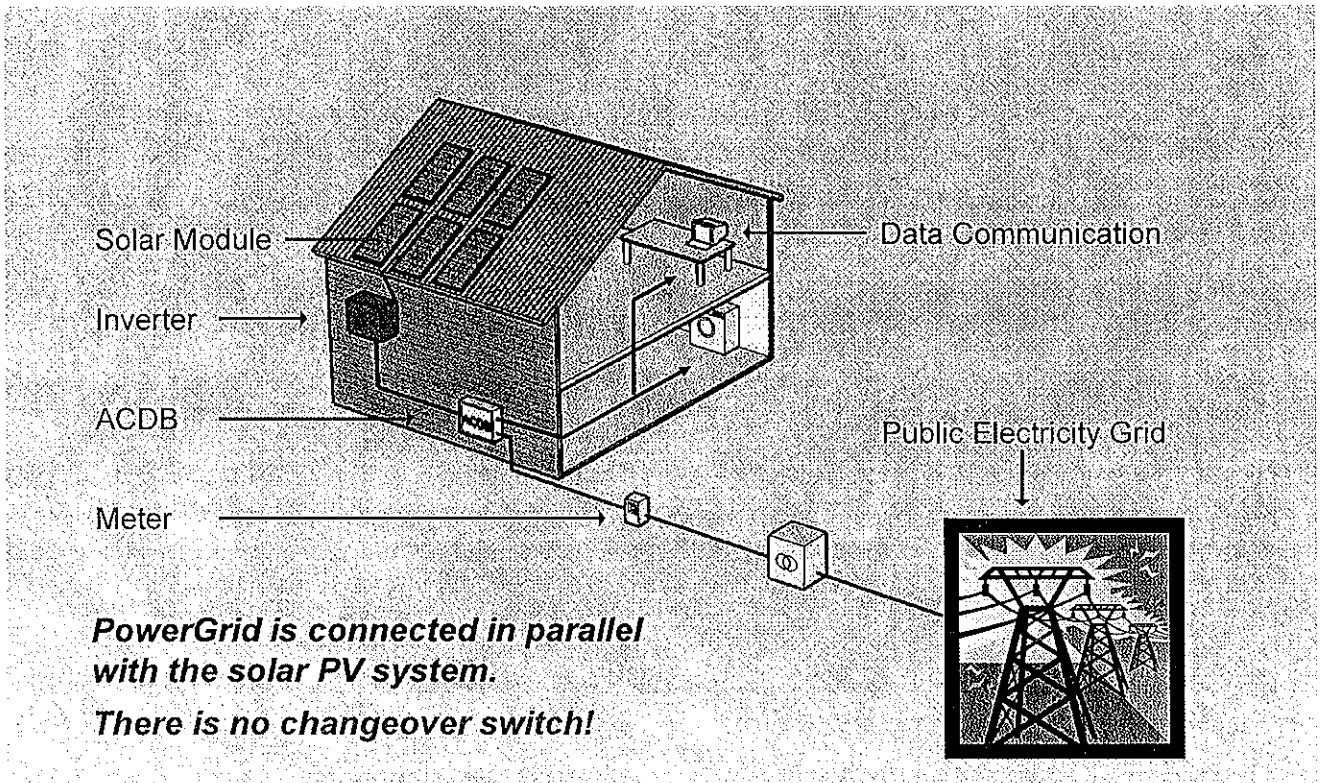
Fully customised BIPV puts an accent on a building



Perimeter modules have curved outer edge



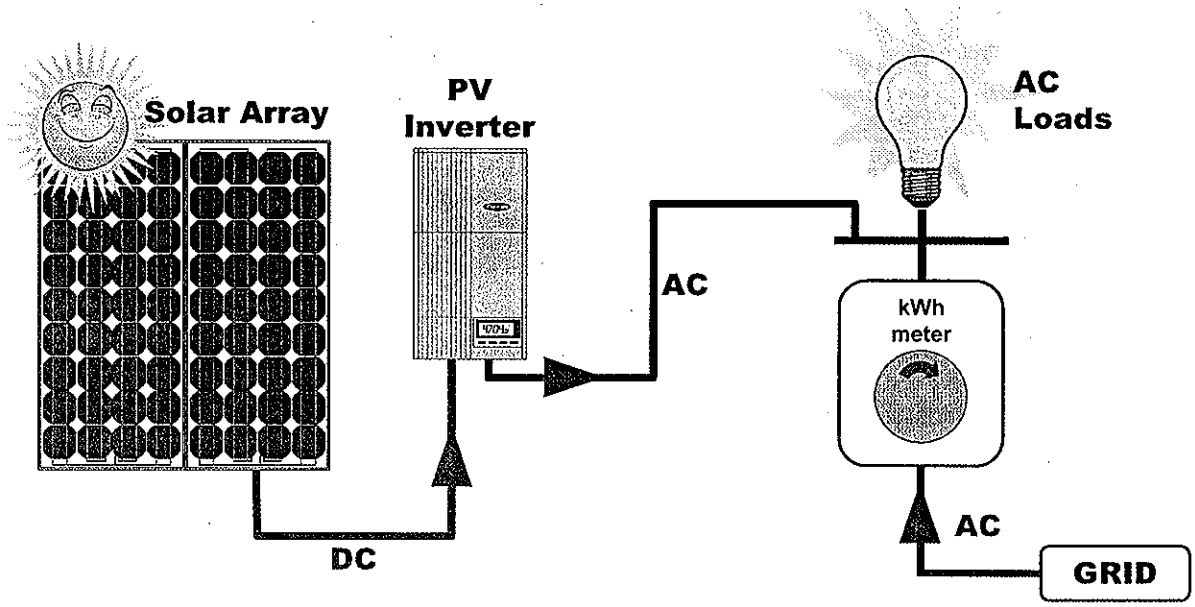
Grid-tied system configuration - very simple



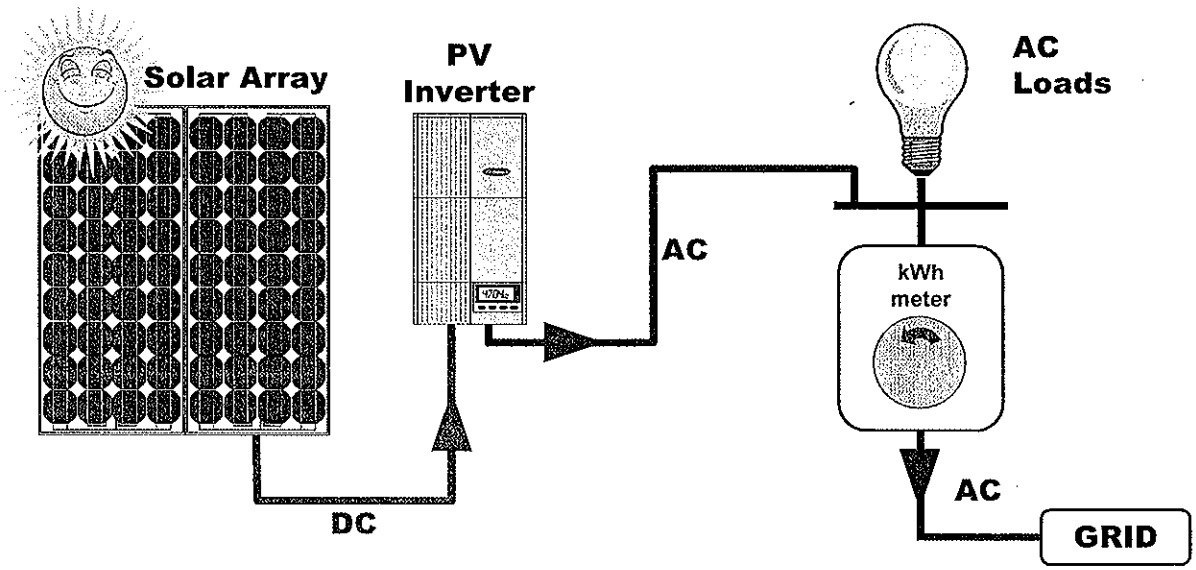
PowerGrid is connected in parallel with the solar PV system.

There is no changeover switch!

Daytime, PV + grid jointly supply the load

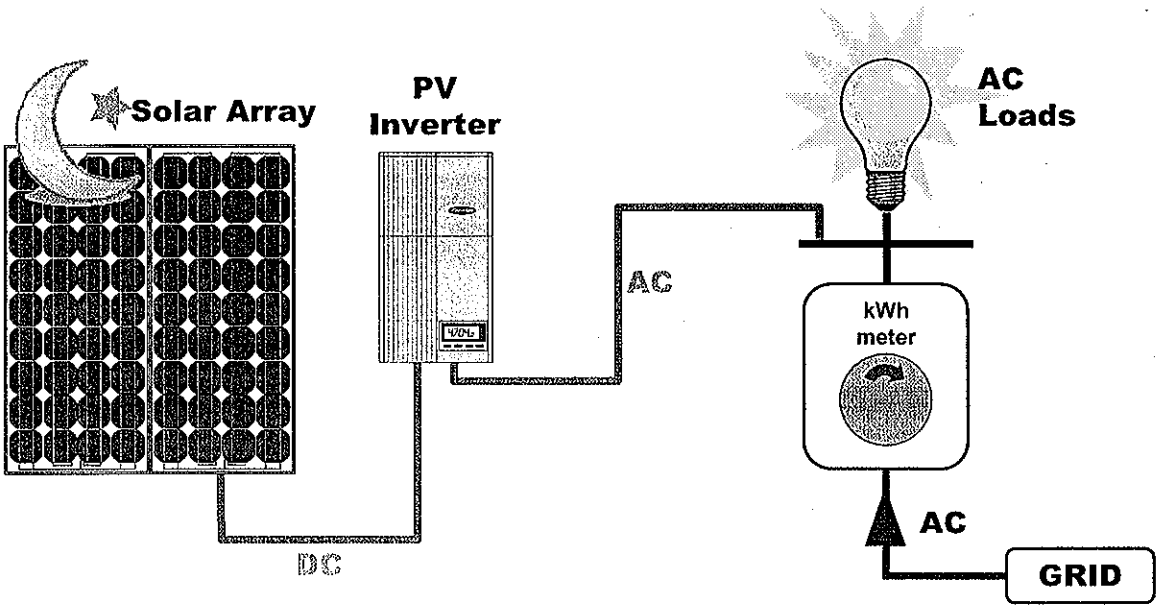


Daytime (load switched off) - PV feeds into PowerGrid



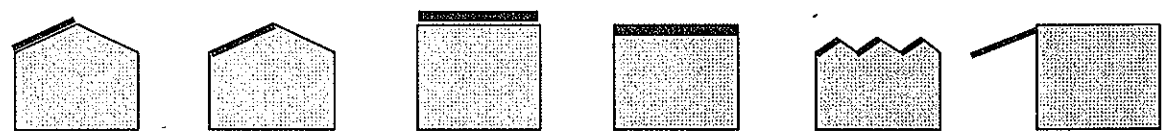
No battery for 8' pre application.

Night-time, load powered by grid only

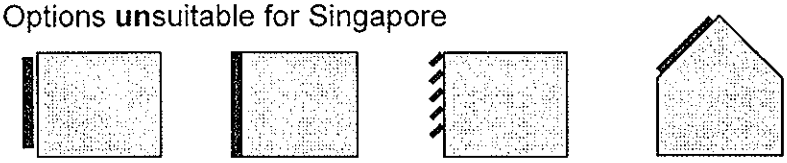


Many options for installing BIPV

Options suitable for Singapore

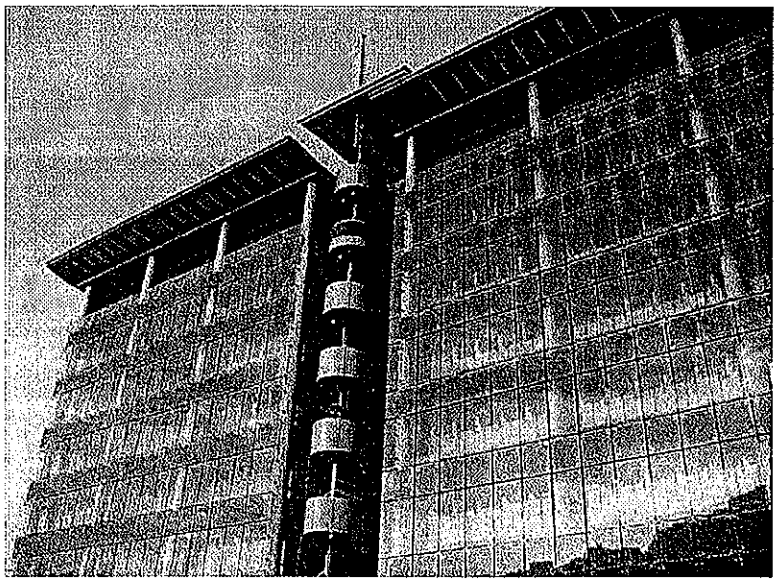


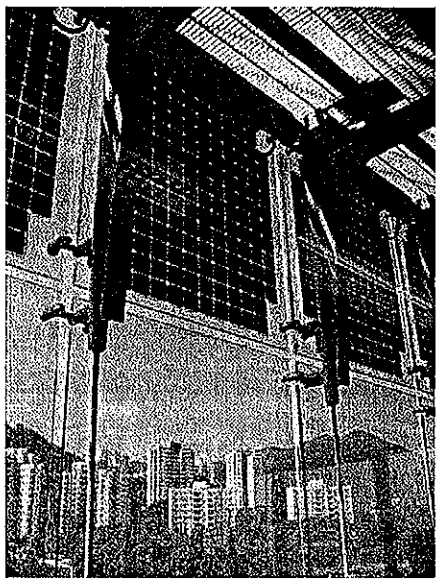
Options **un**suitable for Singapore



BIPV façades look high-tech, but suboptimal for equatorial sun

84kWp BIPV façade on HK Science Park's Innovation Centre

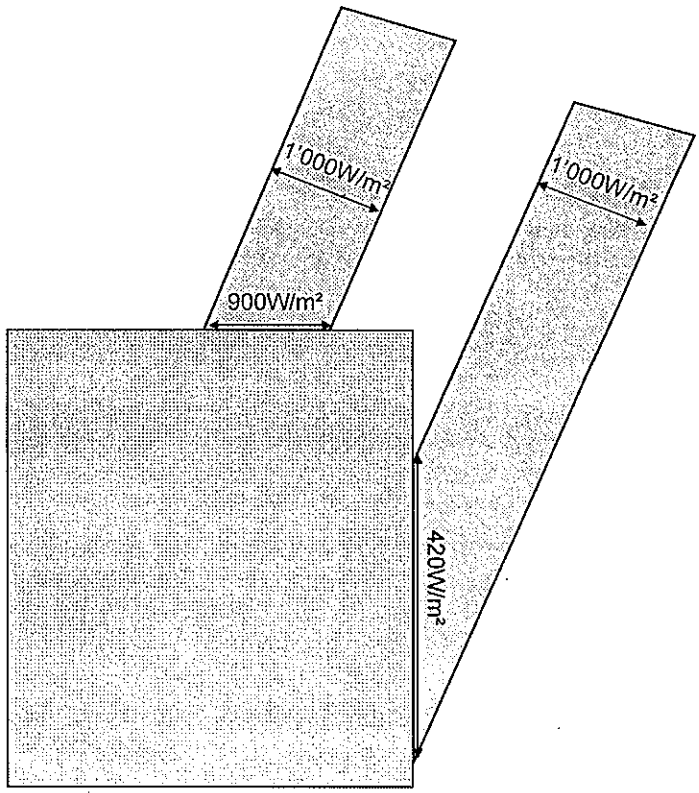




Client: HK Science Park
Architects: Architectural Services Department of Hong Kong
Main Contractors: Dickson

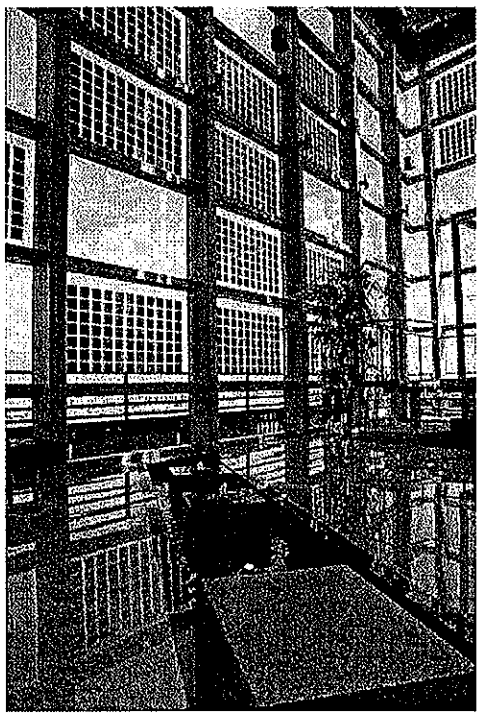
Near the Equator, the sun shines overhead!

- Equatorial sunshine strikes the roof more intensely than the walls
- Obstructions cast only short shadows on the roof, but long shadows down the walls (that's why even small window shades are effective!)



Biopolis Visitor Centre boasts Singapore's first BIPV façade

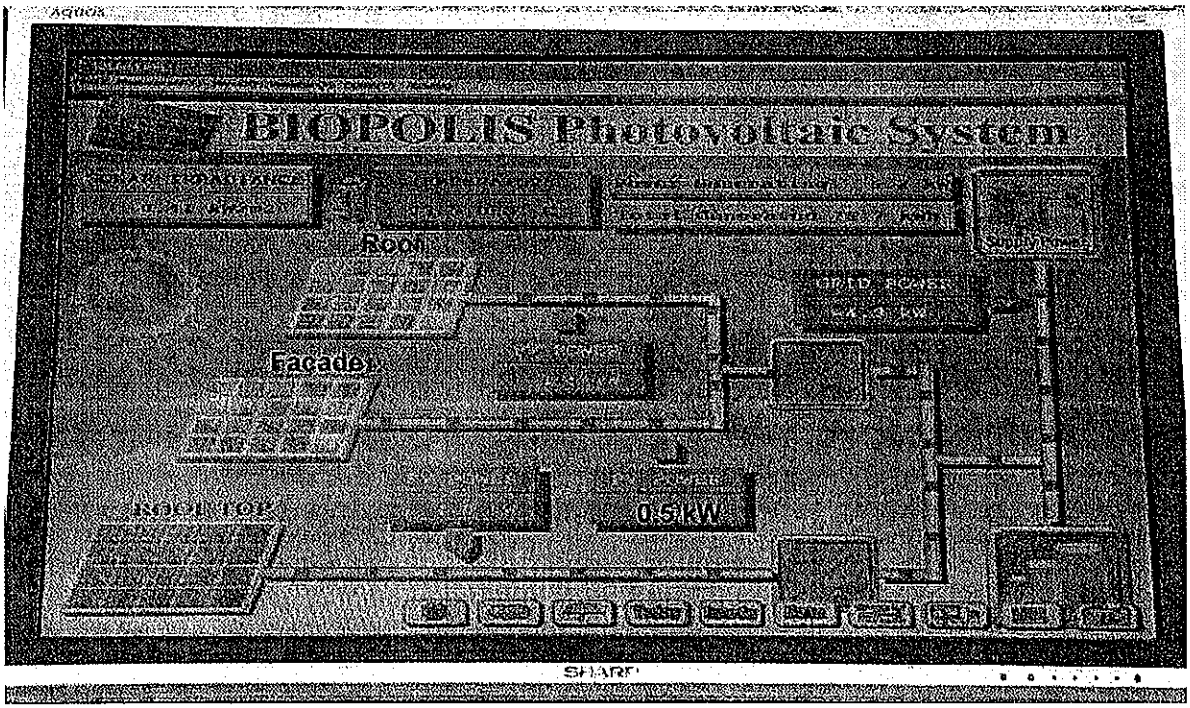
Full-custom: large laminates



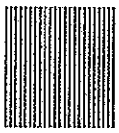
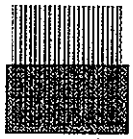
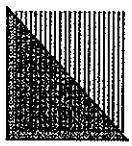
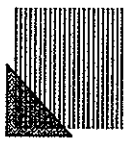
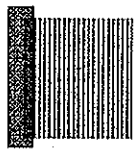
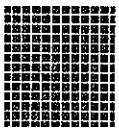
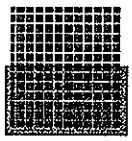
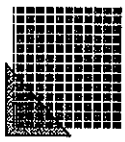


Owner: JTC Corporation
Master Planner: Zaha Hadid Architects Ltd
Project Manager: Jurong Consultants Pte Ltd
Main Contractors: (Superstructure) Samsung Corporation

Façade generates <25% of roof canopy's power

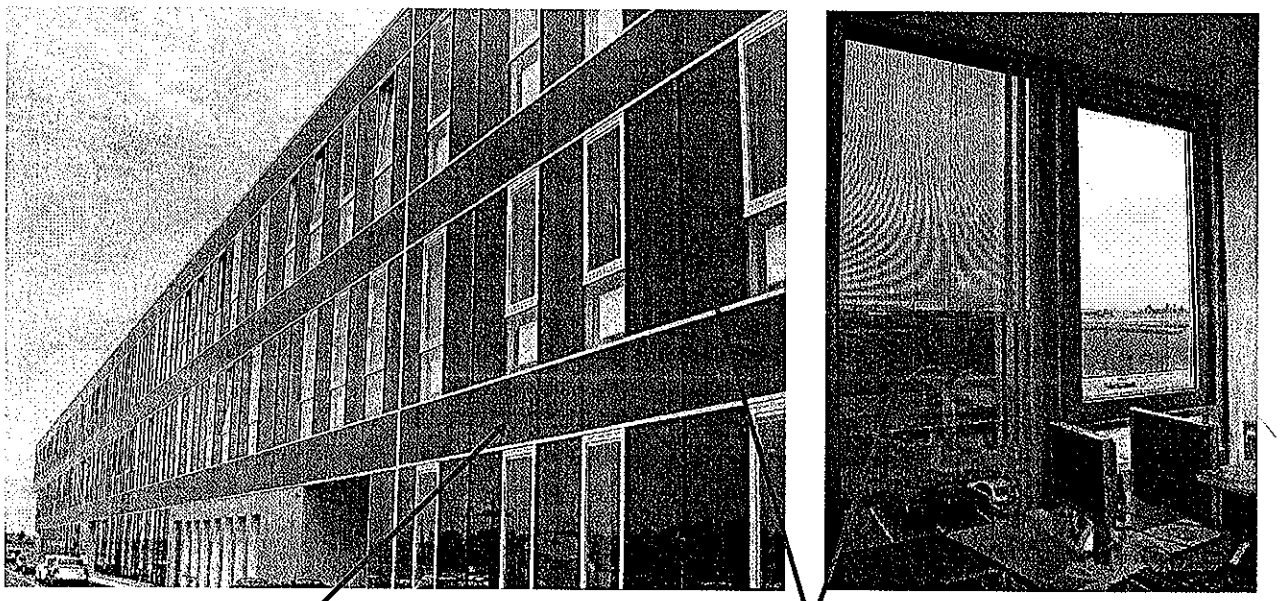


Long cells on thin film modules tolerate shade better

Thin film module (10Wp)					
Shading	**None**	**50% vertical**	**50% diagonal**	**12.5% diagonal**	**2 cells**
Thin film power [W]	**10.6**	**5.3**	**1.1**	**8.5**	**6.9**
Crystalline power [W]	**11.2**	**2.7**	**0.1**	**4.9**	
Crystalline silicon module (12Wp)					

Equatorial façades will work better with thin film technology

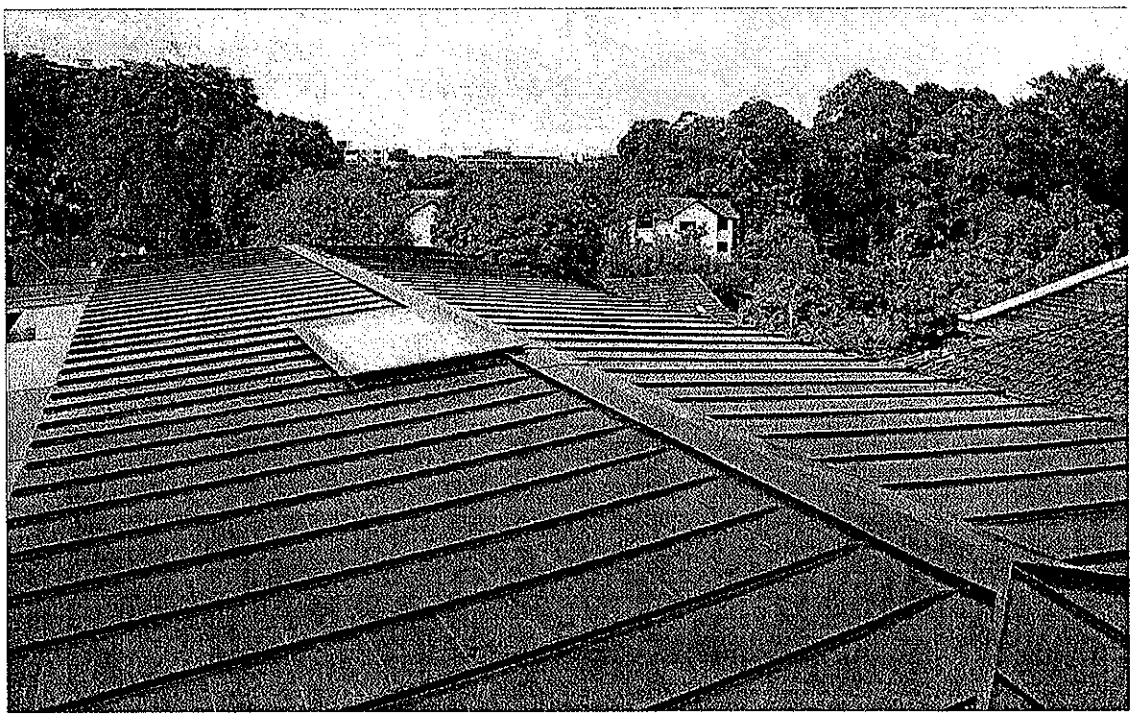
Audi IT Centre with 60kW of amorphous silicon thin film BIPV



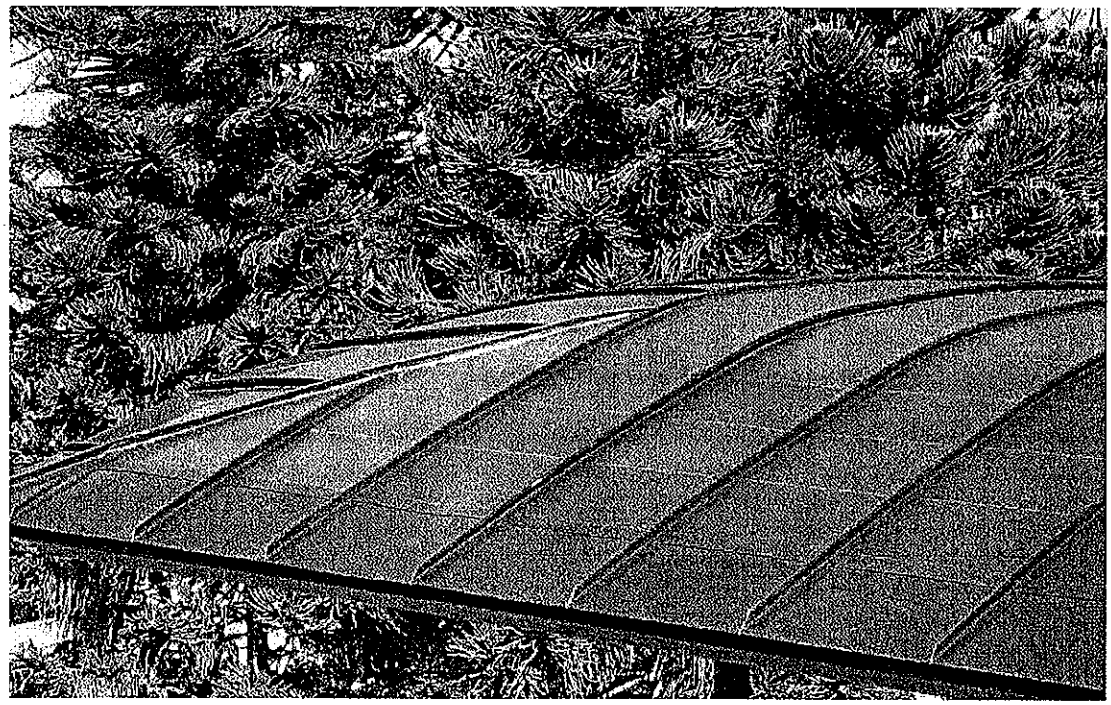
Case studies in Singapore and the region

1. Flexible thin film technology
2. Rigid thin film technology
3. Crystalline silicon technology
4. BIPV – crystalline and thin film

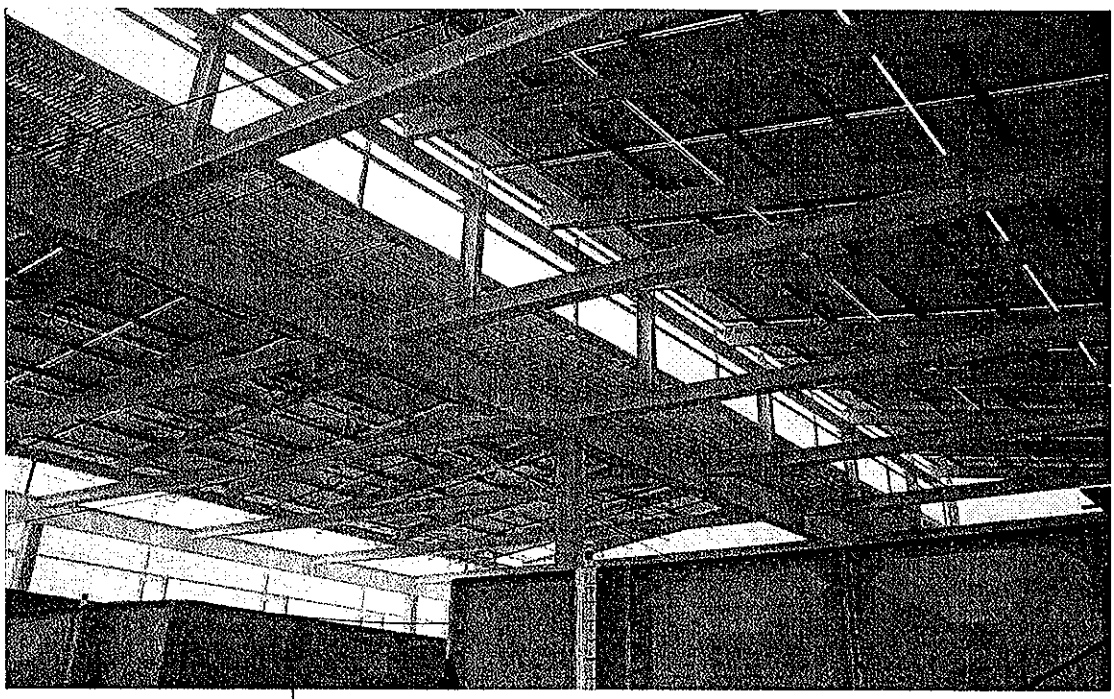
Flexible thin film laminates blend in with this roof



Flexible thin film laminates on a curved roof

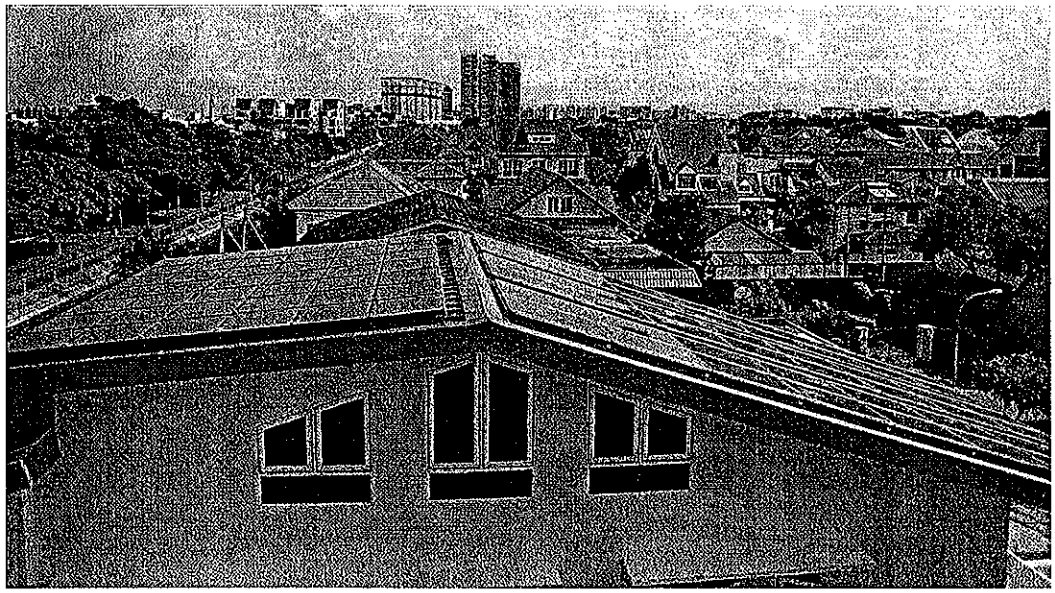


Rigid thin film array above a water tank – 10.2kWp



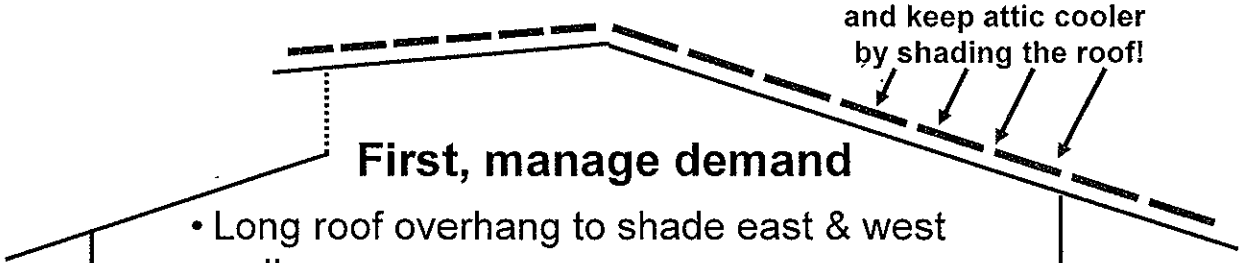
CI Tank

Zero Energy Home – rigid thin film 8.58kWp



Zero-energy home features

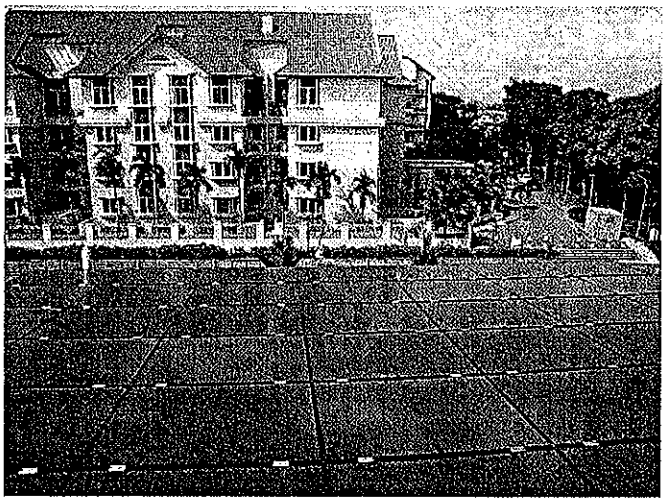
Solar modules on 75% of the roof generate approx 900kWh/month, and keep attic cooler by shading the roof!



First, manage demand

- Long roof overhang to shade east & west walls
- Inverter air con in upstairs bedrooms and study, but mostly only use ceiling fans and natural ventilation
- ***No air con downstairs at all*** – plenty of fans
- **Energy consumption <25kWh/m²/yr**

Zero Energy Home features two types of thin film PV

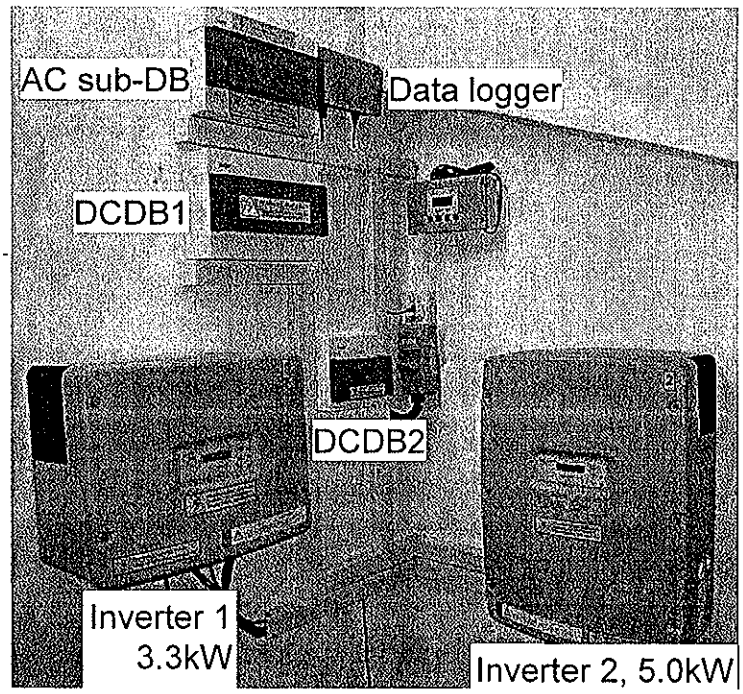


3'780Wp of thin-film modules fit nicely onto the upper west roof flank, covering an area of approx 8x6m, just allowing space to walk around the perimeter



4'800Wp of thin-film modules arranged in 6 columns on the east (front) roof, covering an area of approx 7x12m, including two gangways for maintenance.

Control centre in the attic – one inverter per PV array



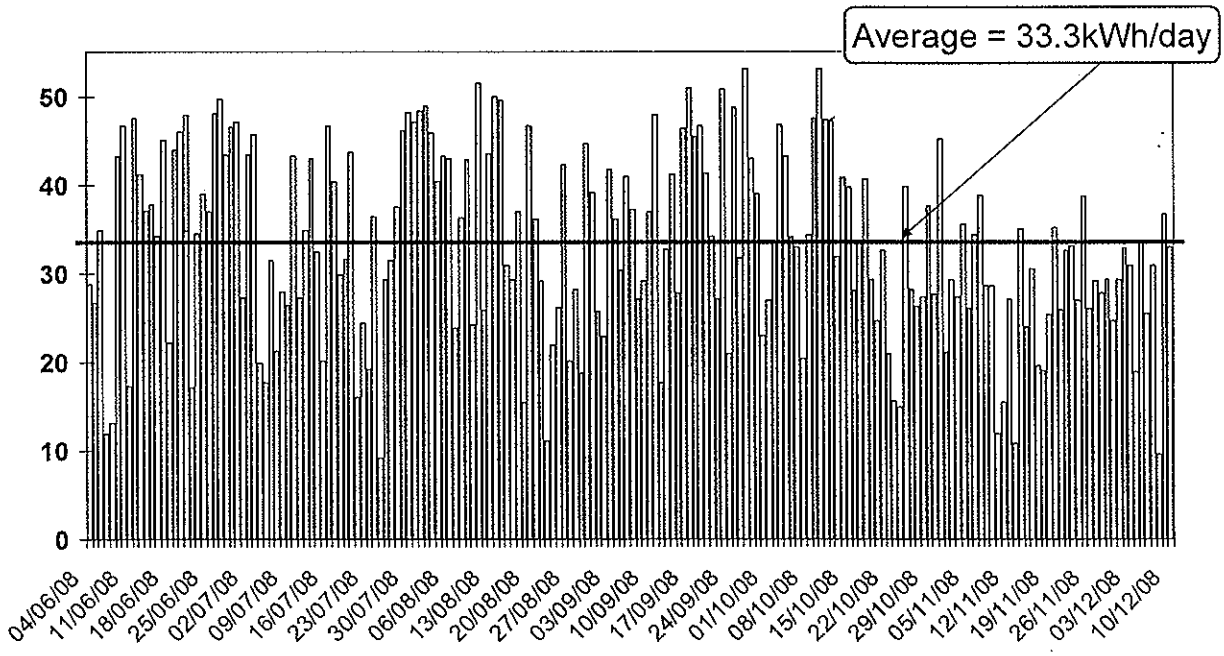
SP Services bill credits surplus electricity fed to grid

Utility Bill 24 July – 20 August 2008

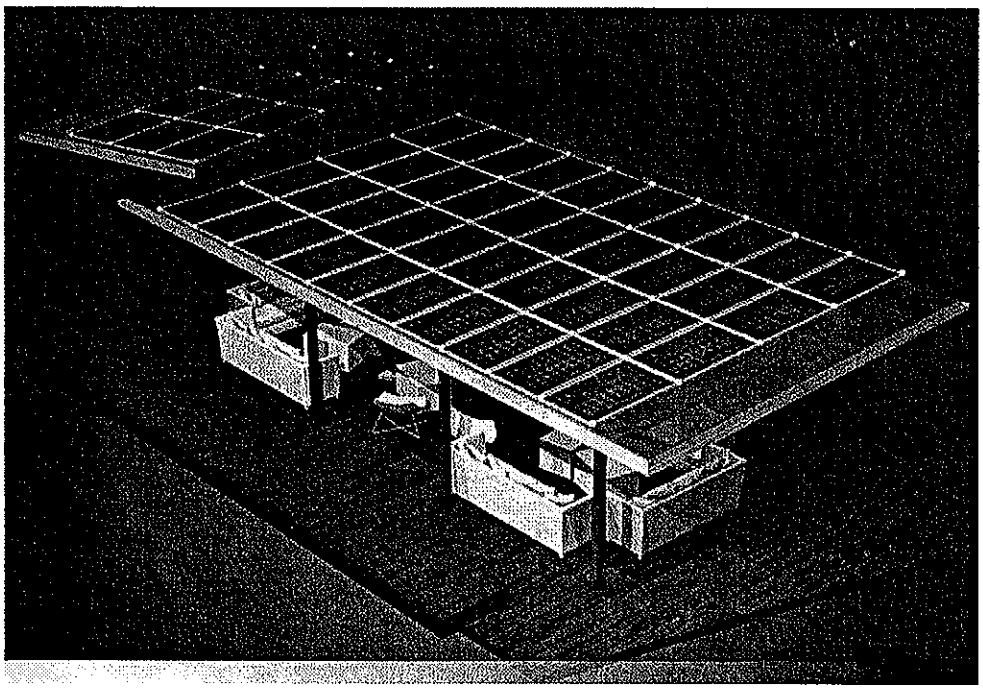
CURRENT MONTH CHARGES	Usage	Rate ($)	Amount ($)	Total ($)
Electricity Services				
Reading taken on 20-08-2008 : 1566				
Reading taken on 20-08-2008 : 908				
Import of elect for PV meters	358 kWh	0.2507	89.75	
Export of elect for PV meters	690 kWh	0.1972	-136.07	**-46.32**

Performance charts – daily energy since 4/06/08

Daily energy yield depends on sunshine intensity

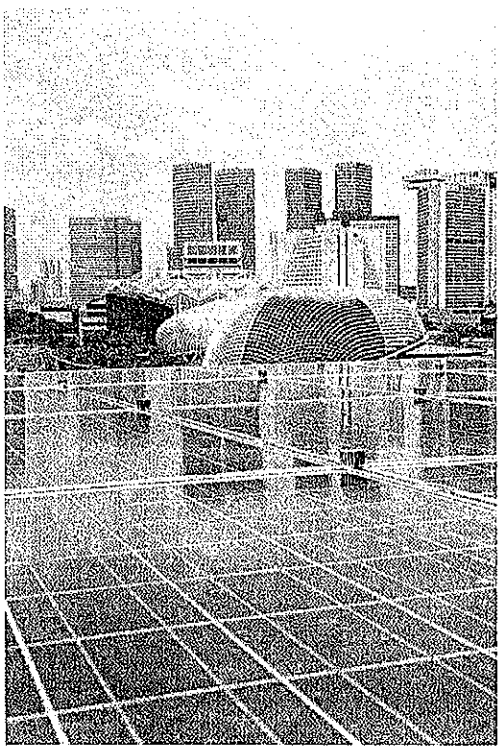


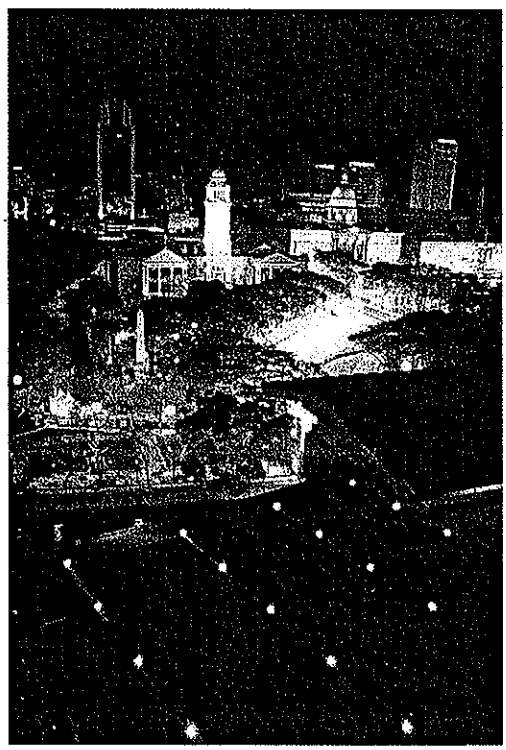
Low carbon VIP Sky Lounge with 11.4kWp PV canopy



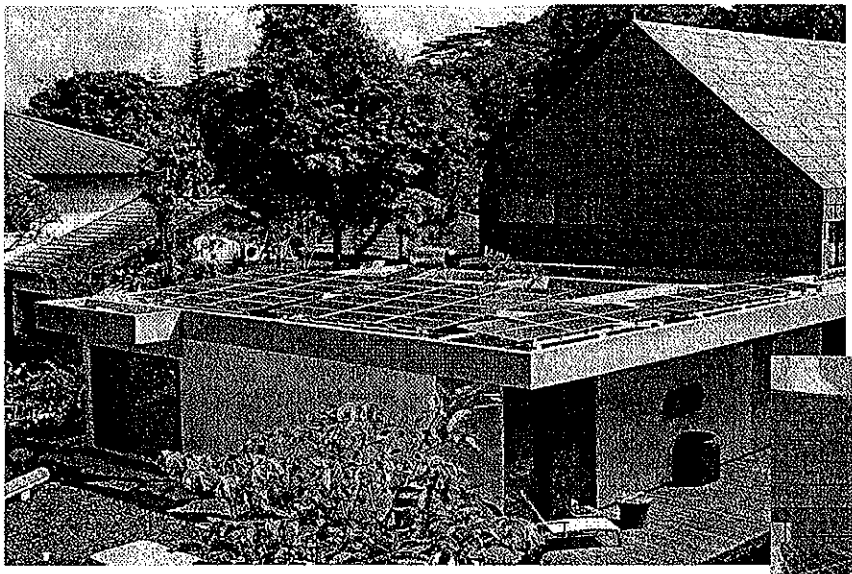
Rendering by Right-Space

Low carbon VIP Sky Lounge by day and night

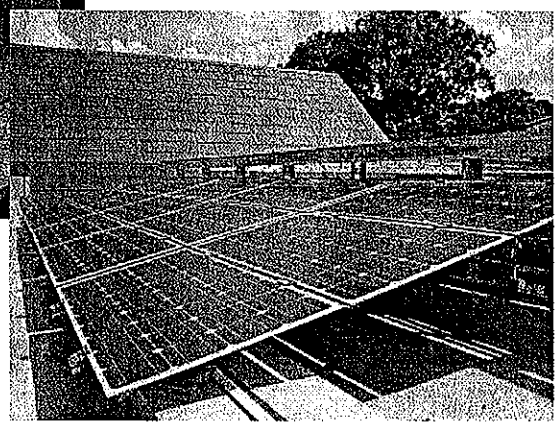




Sgp's largest residential PV system, 15.66kWp crystalline

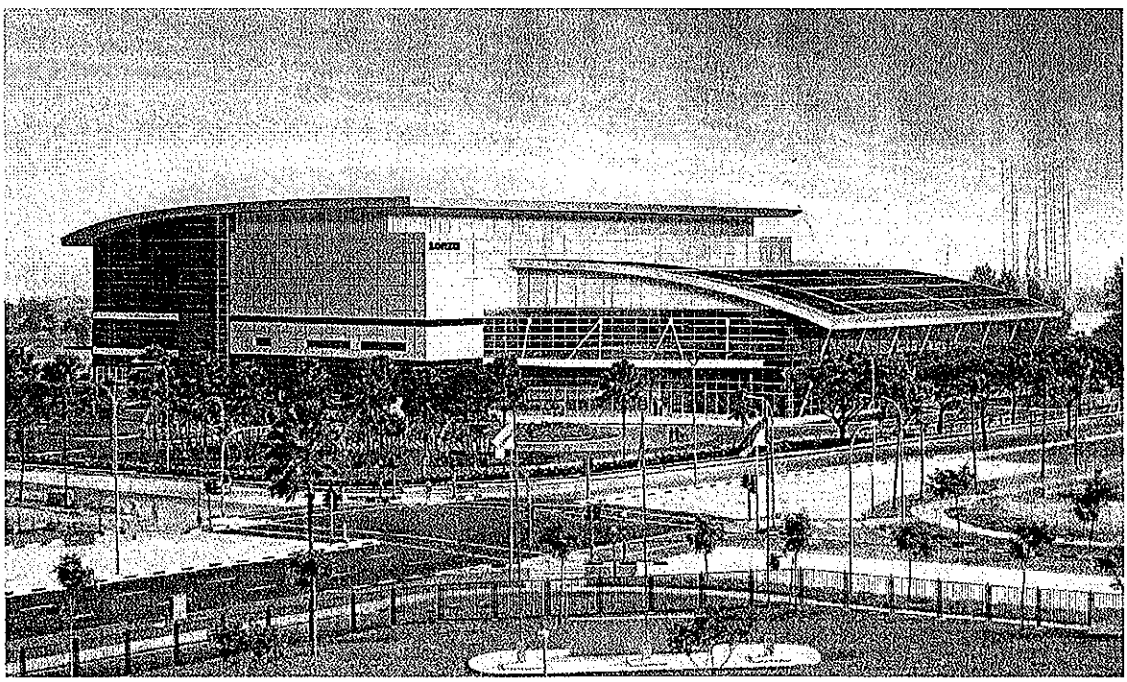


Arrays mounted at only 5° pitch are invisible from ground level



Frameless modules allow rain to wash off unimpeded, even at 5° pitch

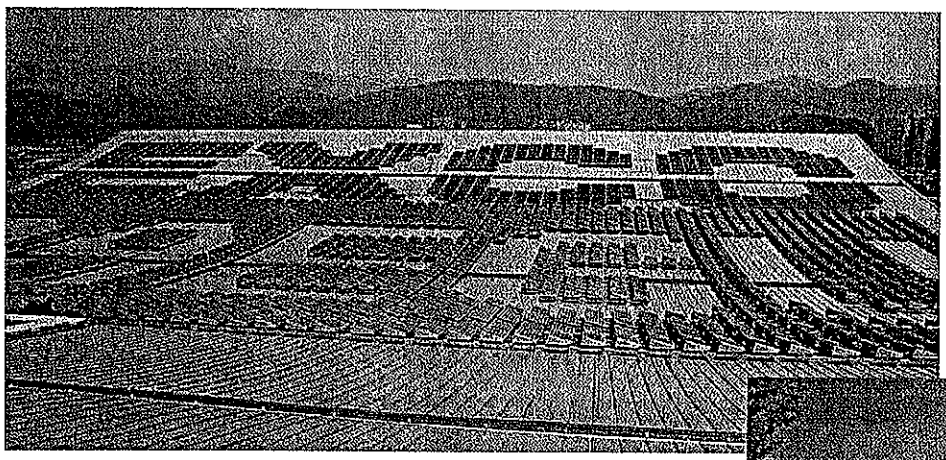
Lonza Biologics offers max yield with high visibility – 181kWp

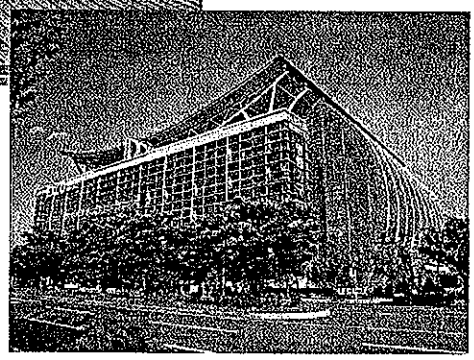


Rendering by RSP Architects Planners & Engineers Pte Ltd

The ultimate solar advertising logo

Standard multicrystalline modules applied to stainless steel roof





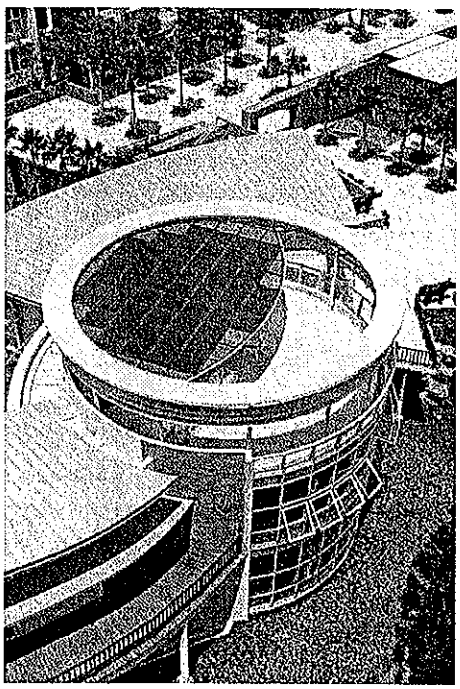
Building: Daegu Exhibition & Convention Centre, Korea

System size: 222kWp

Energy: 256MWh/yr = 3% of total EXCO electricity (2005)

CDL's Savannah Condo uses BIPV in a canopy

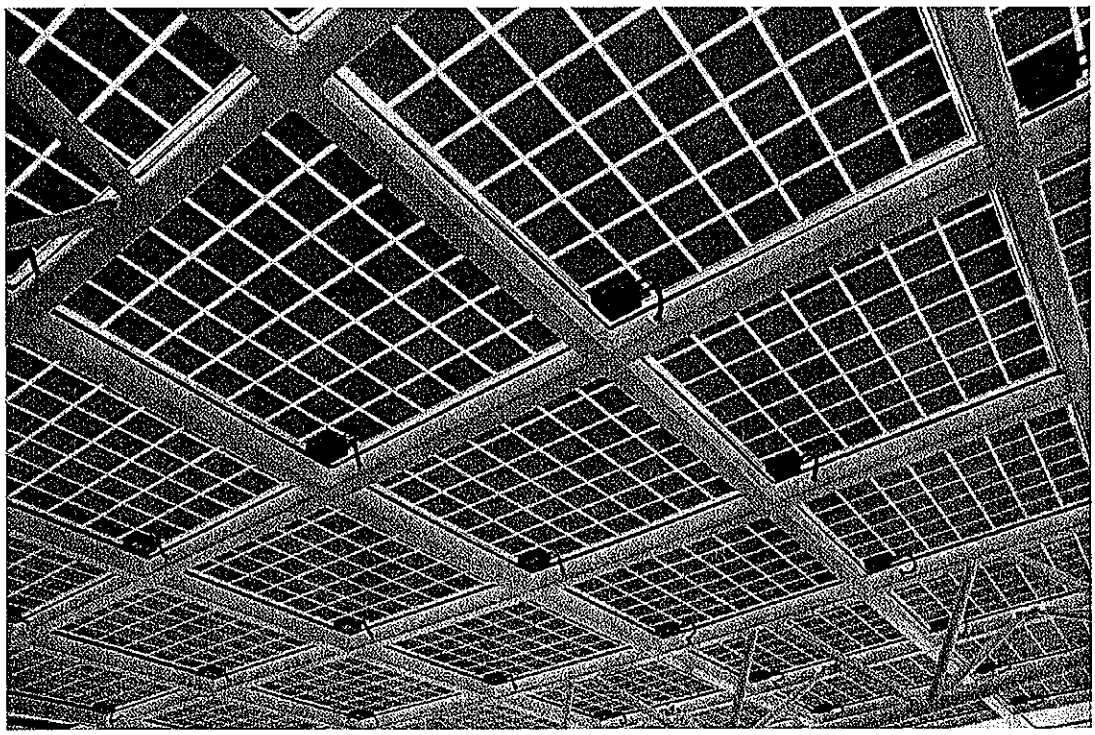
Frosted rear glass softens the shadow pattern.



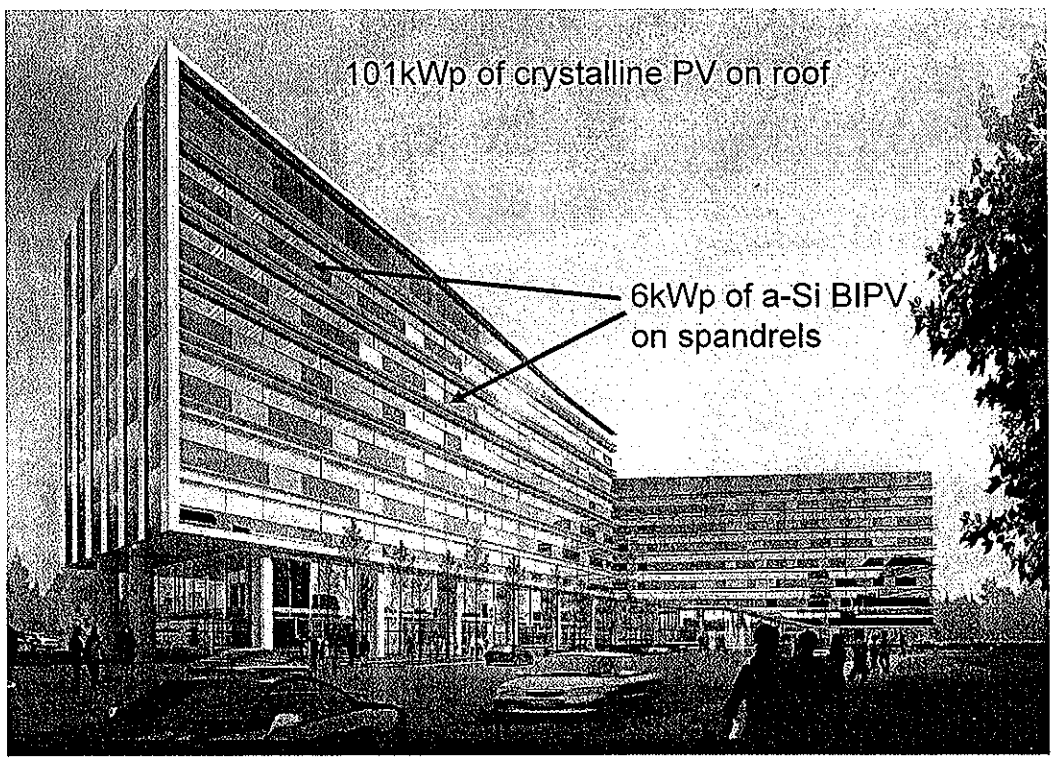
Developer: City Developments Ltd
Architect: Axis Architects Planners
Contractor: Dragages Singapore



Cabling routed inside RHS support structure



CDL's Tampines Grande with BIPV and rooftop PV

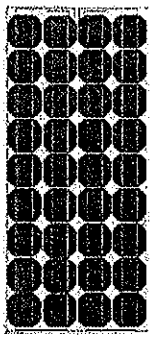


Rendering by Architects 61 Pte Ltd

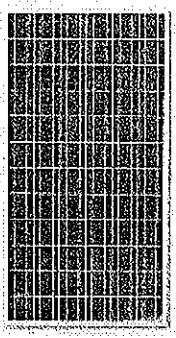
PV fundamentals - contents

- What is BIPV?
- Grid-connected operation
- Good and bad locations for BIPV near the Equator
- Case studies
- **Range of technologies**
- Energy yield and economics
- Conclusions

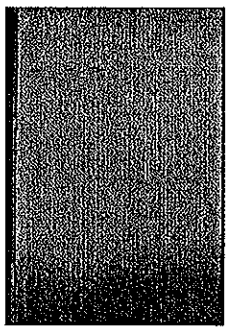
PV building blocks – crystalline and thin film modules



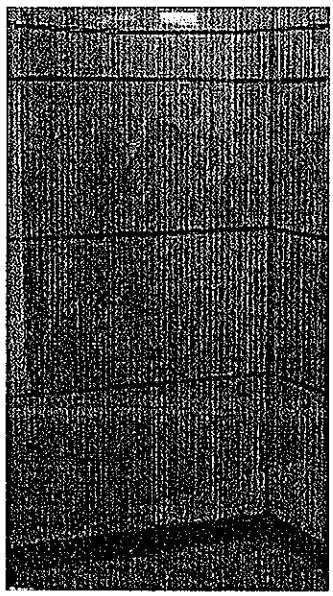
Mono-Si



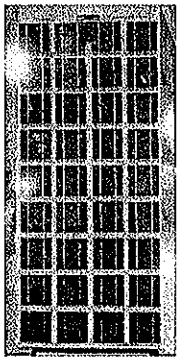
Multi-Si

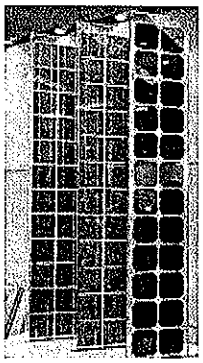


CIGS thin film

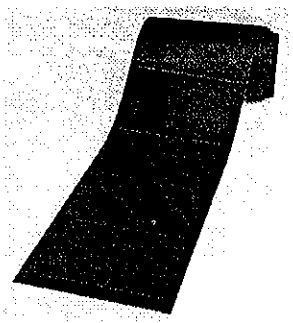


BIPV with semi-transparent thin film



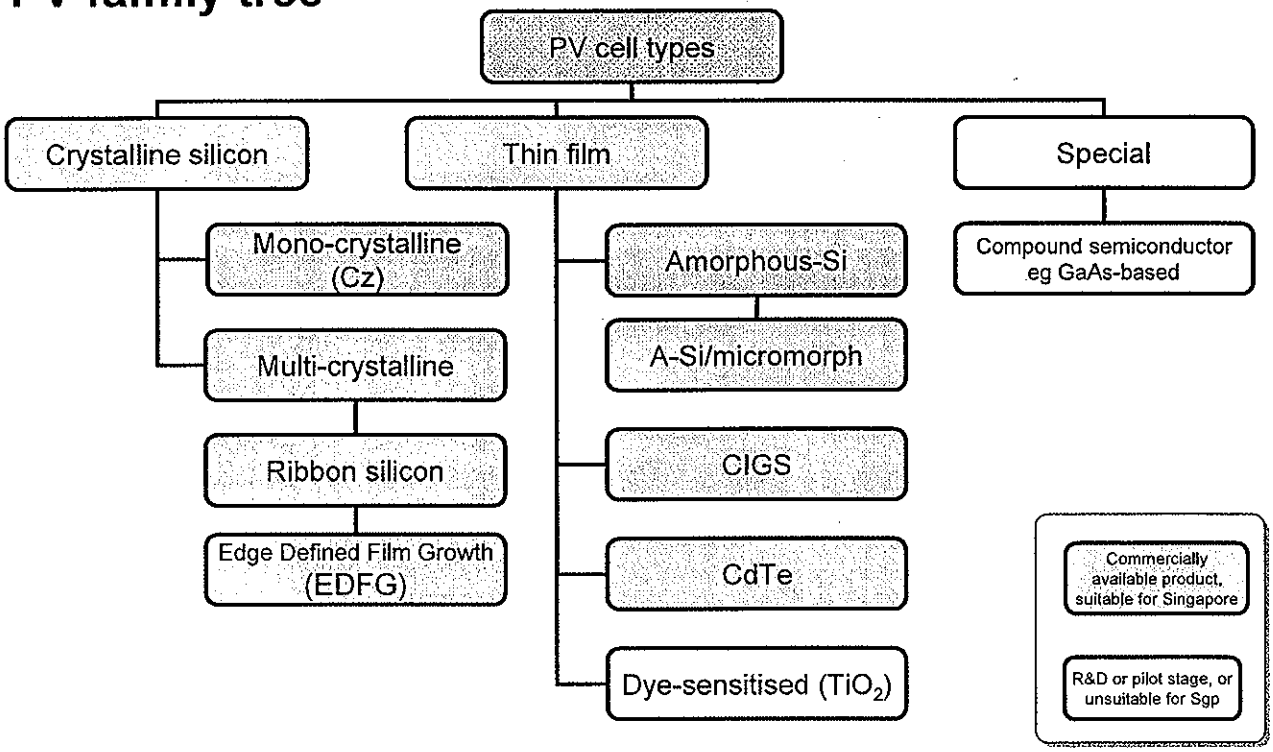


BIPV with crystalline cells



Flexible a-Si thin-film

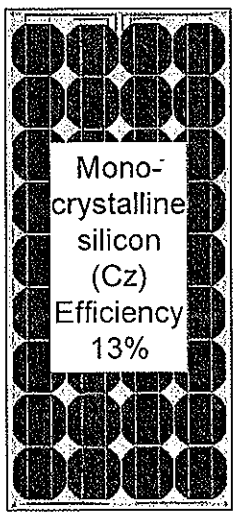
PV family tree

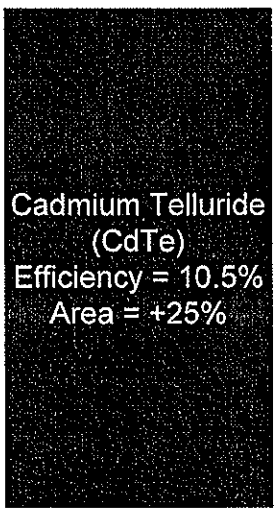


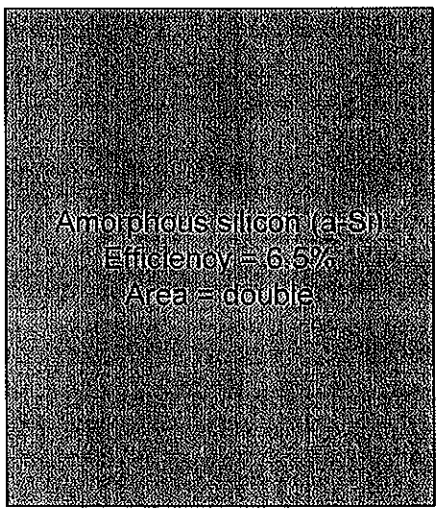
Thin film takes more area per kWp than crystalline technology

No easy answer (space/budget)

Bigger area means slightly higher cost of structures and cabling …







… but thin film modules compensate with lower price per kWp

PV fundamentals - contents

- What is BIPV?
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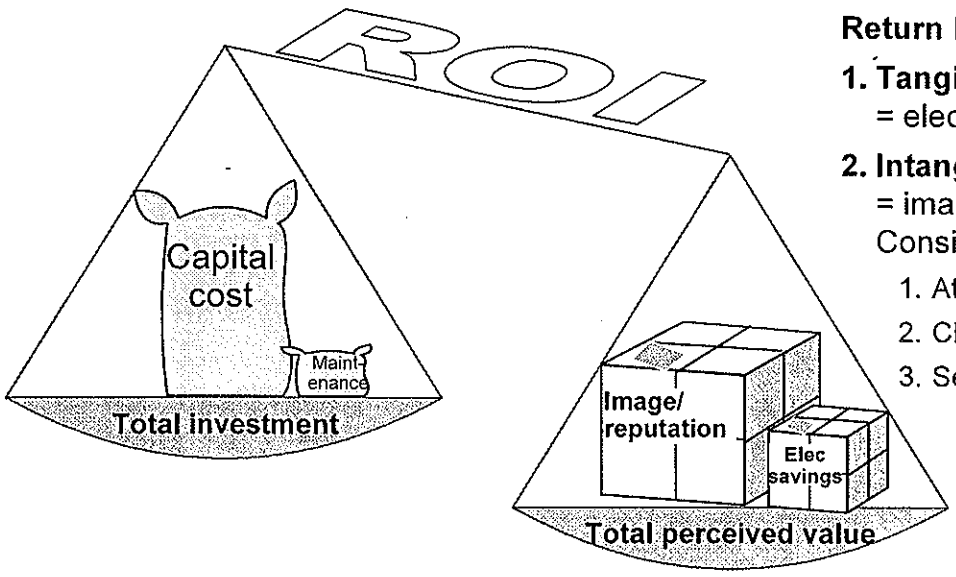
- **Energy yield and economics**
- **Conclusions**

Health warning – ROI must include intangibles!

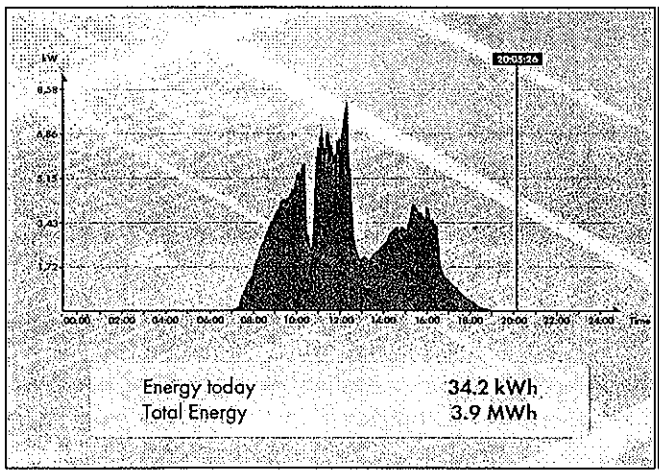
Calculating return on investment (ROI) needs a close look at both sides of the equation:



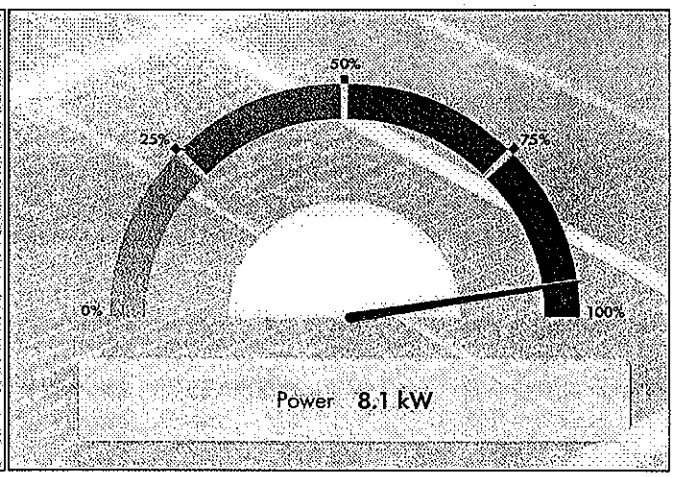
Return has two components:

1. **Tangible return**
   = electricity generated
2. **Intangible return**
   = image and reputation.
   Consider value of:
   1. Attracting more customers
   2. Charging a premium
   3. Selling faster (cashflow)

Live monitoring promotes awareness among clients



Graph tracking power against time



"speedometer" showing instantaneous power output

Graphics: SMA

Solar capabilities scheme is very attractive

Criteria

- New or refurbished building with Green Mark Gold or better
- Innovation, design, effectiveness, skill development
- Min PV system size = 10kWp
- 30-40% subsidy, capped at S$1'000'000
- 70% of award granted upon commissioning
- 30% disbursed after 2 years, subject to meeting performance targets

Benefits

- Cost down from S$1m to S$650k after subsidy – for 100kWp system
- Payback drops from 35 to 22 years - at S$0.25/kWh tariff

Guidelines and rules of thumb

- 80-130W/m² roof space for crystalline modules 100W/m²
- 40-80W/m² roof space for thin film modules 50W/m²
- **90kWh/kWp energy yield/month (ca 1'100kWh/kWp per year)**
- S$10-30/Wp installed capacity
- **Energy-efficient** semi-D needs ca 10kWp to cover electricity demand
  - Ca 100m² of roof space (crystalline modules) and S$120'000 investment
  - Generates ca 900kWh/month, or 110'000kWh/year
  - System will export excess daytime electricity to grid, and offset with imports at night
- No need to clean modules if mounted at a tilt angle (rain will clean)
- Do not add batteries to grid-connected system!

Photovoltaics – powering the future, today.

Thank you

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Tel +65-6511 9339

How and why to select electrical protection and connection devices for PV installation.

Synopsis:
This presentation covers the selection of equipment and devices to meet requirements in IEC and the new amendment to SS CP5. It will highlight the safety and efficiency of PV installations being connected to the power grid.

By Er. Lim Say Leong
AVP, Marketing, Automation Products Division, ABB Industry Pte Ltd

Introduction

Amongst renewable energy technologies, photovoltaic were once the most expensive; but they are becoming cheaper with increasing volume of the world market. Notwithstanding this trend, PV installations are still long-term investment of substantial capital costs with low return on investment. Furthermore they are best installed at open areas to maximize efficiency.

Risks of access to people and animals; risks of damage by environment are important factors not to be neglected.

Knowing how and what to protect will be important. PV voltage output is increasing through connection of the PV-modules in combinations of series and parallel configurations. Very common is a series connection of modules. Modules string can be between 150 V and 1000 V for today's grid connected PV-systems.

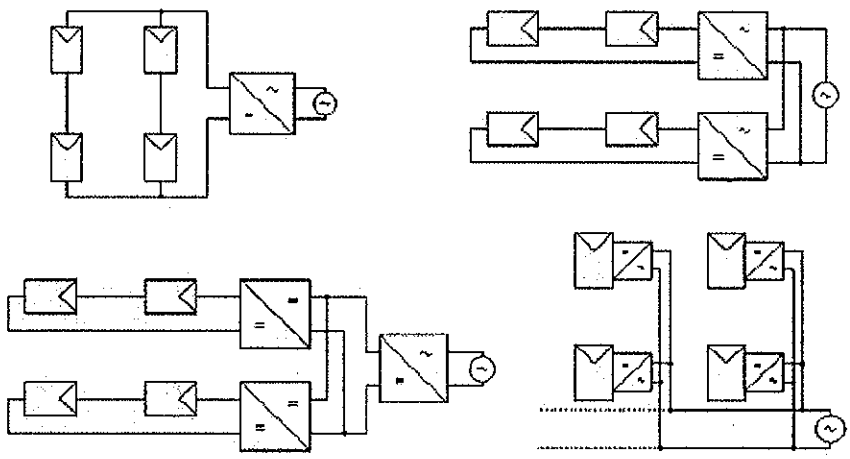


Figure 1 Connections of PV modules
Source NORPIE/2008

Evolution on the electricity system

Distributed generation or DG is the trend to allow and inter-connect other forms of electrical energy onto the grid of the electricity system. Therefore standards concerning safety in the distribution system are important as there are much interest of what can be expected of future standards considering factors such islanding detection in distributed generation. The important aspect is how to meet requirement in order to facilitate further integration of distributed generation in the power system for direct connection of photovoltaic cells to the Grid.

Direct connection of photovoltaic cells to the Grid in order to avoid the use of battery is the trend today for photovoltaic installation. Such direct interfacing of photovoltaic systems with the electric utility systems and practices may vary from location to location. Utility authority and company may have specific requirement. IEC, the world standard for electrical equipment and installation practices also provide a set of requirement for general adoption by member countries. I am glad that Singapore is considering them as well.

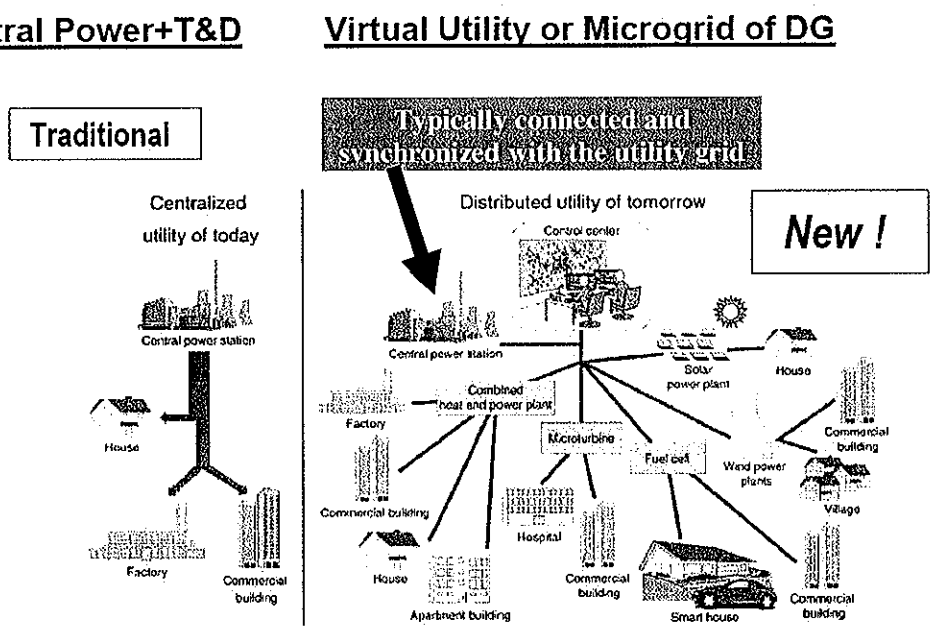


Figure 2
Source: ABB

Although these standards are not necessarily binding on utilities; many utilities are adopting them rather than developing their own. The most important standard focuses on inverters. Traditionally, inverters simply convert the DC electricity generated by PV arrays into AC electricity such as those used in home. More recently, inverters have evolved into remarkably sophisticated devices to manage

and condition power. Some may even contain protective relays, disconnects, and other components necessary to meet the performance and safety standards.

Standard of installation work

IEC 60364-7-712, entitled as Electrical installations of buildings published in 2002, gives requirements for special installations or locations for solar photovoltaic (PV) power supply systems. Amendment No. 1 to CP5:1998 – Code of practice for electrical installations released just last month contains requirement for solar PV power supply systems.

They are intended to supplement IEC 60364 Part 1 to Part 6 and CP5 respectively for safety requirements. It gives definitions that are unique to the PV equipment and their installations. Very important it emphasizes on fundamental safety such as protection against electric shock due to direct and indirect contact and other characteristics of the interface. This recommended practice applies to utility interconnected residential and intermediate size photovoltaic power systems capable of two-way energy flow with the utility.

It addresses the interface between the PV system and the utility, and provides technical recommendations for the characteristics of the interface. See Appendix A for a general description of the photovoltaic system and the interface

Besides knowing the standards, let also take cue of the practices in countries where PV installations have been in large volume and of varied scales. Countries of such are USA, Germany, Spain, Switzerland, USA, etc.

In the USA, installers must demonstrate that they have special knowledge about installing PV systems. This special knowledge may be demonstrated in one of the following ways:

- Possession of a solar contractor specialty license, issued by a local building jurisdiction, that recognizes through testing or other means.
- Certification in PV systems by a group such as the state chapter of SEIA
- A letter from the PV system manufacturer stating that the installer has the experience and training needed to install the system properly.

SEIA or Solar Energy Industries Association is focused on:

- Reducing regulatory barriers to PV installation through the spread of standardized and technical standards for interconnection and net metering.
- Increasing markets for PV nationwide through meaningful and appropriate incentive programs at the state and Federal level.

- Ensuring robust and continuing Federal research and development into PV devices and supporting technologies (inverters, balance-of system equipment, etc.)

For those who want more details you may visit their website as follows:

✓ http://www.seia.org

Solar Energy Industries Association
805 15th Street, NW Suite 510
Washington, DC 20005

In Singapore, we have now the Amendment No 1 to CP 5 for PV installation, EMA or Energy Market Authority Handbook and BCA Guidebook to help anyone wanting to embark on having PV installation.

Hence we could say that the major agencies that are involved in the requirements of PV installations are:

- Electricity Licences by *Energy Market Authority (EMA)*
- Licensed Electrical Workers ("LEWs) by *Energy Market Authority (EMA)*
- Electricity market rules,market registration, process, and market charges by *Energy Market Company (EMC)*
- Connection to the power grid by *SP PowerGrid Ltd (SPPG)*
- Building and construction safety by *Building and Construction Authority (BCA)*

Salient IEC specification for the PV installations are:

It may be appropriate to share here some other IEC standards:

IEC 60364-7-712
Electrical installations of buildings –
Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems

IEC 61727
Photovoltaic (PV) systems – Characteristics of the utility interface

IEC 61730
Photovoltaic (PV) module safety qualification –
Part 1: Requirements for construction
Part 2: Requirements for testing

Safety

Whenever there is sunlight, the PV will generate energy. PV installation is therefore considered as live all the time. Furthermore when PV installation is connected to the grid; safety for unintended islanding when the grid is being tripped has to be taken into consideration.

CP5 with the new amendment gives the technical terms and additional guides for PV systems. It also considers an *electrical installation* refers to any electrical wiring, fitting or apparatus used for the conveyance and control of electricity in any premises. Hence any PV system connected to the electrical installation is considered part of the installation.

- Assessment of general characteristics
  - Types of earthing and its arrangement
- Protection for safety
  - Automatic disconnection of supply
  - Protective measures by double or reinforced insulation
  - Extra-low voltage, SELV or PELV
- Protection against overcurrent
  - Overload on the d.c side
  - Fault current
- Protection against electromagnetic interference (EMI)
  - Minimizing voltages induced by lightning.

Diagram: PV System Forming Part of the Consumer's Electrical Installation

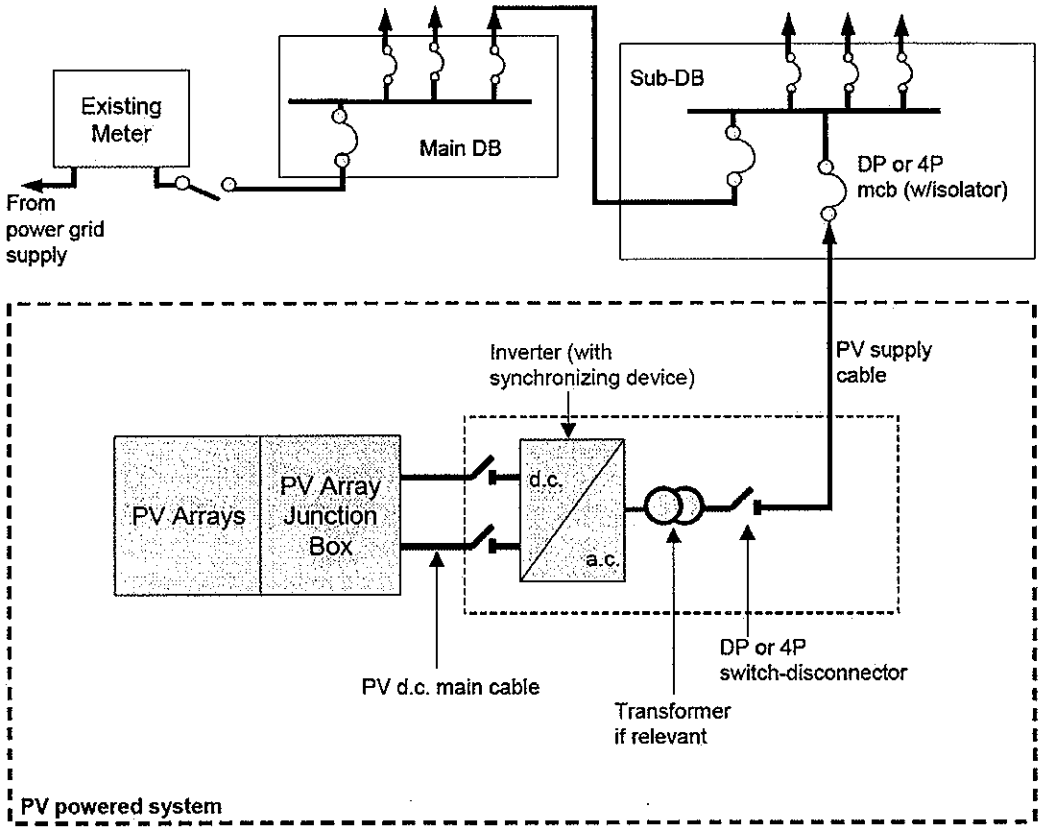


Figure 3
Source: EMA Guidebook on PV installation

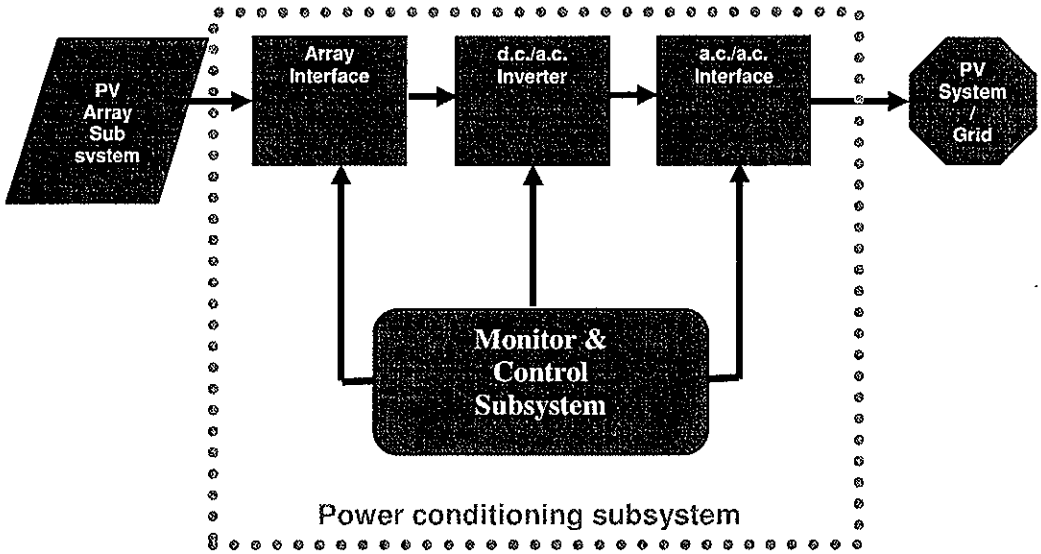


Figure 4
Source: EMA Guidebook on PV installation

Figure 4 shows a typical modules of PV installation; identifying the various interface helps to understand the installation better and to know where the necessary protective devices such as switch-isolators, circuit breakers, surge protective devices, timer , etc are required in a PV installation when connected to the grid. In brief, they are :-

- Power flowing between the power converter, the connected load and the Grid.
- Provision for measurement of a.c. energy (kWh) meter
- Provision of switch-isolator for safety and maintenance
- Possibility of providing protection function such as isolating transformer, relays, diodes, SPD, etc.

Islanding

Islanding is typically defined as "*A condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the remainder of the utility system.*"

With distributed generation (DG) where power is generated in the LV distribution network, islanding is more likely to occur for instance when the PV feeding power back to the Grid and in a condition of a power blackout. The PV continues to power the building, the building becomes an "island" with power surrounded by a "sea" of unpowered buildings.

Islanding in a Distribution Network

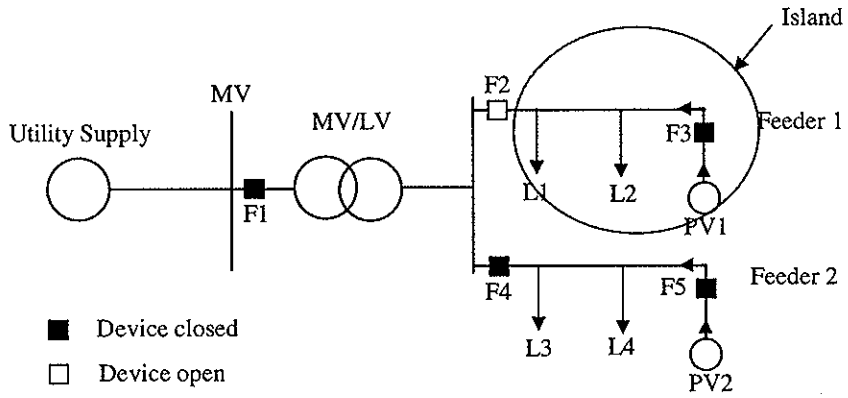


Figure 5
Source: ABB

Islanding could be deemed to be dangerous to anyone, who may not be aware that the building is still powered even though there's no power from the Grid. Hence the need to provide safety and fire protection for :-

- un-informed persons, including owner/occupier and users of the premises where photovoltaic arrays are installed;
  informed workers (e.g. electricians) working on these systems; and
- emergency workers (for example fire fighters).

For this reason, islanding must be detected and immediately activate the necessary disconnection of PV power. Detecting the absence of power from the Grid is complicated because the PV itself is a source of power whose voltage is identical to the voltage from the grid.

Islanding may be detected passively, actively or by utility notification.

- Passive detection is done by detecting the rate of change of frequency, voltage phase jump and three-phase voltage drop monitoring.

- Active detection is done by purposely adding a disturbance to the line, and seeing its effect. The principle is that the Grid offers

essentially a zero ohm impedance. In the absence of the Grid, the impedance that is seen is the load in the building, which is substantially higher. With active islanding operation detection method frequency shift, active frequency drift, monitor the impedance and reactive power fluctuation.

- For Utility notification, the Utility knows when it removes power to the building, and disconnect the inverter to the Grid.

Protection of People and Property

Array wiring

Cable type 3x - No additional protection o/c.

- Double-insulated cable
- UV-light resistant
- Fire-retardant
- Low emission

Earthing

- Metallic structure & accessories must be earthed.

PV System Earthing

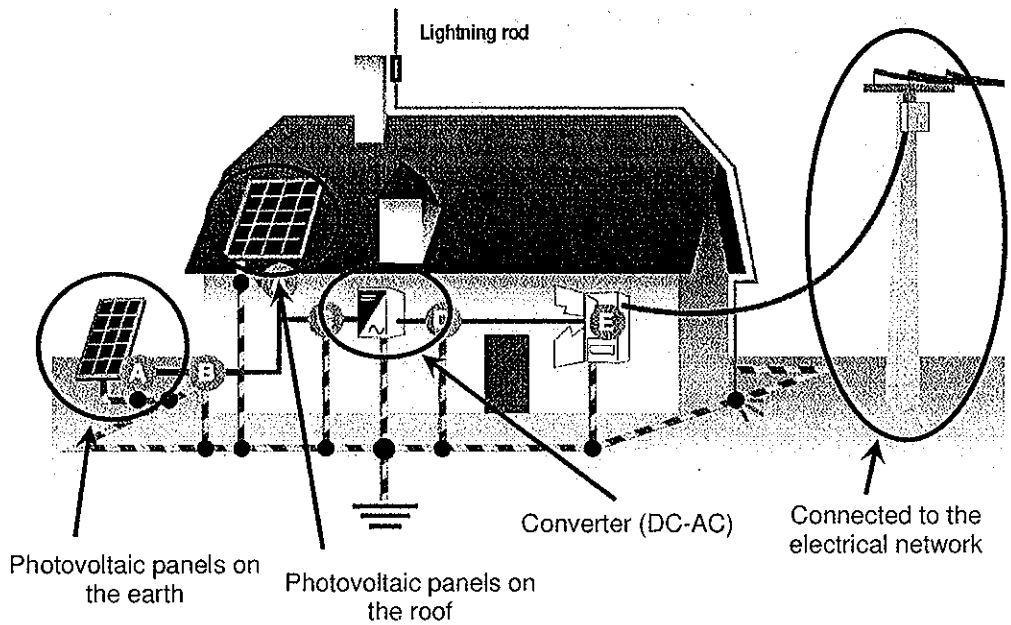
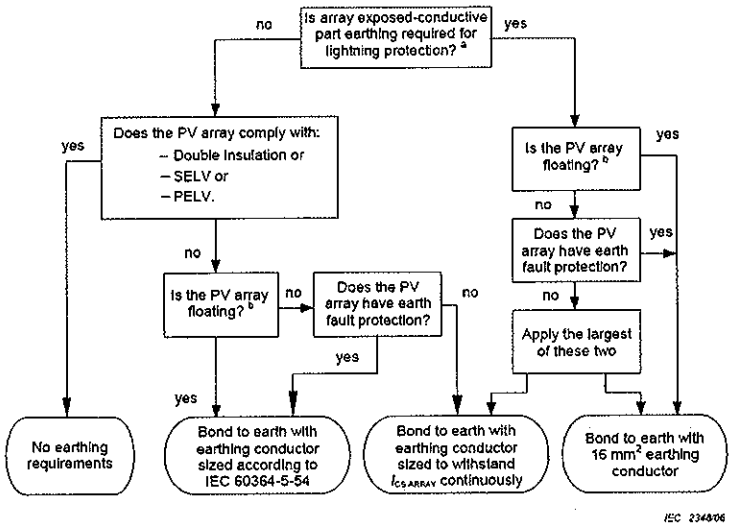


Figure 6
Source: ABB

PV System Earthing



a To answer this question, you can follow the recommendations of IEC 62305-2 and IEC 662305-3 or refer to local information such as number of thunder days per year or other lightning characteristics. Assessment should include relative position on the PV array to other buildings, structures, environmental stuff able to protect the PV array from lightning strokes.

b Floating PV array means an array which is not directly connected to earth but is connected to an application circuit which is either unearthed or isolated.

Figure 3 – PV array exposed-conductive parts earthing decision tree

Figure 7
Source: IEC

Under/under voltage & frequency

- When the interface voltage or frequency is outside the specified limit, the PV system must be disconnected.

Relay	Setting	Time
UV	90%	<0.1s
OV	110%	<0.1s
UF	49.7Hz	<0.1s
OF	50.3Hz	<0.1s

Figure 8
Source: IEEE

Utility recovery

- PV system once disconnected from the Grid, must remain disconnected until PV system voltage has recovered to within Grid's acceptable voltage and frequency limit.
- Recommended time 30 sec to 2 minutes.

Direct-current isolation

- PV system must not inject d.c. into a.c. interface, both normal & abnormal condition.
- Max. allowable d.c. current injection < 0.5% of rated power converter based on d.c. rating.

Lightning & Surge protection

- Metallic frame, supporting structure and exposed metallic parts must be earthed and connected to the earth system.
- SPD must be used on incoming and outgoing of the power converter.

Safety isolation

- Lockable, accessible manual or electromechanical switch-isolator must be installed between power converter and the Grid
- DC isolators and protection relays must be provided if they are not part of the power converter.

PV System-Grid Installation as illustrated in IEC

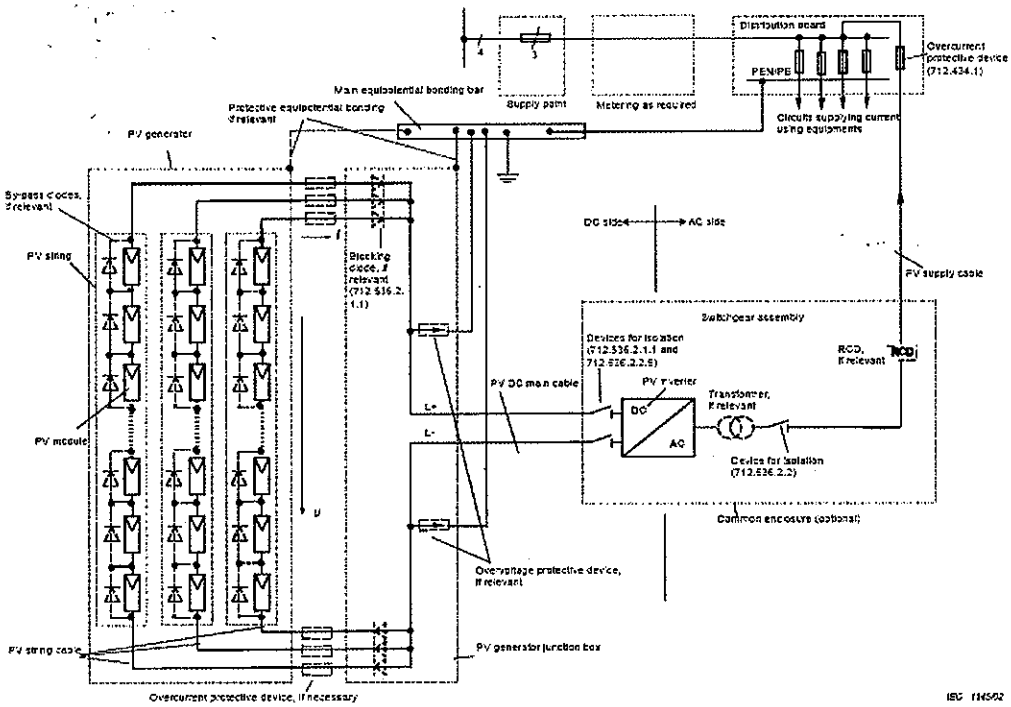


Figure 9
Source: IEC

Conclusions

Photovoltaic energy is expected to be a long-term renewable energy and with good technology grid-connected PV installations will in many cases be integrated in buildings. Safety and system efficiency will continue to be enhanced through experiences and continued development.

2009-03-17
Er. Lim Say Leong

Design of Grid-Connected Photovoltaic Power Supply Systems

By: Er Chan Chee Hin

Deputy Director

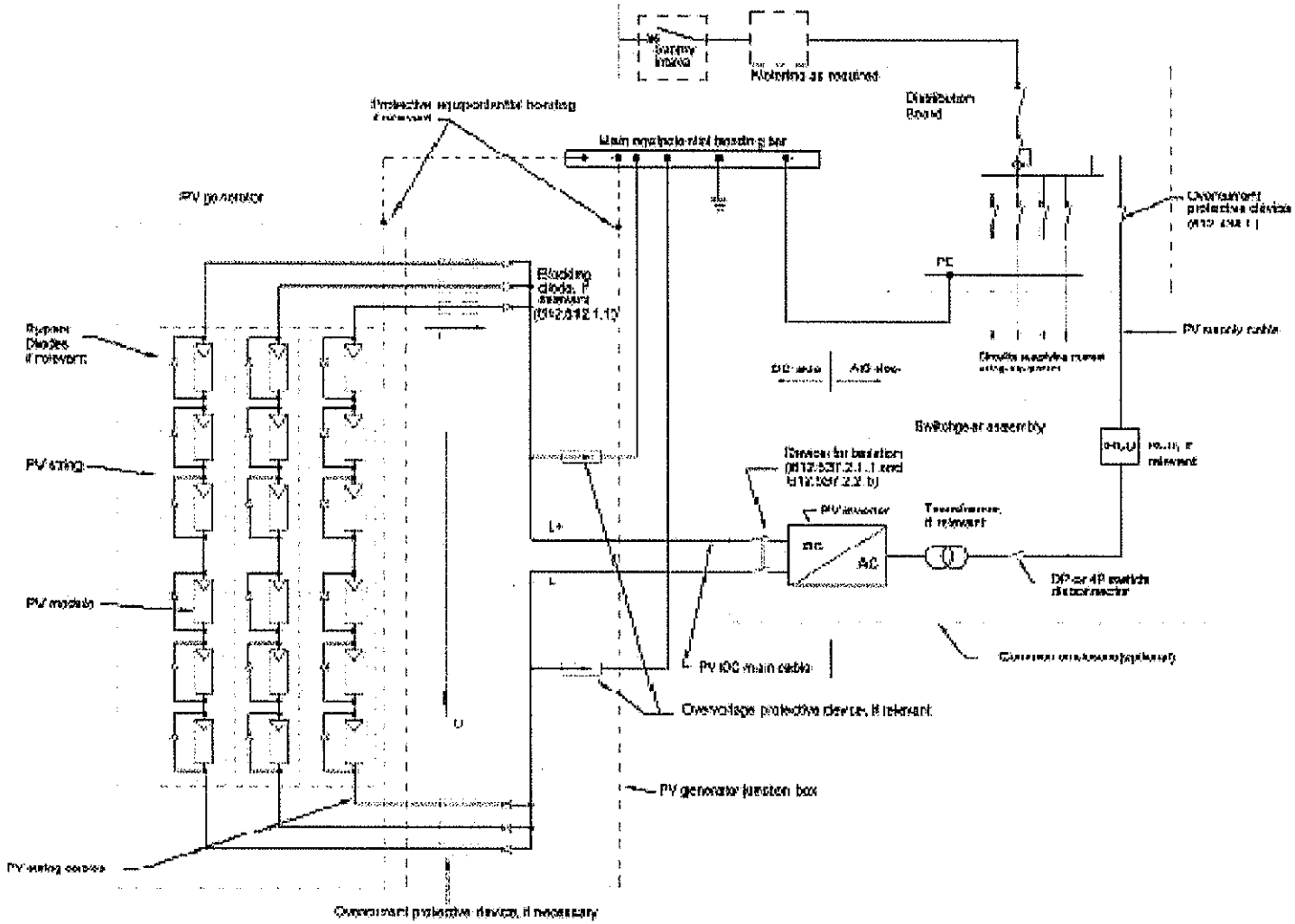
Electrical Engineering Division

Ngee Ann Polytechnic

Contents

1. Factors affecting the Performance of PV system
2. Choice of cell materials and PV module
3. Selection of DC system voltage
4. Earthing of Grid-connected PV system
5. Selection of Inverters
6. Safety and Design Requirements
7. Power Quality of PV system

Typical Grid-connected PV system



Source: Amendment No.1 to CP5:1998

1. Factors Affecting the Performance of PV system

The performance will depend on:

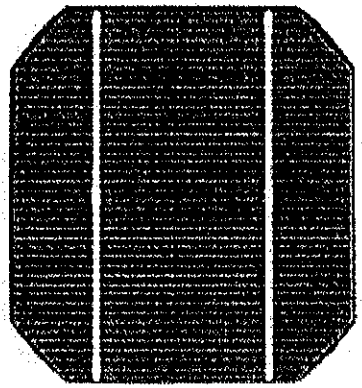
- The type and efficiency of solar modules
  - Amorphous
  - Mono-crystalline
  - Poly-crystalline
- The location and configuration of the PV modules
  - The orientation (for max. solar energy)
  - Shading from trees and nearby buildings
  - The PV array configuration (to reduce shading effects)

- The installation method
  - Allowance for air circulation below the modules
  - Inclination of module to allow rain to run off and removal of dust
- Efficiency of the "Balance of System" (BOS)
  - Inverter configuration and losses
  - Cable sizing and losses

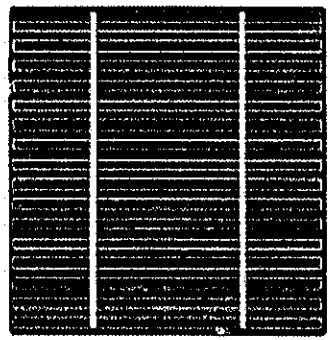
2. Choice of Cell Materials & PV Modules

- Crystalline cells
  - Monocrysalline cells
  - Polycrysalline cells
- Thin film cells
  - Amorphous silicon
  - Copper Indium diselenide (CIS)
  - Cadium Teluride (CdTe)
  - Dye
  - Microcrystalline and micromorphous

- Hybrid cells
  - HIT (heterojunction with intrinsic thin layer) cell



Mono-crystalline solar cell



Polycrystalline solar Cell

Efficiency of different cell types

No.	Cell Material	Efficiency in % Lab	Efficiency in % Production
1	Mono-crystalline silicon	24	14~17
2	Polycrystalline silicon	18	13~15
3	Amorphous silicon	13	5~ 7

Remarks on thin-film solar cells

1. Low efficiency of thin-film modules means a larger area is required to achieve the desired power
2. The low efficiency does not affect the specific energy yield per kW of thin file module
3. Thin-film module has better spectral sensitivity; can absorb visible light with short and medium wavelengths, achieve better efficiency in low irradiance
4. Thin film with greater shading tolerance but light degradation problem

for defused light sunlight

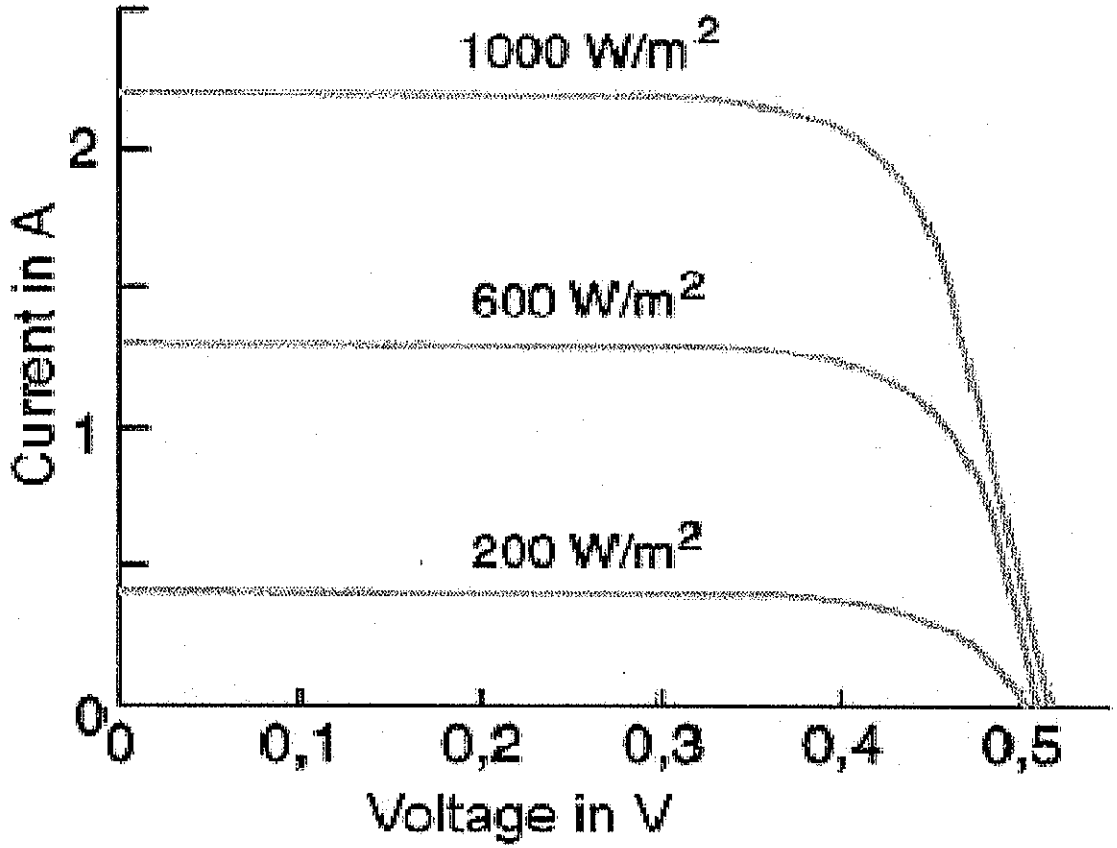
Area requirement for PV Modules

- The number of modules that can be accommodated in the given area will determine the overall power of the PV system
- Rule of thumb
  - 1 kWp ~ 10 m^2 PV area (crystalline PV module)

PV areas for different type of solar cell materials

No.	Cell Material	PV area for 1kWp
1	Mono-crystalline silicon	7 - 9 m^2
2	Polycrystalline silicon	7.5 - 10 m^2
3	Copper Indium Diselenide (CIS)	9 - 11 m^2
4	Cadmium Tellurdide (CdTe)	12 - 17 m^2
5	Amorphous silicon	14 - 20 m^2

Shading & Orientation affect the energy output of the solar cell



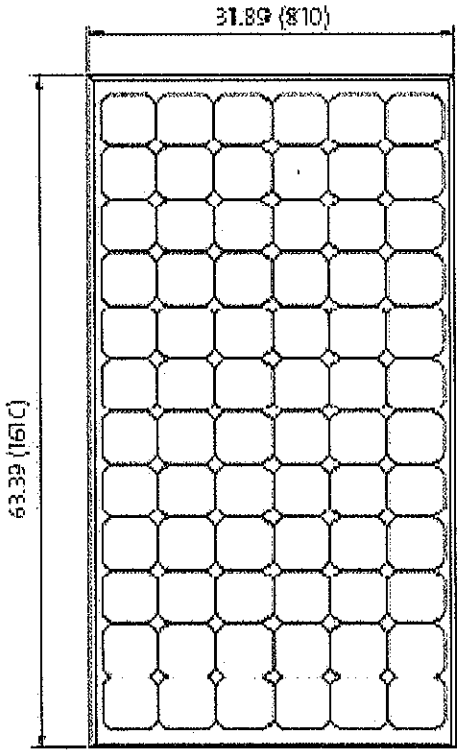
Characteristics of a solar cell

1. Voltage of each cell is low (0.5~0.6 V) ✓
2. Current output increase with irradiance level
3. Higher cell temperatures lead to lower output

PV modules

- Output of each cell is small, many cells are interconnected to form PV module and can achieve great power output
- In PV modules, the cells are largely connected in series to create higher voltage

Sample PV module Specification



1. There are 72 cells per module 0.5 to 0.6 V/cell.
2. At STC
   a) Max. power 175Wp
   b) Open circuit voltage 44.4V
   c) Short cct current 5.3A

Standard Test Conditions (STC)

a) Irradiance of 1000 W/ m^2
b) Cell temperature of 25 °C
c) Define light spectrum (IEC 60904-3)
d) Air Mass AM =1.5

Note: The max. power Wp refer to power output at STC only.

Specifications of a solar Module

Performance under standard test conditions

		SW 155	SW 165	SW 175
Maximum power	P_{max}	155 Wp	165 Wp	175 Wp
Open circuit voltage	V_{oc}	43.6 V	44.0 V	44.4 V
Maximum power point voltage	V_{mpp}	34.8 V	35.1 V	35.8 V
Short circuit current	I_{sc}	4.90 A	5.10 A	5.30 A
Maximum power point current	I_{mpp}	4.45 A	4.68 A	4.89 A

Performance at 800 W/m², NOCT, AM 1.5

		SW 155	SW 165	SW 175
Maximum power	P_{max}	112.8 Wp	118.0 Wp	125.1 Wp
Open circuit voltage	V_{oc}	39.4 V	39.8 V	40.2 V
Maximum power point voltage	V_{mpp}	31.2 V	31.6 V	32.1 V
Short circuit current	I_{sc}	4.06 A	4.22 A	4.38 A
Maximum power point current	I_{mpp}	3.55 A	3.73 A	3.90 A

Minor reduction in efficiency under partial load conditions at 25°C: at 200 W/m², 95% (+/- 3%) of the STC efficiency (1000 W/m²) is achieved.

Component materials

Cells per module	72
Cell type	monocrystalline silicon
Cell dimensions	125 x 125 mm

System integration parameters

Maximum system voltage SC II	1,000 V_{DC}
Maximum system voltage USA NEC	600 V_{DC}
Maximum series fuse rating	15 A

3. Selection of DC System Voltage

- PV modules are connected in series and parallel to form the PV generator
- The number of series-connected modules determine the system voltage of the grid-connected systems which corresponds to the input voltage of the inverter.

- Voltage domains for PV arrays

Voltage Domain	AC	Smoothed DC
ELV	Un ≤ 50V	Uoc ≤ 120 V
LV	50 V < Un ≤ 1000V	120 V < Uoc ≤ 1500V

Source: IEC 62257, ELV limits by IEC 61201

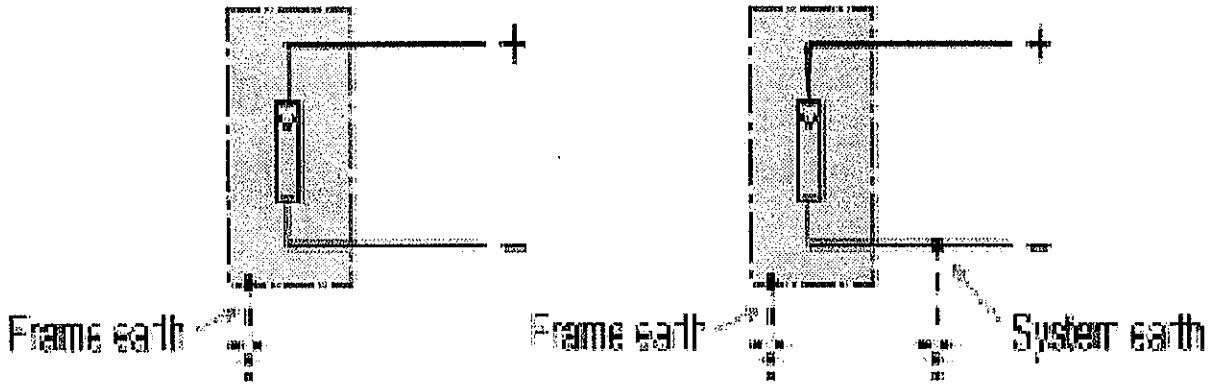
- Extra Low Voltage system (U oc ≤ 120 V)
  - Few modules are connected in series in a string
  - Reduce shading effect
  - Protection for Class III
  - High current; high cable cost

- Low voltage system (Uoc > 120 V)
  - Use longer strings and higher voltage
  - Smaller cable sizes because lower current
  - Protection class II (Double Insulated)
  - Greater shading losses due to the longer strings

4. Earthing of Grid-connected PV system

- PV array system earthing
  - Unearthed dc supply
  - Earth the negative of the DC conductor of non-centre-tapped system
  - Earth the mid-point of the centre-tapped PV array
- Equipment Earthing
  - This refer to the bonding to earth of all exposed conductive parts and frames of the PV array including any structural metalwork

- System earthing arrangement
  - Unearth DC system
  - Earthing of one of the live conductors of the dc side is permitted, if there is a simple separation between the a.c and the d.c side



Non-earthed

Negative Earthed

S.S: The AC & DC must be separated Then can earth -ve (T/F ok)

Simple Separation: Separation between circuits or between a circuit and earth by means of basic insulation

- PV system earthing conductor
  - If the PV array is earthed, the PV system earthing conductor shall be sized to carry 1.25 times of the array short circuit current

    i.e. $I = 1.25 \times I_{sc\ array}$

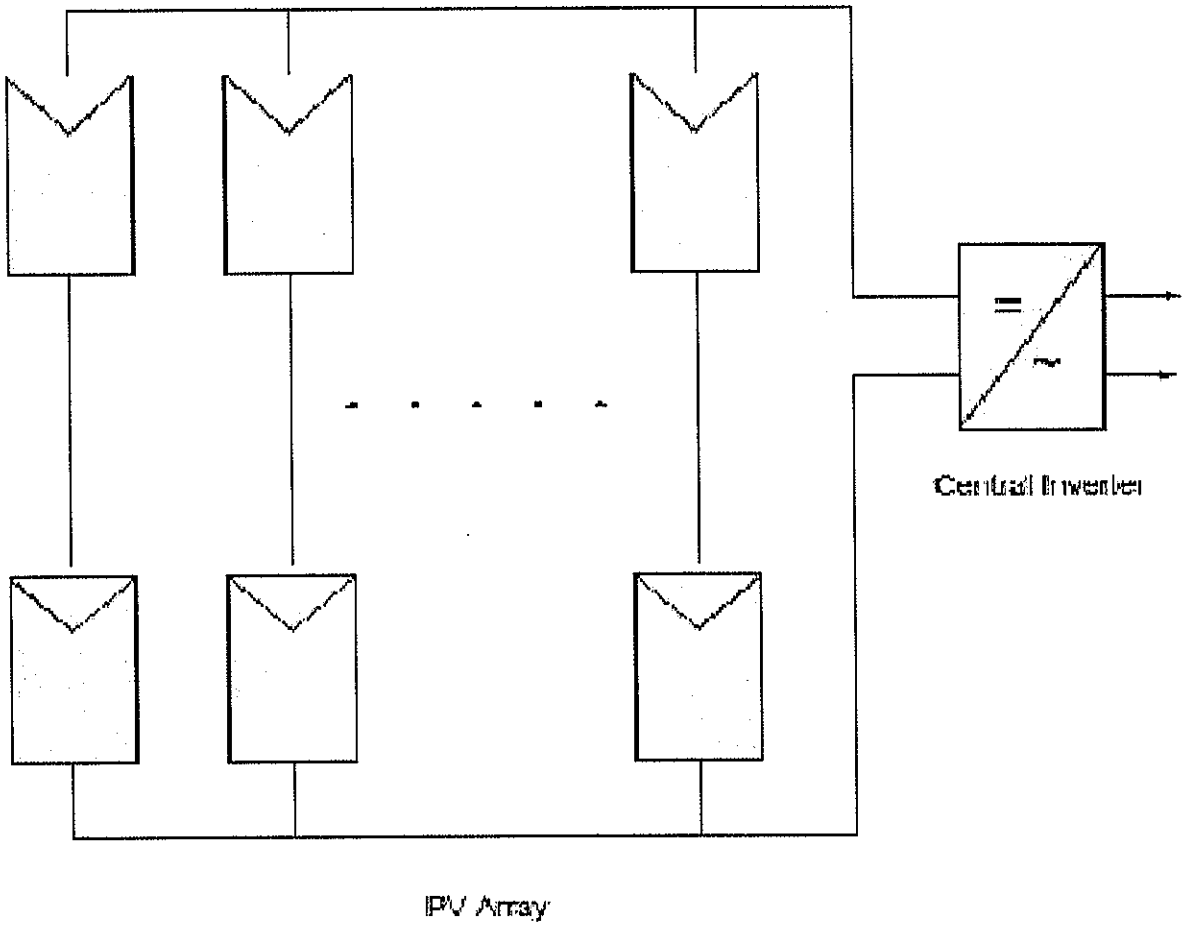
5. Selection of Inverters & Inverter Systems

- Grid-connected Inverter shall perform the following functions:
  - Convert dc generated by the PV arrays to ac
  - Adjust the inverter operating point to the MPP (Max. Power Point) of the PV arrays
  - Recording of the operating data and signaling
  - Provide dc and ac protective devices (polarity protection, over-current, over-voltage etc)

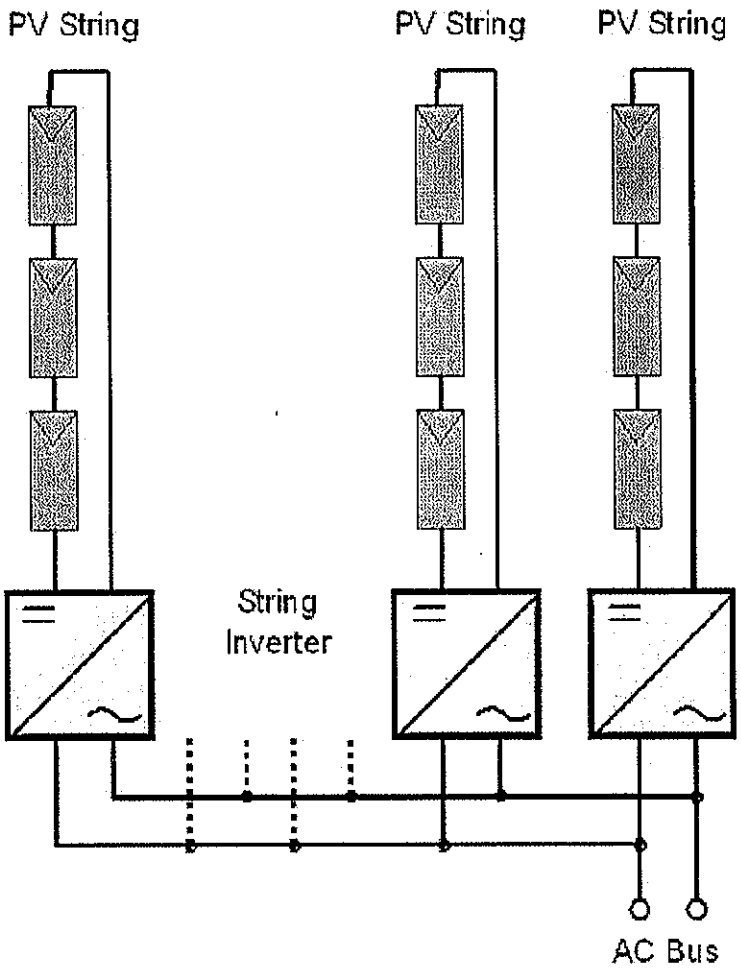
Selection of Inverter System

- Inverter System Design
  - Central inverter system
  - String inverter system
  - Module inverter system
  - Master-slave inverter system (for large PV system)

Central Inverter System

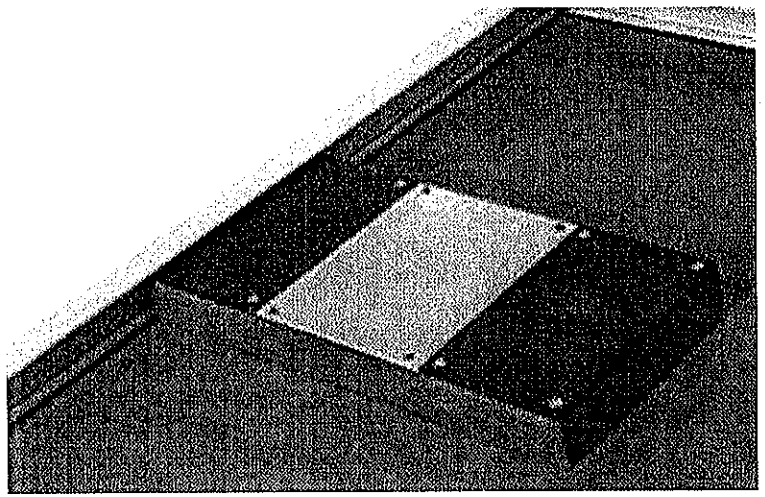


PV modules are connected in strings with String Inverters

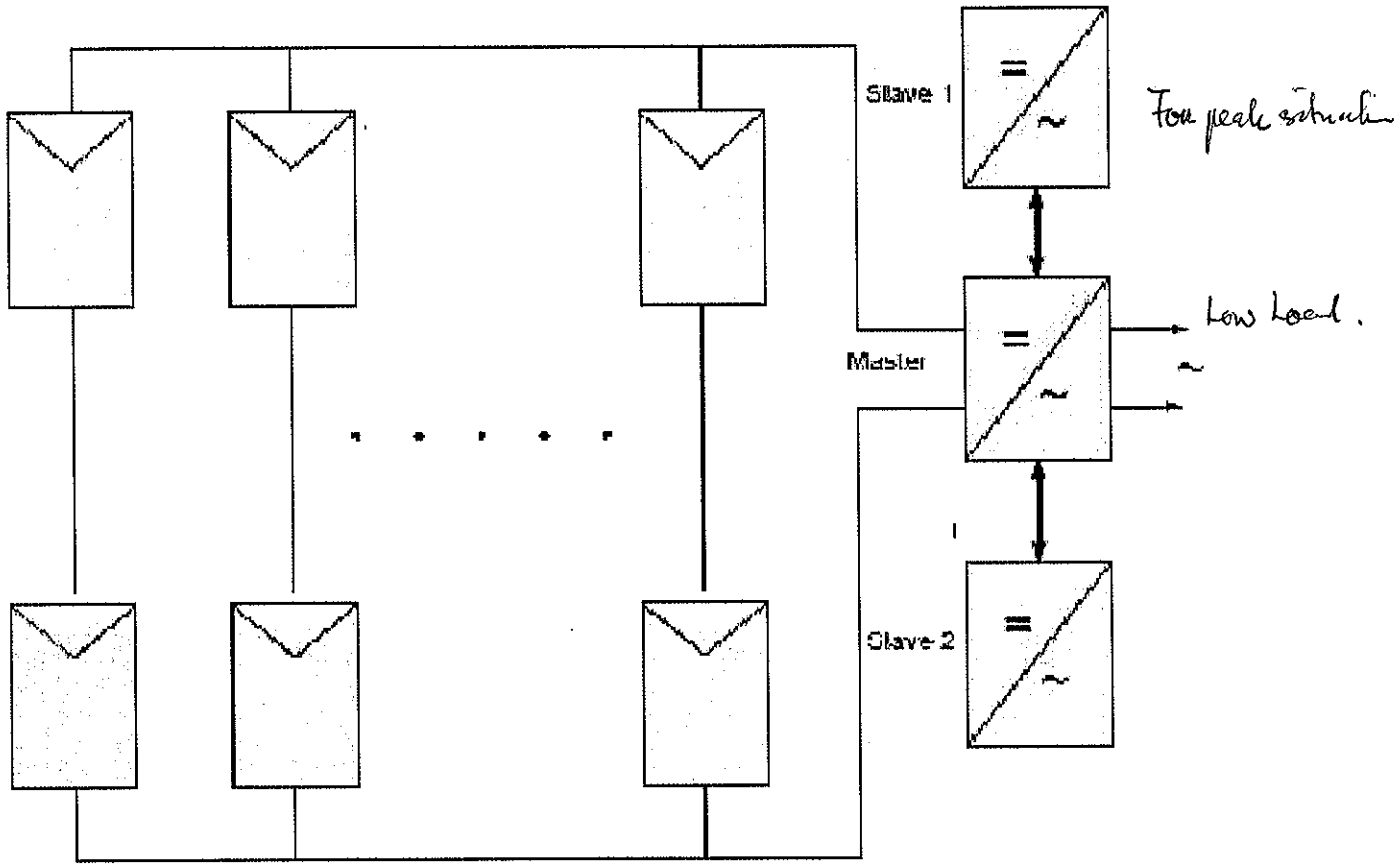


Module Inverter (AC module)

- AC module is mounted to the PV panel. All dc wiring is enclosed in the compartment near the PV frame or in the module junction box.
- The PV system can be extended easily
- The low efficiency is compensated for the greater yield from improved matching with the respective module MPP point



Master-slave Inverters

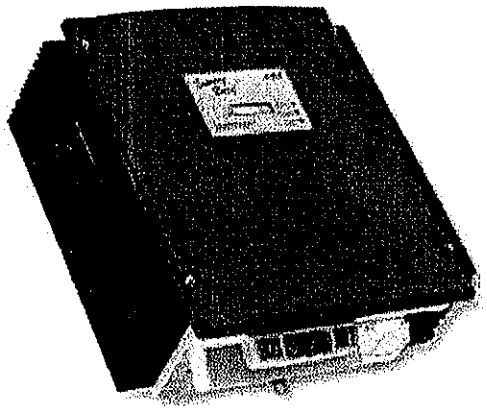


The master inverter operates at low irradiance and the slave inverters are connected at higher irradiance

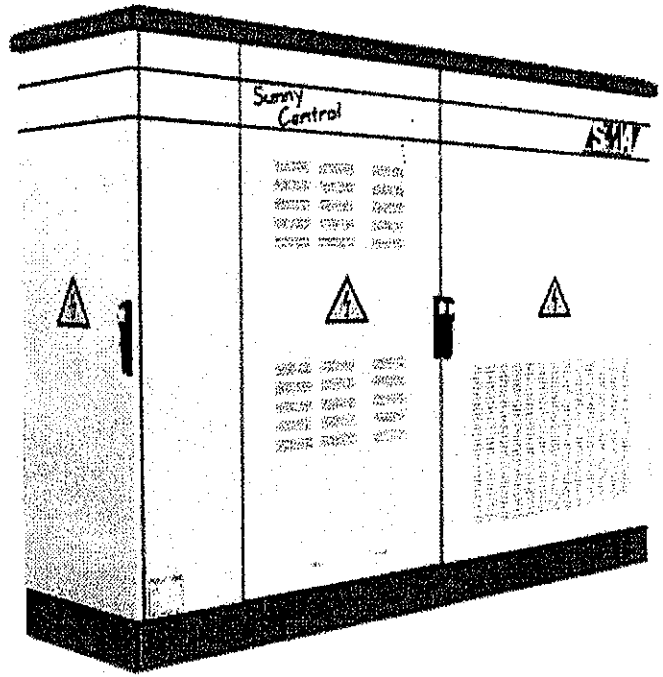
- Type of Inverters
  - Inverter with low frequency transformer (50 Hz)
  - Inverter with high frequency transformer (10k ~50kHz)
  - Transformerless inverter

Comparison of Inverters with Transformer and transformerless inverter

	With Transformer	Transformerless
lessFeatures	•input and output voltage are isolated	•Must use higher PV generator voltage or use DC-DC step-up
Advantages	•Can use Extra low voltage •Low EMI •Used for many years	•Higher efficiency •Reduced weight •Reduce size
Disadvantages	•Transformer loss •Increased weight •Increased size	•Use Type B RCD •Fluctuation of the operating point •Increased EMI •Entire installation to Protection class II



Transformerless Inverter for small PV system

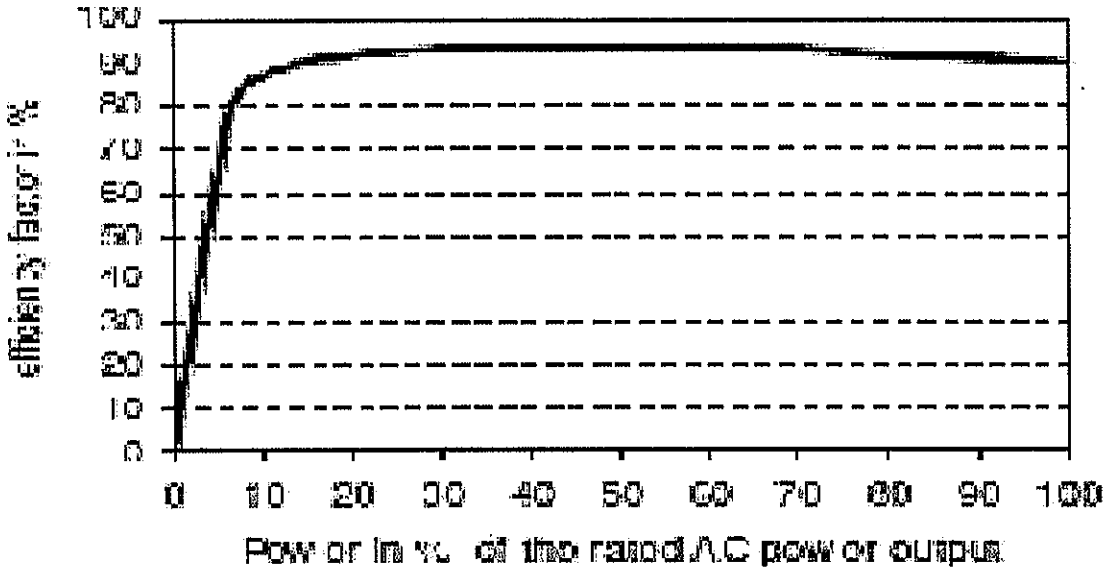


Treansformerless inverter for large PV system

- Sizing of inverter
  - The number and power rating of inverters are determined by the overall power of the PV system and the inverter configuration
  - A ratio of 1:1 between the PV array power and inverter power are generally used for sizing

Note:
For amorphous modules, the power for the first few months can be 15% higher before reducing to nominal value as a result of the initial light degradation. This effect has to be taken in voltage and current sizing of the inverter

Typical Efficiency of inverter vs Power output



Graph of the efficiency factor for power inverter

Characteristics of Inverters

- Conversion Efficiency (η_{con})
  - give the losses arise when converting DC to AC
  - Strongly dependent upon input power and changes by a few percentage depending upon the input voltage

η_{con} = Input real power / Input real power

- Tracking Efficiency (η_{TR})
  - The quality of the inverter to automatically track the optimum operating point (MPP) of the PV array

η_{TR} = Instantaneous real DC power input / Max. instantaneous PV array power

- Static efficiency (η_{INV})
  - The product of conversion and tracking efficiency

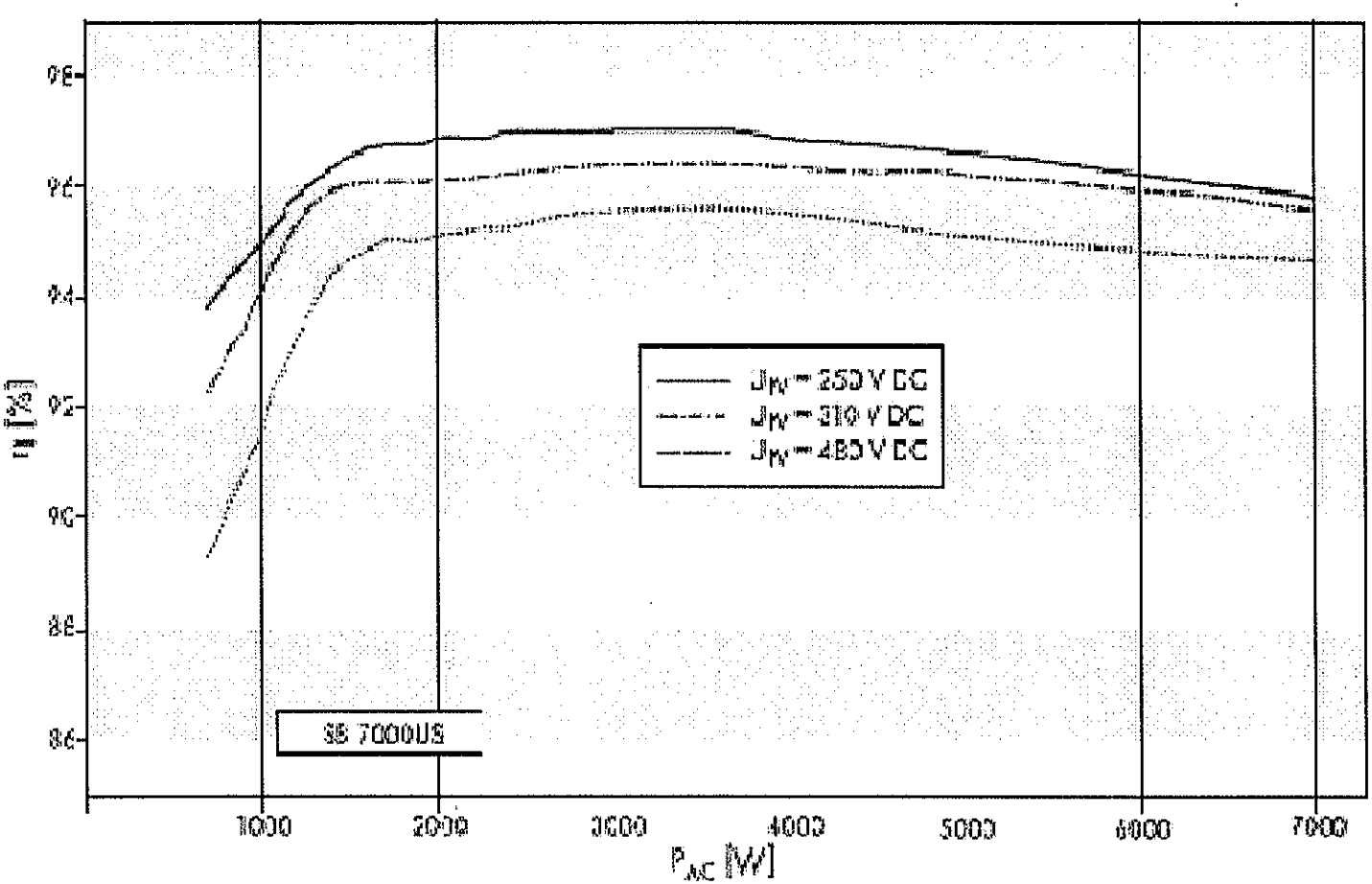
$$\eta_{con} = \eta_{TR} \times \eta_{INV}$$

- Euro Efficiency (CEC) Weighted 50% heavily.
  - This is the weighted efficiency for the European climate

Inverter Specification (sample)

Input Data (DC)	
Max. Recommended Array Input Power (DC @ STC)	6250 W
Max. DC Voltage	600 V
Peak Power Tracking Voltage	250 – 480 V
DC Max. Input Current	21 A
DC Voltage Ripple	< 5%
Number of Fused String Inputs	4
PV Start Voltage (adjustable)	300 V
Output Data (AC)	
AC Nominal Power	5000 W
AC Maximum Output Power	5000 W
AC Maximum Output Current (@ 208, 240, 277 V)	24 A, 20.8 A, 18 A
AC Nominal Voltage / Range	183 – 229 V @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V
AC Frequency / Range	60 Hz / 59.3 Hz – 60.5 Hz
Power Factor	1
Efficiency	
Peak Inverter Efficiency	96.8 % *
CEC weighted Efficiency	95.5 % @ 208 V 95.5 % @ 240 V 95.5 % @ 277 V
Mechanical Data	
Dimensions W x H x D in inches	18.4 x 24.1 x 9.5
Weight / Shipping Weight	143 lbs / 154 lbs
Ambient temperature range	-13 to +113 °F
Power Consumption: standby / nightime	< 7 W / < 0.25 W
Topology	PWM, true sinewave, current source
Cooling Concept	Convection with regulated fan cooling
Mounting Location Indoor / Outdoor (NEMA 3R)	● / ●
Features	
LCD Display	●
Lid Color: aluminum / red / blue / yellow	● / ○ / ○ / ○
Communication: RS485 / Wireless	○ / ○
Warranty: 10-year	●
Compliance: IEEE-929, IEEE-1547, UL 1741, UL 1998, FCC Part 15 A & B	●

Inverter Efficiency curve



Note: Efficiency reduces with higher operating voltage

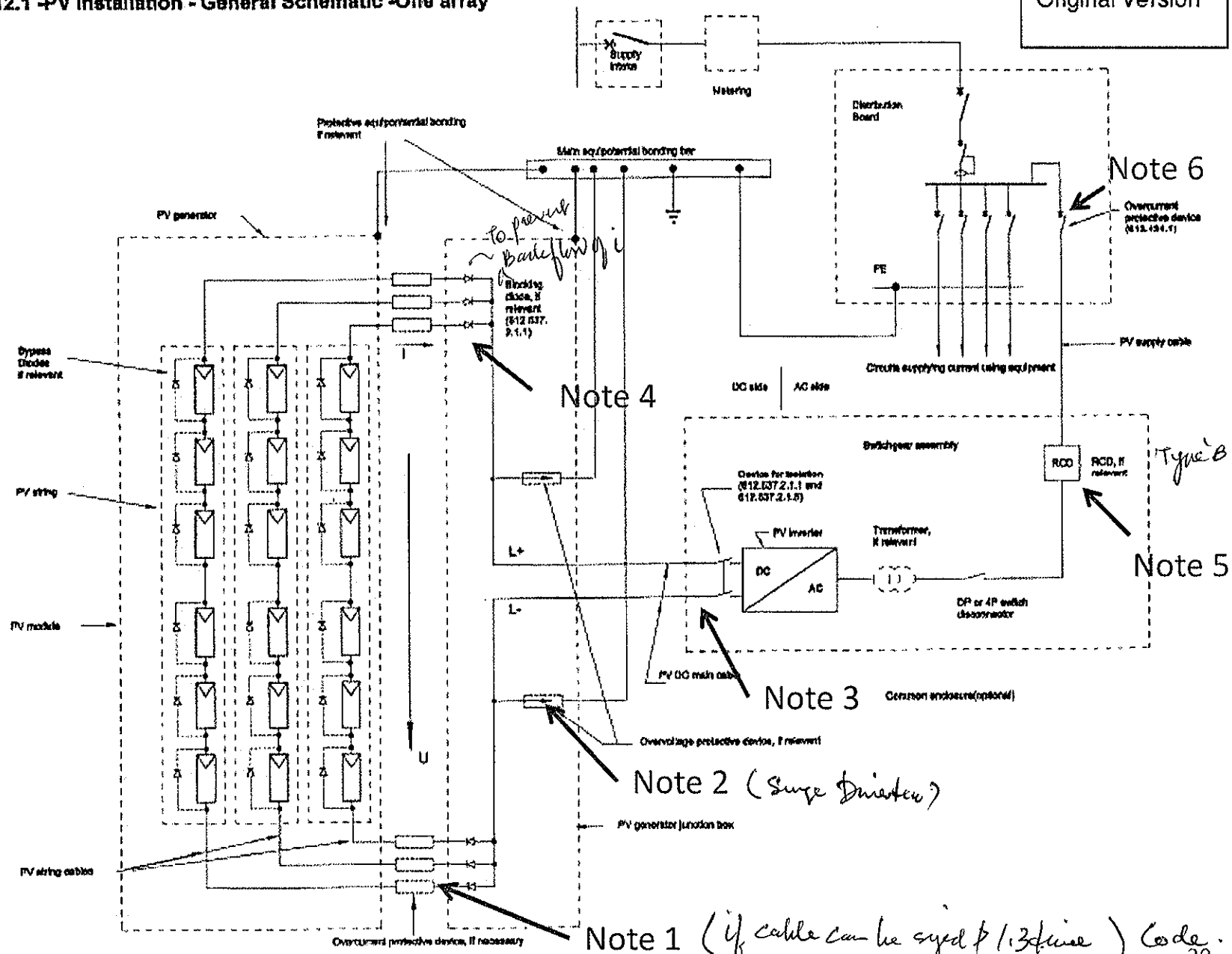
6. Safety and Design Requirements

- PV equipment on the d.c. side shall be considered to be energised, even when the system is disconnected from the a.c. side
  - Open voltage of each module may be low

    (eg. 30 ~ 50V) but when 6 to 12 modules connected in a string, the string voltage can be as high as 500 to 600V

Figure 612.1 -PV Installation - General Schematic -One array

Original Version



- Note 1
  - The dc rated overcurrent protective device is to protect the PV string from overload
  - The overcurrent protective device for PV string and PV array cables may be omitted if the continuous current-carrying capacity of the cable Is equal or greater than 1.25 times of the short circuit under Standard Test Conditions (STC)
  - $I_n \geq 1.25\ I_{SC}$

STC : Generally refer to cell temperature of 25° C, irradiance of 1000W/m^2 (IEC 60904-3)

- Note 2
  - Recommended by BCA to install surge arrestors on the DC side
- Note 3
  - Over-current protective device for PV main cables may be omitted if the continuous current-carrying capacity of the cable is equal or greater than 1.25 times of the short circuit under Standard Test Conditions (STC)

$$I_n \geq 1.25\ I_{SC}$$

- Note 4
  - If blocking diodes are used, their reverse voltage shall be rated for 2 times the Open circuit voltage ($U_{OC\,STC}$) under standard test conditions across an open PV generator

- Note 5
  - If there is no simple separation between the ac side and dc side, a type B RCD shall be installed to provide fault protection
  - If the PV inverter by construction is not able to feed dc fault current into the electrical installation, a type B RCD may be omitted

Simple Separation: Separation between circuits or between a circuit and earth by means of basic insulation

Why use Type B RCD?

- Type B RCD can detect:

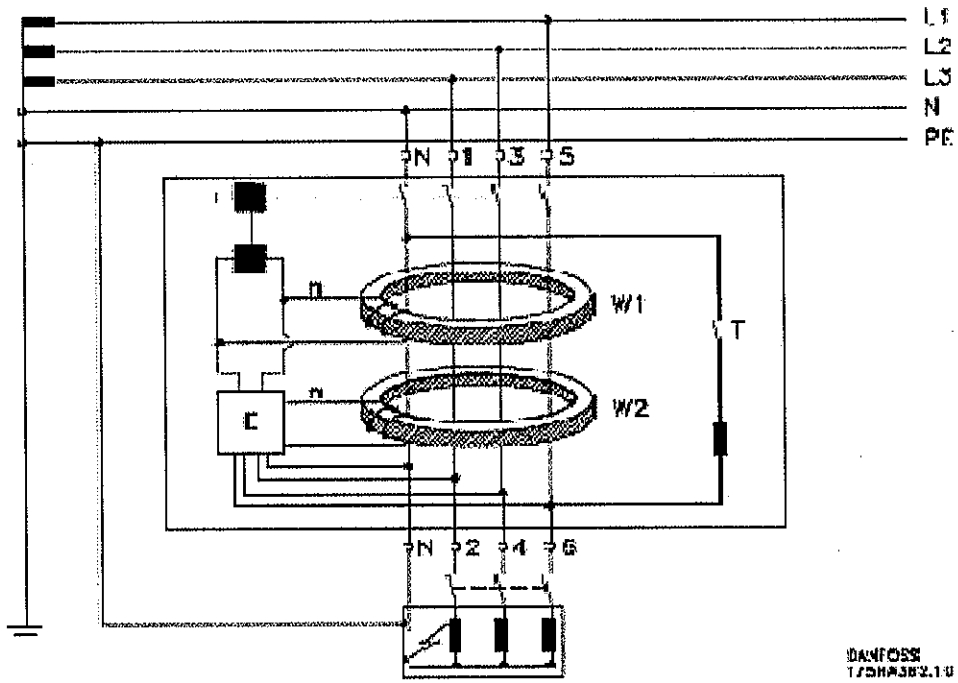
  residual sinusoidal currents , pulsating direct current and pure direct current

  Note

  Type AC RCD can detect only residual sinusoidal current

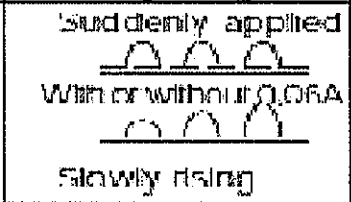
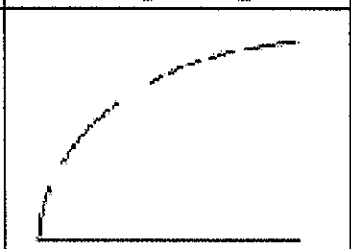
  Type A RCD can detect residual sinusoidal current and pulsating direct current

Construction of Type B RCD



W1 : core balance transformer to detect AC fault current
W2: core balance transformer to detect smooth DC fault current

Fault current that can be detected by various RCD

	Form of residual current	Correct functioning of RCD		
		AC	A	B
Sinusoidal A.C.		+	+	+
Pulsating D.C.			+	+
Smooth D.C				+

- Note 6
  - An over-current protective device shall be provided at the connection to the ac mains

7. Power Quality of PV system

- The power quality at the Point of Common Coupling(PCC):
  - Harmonics
    - Max. total harmonic voltage distortion ≤ 5%, with
    - All odd harmonics ≤ 4%
    - All even harmonics ≤2%
  - Voltage fluctuation
    - Voltage fluctuation ≤ 3%

- Voltage Unbalance
  - Max. negative phase sequence component of phase voltage ≤1%
- DC Injection
  - DC injection ≤ 20 mA under normal operation
  - DC injection ≤ 0.5% of the inverter rating with max. cap of 100mA under abnormal conditions

Local Code of Practice on PV Systems

- Singapore Standard SS CP5: 1998 -Code of Practice for Electrical Installations Amendment No. 1
- Handbook for Photovoltaic (PV) Systems, fourth edition, EMA
- Green Handbook- Photovoltaic (PV) systems in buildings, BCA

Thank You!

IES seminar on Solar Photovoltaics
25 March 2009

Solar-wind hybrids for stand-alone systems

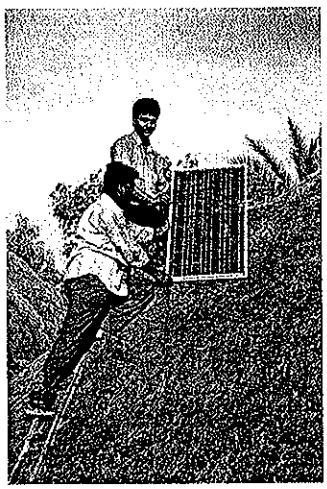
by
Dr. Lim Ewe Chye
Chairman
Clean Energy Interest Group
Institution of Engineers, Singapore

Wind-solar hybrid systems

- The term hybrid power system is used to describe any power system that combines two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome limitations inherent in either.
- A wind-solar hybrid system can make a positive contribution to the sustainability of rural communities in developing countries that do not have access to grid electricity.

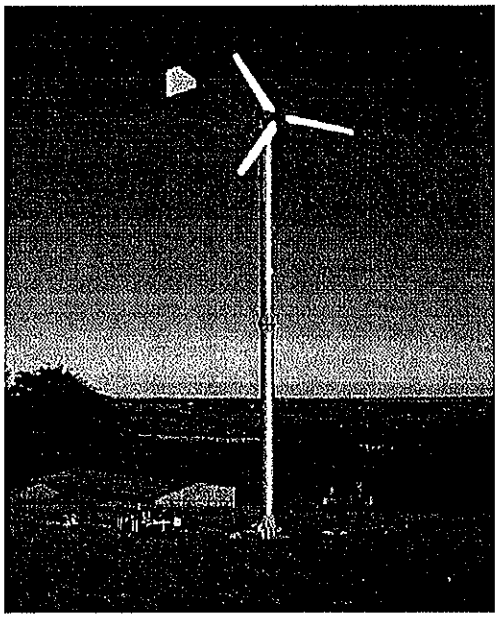
Various types of hybrid systems

- Hybrid power systems use one or more sources of power to generate electricity
- Most common are
  >> solar-wind,
  >> solar-diesel generator,
  >> wind-diesel generator and
  >> solar-wind-diesel generator.

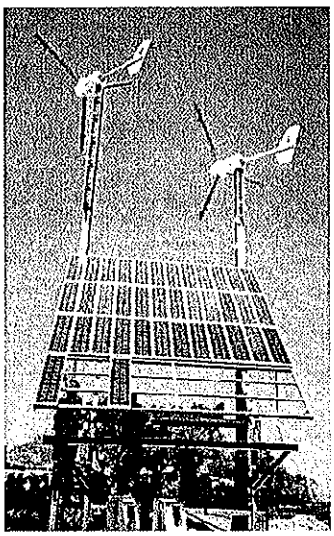


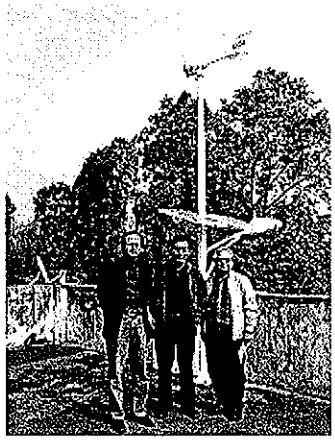
Use of small solar PV panels for homes in rural India



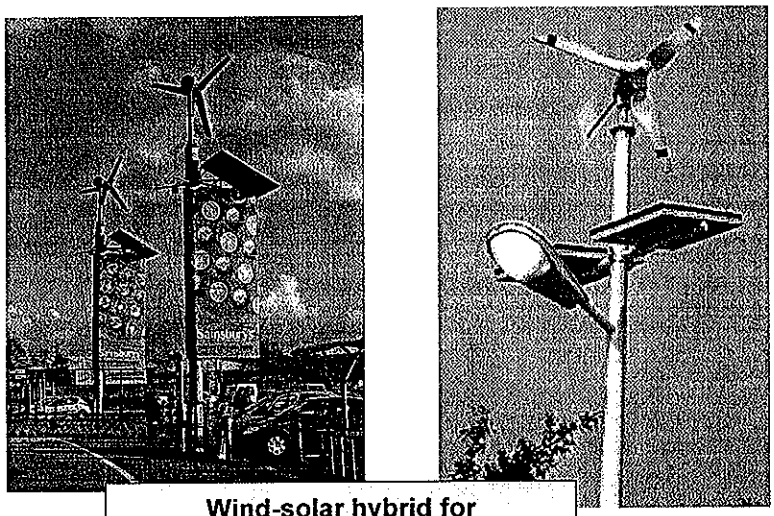


A small wind turbine:
10kW, 7 m blade diameter,
Cut-in wind speed 3 m/s,
Tower 12 m high

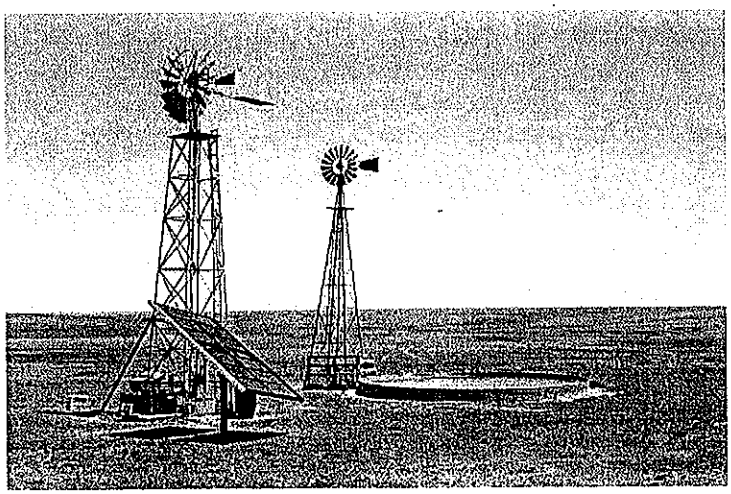




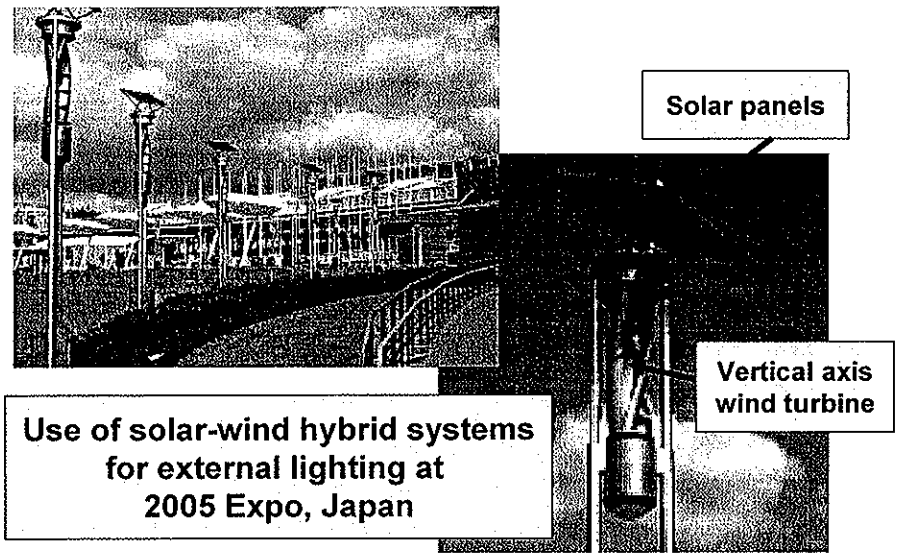
Example of
wind-solar hybrid system



Wind-solar hybrid for street lighting



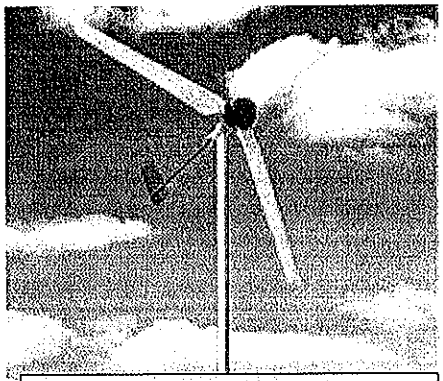
Wind-solar hybrid for pumping water



Use of solar-wind hybrid systems for external lighting at 2005 Expo, Japan

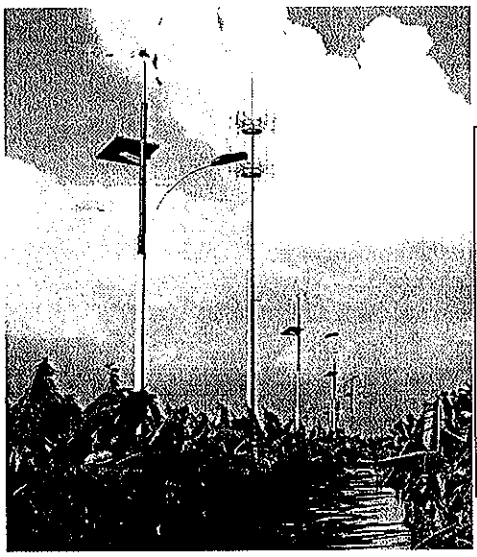
Usage of hybrid power systems

- They are designed to provide electrical generating capacity to remote communities that are usually not connected to a power-grid.
- Such hybrid systems are stand-alone (or off-grid) installations.
- Previously, remote communities depended on diesel-engine linked generating sets as the sole source of power.
- The introduction of hybrid systems reduces reliance on diesel fuel, which causes pollution and is expensive to transport.



Small sized wind turbines can be used with solar modules as a wind-solar hybrid system

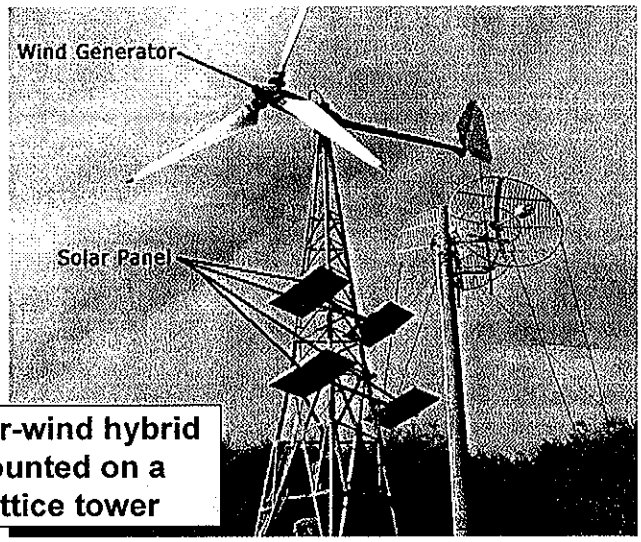
Rated output: 1,000 W
3 GRP blades
Blade diameter 3.1 m
Start-up wind speed 3.5 m/s
Rated wind speed 9 m/s
Cut-out wind speed 12 m/s
Tower height 8m



Example of wind-solar hybrid system

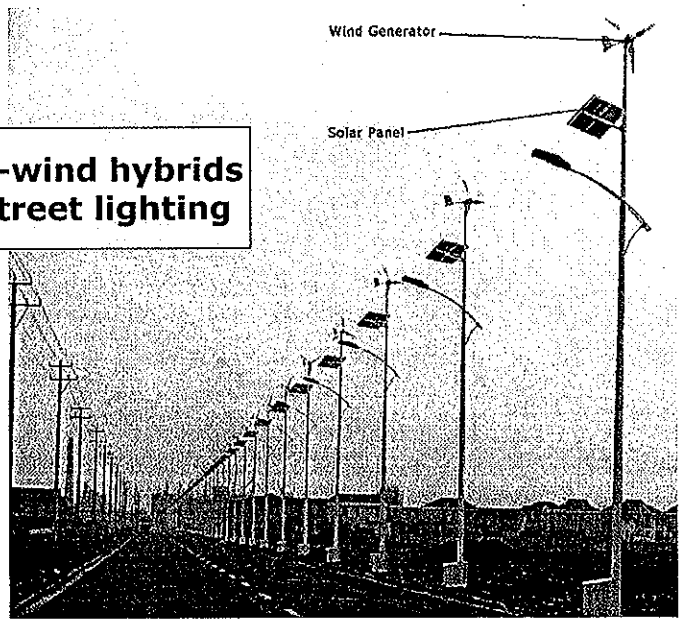
<u>Wind-solar hybrid street lighting</u>:

Wind turbine: 400 W
Solar panel: 100 W
Height of tower: 5m
Approx. cost:
about US$2,000/= each



Solar-wind hybrid mounted on a lattice tower

Solar-wind hybrids for street lighting



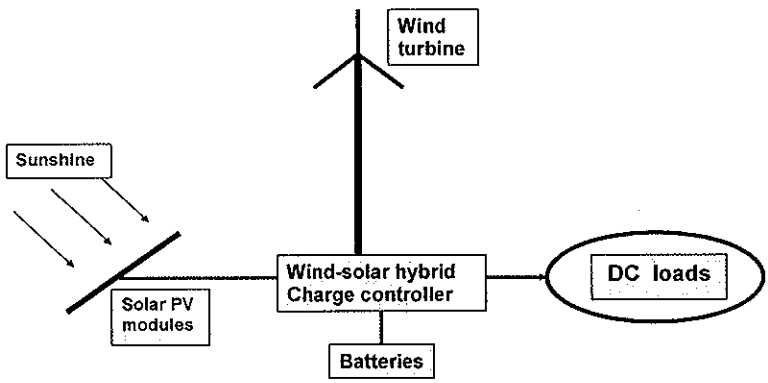
Components of wind-solar hybrid system

- **Grid-connected system**:

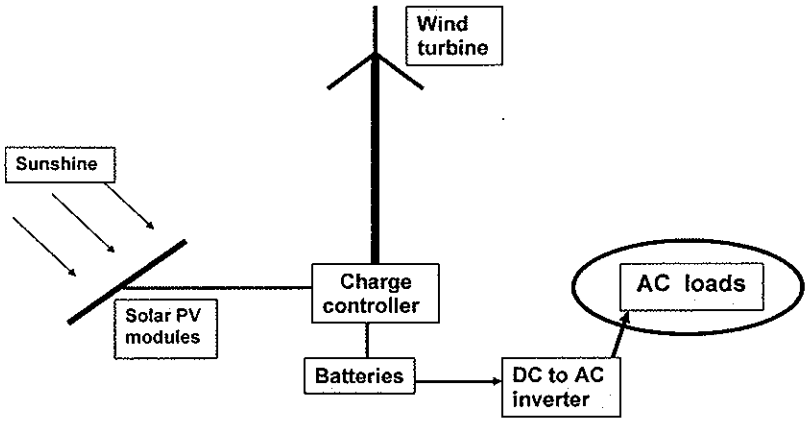
1] wind turbine
2] solar PV modules
3] inverter (to convert DC to AC)
4] Balance-of-system
(cabling, poles, light fixtures and other ancillary equipment)

- **Stand-alone system (i.e. off-grid)**:

1] wind turbine
2] solar PV modules
3] solar charge controller
4] inverter *(optional)*
5] batteries
6] balance-of-system
(as given above)



Wind-solar hybrid system (stand-alone system, with charge controller & batteries) generating DC electricity



Wind-solar hybrid system (stand-alone system, with charge controller, inverter & batteries) generating AC electricity

Use of batteries

- Batteries are often used in PV systems to store energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather).
- Other functions are:

  >> to operate the PV array near its maximum power point,

  >> to power electrical loads at stable voltages.

Use of batteries

- Deep cycle batteries are designed to be discharged and then re-charged hundreds or thousands of times.
- These batteries are rated in ampere hours (AH).
- For example, a 350AH battery can supply 35 continuous amps for 10 hours, or 17.5 continuous amps over 20 hours.
- In a 6V 360AH battery, the total watts potentially available equals

  360AH x 6 V = 2,160 watt-hours = 2.16 kWh.
- Like solar panels, batteries are wired in series and/or parallel to increase voltage to the desired level and increase amp. hours.
- Lead-acid batteries are the most common in PV systems because their initial cost is low and they are readily available nearly everywhere in the world.

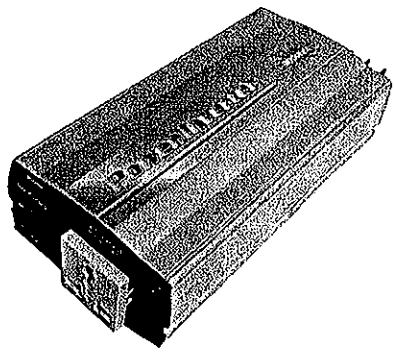
Use of solar charge controllers

- Charge controllers are included in most PV systems to protect the batteries from overcharge and/or excessive discharge.
- The minimum function of the controller is to disconnect the array when the battery is fully charged and keep the battery fully charged without damage.
- Charge controllers are rated based on the amount of amperage they can process from a solar array.
- If a controller is rated at 20 amps, this means that one can connect up to 20 amps of solar panel output current to this one controller.



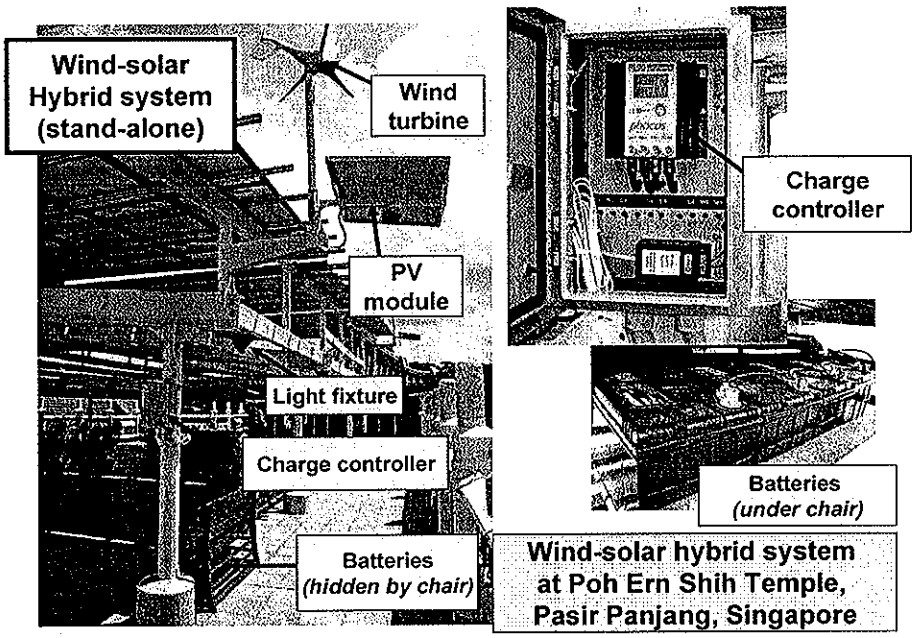
Inverters

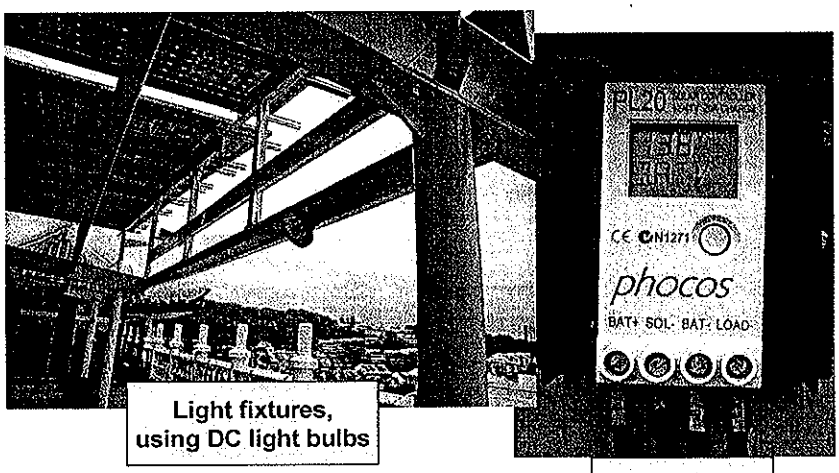
- An inverter is a device that changes DC power to standard 110/220 volt AC electricity.
- Nearly all lighting, electrical appliances, motors, etc., are designed to use AC power, so it takes an inverter to make the switch from DC to standard AC power.



Inverters

- In an inverter, direct current is switched back and forth to produce alternating current.
- It is then transformed, filtered, stepped, etc., to get it to an acceptable output waveform.
- The more processing, the cleaner and quieter will be the output, but the lower the efficiency of the conversion.
- The aim is to produce a waveform that is acceptable to all loads, without sacrificing too much power into the conversion process.





Wind-solar hybrid system at Poh Ern Shih temple, Pasir Panjang, Singapore

Examples of PV hybrid systems in Thailand

- **For hybrid systems in Thailand, it is reported that up to 2005, a total of about 40kWp by PV modules, 23kW by wind turbines and 220 kW by diesel generators have been installed, with a total initial capital outlay of about 31 mil. Baht.**

  (ref: PV hybrid systems for rural electrification in Thailand,
  by N. Phuangpornpitak & S. Kumar (2006), Elsevier Ltd.)

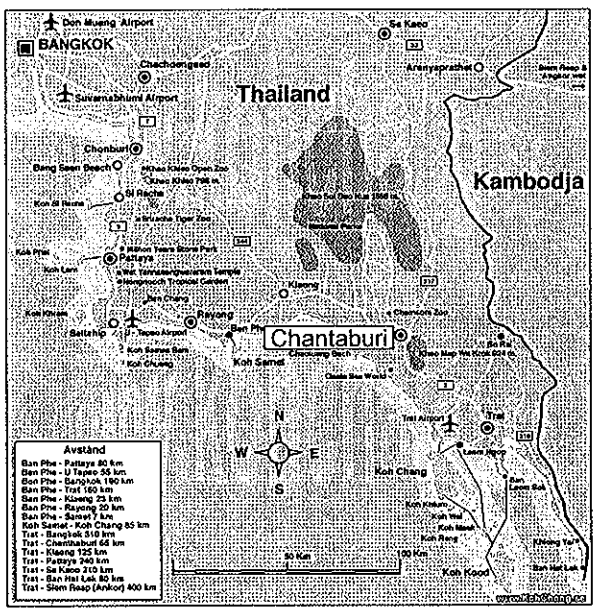
- **The above off-grid systems are installed in remote and rural areas.**
- **Over 60% were installed in national parks and wildlife sanctuaries, where these systems provided electricity for offices and visitor's lodges. About 30% were installed in isolated islands and the rest were in mountainous villages.**
- **The costs of stand-alone systems are about 95 to 140 Baht/watt, and for grid-connected systems the cost are about 70Baht/watt.**



Specific hybrid projects in Thailand

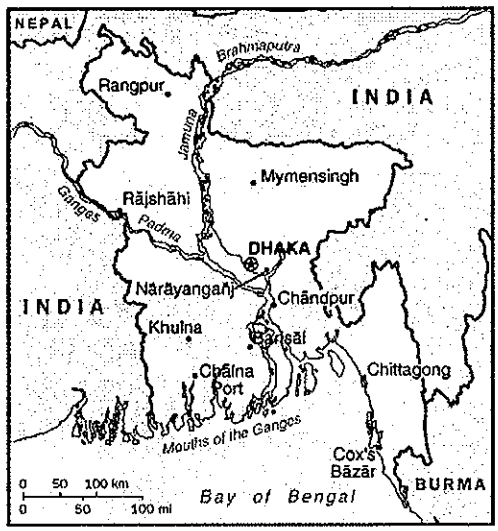
- **Wat Chan Royal Project, Chiangmai:**
  Provision of electricity to mountainous villagers....
  >> PV/diesel hybrid system
  >> 600Wp PV array
  >> 5.25 kVA diesel generator
  In operation since 2002;
  Installation costs: 329,782 Baht

- **Kohjig, off Chantaburi:**
  Provision of electricity to islanders.....
  >> PV/wind/diesel hybrid system
  >> 7.5 kWp PV array
  >> 10 kW wind turbine
  >> 65 kVA diesel generator
  In operation since Nov. 2004
  Installation cost: 7,750,400 Baht



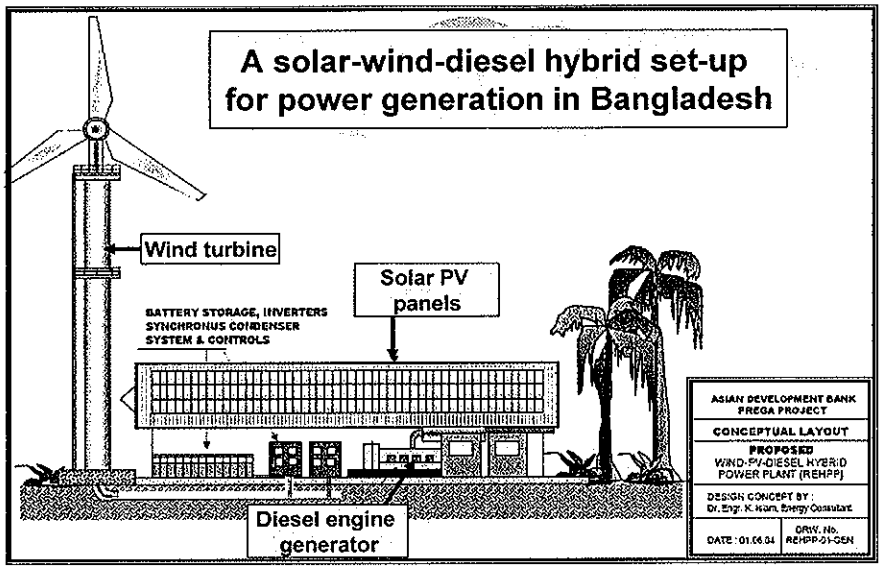
Hybrid project in Bangladesh

- **Solar-wind-diesel hybrid systems are used in Bangladesh for power generation in small towns and villages.**



Hybrid project in Bangladesh *(continued...)*

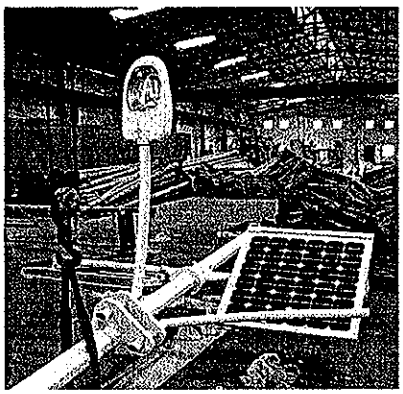
- **One project used two wind turbines (50kW each), a 25kW solar system and a 20kW diesel unit plus a battery bank (200kWh capacity).**
- **When maximum wind is available, the system will draw peak power from the wind turbine, reducing power draw from the solar PV system.**
- **In times of very low wind (below cut-in speed), it will draw more from the solar PV and the battery.**
- **Only in the case of very low availability of both wind and solar, will the diesel engine gen-set be switched on through a control-operated relay switch.**

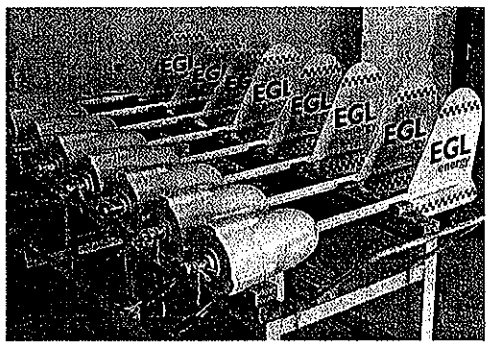


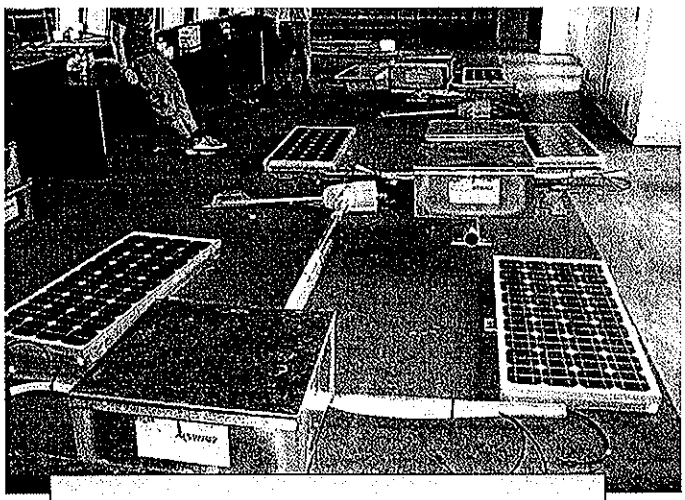
Miscellaneous photos
of projects showing:

>> storage of hybrid equipment;
>> installation of equipment;
>> training of technical personnel in basic solar technology

Storage of hybrid equipment

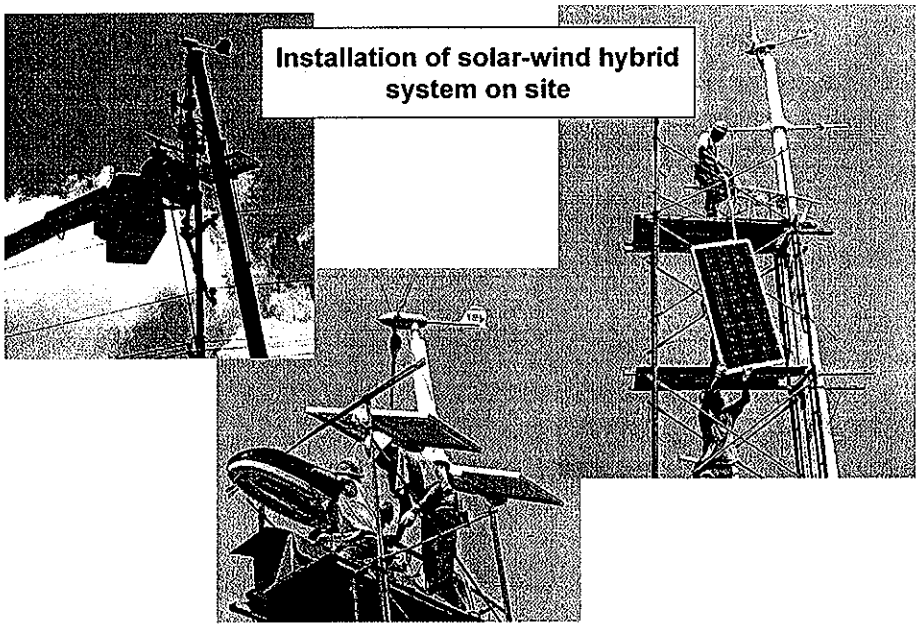




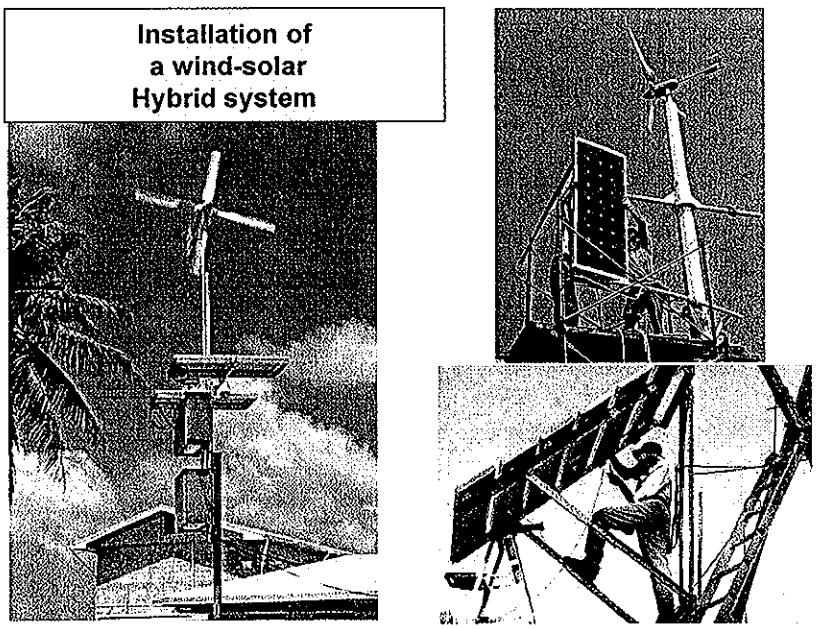


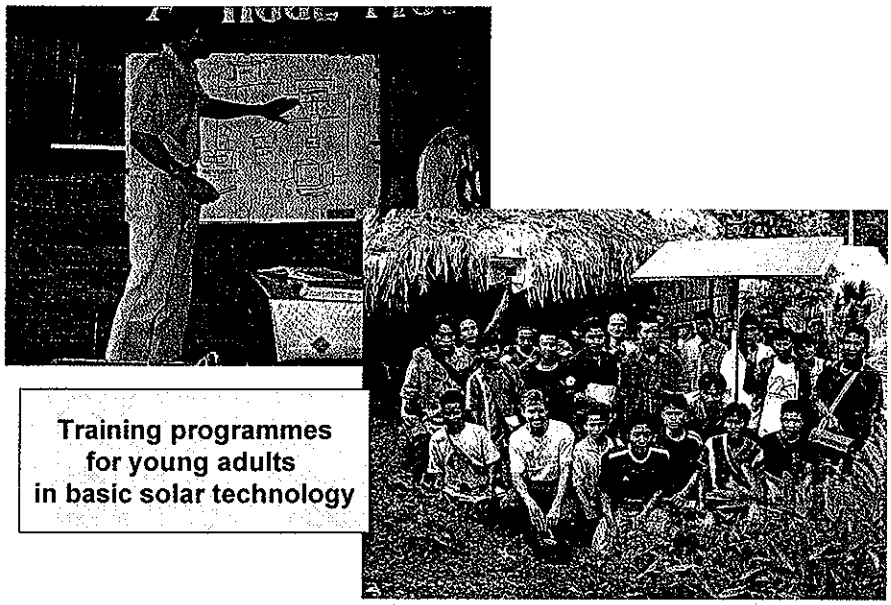
Layout of components prior to site installation

Installation of solar-wind hybrid system on site

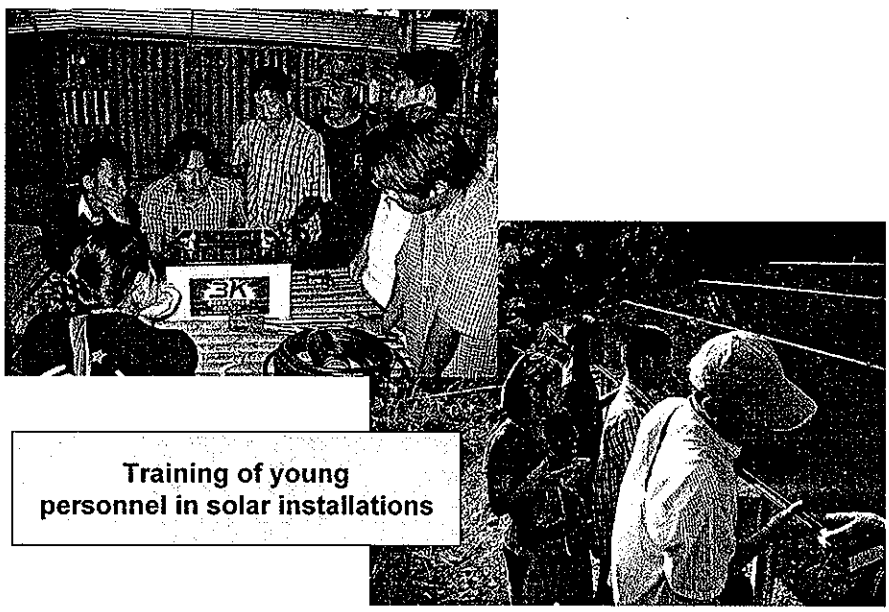


Installation of a wind-solar Hybrid system

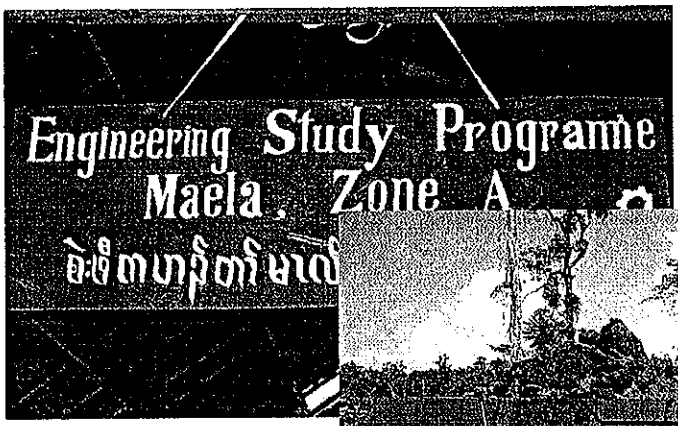




Training programmes for young adults in basic solar technology



Training of young personnel in solar installations





Education & training programmes in a rural South-East Asian community

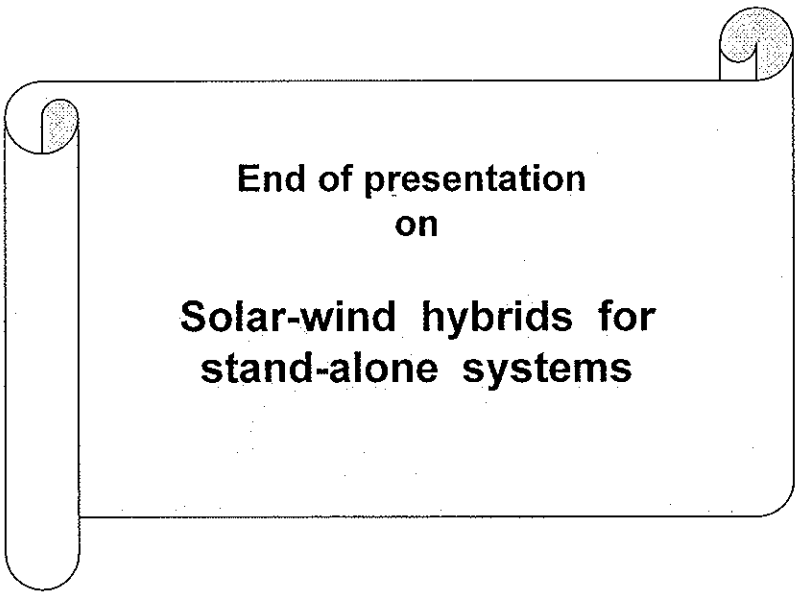




Installing of solar PV panels in a rural Asian community

Concluding remarks

- There is potential for the use of solar-wind hybrid systems in rural communities in many countries, both developed as well as developing countries.
- In the regional countries, solar-wind hybrids can be installed in regions with good wind speeds, such as in hilly areas and coastal sites.
- Villagers can combine their financial and labour resources together to make such hybrid projects successful.
- Education and training is important, so that the installed equipment function well and are maintained.
- Security is also important, in that the installed equipment must not be damaged or stolen.



One- day Seminar on SOLAR PHOTOVOLTAICS on 25 Mar 09 @ Novotel, Clarke Quay, Singapore

ENVIRONMENTAL IMPACT OF SOLAR PV SYSTEMS

Dr Adhityan Appan

Technical Advisor

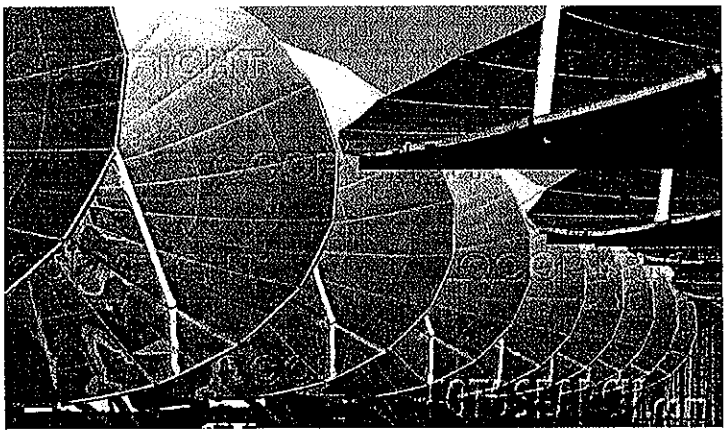
HYFLUX

Singapore

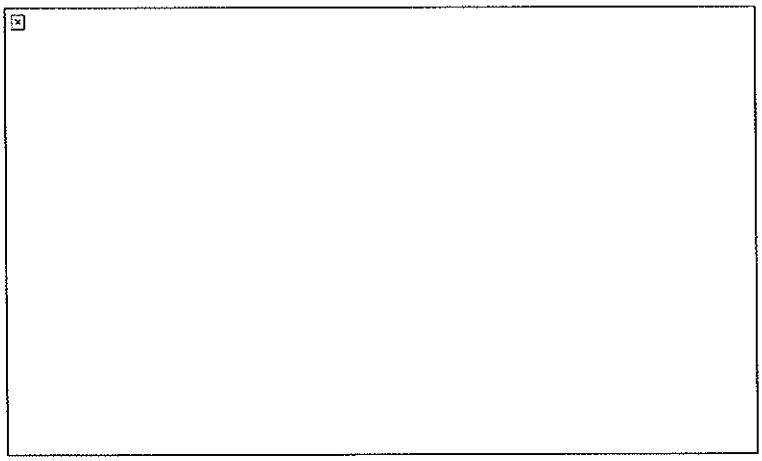
SOLAR ENERGY - Panels

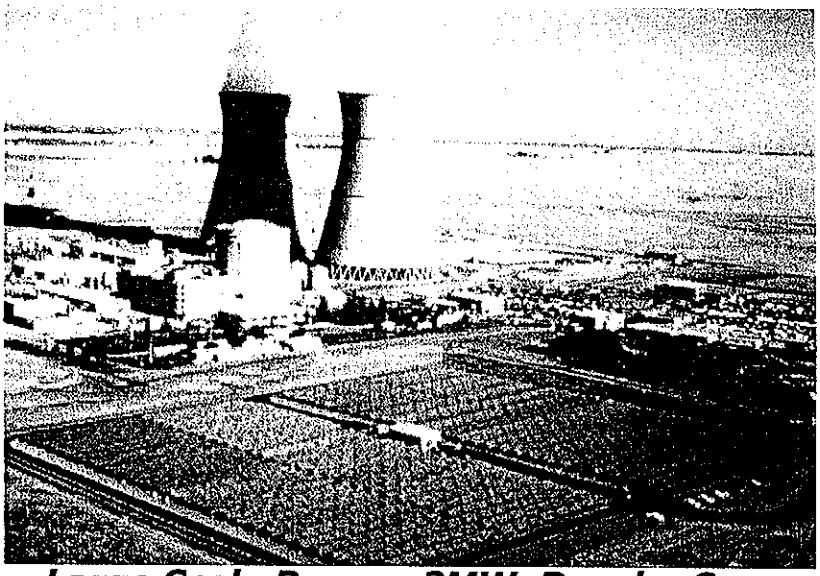


SOLAR ENERGY - Dishes



SOLAR PANELS – in Rows





Large Scale Power- 2MW Rancho Seco Nuclear Plant at CA,USA

INTRODUCTION

- *The photoelectric effect, a phenomenon central to generation of electricity through solar cells - work of Albert Einstein (1921) – Noble prize ?*
- *First Si solar cell generating a measurable electric current (1954) - Bell Laboratories (now AT&T labs)*
- *The "Space Race" of 1950s & 60s - lead to progress in solar energy use - as satellites & crafts used solar paneling for electricity.*

3 salient factors for growth of solar PV cells

- ***Abundant solar energy available (Sun)***
- ***Rate of growth of solar industry***
- ***Progressively decreasing cost of solar power***

IMPORTANT: In development of solar industry, it should be ensured that in no way should there arise, IN THE FUTURE, the mammoth global environmental problems caused by Conventional Energy Sources

SOLAR ENERGY- ITS AVAILABILITY, CURRENT USE & COST

- ***Available solar energy: The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year (Smil, 2006).***
- ***In 2002, this was more energy in one hour than the world used in one year (Morton, 2006).***

***USE & Cost*: With the introduction of primarily solar PV**

modules, the increase in its use has been dramatic as

shown in:

- ***Figure 1*(Country- basis) – Upto 2007**

Germany -1250 MW; Japan - 400 MW; USA – 290 MW

EU - 270 MW; ASIA – 120 MW

- ***Figure 2* (Cumulative):**

1980 to 2000 – 1700 MW

2000 to 2007 – 12,200 MW

COST – see Figure 3 (fr $100 in 1975 to < $5/Watt

Figure 1: Rate of Growth of PV Systems – Country basis

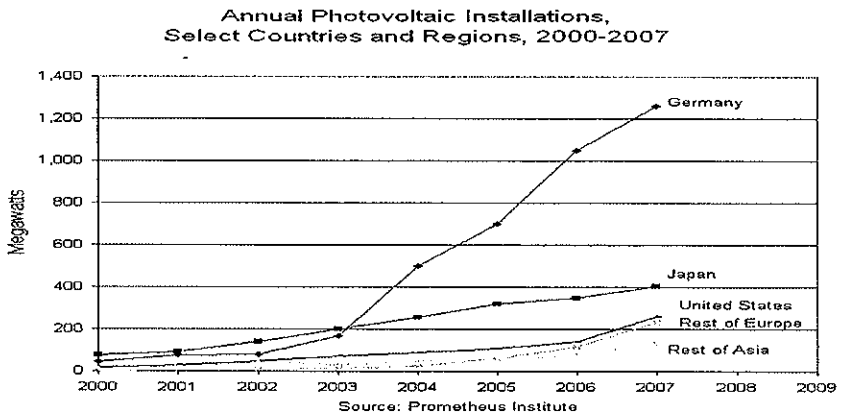


Figure 2: Rate of Growth of PV Systems – World basis

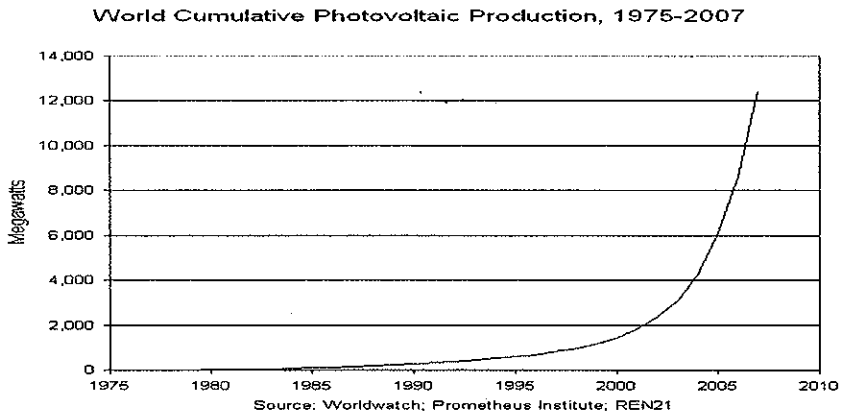
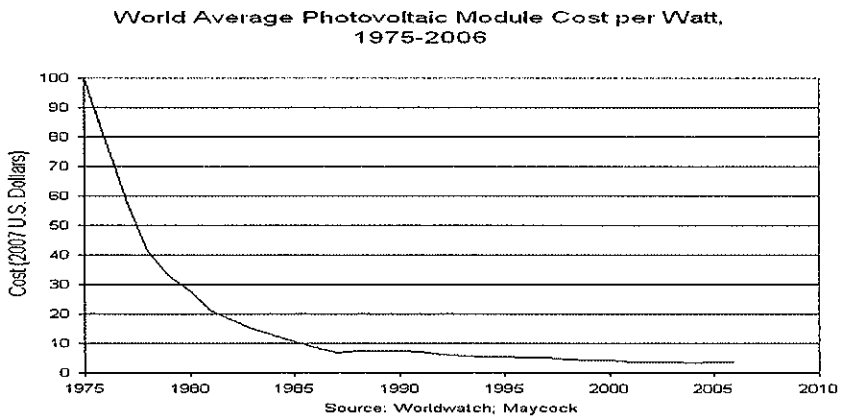


Figure 3: Varying Cost of Solar PV Modules



TYPES OF SOLAR PANEL

- ***Si cells* - most commonly used PV cells.**
- ***Crystalline Si cells* expected to continue as the dominant type for next 5 to 10 years.**

Expected future trend in PV industry

- ***to produce more thin-film PV cells –***
- ***higher energy efficiency***
- ***hence lower cost/ per unit of electricity generated.***

contd.....

Types of Solar Panel (contd...)

- ***Of the compound thin-film PV cells, CdTe (Cadmium Telluride) and CIS (Copper Indium Selenide) - likely to be produced on a larger scale in near future.***
- ***Other types of thin film cells – future production - amorphous Si cells and CIGS (Copper Indium Gallium diSelenide)***

INFLUENCING ENVIRONMENTAL FACTORS

a. Air Pollution & Energy

- ***Unlike fossil-fuel based technologies, Solar power does NOT lead to any harmful emissions during operation. Hence they generate no air pollution.***
- ***Energy is required to manufacture & install solar components - ANY fossil fuels used for this purpose will generate emissions.***
- ***Thus, an important question is: " How much fossil energy input is required for solar systems compared to fossil energy consumed by comparable conventional energy systems ?"***

Air Pollution & Energy **(Contd..)**

- ***Solar power does not lead to any harmful emissions during operation, but the production of the panels leads to some amount of air pollution.***

If the energy input to produce the panels is higher than the output it produces, the system will be environmentally more harmful than beneficial

b. Life-cycle greenhouse gas emissions

Emissions for OTHER energy sources at present are as follows:

- ***For Gas-fired Power Plant - 400 g/kWh***
- ***For Coal-powered Power plant -915 g/kWh***
- ***For Nuclear Power - 6 to25 g/kWh***
- ***For Wind Turbines - 11 g/kWh***
- ***For Solar panels, - 35 to45 g/kWh***

(Note: This could decrease to 15 g/kWh in the future).

c. Environmental Health & Safety Issues

- ***Primary environmental, health, & safety issues in use of solar panels involve how*** *they are* ***manufactured, installed &ultimately disposed of.***
- ***Materials used*** *in* ***some solar systems can create health and safety hazards*** *for workers. In particular, manufacturing of some photovoltaic cells requires* ***hazardous materials such as arsenic & cadmium***

d.Silicon

- ***Human health concerns are the use of toxic gases & solvents during mfg.Arsine & Phospine gases are used in the production of Si –based cells***
- ***The potential impacts are primarily at the manufacturing facilities for workers and for nearby residents, if accidents occur.***
- ***The completed, installed Si-based cells pose minimal risks to human health or the environment.***
- ***Even relatively inert Si - a major material used in solar cells - can be hazardous to workers if it is breathed in as dust.***
- ***Workers involved in mfg PV modules & components must be protected from exposure to these materials.***

e. Cadmium

- ***Cd is potentially of concern with thin-film technologies and generally used in small quantities***
- ***Cd compounds are NOT USED by Amorphous Si and Crystalline Si cells***
- ***Cd in its metallic form is a toxic subs that will accumulate in eco food chains.***
- ***However, the amount of Cd used in thin-film is relatively small (5 – 10g/m2)***
- ***With proper emission control techniques in place, Cd emissions from module production can almost be zero.***

f. Chemicals used & Waste generated

- ***A variety of acids or corrosive liquids are used in fairly large quantities during the mfg process.***
- ***They include Hydrochloric acid, Sulphuric Acid, Nitric Acid and Hydrogen Fluoride, chemicals primarily used for cleaning of wafers or to remove impurities from raw semiconductor materials***
- ***The wastes generated by Si-based PV industry are similar to those from the general semiconductor industry, although the quantities are, in general, less.***

g. Completed Installations

- ***At completed installations of PV systems for power generation, the potential for chemical releases appears to be small since the chemicals are present in the sealed PV modules.***
- ***Releases are likely to occur only due to fires or other unusual accidents. Cd could be a potential concern in this setting with thin-film technologies, as would arsenic and zinc to a lesser extent.***

h. Leaching of Metals

- ***Leaching of metals from installed modules is not likely to be a concern (Steinberger ,1998).***
- ***Leaching from small cells used in electronic devices is also unlikely to be a concern, because of the small amounts of chemicals present and sealed nature of the devices.***

i. Disposal of Modules

- ***Little information on disposal of used photovoltaic modules is available.***
- ***Both Cd and Cu are a potential concern to biota due to their acute toxicity***
- ***This, depends on the conditions in a given waterbody and the specific type of biota.***

j. Off-site Disposal

- ***Waste materials produced by photovoltaic facilities are also sent off-site for disposal.***
- ***Disposal methods for these waste materials are land- filling and incineration.***
- ***Because many of the chemicals used in large quantities are liquids, disposal in landfills is not likely to be the primary disposal option.***
- ***Incineration or other thermal treatment has been used as a disposal method for photovoltaic waste***

k. Recycling of Photovoltaic Modules

- ***Reason for developing feasible, cost-effective approaches for recycling PV modules is the scarcity of some of the exotic metals used in the PV cells. (The crustal abundance of metals, current reserves, and amount used in selected PV cells are shown in Table 1.)***
- ***In the future, recycling is thought to be the likely handling method for spent PV modules.(Because the expected life of most modules is about 30 years, there is limited experience with large-scale programs.)***
- ***Currently, scrap PV modules are recycled by large metal smelters that also recycle electronics and telecommunication equipment. About 95% of the Tellurium and 96% of the Lead is recovered.***

Cal. Te - limited

I. Use of land

- ***A large amount of land required for utility-scale solar power plants - app one square km for every 20-60 megaWatts generated.***
- ***This poses an additional problem, especially where wildlife protection is a concern.***
- ***However, this problem is not unique to solar power plants.***
- ***Generating electricity from coal actually requires as much or more land per unit of energy delivered if the land used in strip mining is taken into account.***
- ***Likewise hydro-power plants can also make large demands with respect to land being inundated.***

n. Use of Water

- ***Solar-thermal plants (like most conventional power plants) also require cooling water, which may be costly or scarce in desert areas.***

CONCLUSIONS

- ***With abundant sunlight available, the dwindling conventional energy sources and the progressive decrease in solar energy cost, there is bound to be an increase in the use of solar energy.***
- ***The era of solar energy has arrived !***

(contd....)

CONCLUSIONS (contd...)

- ***None of the hazards encountered in the production, use & disposal of PV systems is much different in quality/magnitude from innumerable hazards people face routinely in an industrial society.***
- ***This is particularly so when current energy sources such as coal, petroleum, hydro-power etc are being utilized.***
- ***Thru effective regulation, dangers can very likely be kept at a very low level***

CONCLUSIONS (Contd...)

- ***The large amount of land required for utility-scale solar power plants - poses an additional problem, especially where wildlife protection is a concern.***
- ***This problem is not unique to solar power plants.***
- ***Generating electricity from coal actually requires more land per unit of energy delivered if the land used in strip mining is taken into account.***
- ***Likewise, hydro-power plants can also make large demands with respect to land being inundated/ catchment areas***
- ***Solar-thermal plants (like most conv. power plants) also requirecooling water, which may be costly or scarce in desert areas.***

(Contd....)

CONCLUSIONS(Contd...)

- ***Recycling - preferred disposal option for spent PV modules in the future, in order to minimize the potential for env impacts, reduce disposal costs of spent modules & recover source metals.***
- ***PV systems are in a good position to compete with other conventional energy technologies in terms of life-cycle greenhouse gas emissions***

The End

THANK YOU