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Consulting Services for the “Programme for the Promotion of Renewable Energies: German-Armenian Renewable Energy Fund (GAF-RE) Phase III”, BMZ ID 2012.7029.7

Photovoltaic Power Plants

Specifics, Project Development and Project Assessment
of PV plants for Investors, Developers, Designers

Yerevan, 28.06.2017

BMZ Federal Ministry for Economic Cooperation and Development

CENTRAL BANK OF ARMENIA

KFW

Photovoltaic Power Plants

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Rev No.	Rev-date	Contents / amendments	Prepared / revised	Checked / released
0	28.06.2017	Final	Boris Schwarze	Fabian Knapp
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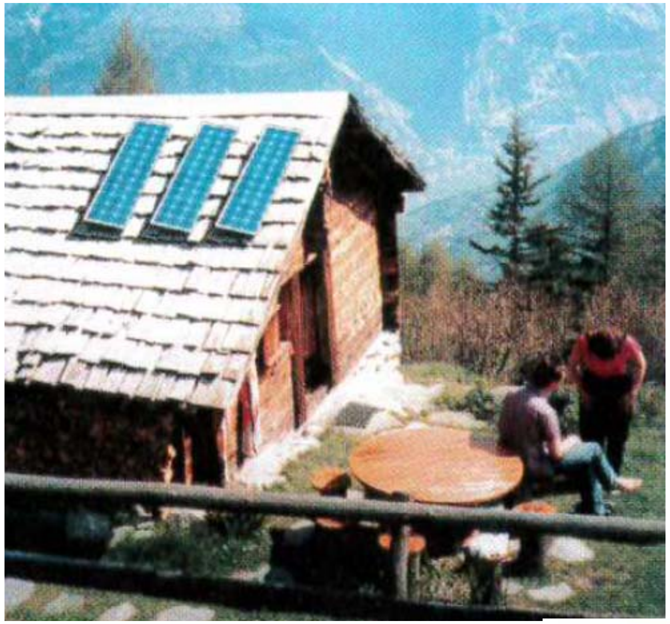
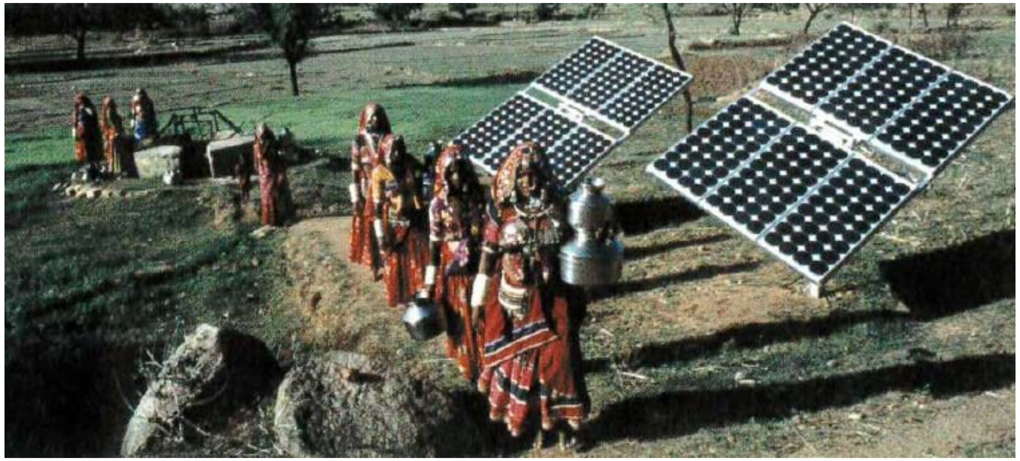
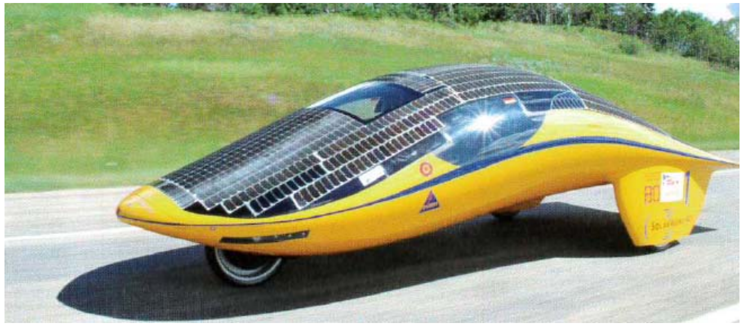
2				

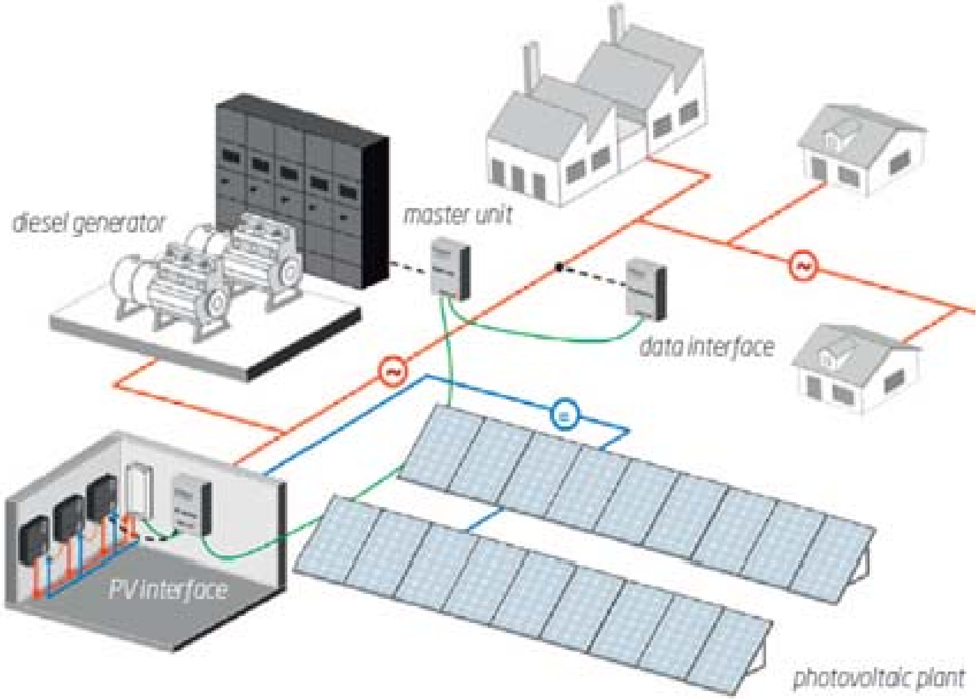
Photovoltaics

PV Applications



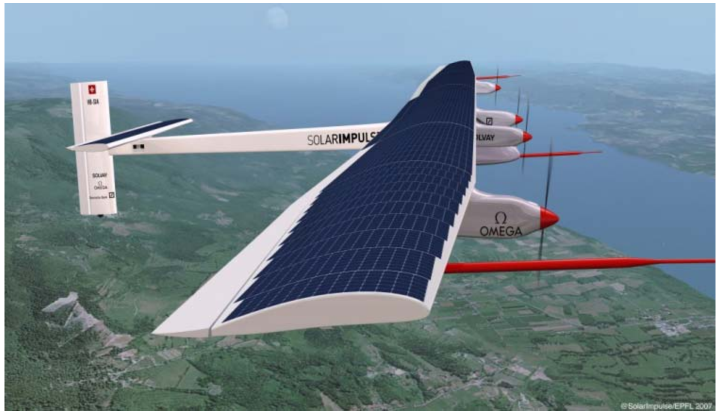






Pictures DGS, Berlin

PV Applications



PV Applications – large scale power plants - I

Source: SunEdison

PV Applications – large scale power plants - II

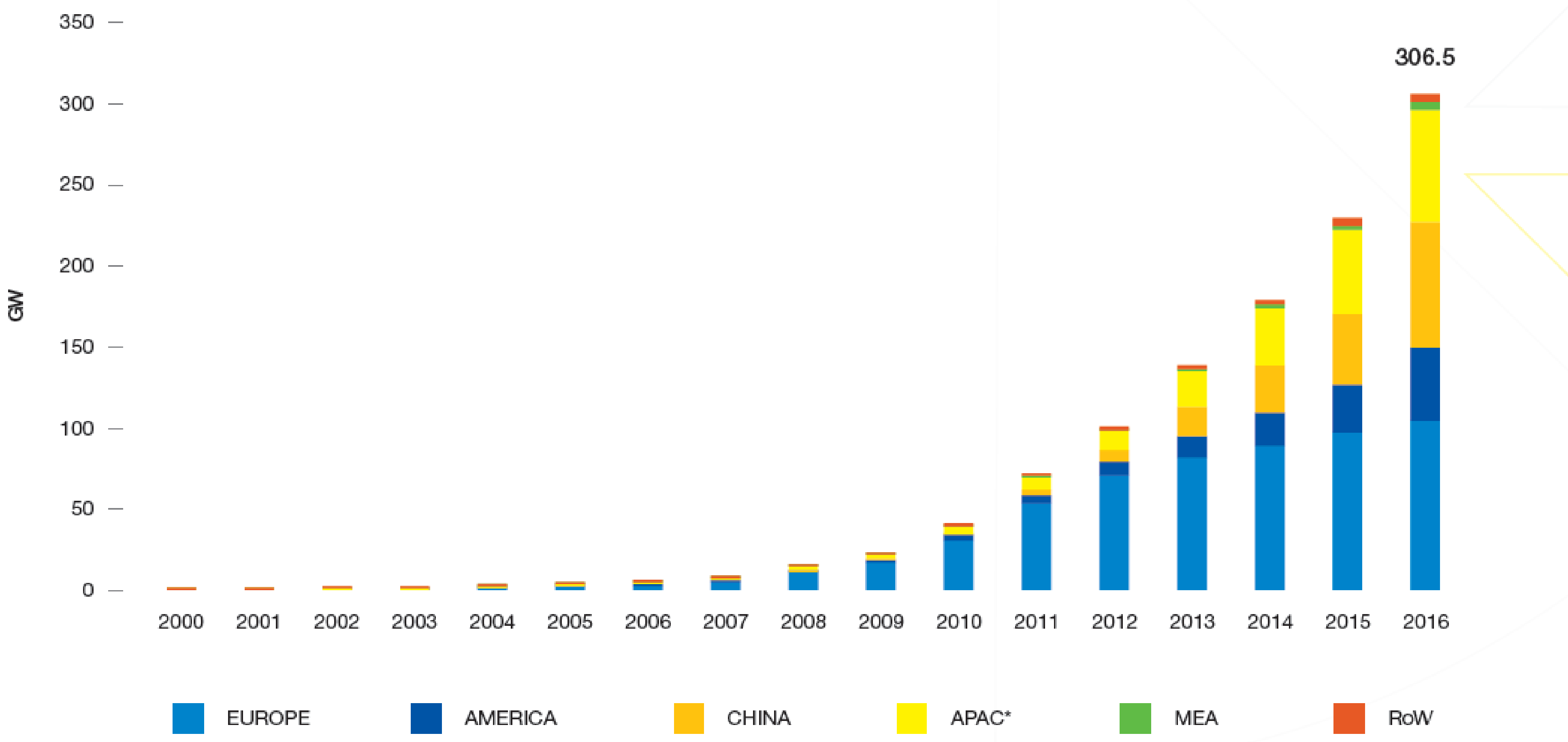
Source: Fichtner

PV Applications – large scale power plants - III

Source:Fichtner

Photovoltaic - Evolution of global installed PV capacity

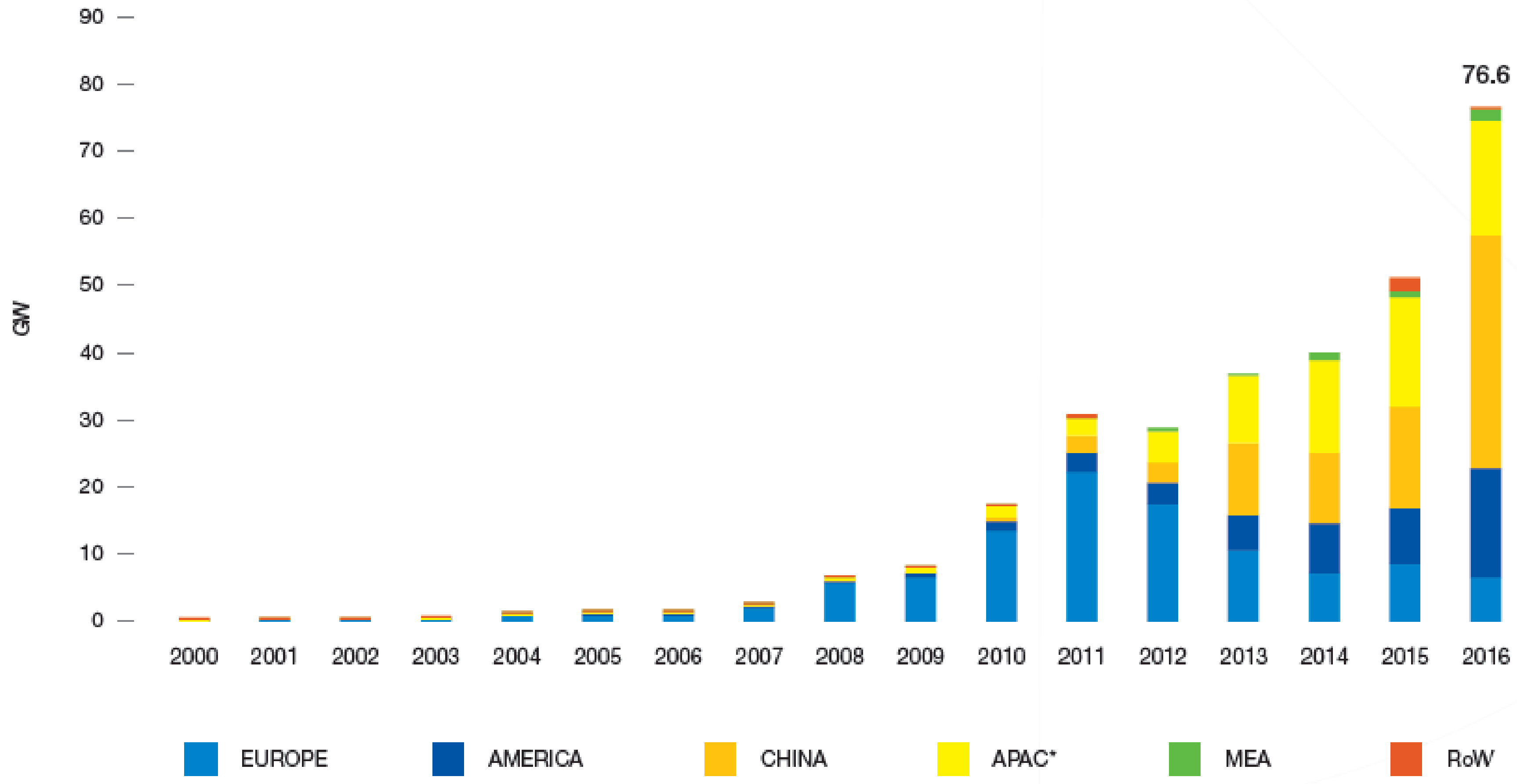
FIGURE 4 EVOLUTION OF GLOBAL TOTAL SOLAR PV INSTALLED CAPACITY 2000-2016



* APAC excl. china

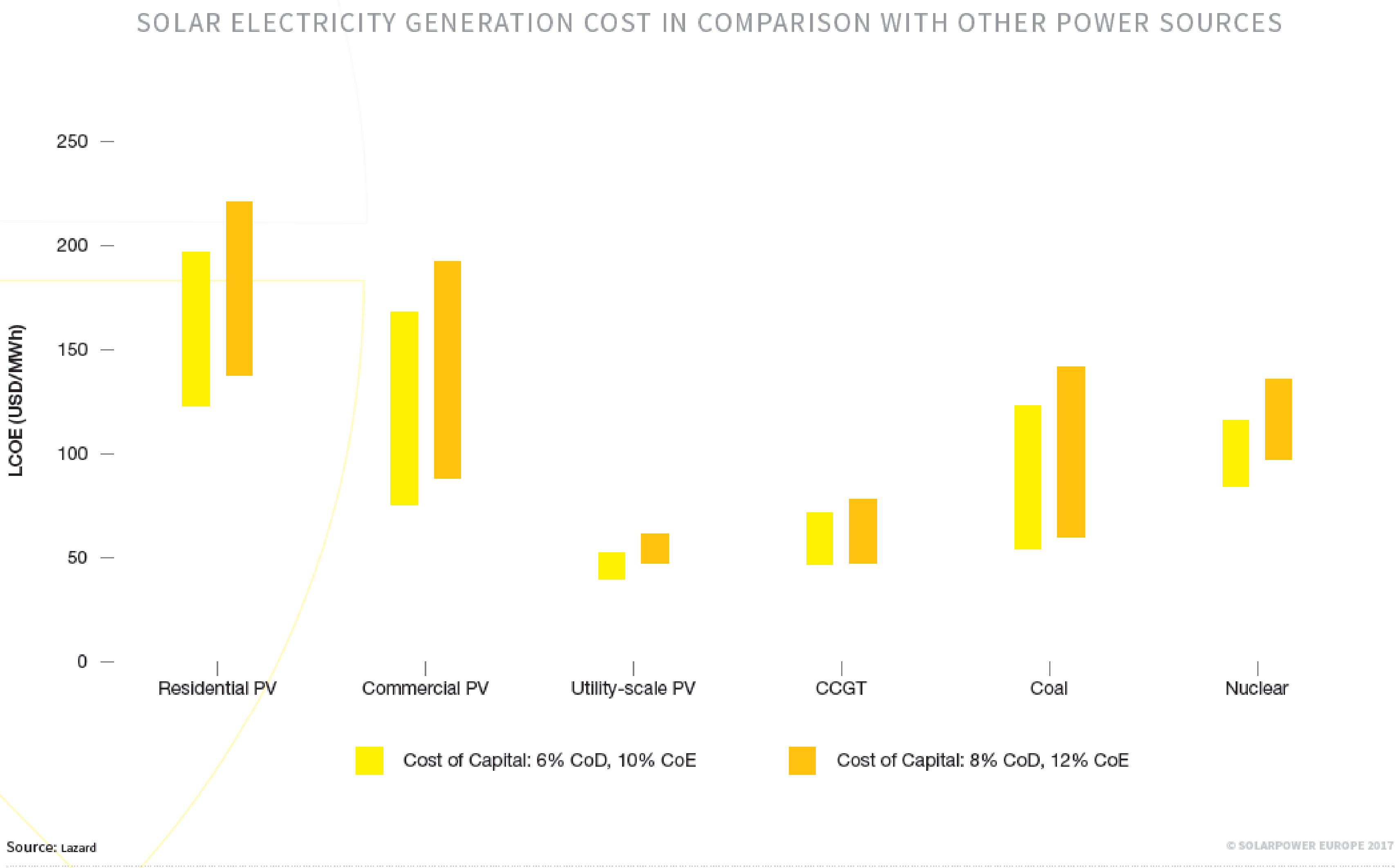
Photovoltaic - Global annual installed PV capacity

FIGURE 3 EVOLUTION OF GLOBAL ANNUAL SOLAR PV INSTALLED CAPACITY 2000-2016



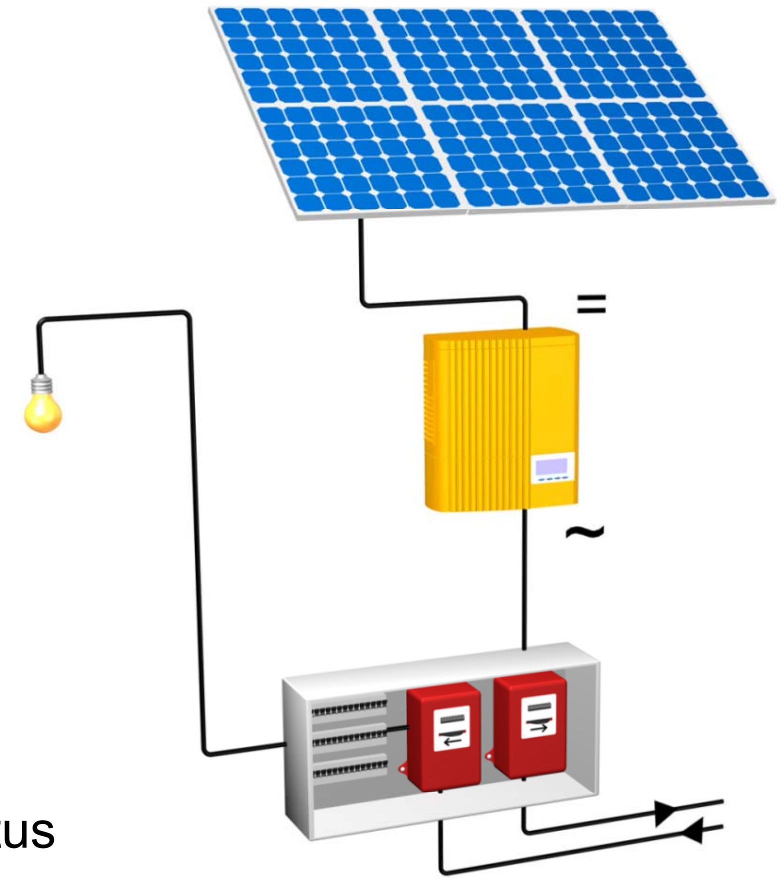
*APAC excl. China

Photovoltaic – Electricity Generation Costs



Photovoltaic

Basic principle of photovoltaic plant



Photovoltaic modules connected in series (strings)

Mounting (or tracking) system

Inverter (DC/AC)

Electricity meter / grid connection

Status

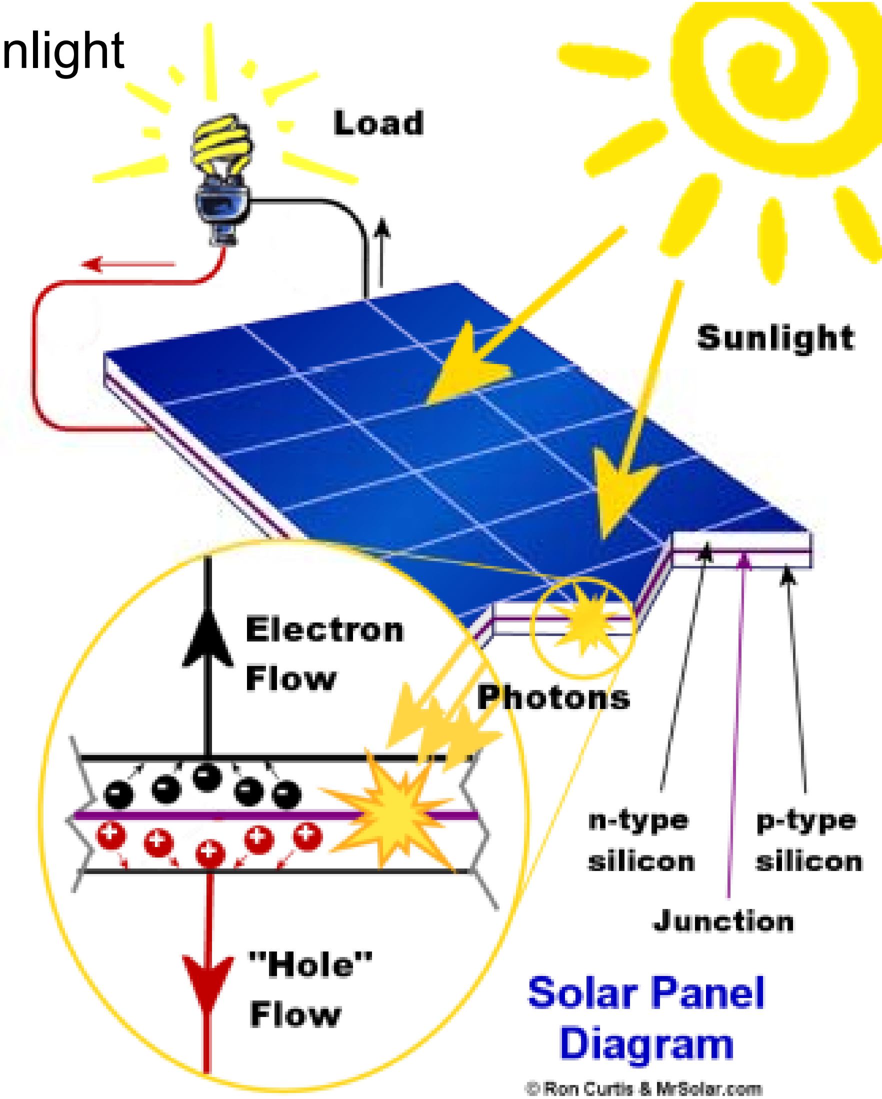
- Components are proven in numerous plants and successfully in operation
- Cost reduction due to mass production, economy of scale and further technological advancements

Photovoltaic

Principle / Characteristics

- Solar cells are used for the collection of sunlight
- Direct transformation of sunlight into electricity by the photovoltaic effect
- Different kinds of Photovoltaic Technologies
  - c-Si (mono- / poly)
  - Thin-film (a-Si, CdT…)
  - Concentrated PV (CPV)
  - Others (organic PV cells etc.)

modular technology



Photovoltaic

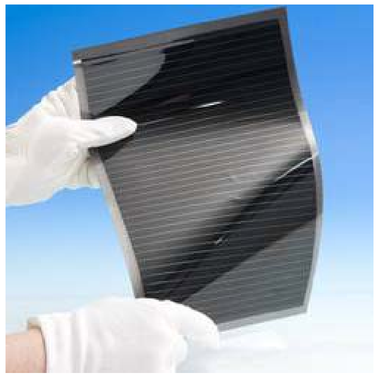
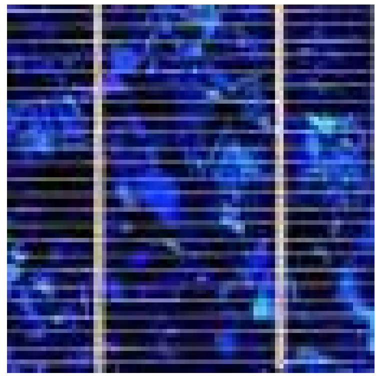
Types of solar cells - Overview

There are basically two different technologies to manufacture PV solar cells:

- Wafer based crystalline silicon solar cells (represent the bulk of the market)
  - Mono-crystalline cells
  - Poly-crystalline cells

- Thin-film technology
  - Different materials and deposition processes



Photovoltaic

Types of solar cells - **Mono-crystalline** cells (mono-Si)

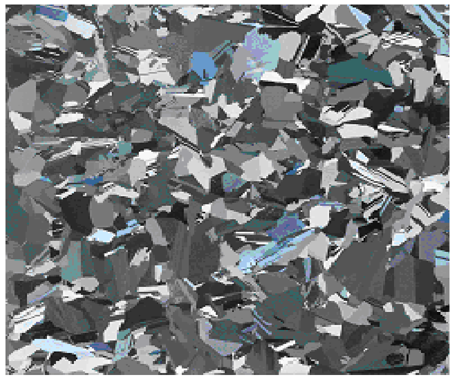
Sunpower

- The silicon block consists of one crystal only
- Manufacturing through growth of large cylindrical ingots is complex and energy intensive
- The arrangement of the atoms is completely homogeneous
- Mono-crystalline silicon as raw material for solar cells is relatively expensive
- Most efficient technology, efficiencies of around 14% - 21%
- Area requirements (large scale power plant):
  11 – 17 m^2/kWp

Photovoltaic

Types of solar cells - **Poly-crystalline** cells (poly-Si)

- Silicon solidifies and forms blue gleaming structures
- The cell structure is heterogeneous
- Light refraction at the solidified edges decreases the efficiency
- Slightly cheaper than mono-crystalline silicon but also less efficient
- Efficiencies of around 14% - 17%
- Area requirements (large scale power plant): 12 – 18 m^2/kWp



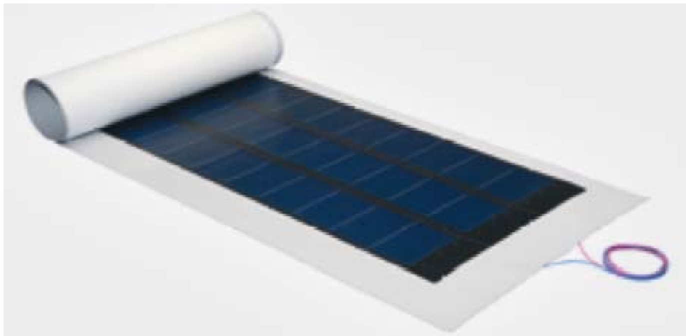
Photovoltaic

Types of solar cells - **Thin-film** cells

- Thin, non-crystalline layers of e.g. amorphous silicon film, e.g. by vapor deposition
- Cheaper than crystalline silicon but less efficient
- Thin Film has advantages for low and diffuse light irradiation
- Lower temperature coefficient ct => advantage at high operating temperatures
- Efficiency between 5% and 15%
- Area requirements (large scale power plant): 15 – 20 m^2/kWp
- Various materials (a-Si, CdTe, CIGS*)
- Thickness of only 1–2 µm compared to c-Si with 150 µm thickness

* Copper indium gallium selenide

First Solar



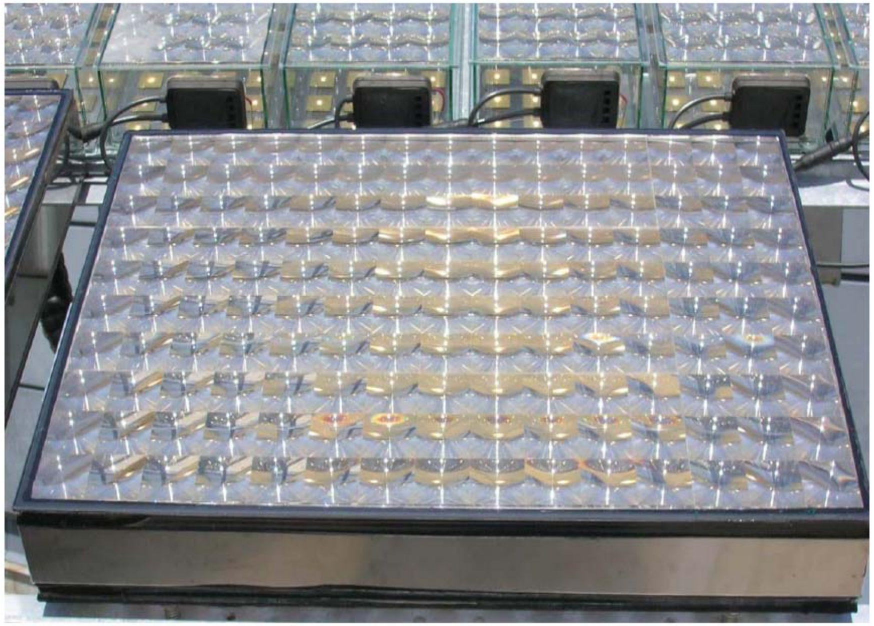
Alwitra

Photovoltaic –Thin Film example: Werder Bremen

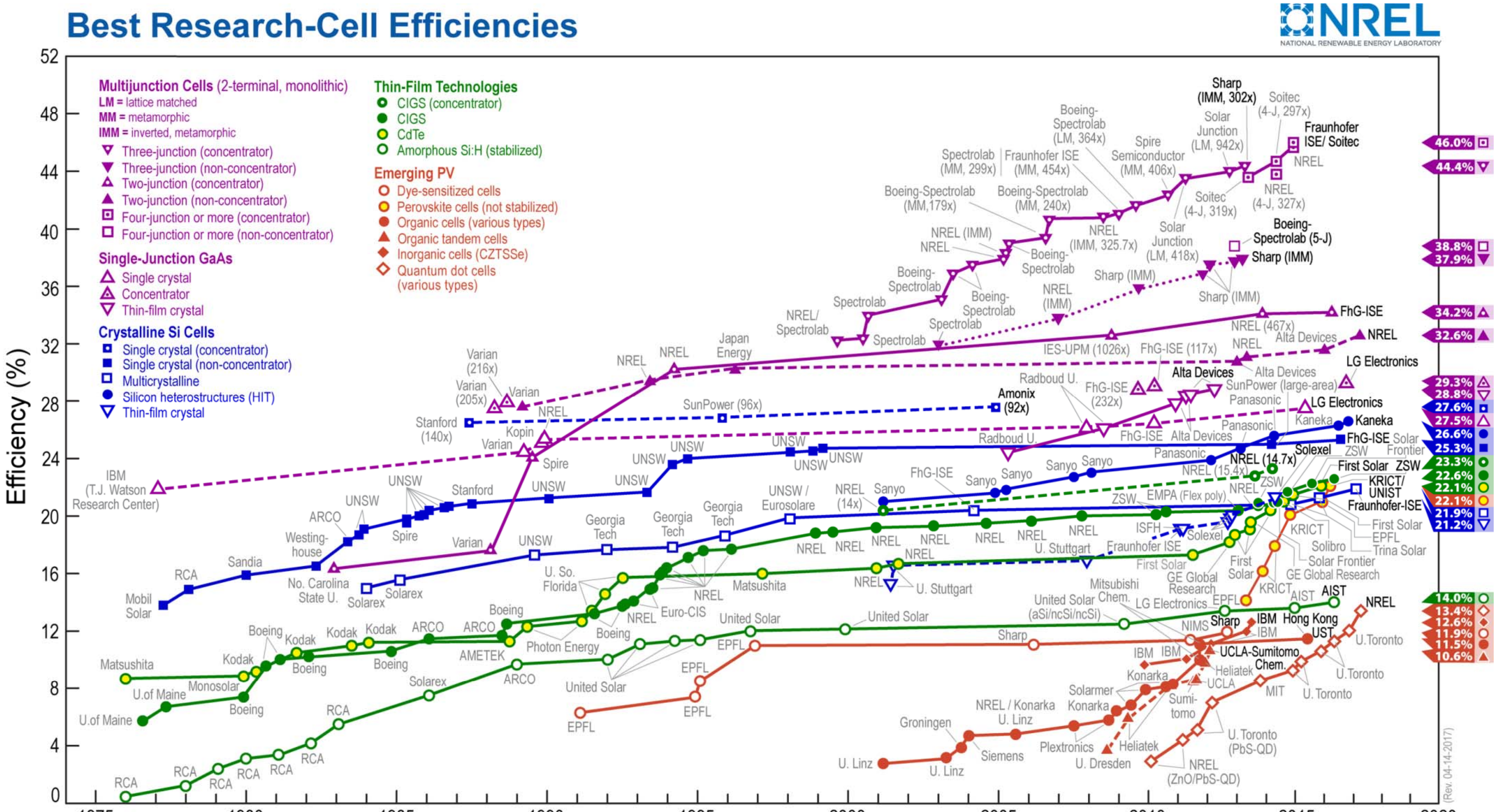
Alwitra

Concentrating Photovoltaic (CPV)

- The CPV modules contain a number of cell units (e.g. 25, 98, 150) integrated in the module (see figure)
- Power output ranging from approximately 75 to 150 Wp
- Size: e.g. 828mm x 428mm x 102mm
- Weight can range from 9 up to 32 kg
- Passive cooling (dissipates the heat from the solar cells by free convection)

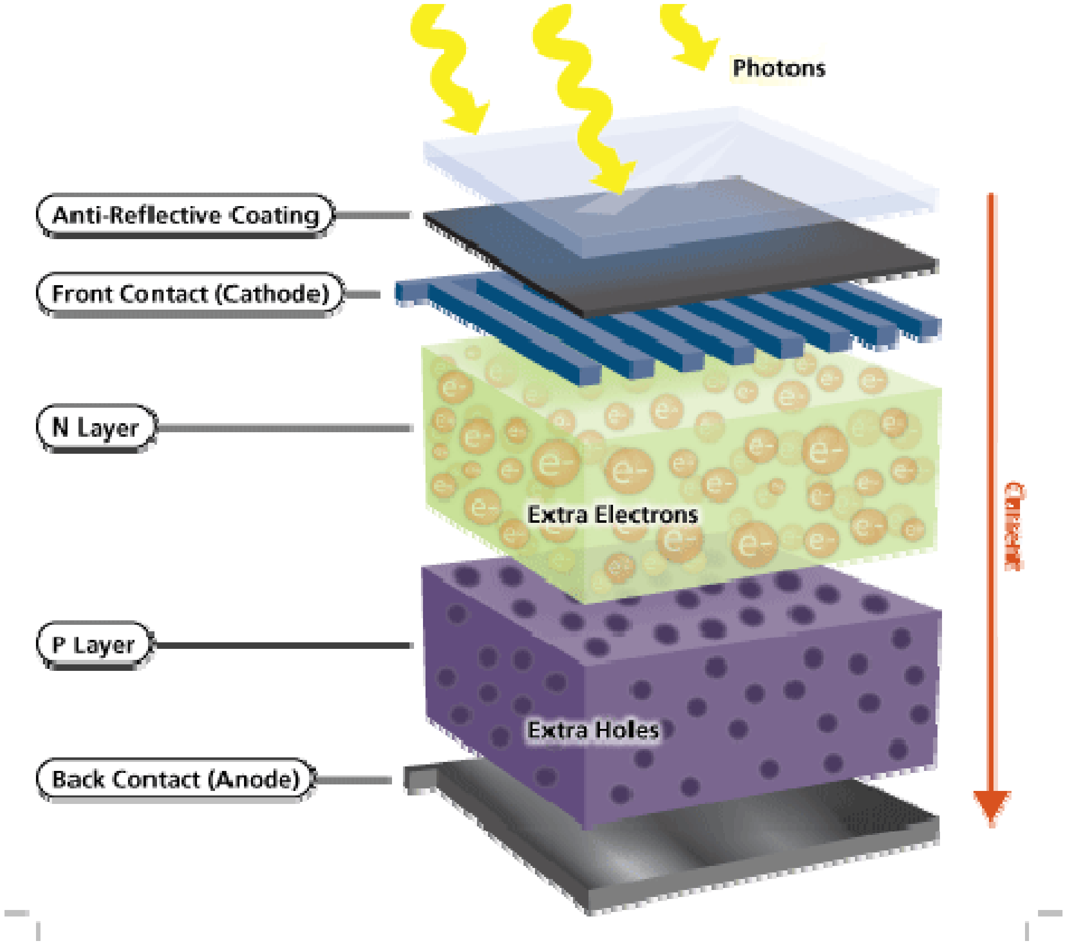


Efficiency of Solar Cells



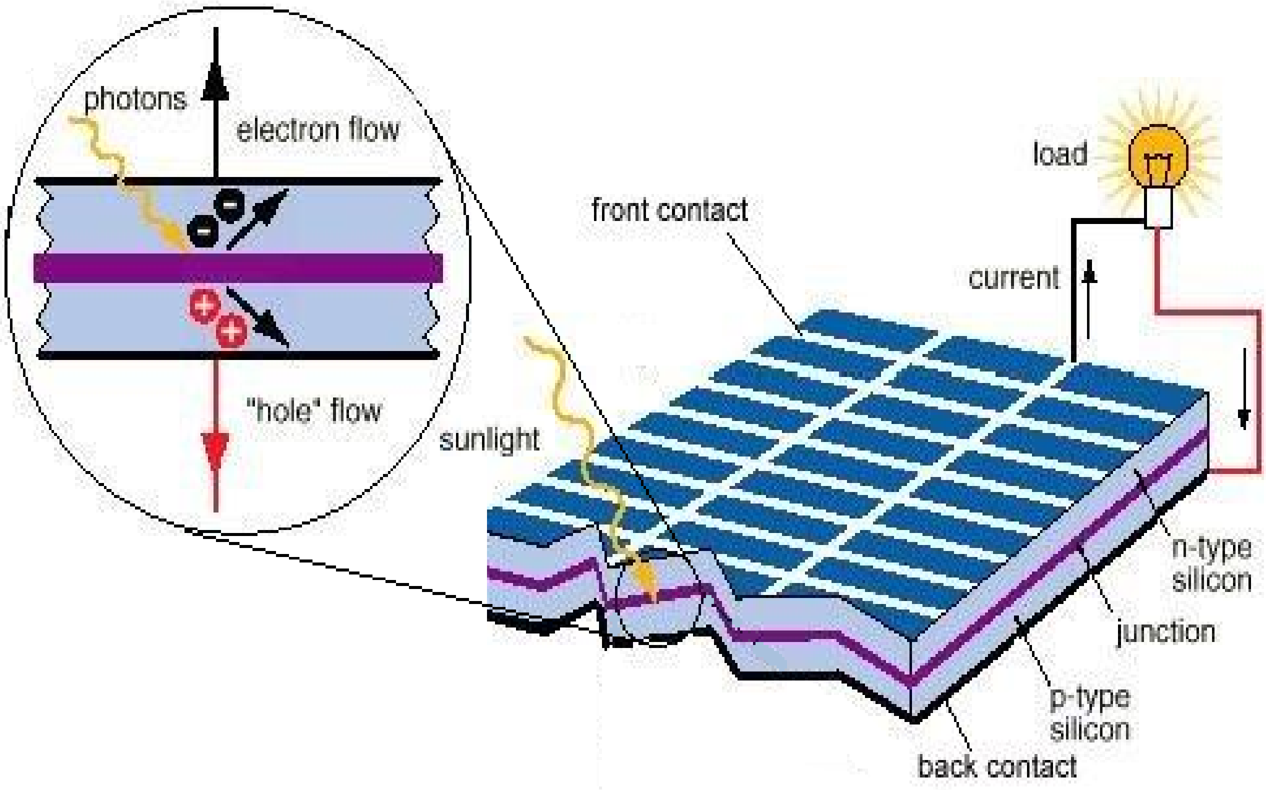
Photovoltaic effect

- Photovoltaic effect enables a direct transformation of solar radiation energy into electrical energy
- Effect appears in semiconductors
- Obtained voltage can be tapped through electrodes
- First observed in 1839 by Becquerel

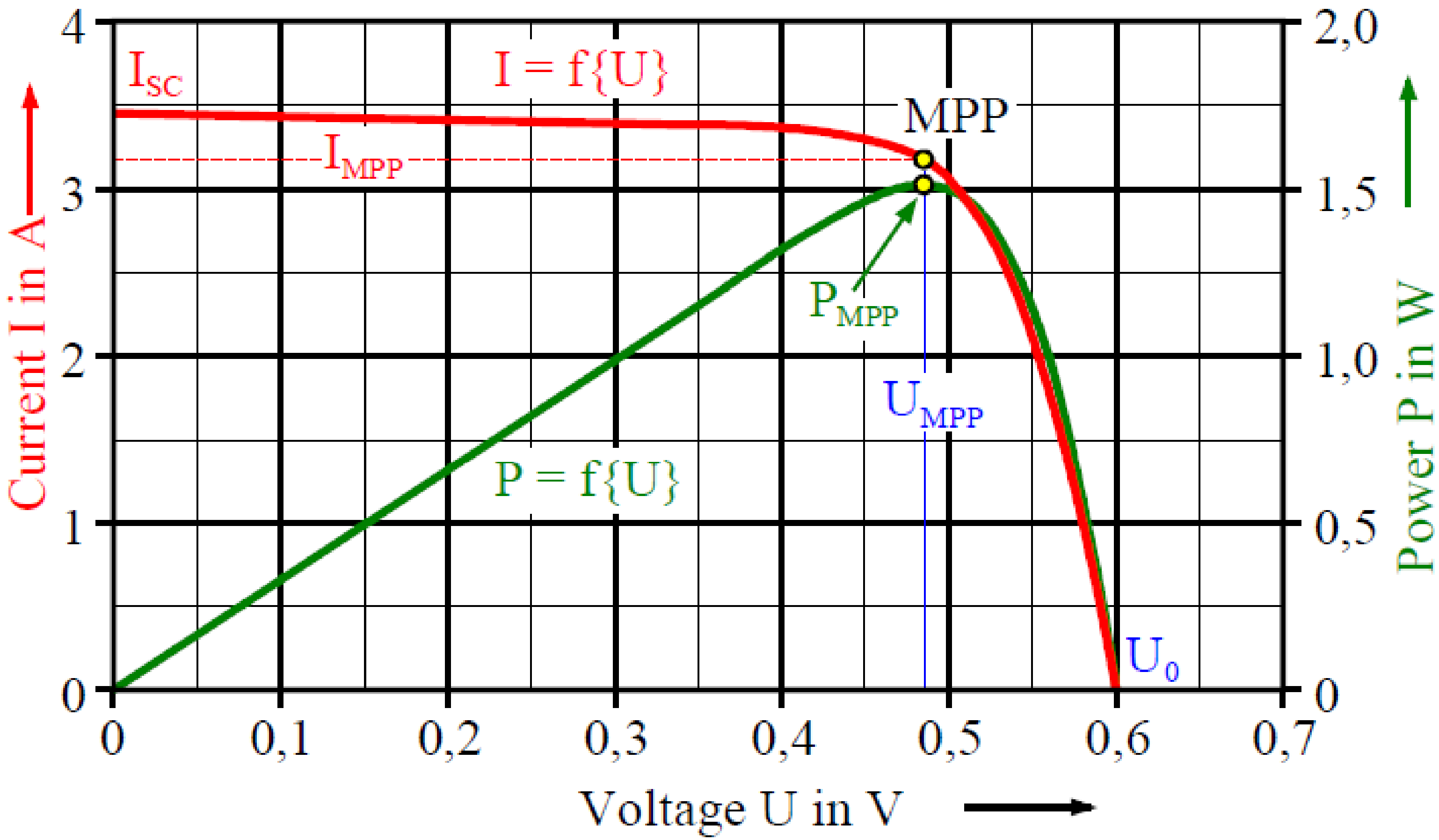


Photovoltaic effect

- Fed energy (electromagnetic radiation) causes free carriers (electrons and holes).
- To generate electricity an internal electric field forces the carriers into different directions.
- The electric field (transitional zone) is caused by a p-n-junction

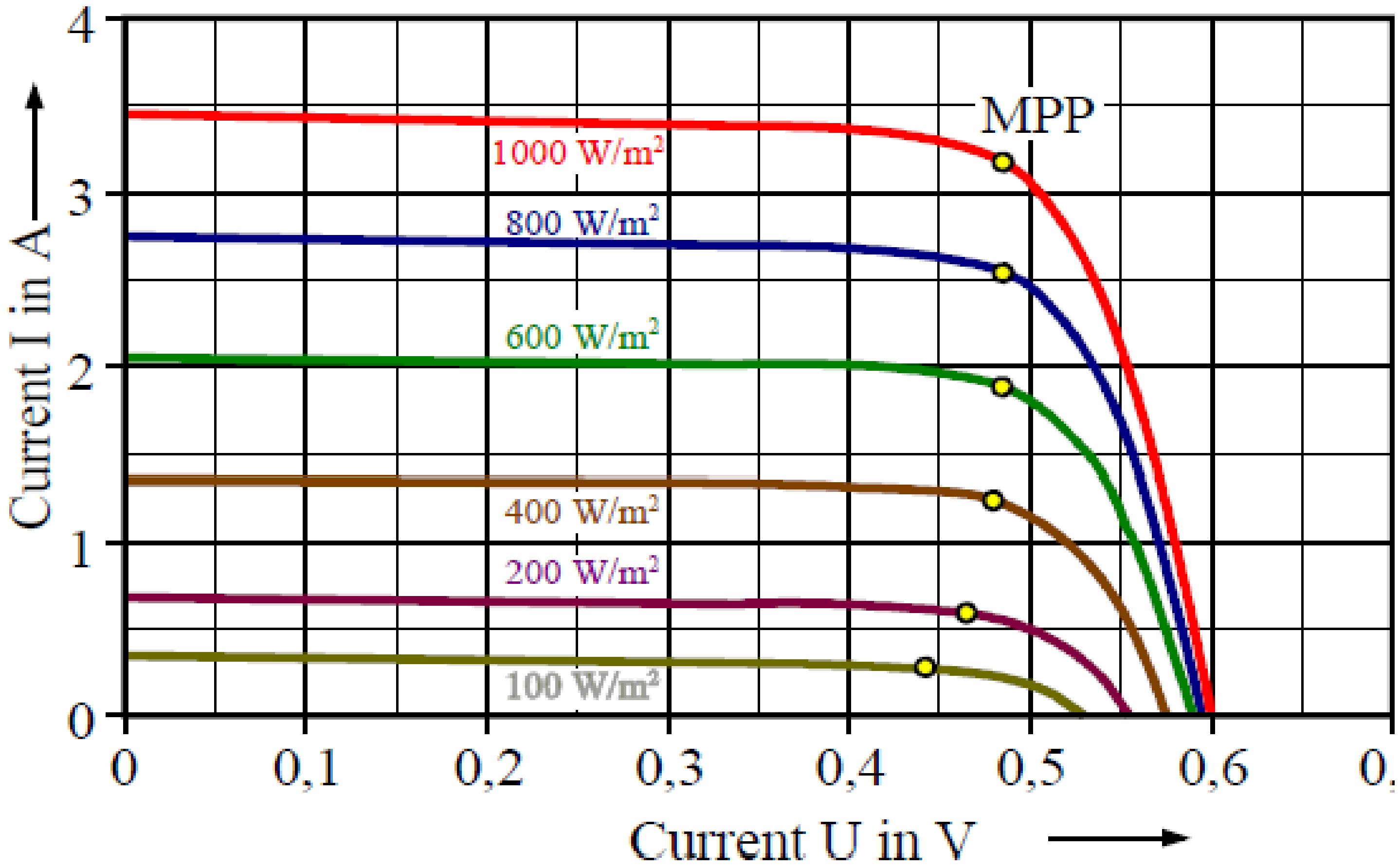


Electrical properties of Solar cells: I-V curve



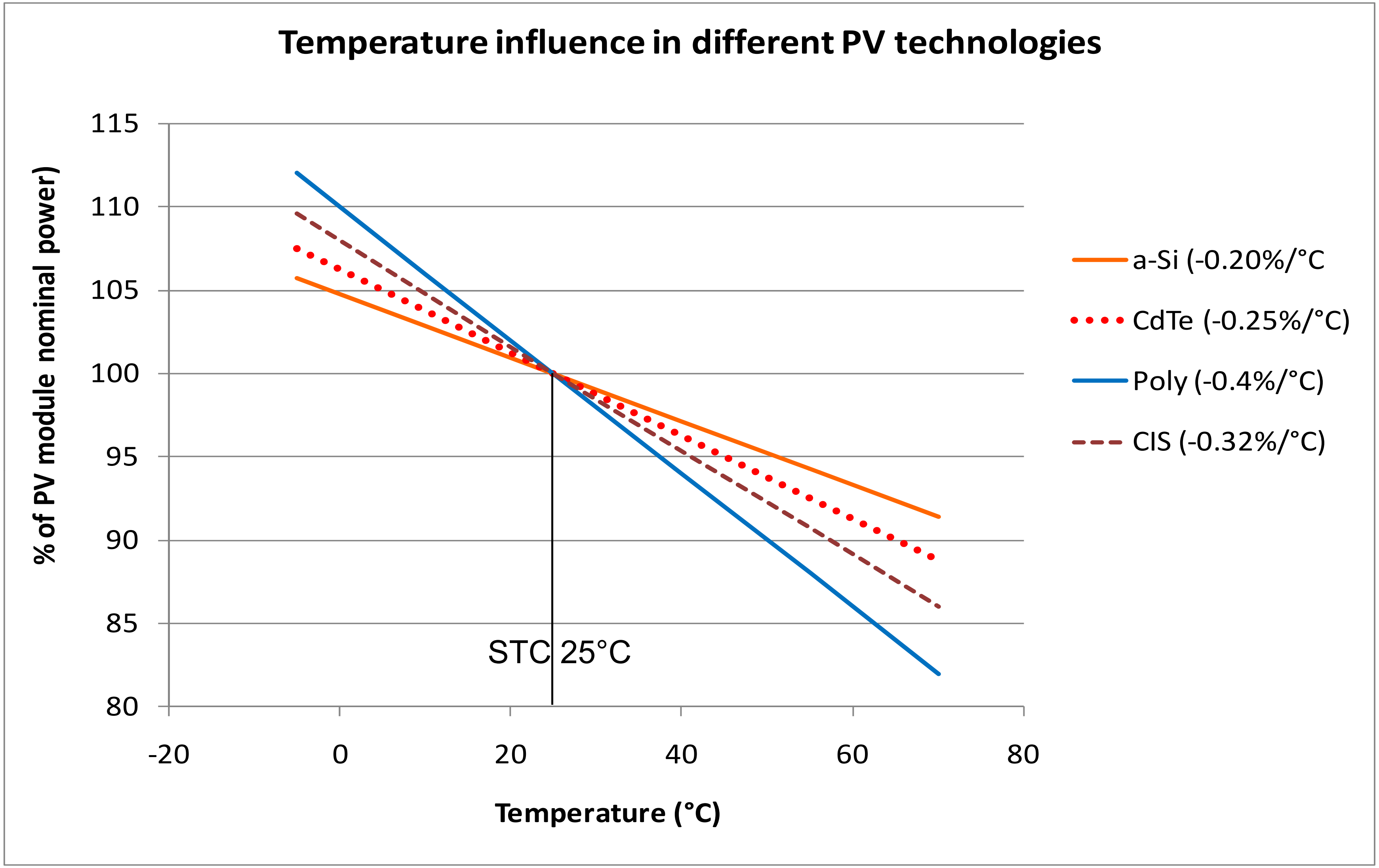
Electrical properties of Solar cells: I-V curve

Effect of irradiation (at constant temperature):

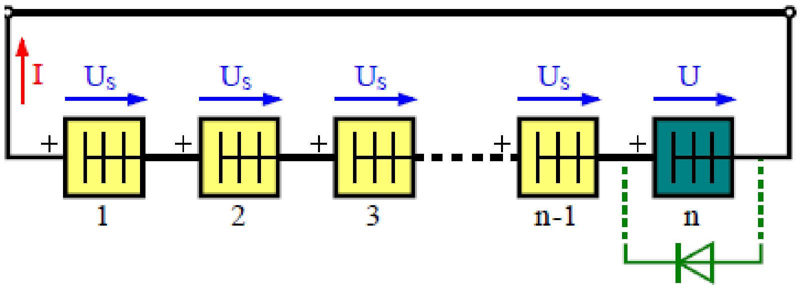


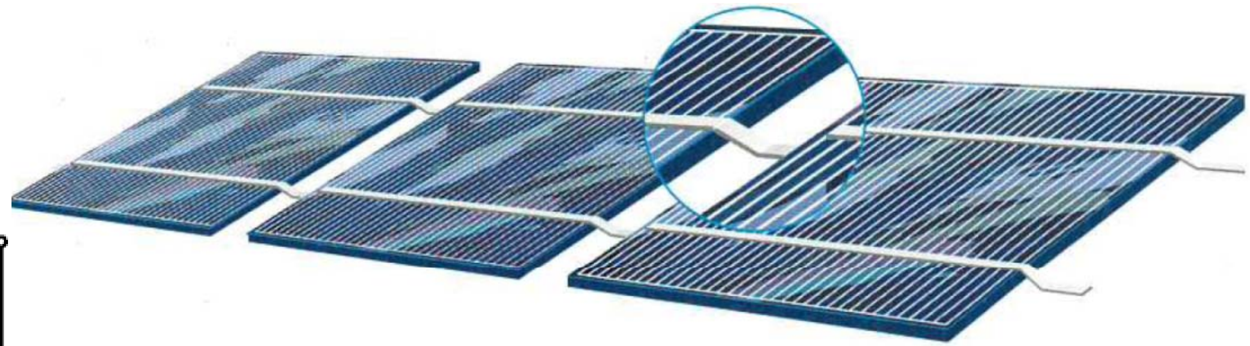
Photovoltaic – temperature behavior

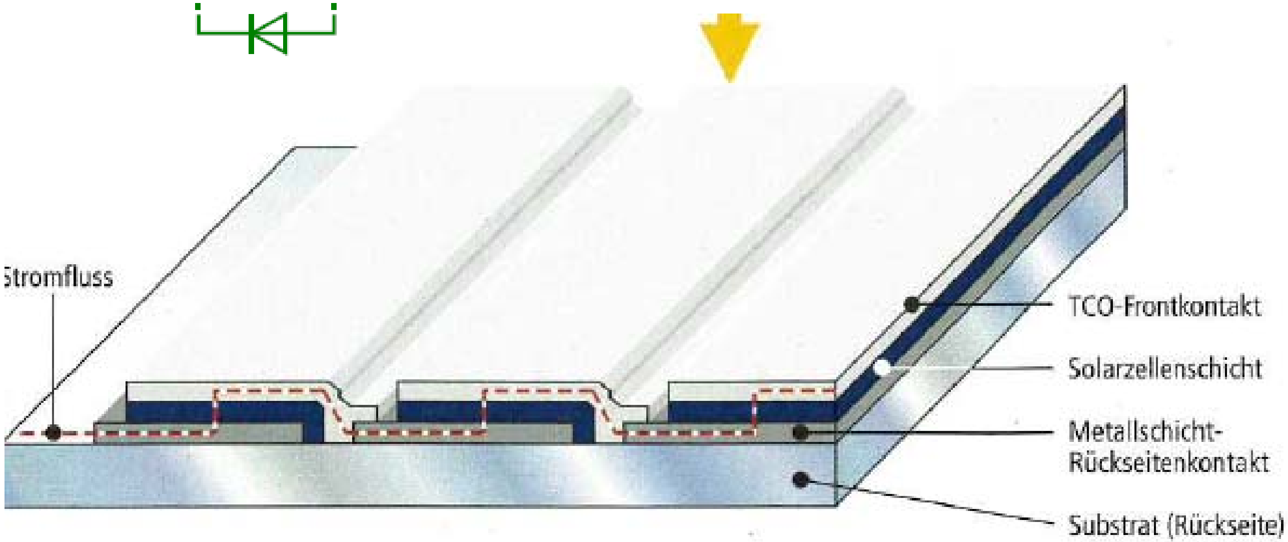
Temperature influence – to be considered in design and planning



Cell interconnection

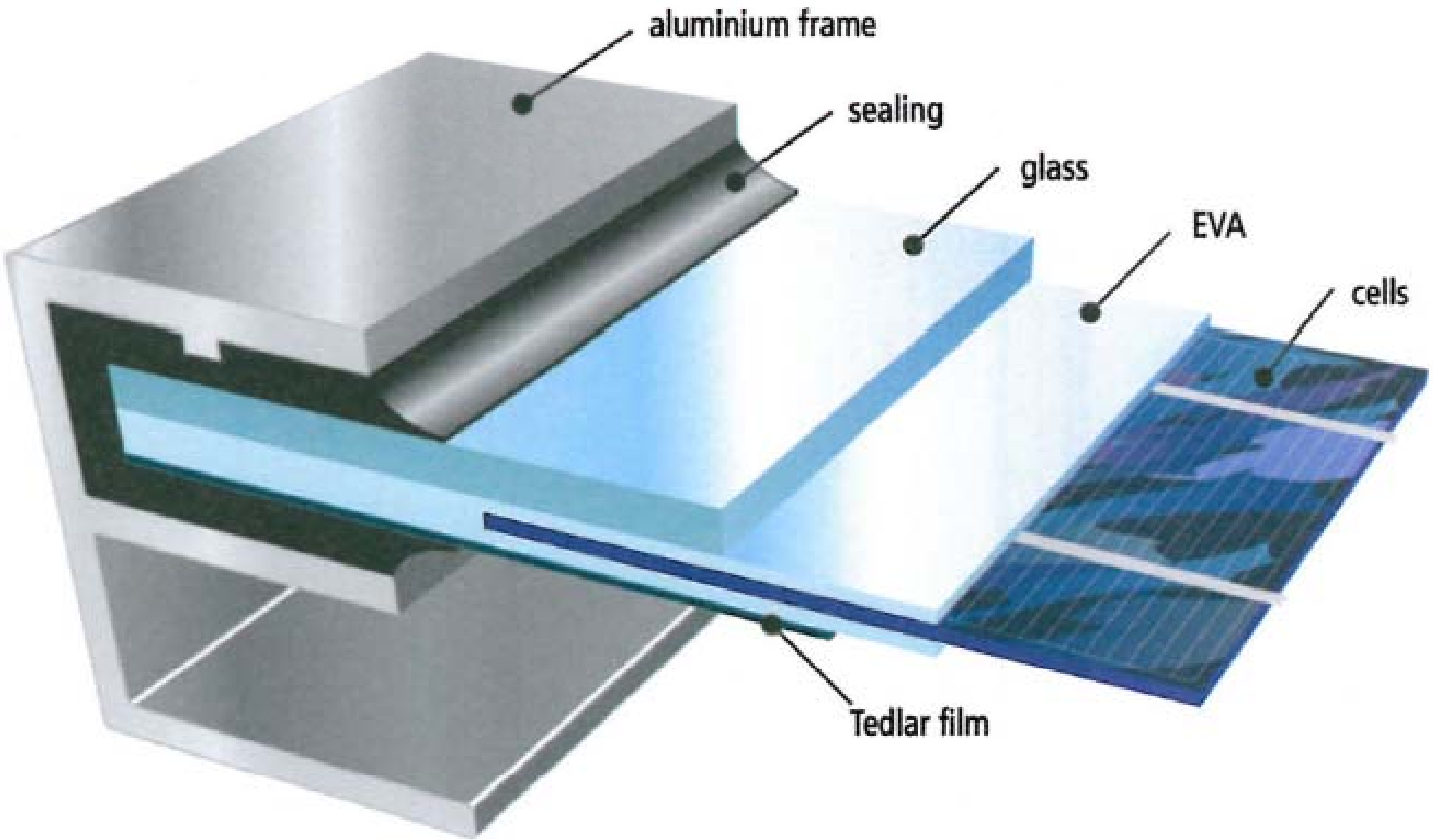






Module cross section

Cross section of crystalline solar modules



EVA = Etyhlen-Venyl-Acetat encapsulation

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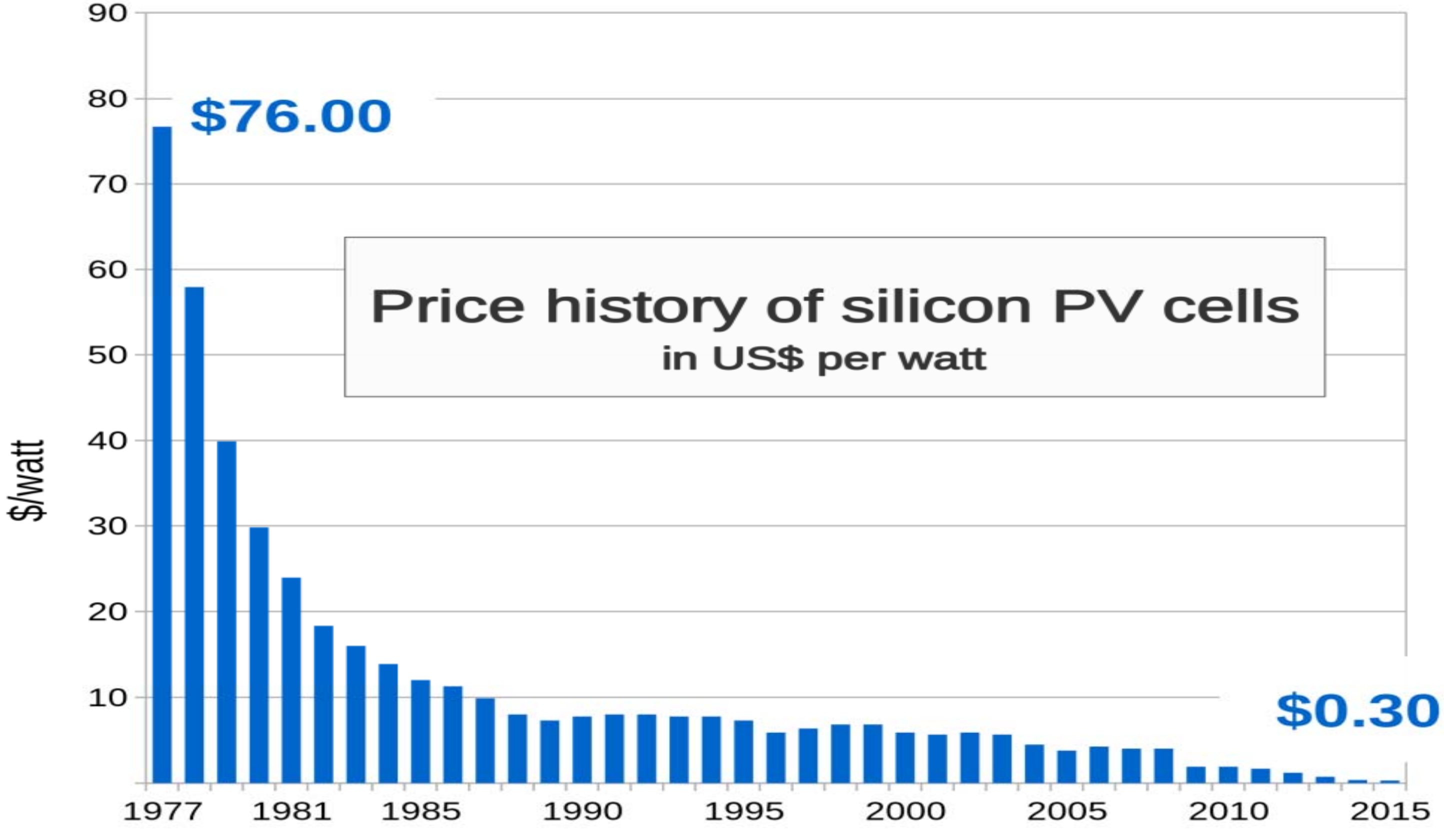
PV Market – Average Solar cell prices 1991 to 2015



Source: Bloomberg New Energy Finance & pv.energytrend.com

- Until the 2004 FiT-stimulated boom in demand, manufacturers lost money.
- Expectations for pricing have been effectively lowered.
- Costs have been decreased by a compound average of 5% annually.
- Prices have been decreased by a compound average rage of 7% annually.

Inverters

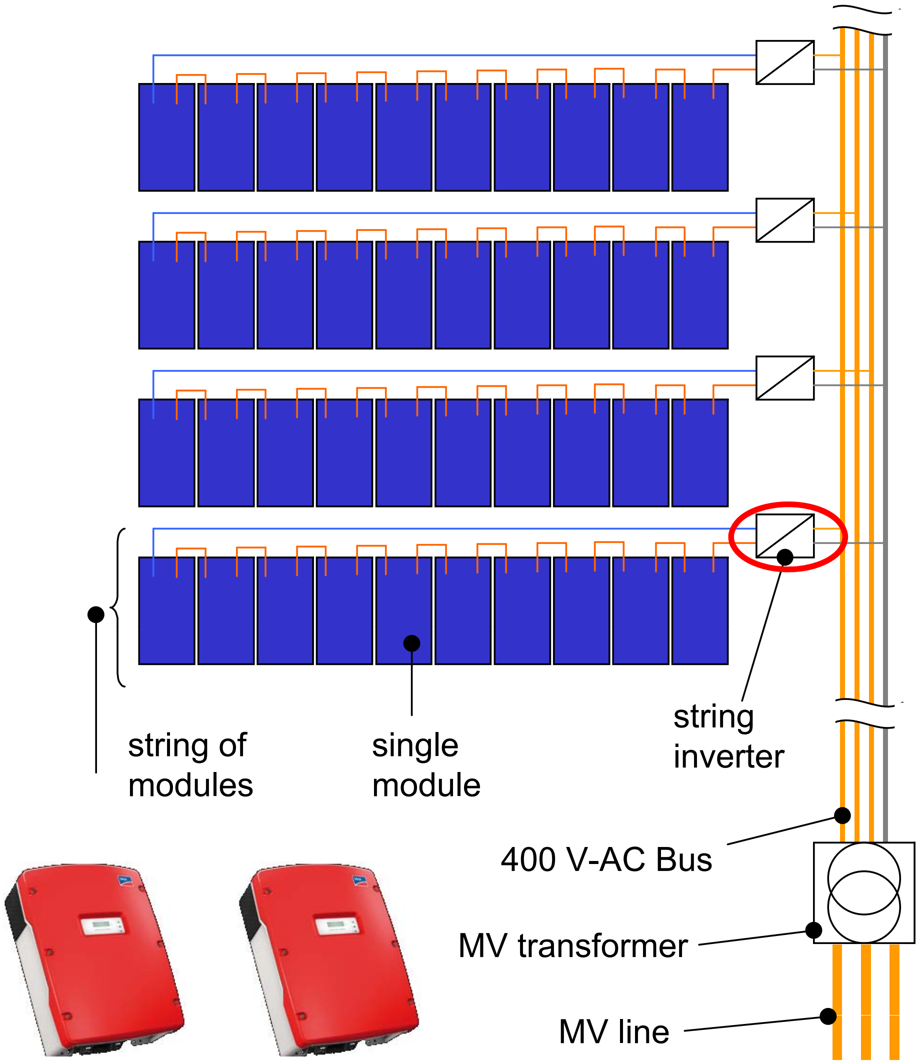
Inverter Concepts:

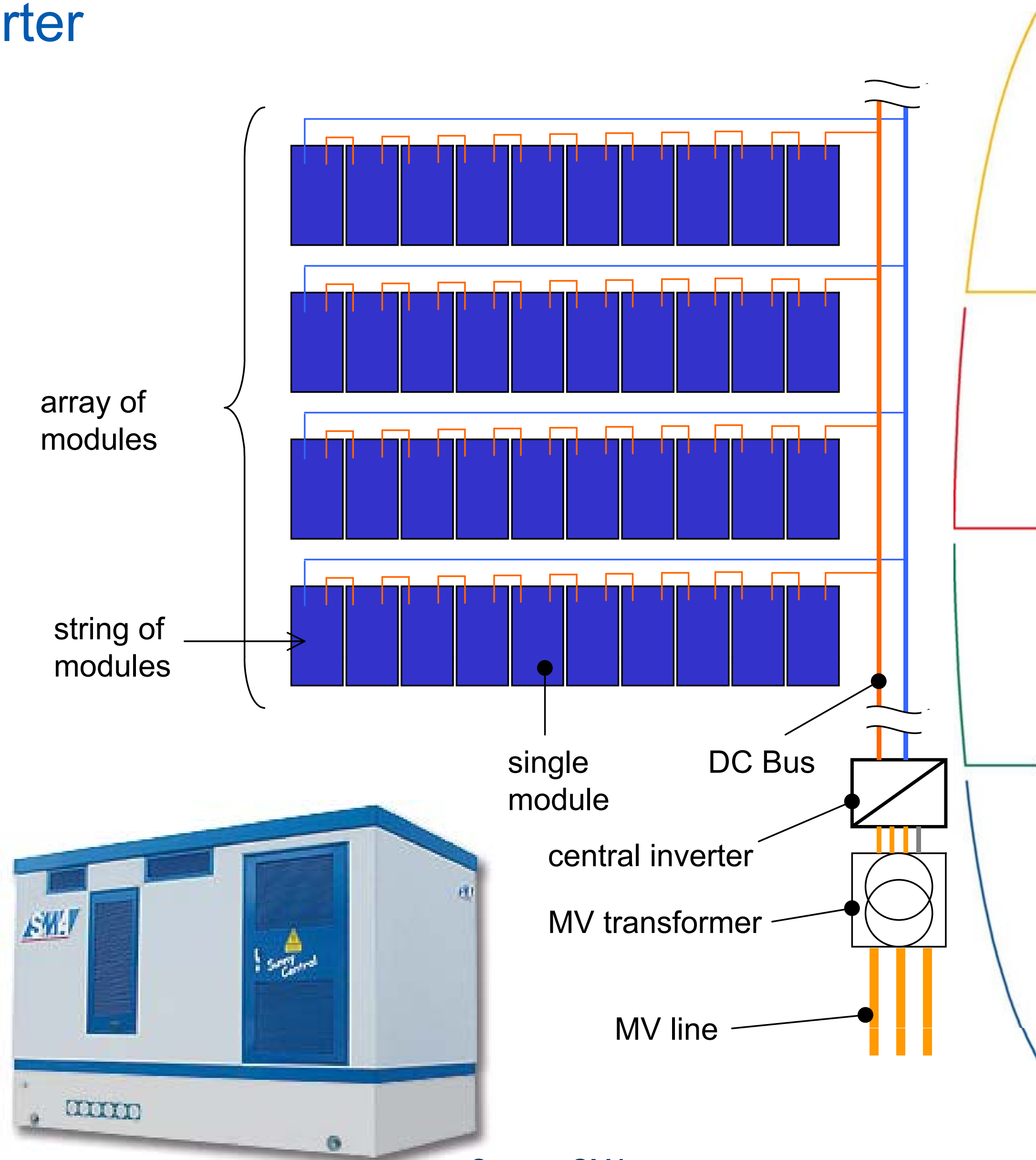
- Conversion of direct-current (DC) to alternating current (AC)
- Maximum efficiency up to more than 98%

- inverters should provide
  - monitoring
  - control and
  - protection functions

Inverters

Inverter Concepts: string vs. central inverter





Source: SMA

Inverters

Inverter Concepts: field examples

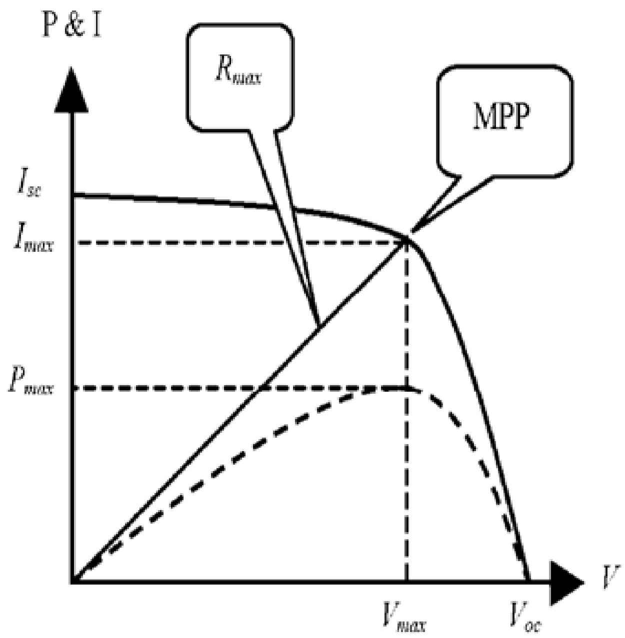
- Example for a rooftop PV power plant with string inverters

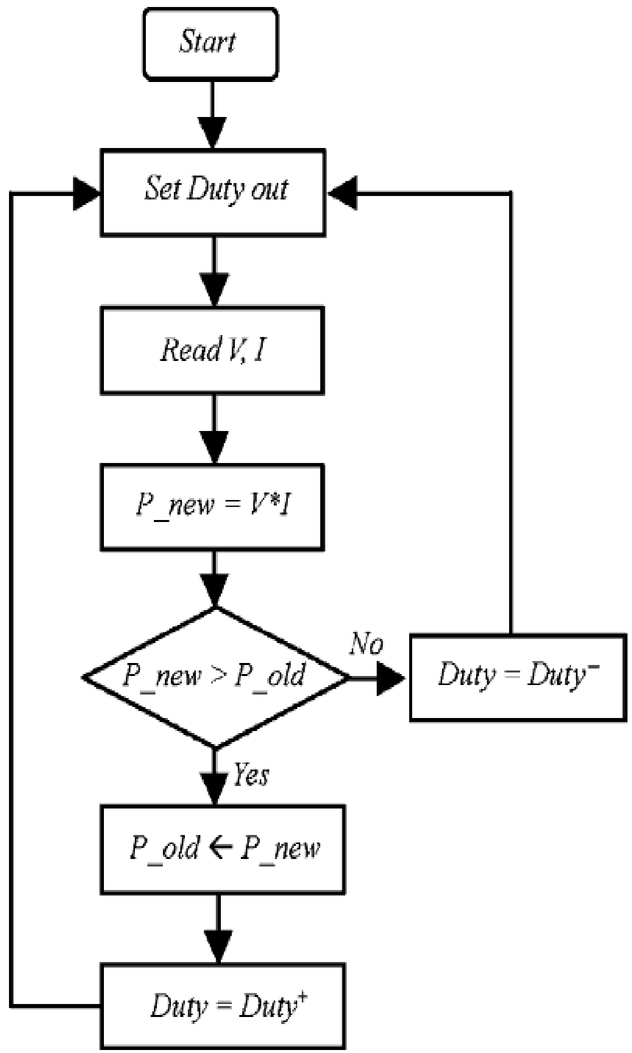
- Example for a large PV power plant with central inverters

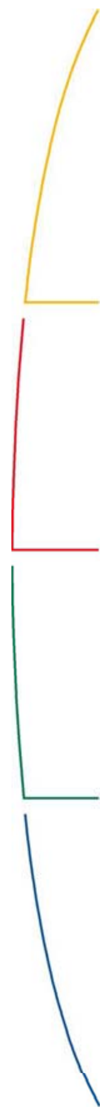
Maximum Power Point Tracking

Inverter Concepts: field examples

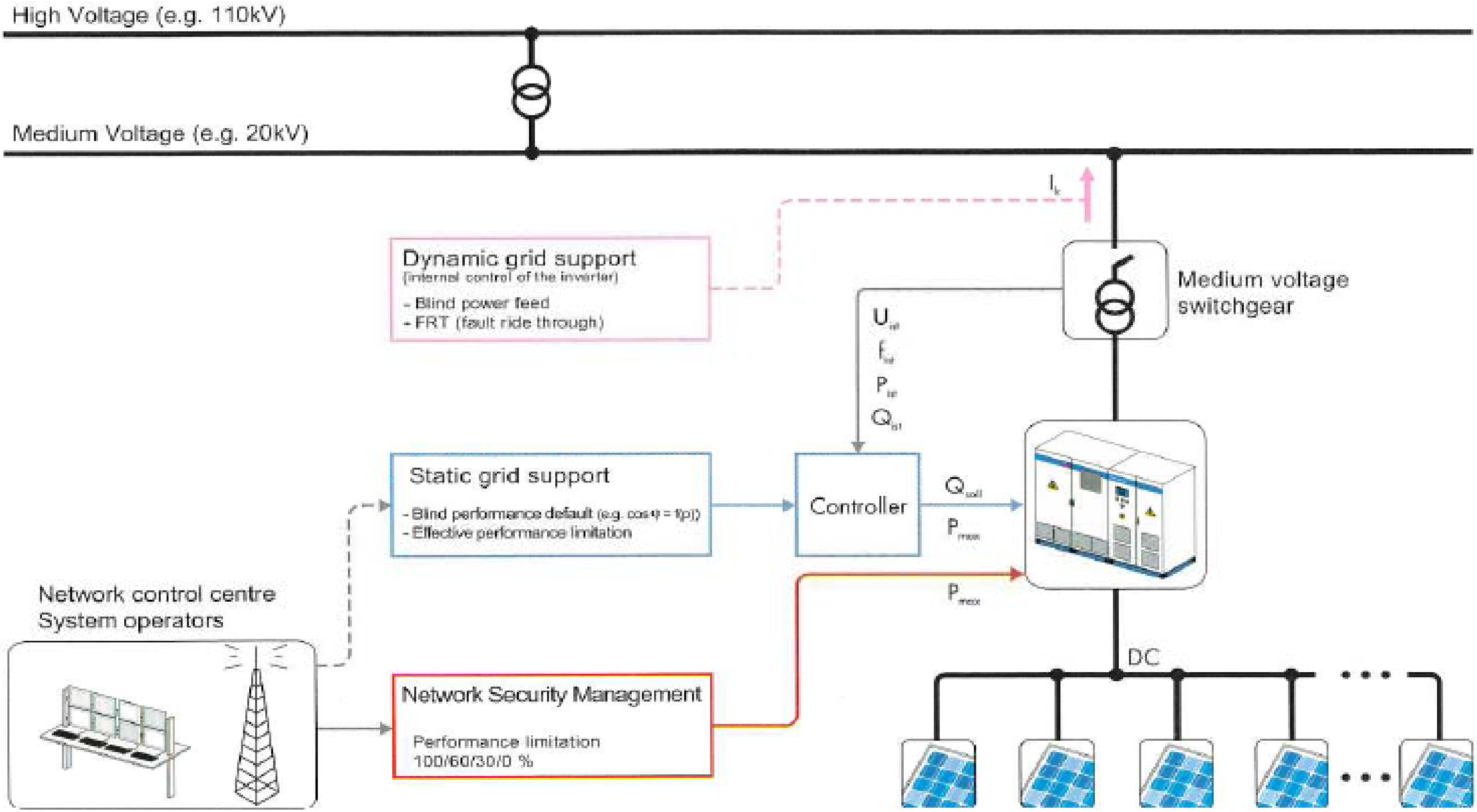
- Inverters track the maximum power point (MPP) of the connected PV array by continuously increasing and decreasing the array voltage
- MPP Tracking range is limited, for central inverters often between about 500 to 850 V
- Fast and exact MP tracking is important for inverter efficiency especially under changing irradiation conditions







Grid support



Source: DGS, Planning and Installing Photovoltaic Systems

Inverter stations

- Central inverters are available for indoor installation or for installation directly outdoor on site.
- Inverters are placed together with medium voltage transformers and switchgears to form a inverter/transformer station

Outdoor inverter transformer station with additional roof for shading

Outdoor inverter with transformer station in prefabricated concrete housing

Inverter stations

Inverter transformer station in standard 40ft container

Inverter transformer station in prefabricated concrete cabin with air condition for cooling

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Mounting systems

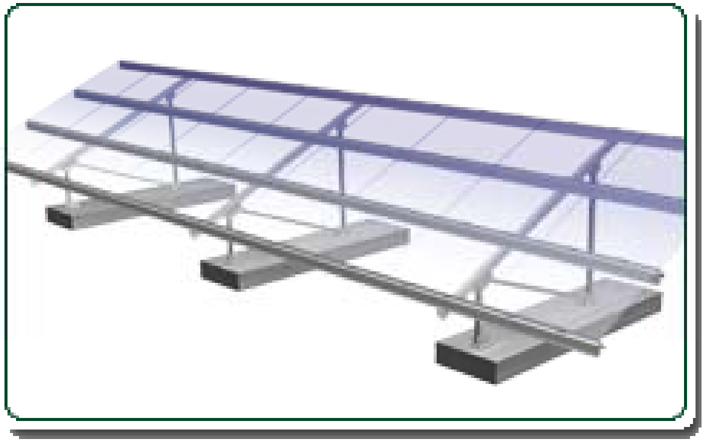
Module mounting systems – Fixed mounted systems

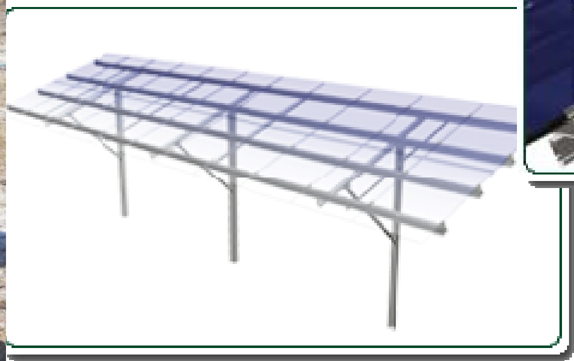
- PV modules require an optimized installation (tilt) angle; which can be calculated over the course of the day and throughout the year to maximize energy production
- Have no moving parts, capital expenditure (CAPEX) and Operating & Maintenance (O&M) costs are lower
- Lower specific yield per area unit compared to tracking systems which means these systems require larger areas to attain the same power output

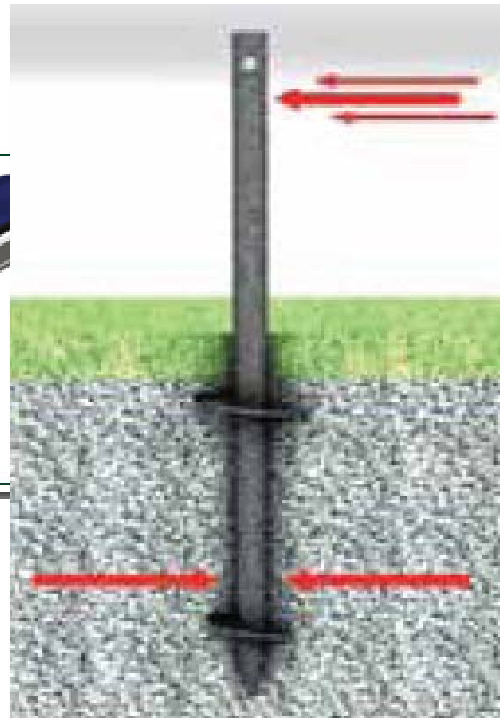
Mounting systems

Fixed mounted systems: foundations

- Ramming - fast and least expensive
- Screwing - for soft soils
- Concrete – on top or in ground







Source: Schletter

Mounting systems

Fixed mounted systems: foundations

- Depending on local soil and climate conditions it is always necessary to perform:

- Geotechnical study
- Structural analysis
- Pull out tests

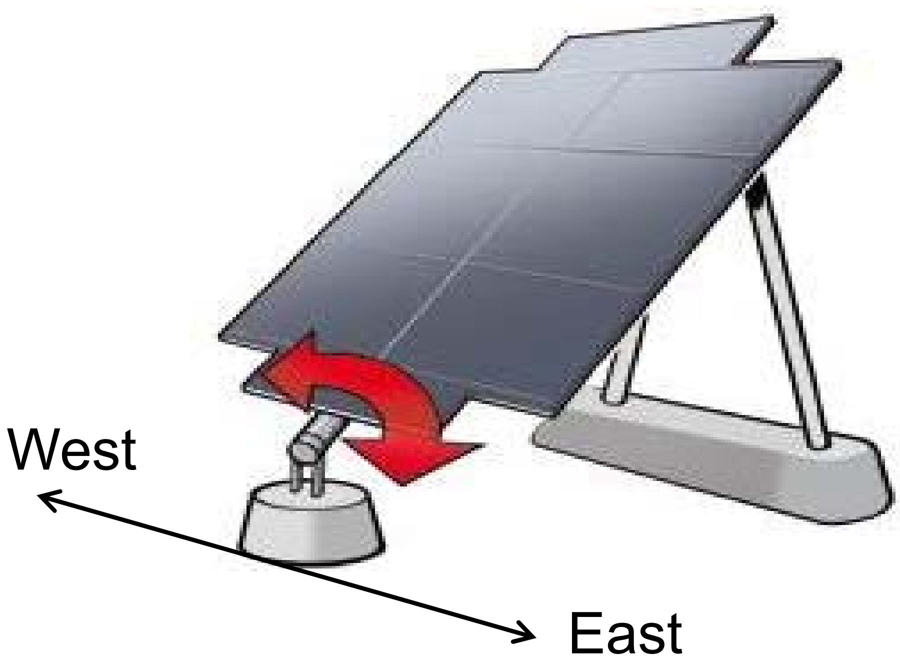
Source: Schletter

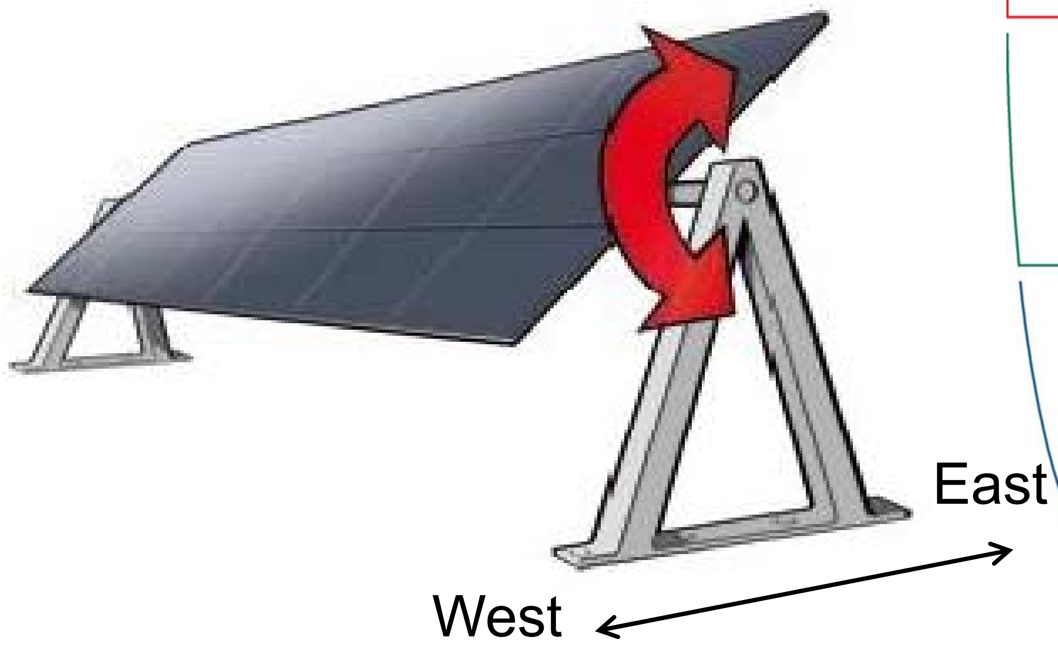
Mounting systems

Module mounting systems – Tracking

Single axis tracking

- Performance and cost competitive alternative system with regard to technological complexity and CAPEX
- Sun tracking throughout the day
- Inclined mounting possible





Mounting systems

Module mounting systems – Tracking

Example for a single axis tracking

- Different inclinations at noon and in the afternoon
- Solar irradiation sensors mounted on the tracking system:
  - in plane of array (POA), and
  - horizontally

Mounting systems

Module mounting systems – Tracking

Two axis tracking (double axis, bi-axial)

- Possible to exactly follow the sun's path so the sunlight hits the module perpendicularly throughout the day and the year
- Highest solar energy yield but capital and O&M costs are higher
- Control via sun algorithm or tracing the brightest point

Mounting systems

Module mounting systems – Tracking

Fix installation or module tracking?

- Tracked systems:
  - Higher demand of construction surface per installed power
  - Higher CAPEX, for small system even much higher
  - Higher O&M cost
  - Qualified and trained personnel required for O&M
  - Higher yield
- Tracking systems are profitable when the gain in energy compensates the higher costs inherent to its acquisition, installation, and operation.
- Fixed mounted system:
  - Easy installation and maintenance
  - Robust technology
  - Local technicians for maintenance mostly sufficient
  - Suitable also for slightly complex and remote sites
  - Lower CAPEX and OPEC but also less yield

Mounting systems

Module mounting systems – Tracking

Approx. gain in irradiation*:

Feste Aufstellung

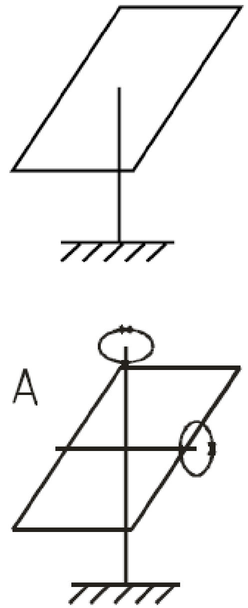
- 0%

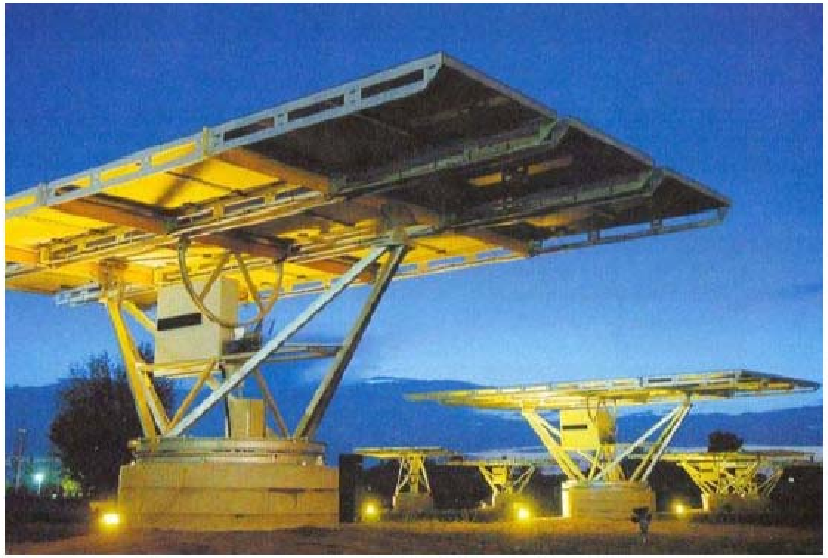
Zweiachsige Nachführung

- approx. 40%

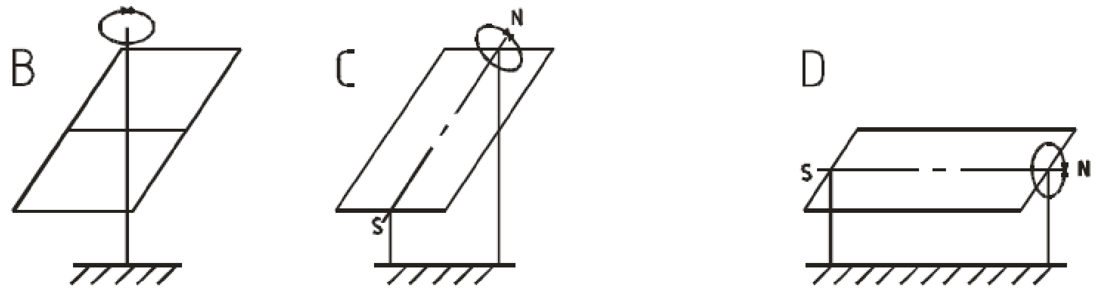
Einachsige Nachführung

- horizontal: 18-20%
- polar / azimuth: 30-34%





Quelle: Photon 7/2004



- azimutal -   - polar -   - horizontal -

Source: ZSW Mohring

Mounting systems

Tracking - Examples

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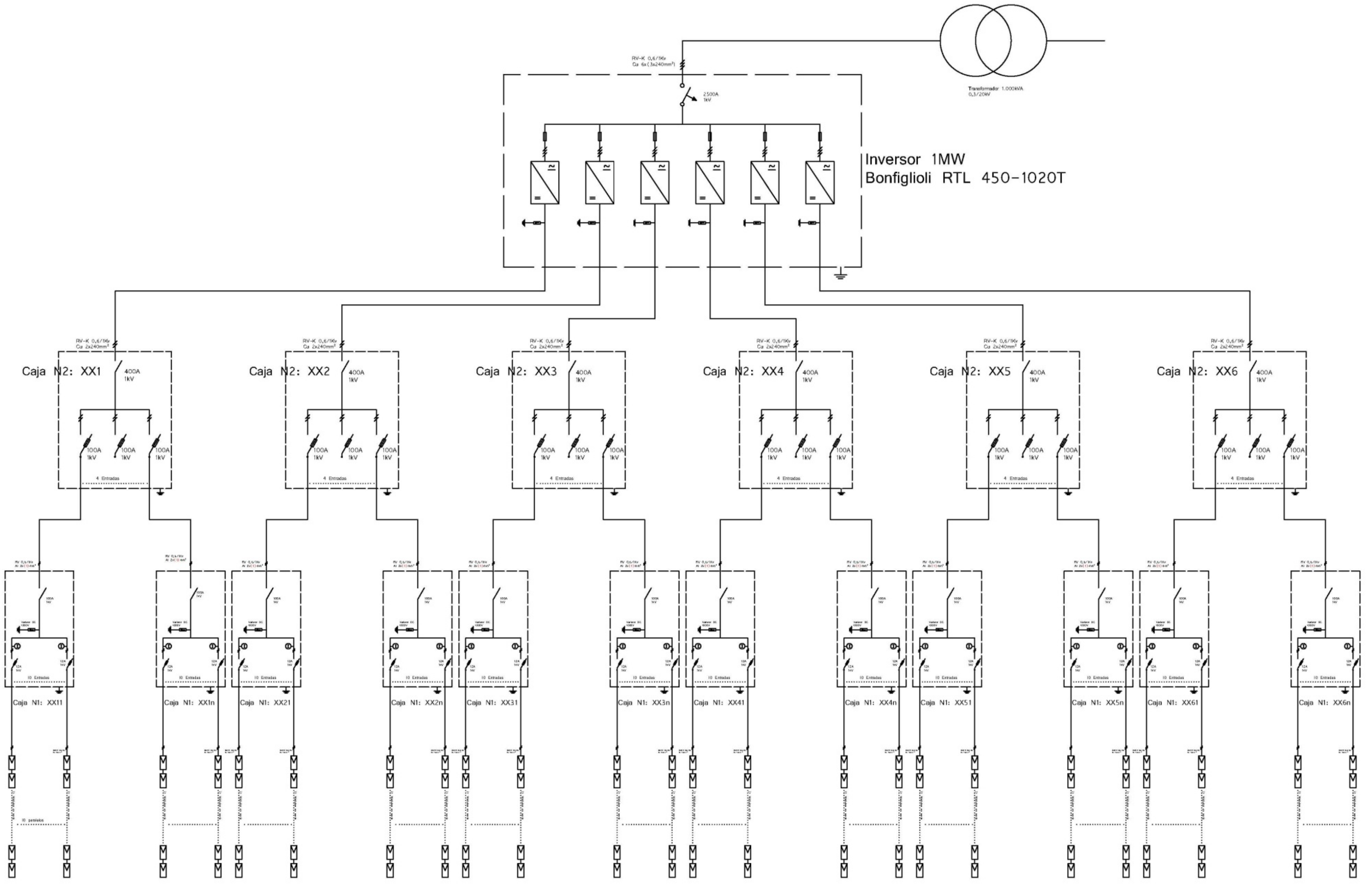
PV Generator basic diagram



Module String connection

- Modules are interconnected in series to strings
  - Number of modules per string depends on module type and inverter
  - Voltage must be within the MPP range of the inverter
  - Voltage (U_{OC}) must not exceed the inverters maximum input voltage even under extreme temperature conditions
  - Voltage is generally limited to a maximum of 1000 V (low voltage)

- Strings are connected in parallel in combiner boxes including
  - String fuses for protection of modules and protection against reverse currents
  - Surge protection
  - DC main disconnection switch (optional but normal)
  - String monitoring device (optional)

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DC cabling

- Short circuit protected cabling with single core double insulated cables
- If current carrying capacity is greater than 1.25 x Isc overload protection may be omitted.
- Cables generally are dimensioned to limit the power loss to 1.5 – 2% under stc conditions between modules and inverter

- For string cabling solar PV cable is used with UV protection and for higher temperatures (e.g. 90°C or 120°C)
- For DC main cabling often XLPE insulated cables are used

DC string connectors

- Different types of PV String connectors
  - No standardization
  - Most MC4 (Multicontact)
  - Many manufacturers claim compatibility but this is not guaranteed

DC string combiner box

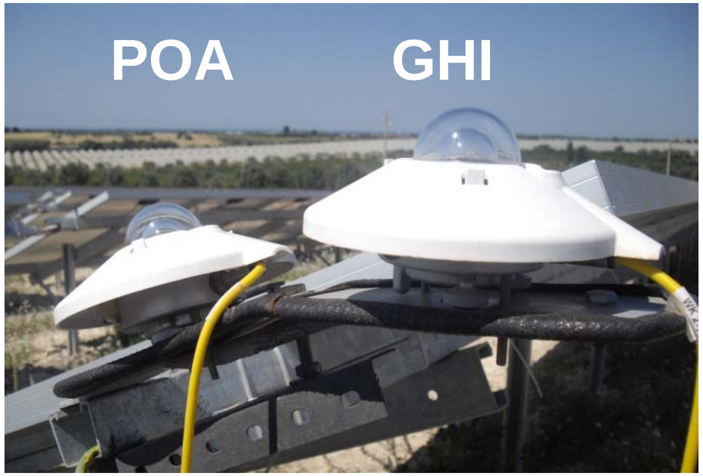
Substation - Grid connection

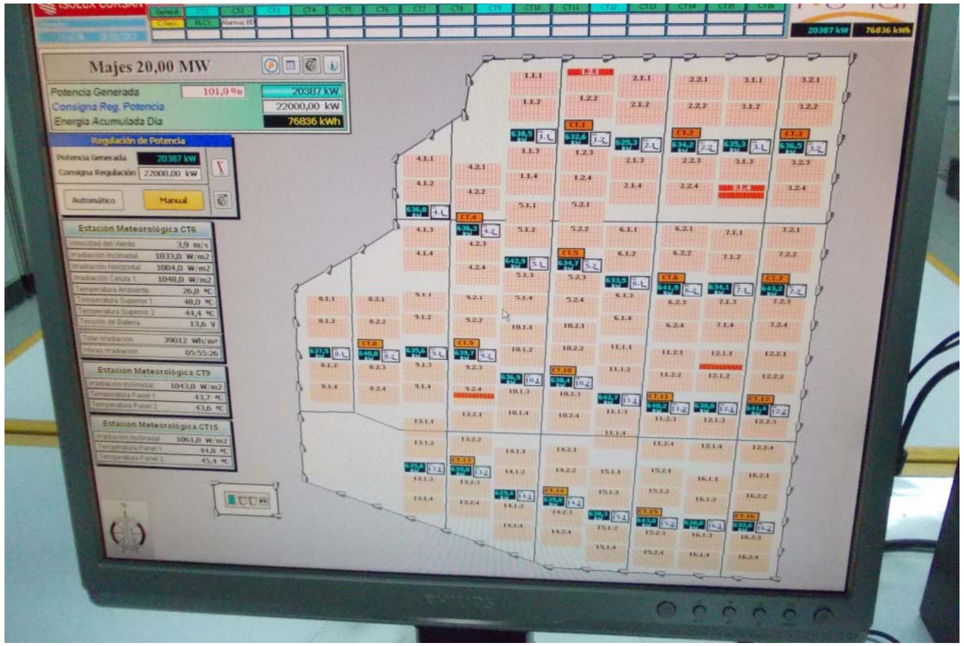
Plant Substation:
Connection to medium voltage grid
or to high voltage grid (bigger PV plants)

Monitoring System

Monitoring of plant operation and performance:

-String monitoring (currents)
-Inverter monitoring (Currents, Voltages, Power…..)
-Automated alarms
-Remote control
-Performance monitoring
-Weather station (solar irradiance, temperature, rain, wind)
- Tracker control and monitoring (if applicable)



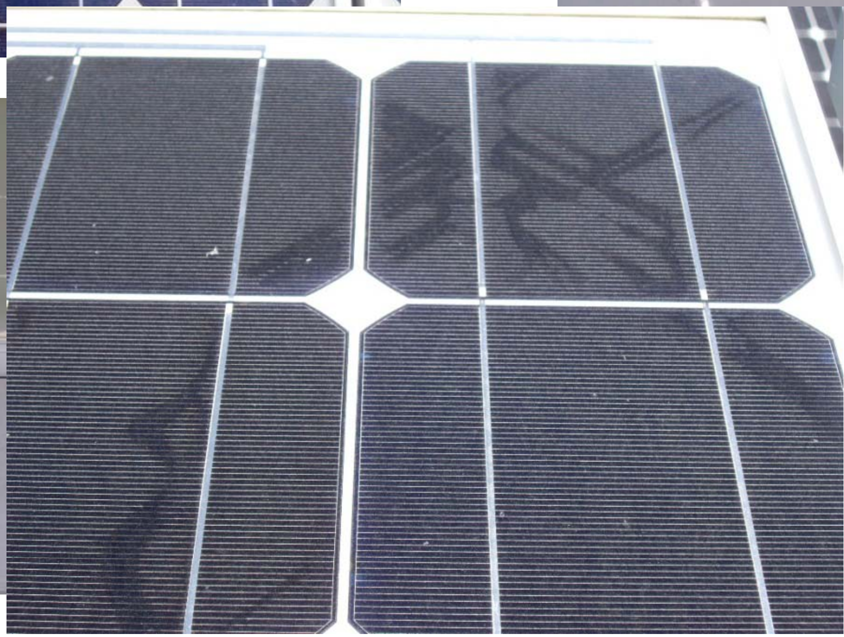


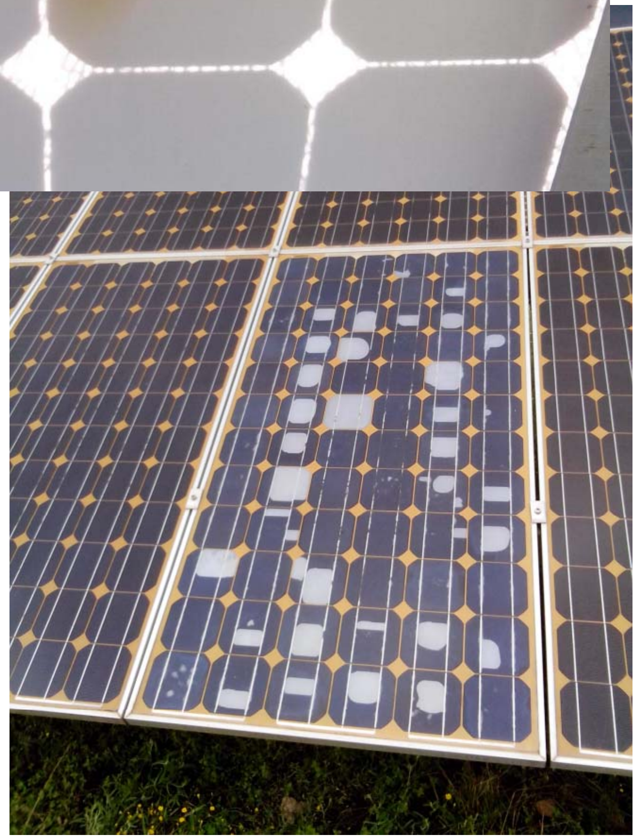
Site Security

- Fencing for basic protection
- CCTV perimeter control
- Active video alarm systems
-Movement detection in Builings
- and/or security guards

Technical Risks, Quality and minimum requirements

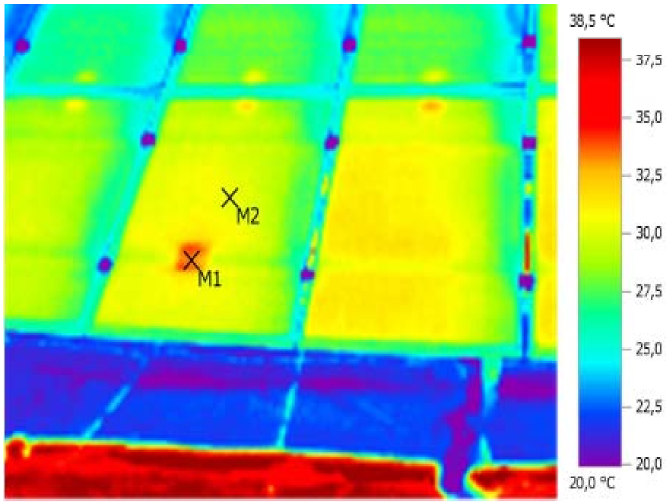
Modules: Hot spots & delamination



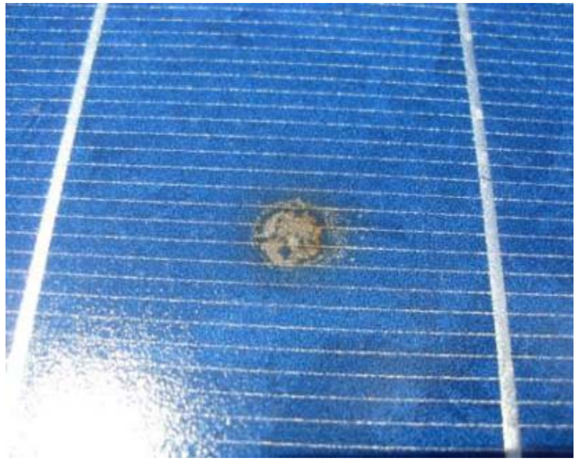


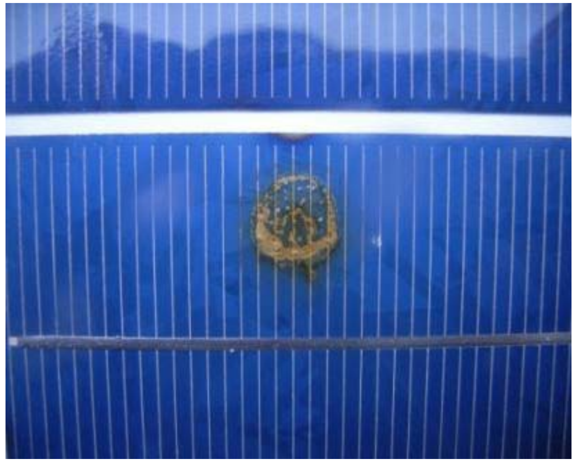
Modules: Hot spots & delamination

Device	testo 875-2	Serial No.:	2067495
Task	IR measurements at the PV-Modules		



Picture data:	**Date:**	11.05.2011	**Emissivity:**	0,85
	Measuring Time:	12:04:48	**Refl. temp. [°C]:**	-40,0
	File:	IV_00073.BMT		





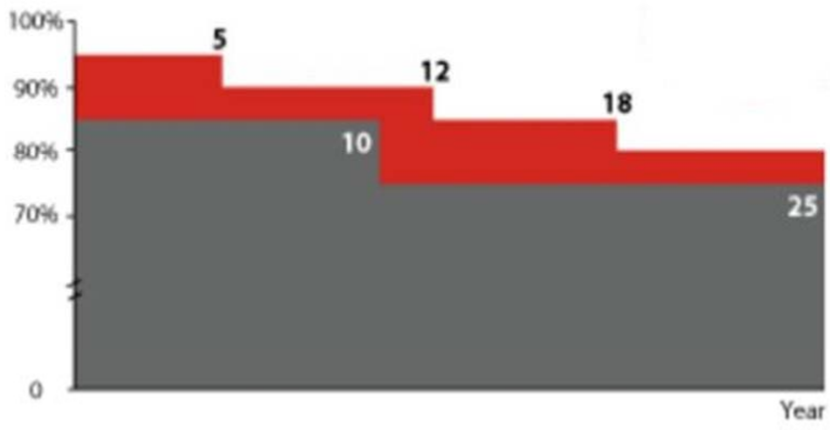
Module degradation

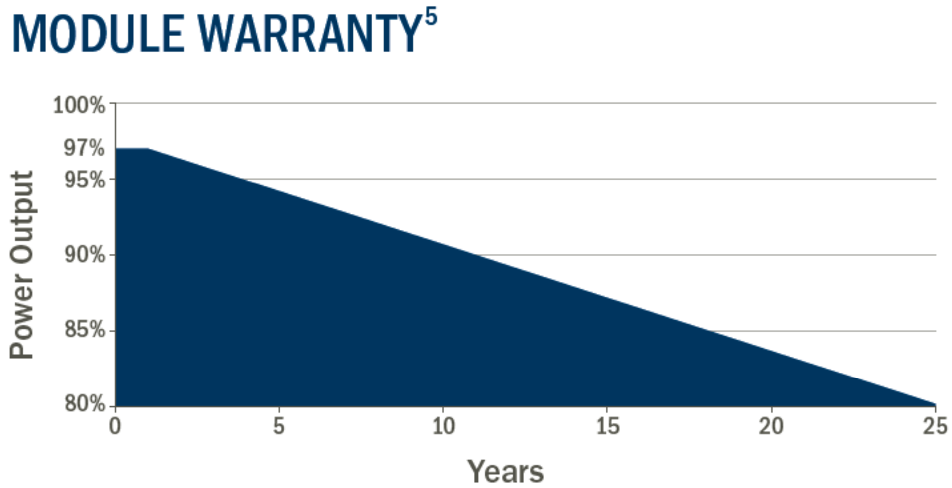
- PV module lose power over their lifetime
- Degradation because of ageing
- Degradation is not linear and can vary for different module technologies
- Percentages may vary but are usually within a margin of 0.25% to 0.8% per year
- Modules also degrade because of:

- Yellowing of EVA
- Glass soiling and corrosion
- Glass breakage
- Front-grid and antireflection-layer oxidation
- Busbar corrosion
- Cell cracks
- Backsheet polymer cracks
- Delamination and bubble formation in the encapsulant
- Back-sheet delamination
- Frame and junction box defects
- Hot spots

Module Warranty and Guarantees

- Product warranty: 5 – 12 years (defects at the frame, glass, cable connectors)
- Power (performance) guarantee: 25 years linear power guarantee
  - 97% of the nominal power after 1 year
  - 0.7% decrease in the following years until year 25
- Tolerances (+/- x% or “plus tolerance” / “plus sorting”), e.g. 300 Wp + 3%





Module Certificates and Tests

Source: TÜV Rheinland

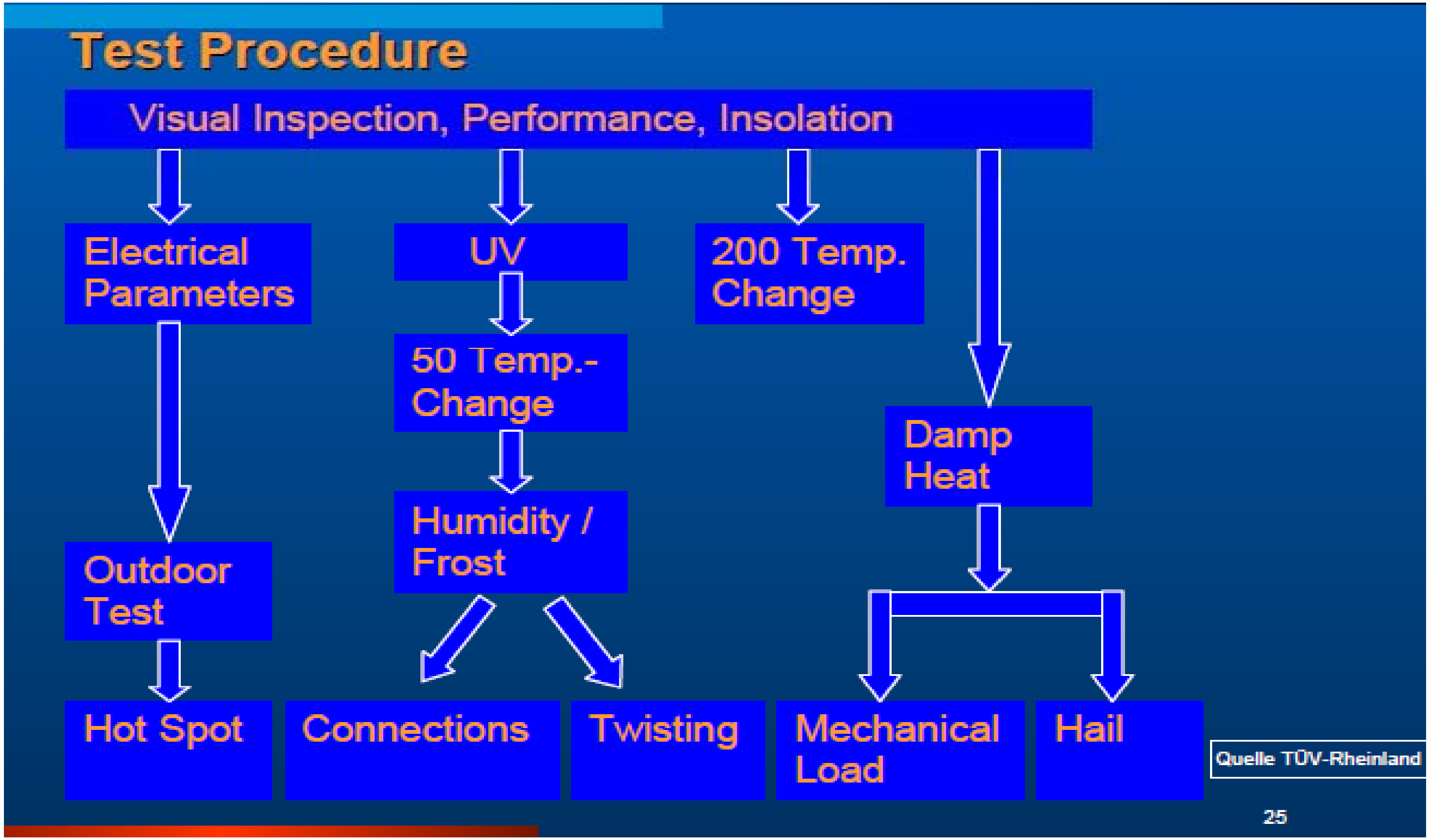
Module Certificates and Tests

- For module safety qualification IEC standard 61730 applies
- For design qualification and type approval the following Tests have to be performed on sample basis (IEC 61215 for crystalline modules and for thin film modules):

10.1 Visual inspection
10.2 Maximum power determination
10.3 Insulation test
10.4 Measurement of temperature coefficients
10.5 Measurement of nominal operating cell temperature (NOCT)
10.6 Performance at STC and NOCT
10.7 Performance at low irradiance
10.8 Outdoor exposure test
10.9 Hot-spot endurance test
10.10 UV preconditioning test
10.11 Thermal cycling test
10.12 Humidity-freeze test
10.13 Damp-heat test
10.14 Robustness of terminations test
10.15 Wet leakage current test
10.16 Mechanical load test
10.17 Hail test
10.18 Bypass diode thermal test
10.19 Light soaking (only thin film)

Module Certificates and Tests

- Testing according to IEC 61215



Module Tests

- Standard tests for design qualification and type approval confirm only the minimum quality requirements for PV modules.   Other tests are:

- IEC TS 62804 PID Test

- IEC 61701 Salt mist corrosion testing
- IEC 62716 Ammonia resistance
- Blowing Sand Test according to IEC 60068-2-68: upcoming standard and recommended for projects in dusty regions (is already applied by some module manufacturers)

- In general, additional tests in independent laboratories with samples of the supplied modules for PV power plant projects are recommendable:
  - Output power determination at STC
  - Electroluminescence images analysis (EL)
  - Wet leakage current test
  - Potential Induced Degradation (PID)

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Inverter warranties

- Standard Warranty conditions: 2 - 5 years

- Extended Warranty up to 20 years
- Technical availability guarantee (note: sometimes average values only)
- Spare parts availability guarantee
- Service agreement (LTSA)
  - Trained and certified local experts
  - First Level
  - Second Level
- Note: careful review of conditions necessary: what is included / excluded?

Lifetime of inverters (exchange after 10-15 years / major components)

Folie 62

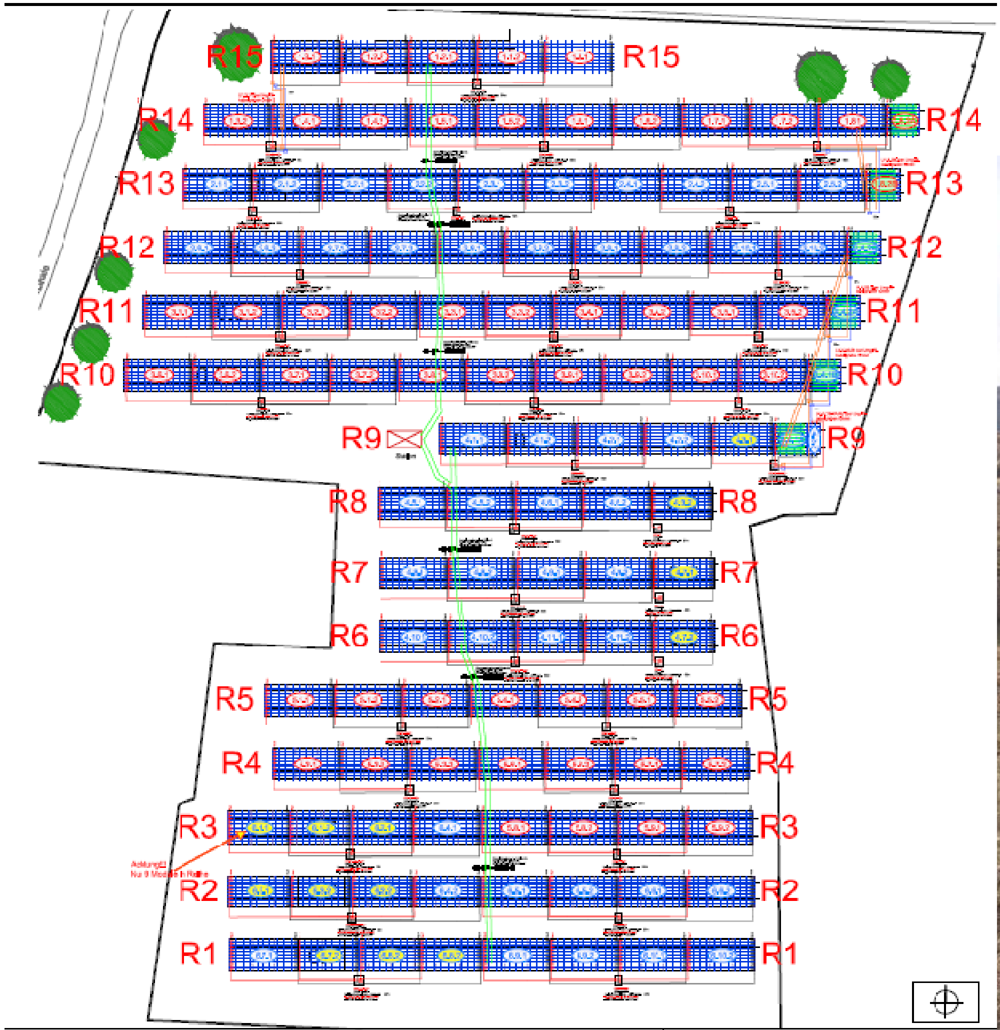
B2 Fehlt noch

Boris, 16/03/2014

General Standards for Installation of PV Systems

- IEC 60364-7-712 Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems
- IEC 62446 Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection
- IEC 62109 Safety of power converters for use in photovoltaic power systems
- IEC 62548 Photovoltaic arrays – Design requirements

PV Plant Design

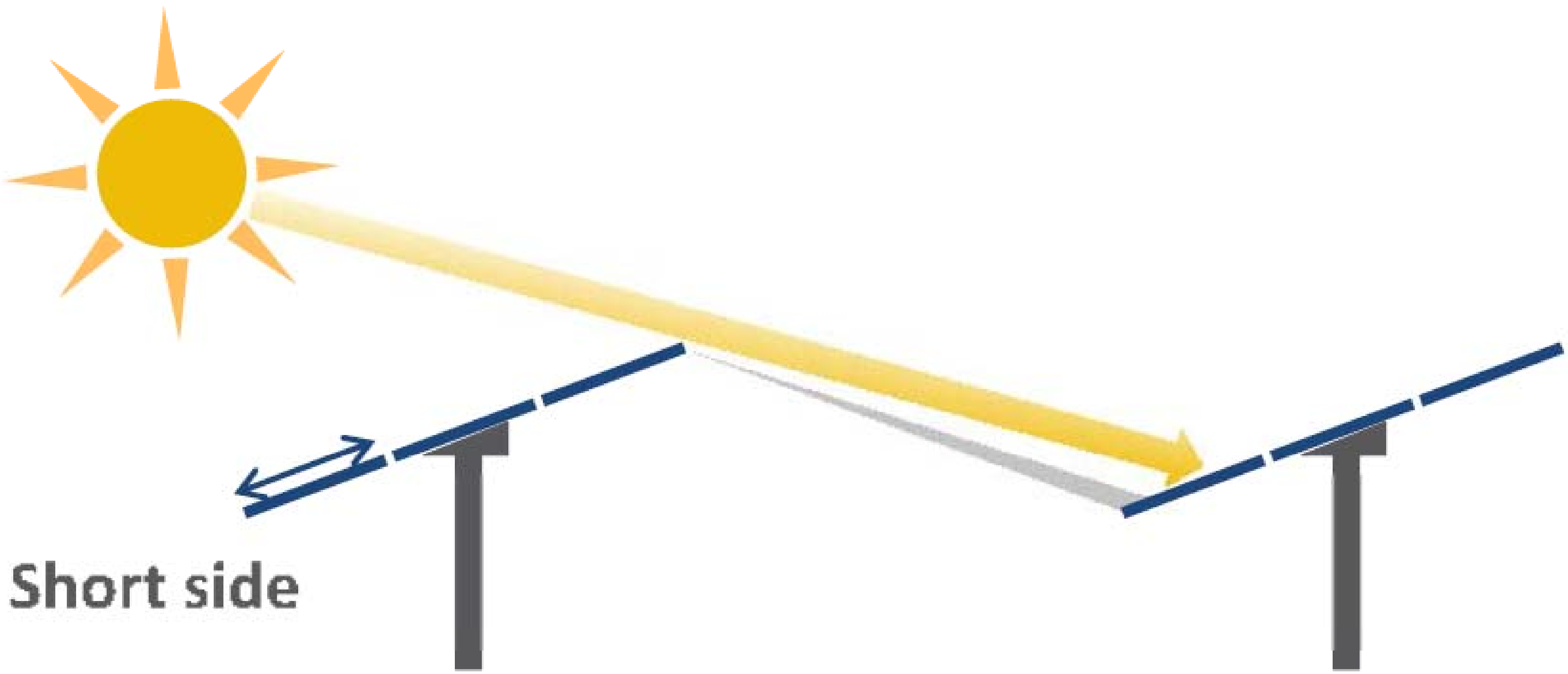


Surface area /kWp

CELL MATERIAL	MODULE EFFICIENCY	SURFACE AREA NEED FOR 1 KWP
Monocrystalline silicon	13–19%	5–8 m²
Polycrystalline silicon	11–15%	7–9 m²
Micromorphous tandem cell (a-Si/μc-Si)	8–10%	10–12 m²
Thin-film copper-indium-diselenide (CIS)	10–12%	8–10 m²
Thin-film cadmium telluride (CdTe)	9–11%	9–11 m²
Amorphous silicon (a-Si)	5–8%	13–20 m²

Module shading

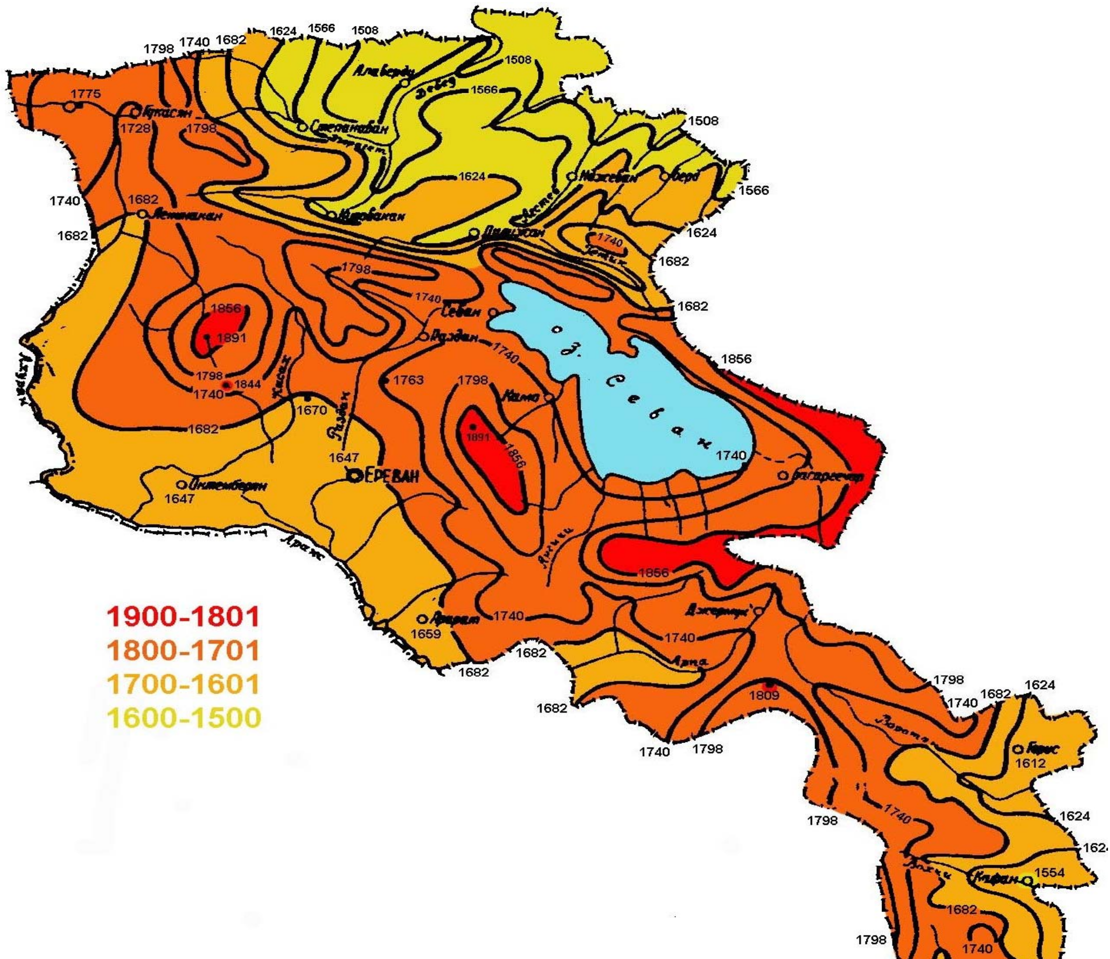
Typical row to row shading



First Solar

Solar Energy - Potential

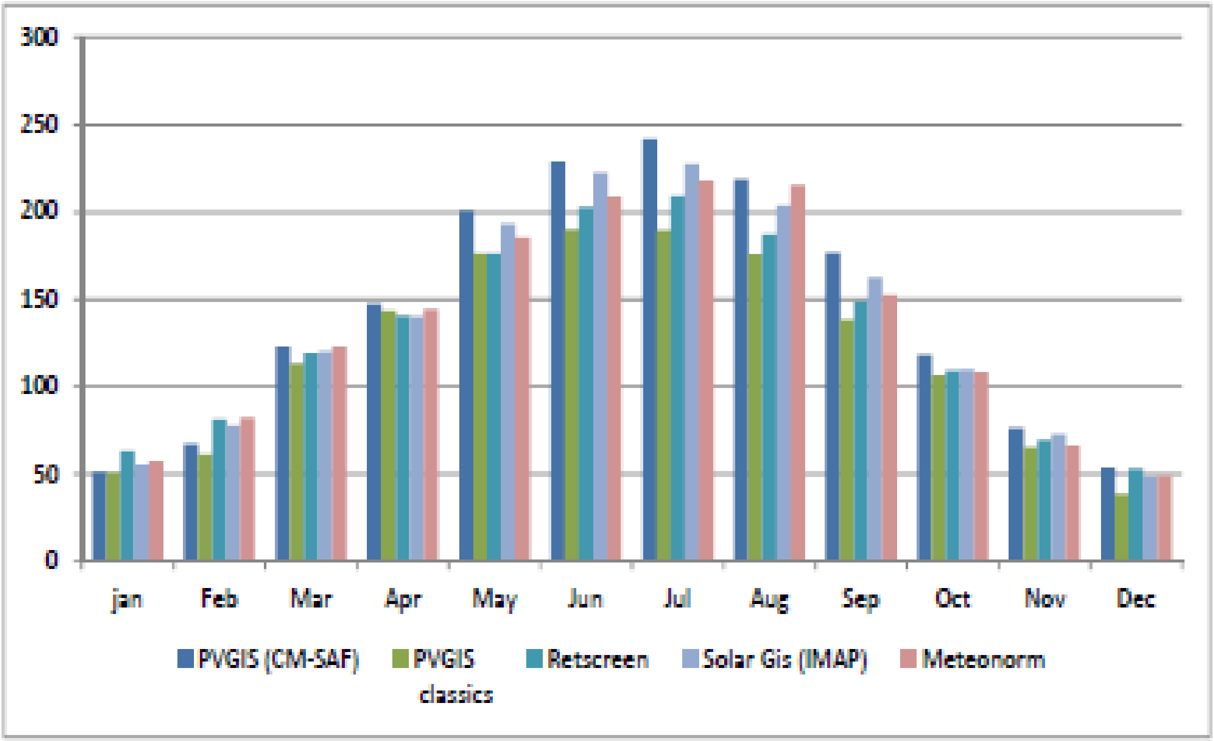
Armenia map of
Solar radiation



Total Horizontal Radiation
(kWh/m2 year)

Photovoltaic – System design Meteo Data

Horizontal irradiation in Yerevan KWh/m²					
	Available for free				
	PVGIS (CM-SAF)	PVGIS classics	Retscreen	Solar Gis (IMAP)	Meteo norm
jan	51,15	50,84	63,24	55,49	57
Feb	67,2	61,04	81,48	77,56	82,4
Mar	122,76	113,15	119,35	120,28	122,9
Apr	147,6	143,40	140,7	140,10	144,3
May	200,88	176,39	176,08	193,44	185,5
Jun	228,9	190,20	202,8	222,30	208,9
Jul	242,42	189,41	209,25	227,54	218,2
Aug	218,86	175,77	187,24	203,67	215,8
Sep	177	138,30	148,8	162,90	152,6
Oct	118,42	106,64	109,43	109,74	108,2
Nov	76,5	65,10	69,3	72,60	66,4
Dec	53,63	38,13	53,01	48,36	49
Year	1704,55	1449,05	1562,2	1635,2	1611



Yield simulation PVSYST

PVSYST V6.62		26/06/17	Page 2/3

Grid-Connected System: Main results

Project : **Yerevan Test 1MWp**

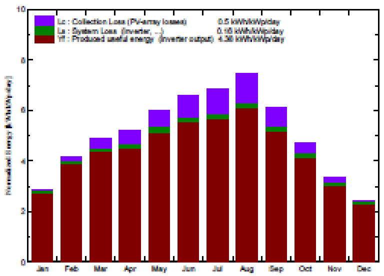
Simulation variant : **Neue Simulationsvariante**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	TSM-320PD14	Pnom	320 Wp
PV Array	Nb. of modules	3132	Pnom total	**1002 kWp**
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter pack	Nb. of units	14.0	Pnom total	**840 kW ac**
User's needs	Unlimited load (grid)			

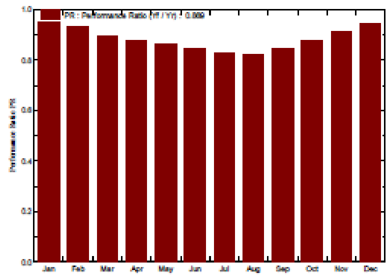
Main simulation results

System Production	**Produced Energy**	**1604 MWh/year**	Specific prod.	1600 kWh/kWp/year
	Performance Ratio PR	86.90 %		

Normalized productions (per installed kWp): Nominal power 1002 kWp



Performance Ratio PR



Neue Simulationsvariante

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	57.0	27.36	-4.36	88.8	85.4	88.1	84.6	0.951
February	82.4	36.87	-0.07	116.7	112.5	113.4	109.1	0.933
March	122.9	53.83	6.37	151.0	145.5	141.0	135.7	0.896
April	144.3	67.43	11.26	155.0	148.8	141.3	136.2	0.876
May	185.5	77.94	15.88	184.9	177.4	165.8	159.9	0.863
June	208.9	79.71	20.75	197.3	189.0	172.7	166.8	0.843
July	218.2	75.59	24.45	212.3	203.8	182.5	176.2	0.828
August	215.8	53.06	24.75	230.6	222.2	196.3	189.4	0.819
September	152.6	52.84	19.70	183.2	176.5	160.8	155.1	0.845
October	108.2	45.67	13.65	146.4	141.1	133.5	128.6	0.877
November	66.4	30.31	5.80	99.5	95.8	94.3	90.7	0.910
December	49.0	27.54	-0.60	75.5	72.5	74.1	71.2	0.941
Year	1611.1	628.14	11.53	1841.2	1770.3	1663.8	1603.5	0.869

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T Amb	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

Yield simulation PVSYST

PVSYST V6.62		26/06/17	Page 3/3

Grid-Connected System: Loss diagram

Project : **Yerevan Test 1MWp**

Simulation variant : **Neue Simulationsvariante**

Main system parameters	System type	**Grid-Connected**		
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PV modules	Model	TSM-320PD14	Pnom	320 Wp
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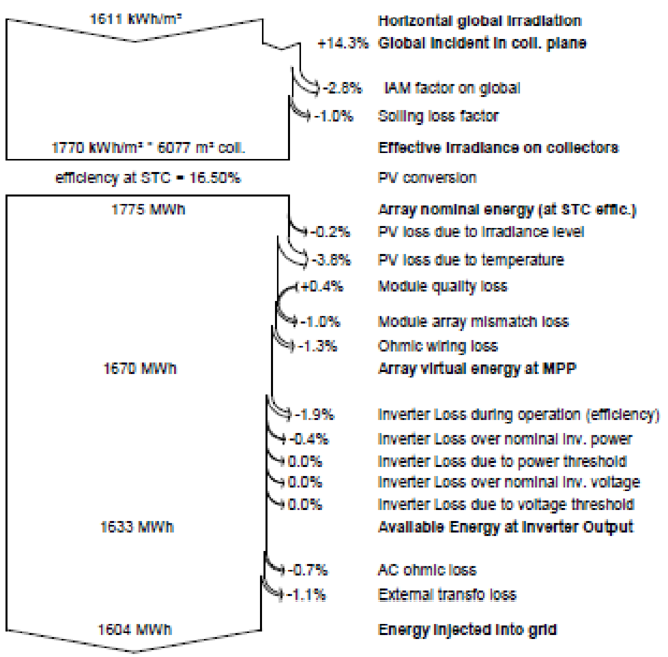
Inverter	Model	Sunny Tripower 60-10	Pnom	60.0 kW ac
Inverter pack	Nb. of units	14.0	Pnom total	**840 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Photovoltaic

Reliability / availability

- High reliability through:
  - Almost no moving mechanical parts (except of tracking systems)
  - Junction boxes with an ingress protection of IP67 and outdoor inverters with IP65 rating
- Technical availability of operating PV power plants is often above 98%
- In case of failure solar modules and string inverters can be modularly exchanged by local personnel with little training only
- Central inverters require more extensive training for maintenance
- Spare parts for the most critical components shall be available on site
- An optional but widely used monitoring system is possible with almost any inverter and can be used to detect any malfunction within minutes. The monitoring data is communicated via internet to experts which can instruct the local personnel.

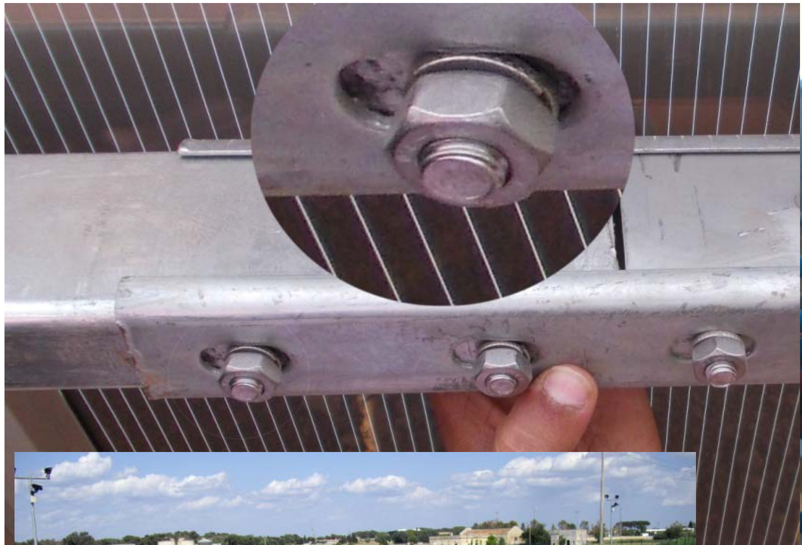
Photovoltaic

Technological risks

- Comparable low due to warranty standards:
  - 10 years product warranty or even more for the modules
  - 5 years product warranty of the inverters with possible extension to 25 years
- Problems can occur to PV modules, e.g.:
  - Yellowing of Ethylene vinyl acetate (EVA)
  - Glass soiling and corrosion
  - Glass breakage
  - Busbar corrosion
  - Cell cracks
  - Delamination and bubble formation in the encapsulant
  - Back-sheet delamination
  - Frame and junction box defects
  - Hot spots
  - Potential Introduced Degradation (PID)
- On islands the salty air of the sea can lead to strong corrosion of the modules and mounting structures if certain precautions have not been taken.

Photovoltaic

Technological and other risks – examples







Photovoltaic

Technological and other risks – examples

Photovoltaic

Operational risks

- High temperature
- Hail
- Rain
- Dust
- Cyclones / flashflood

Commercial risks

- Comparable low due to warranty standards
- Lower irradiation than originally planned decreases the profitability almost linearly. This risk can be minimized by using high resolution (long-term) satellite irradiation and temperature data available of at least 10 years in the planning stage.
- Variable prices in solar panels and electricity

Photovoltaic

www.irena.org

IRENA PROJECT NAVIGATOR

IRENA Project Navigator

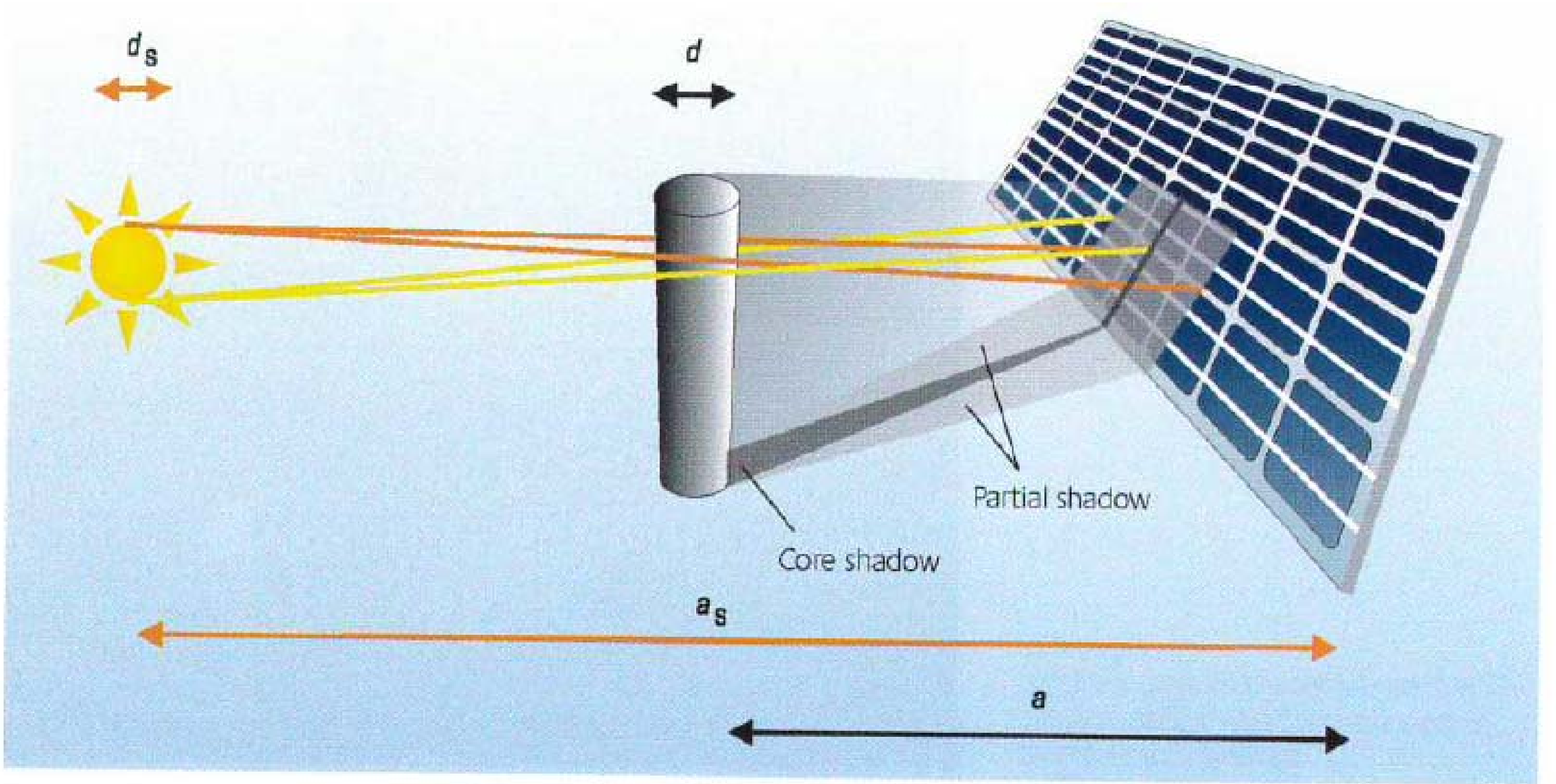
Technical Concept Guidelines

Utility-Scale Solar PV

Workshop 2: System Quality

- Row to Row distance
- Shading
- Backtracking
- DC/AC Ratio
- System losses
- Performance Ratio

Module shading

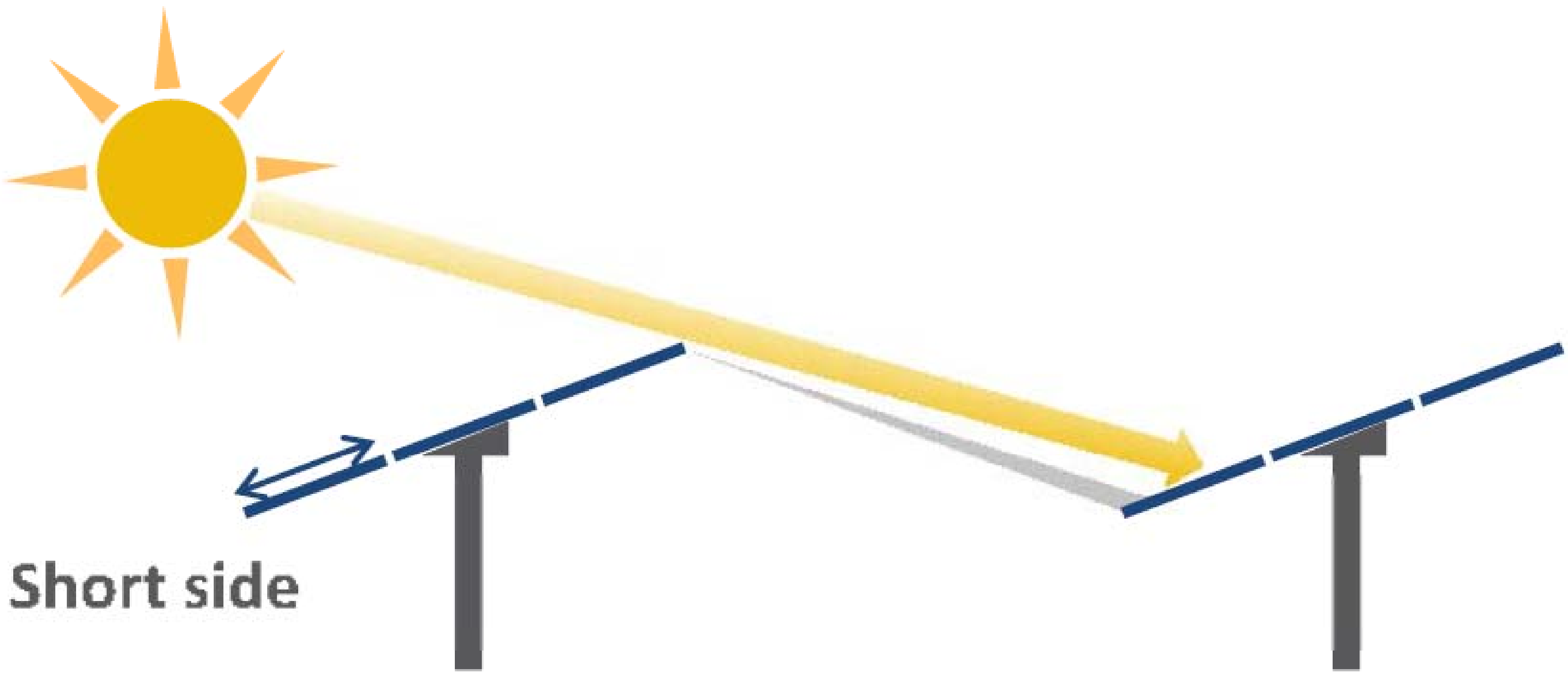


DGS Berlin

$a_{opti} = 108 \times d$

Module shading

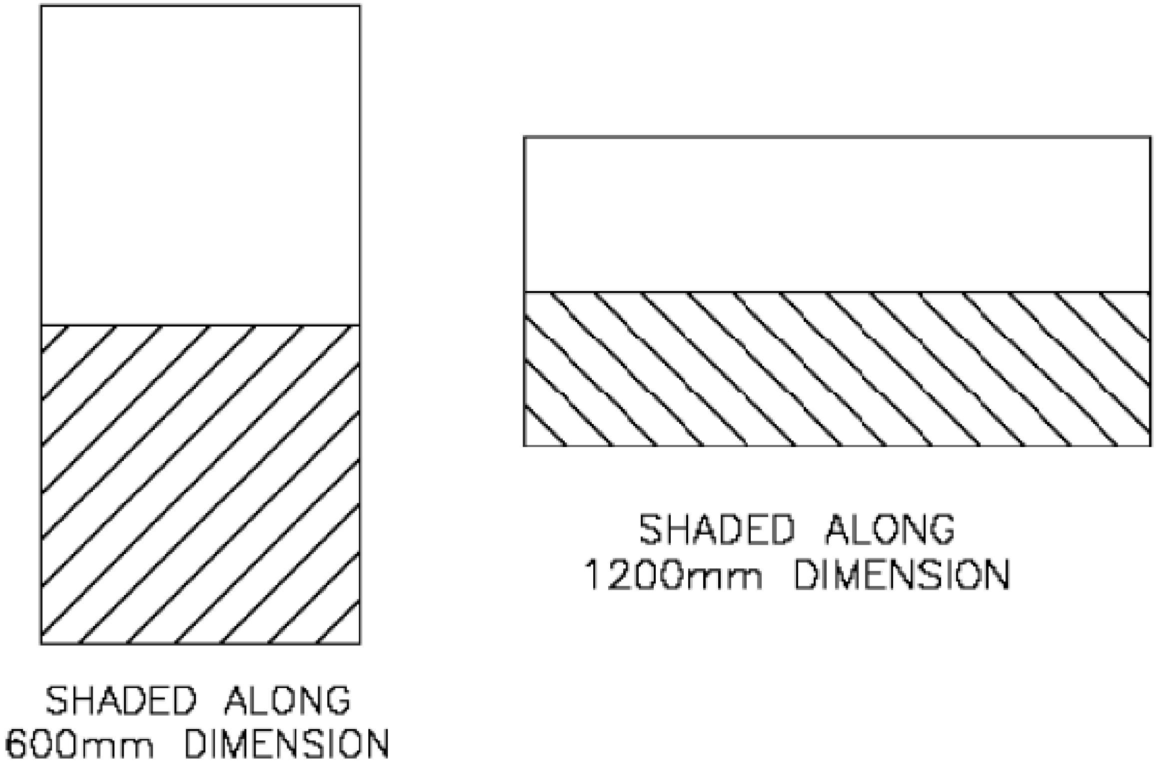
Typical row to row shading



First Solar

Module shading

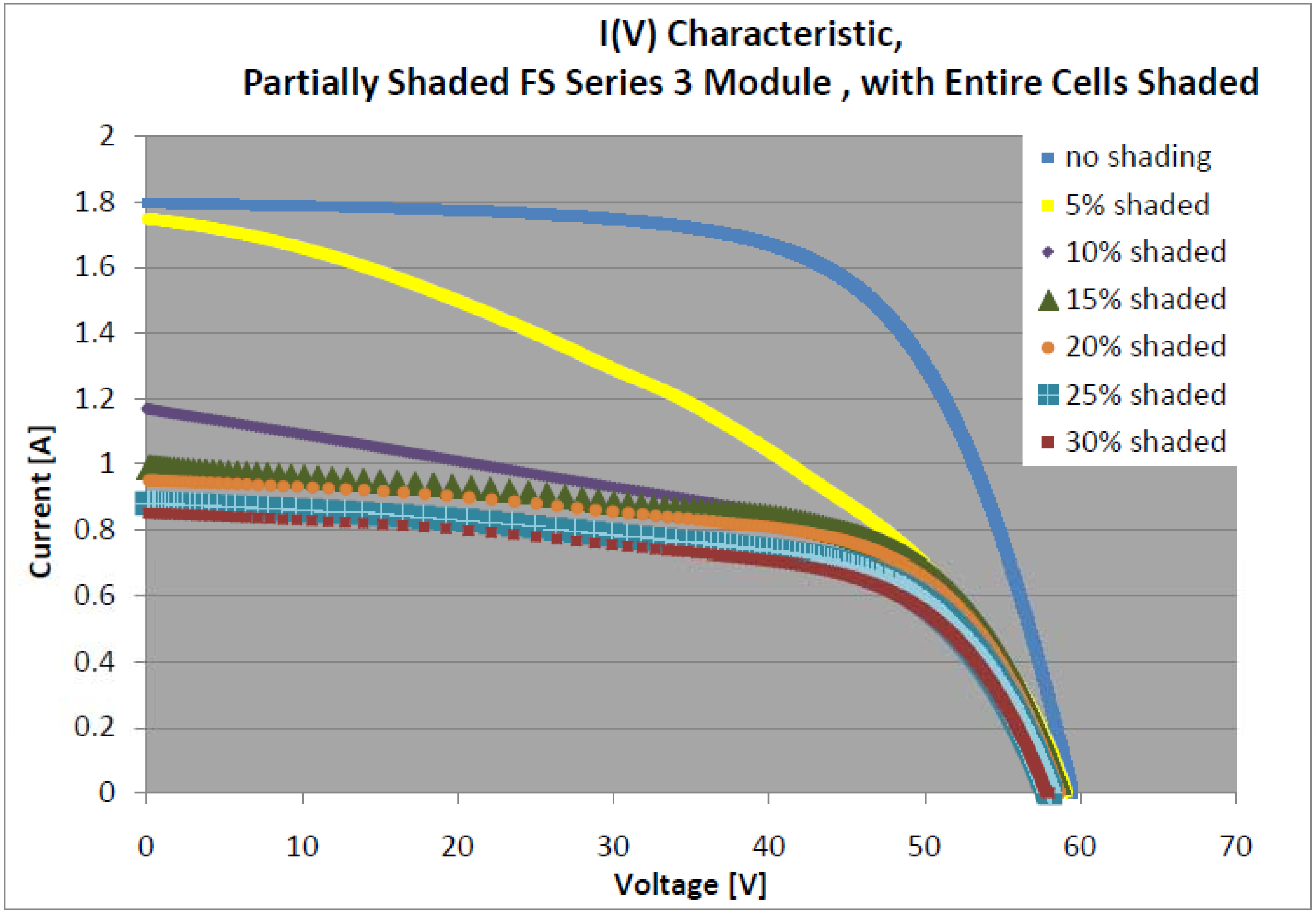
Shading of Thin Film modules: horizontal (“landscape”) and vertical (“portrait”)



First Solar

Module with cell shading

Shading of Thin Film modules



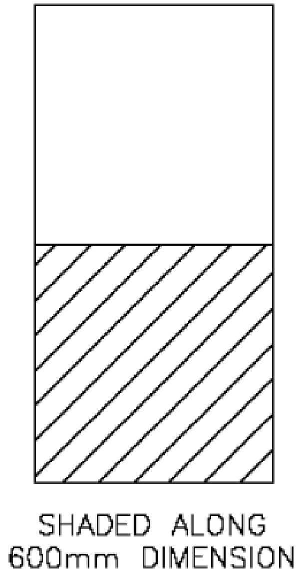


Figure 1. I(V) curves for an FS Series 3 PV Module with some cells entirely shaded. Shading occurred along the 600mm dimension.

First Solar

Module with cell shading

Shading of Thin Film modules

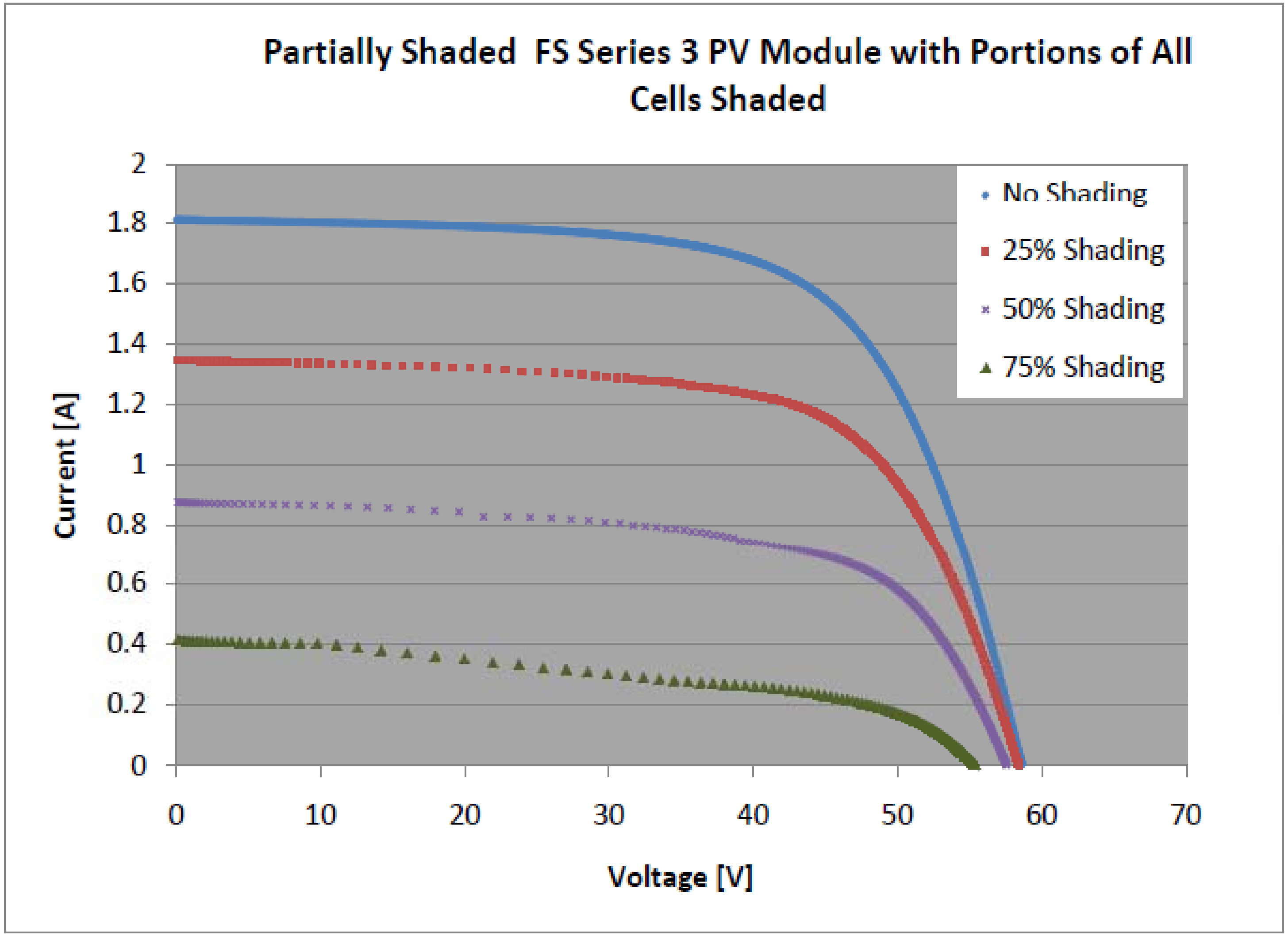
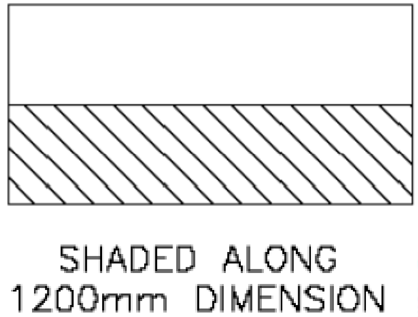


Figure 3. I(V) curves for FS Series 3 PV Module with all cells partially shaded along 1200mm dimension.



First Solar

Module with cell shading

Shading of Thin Film modules

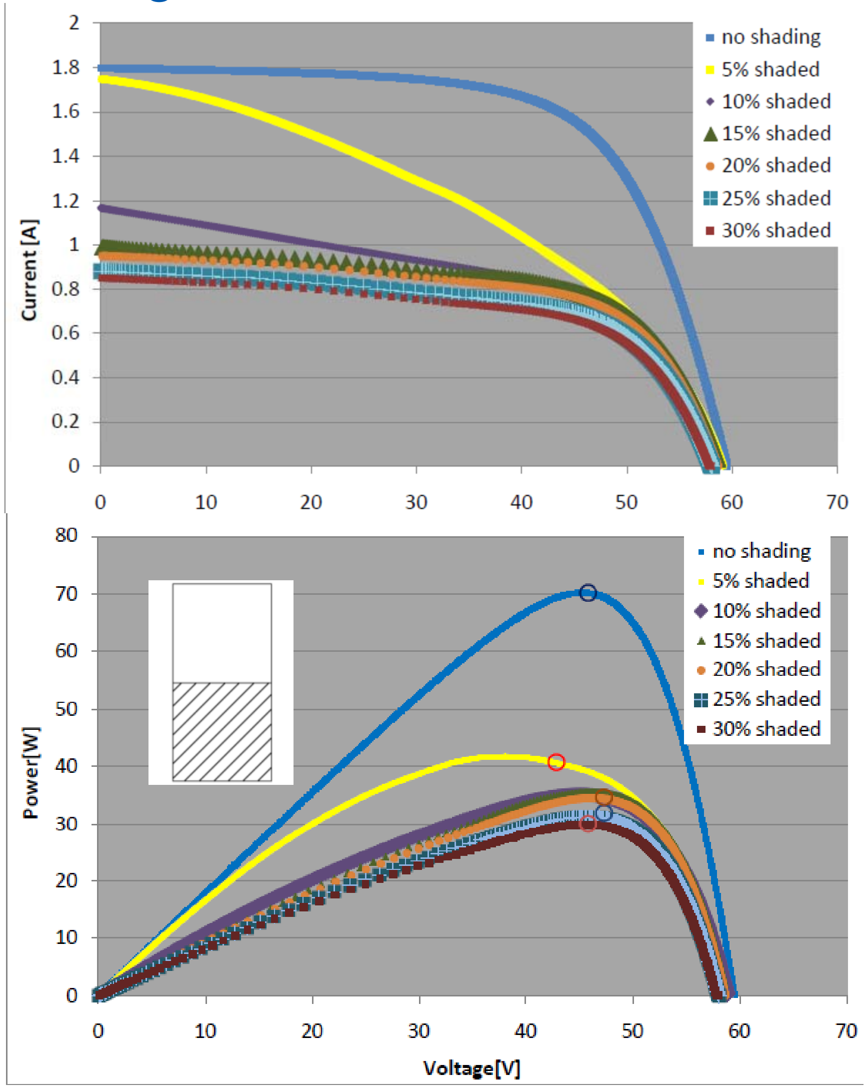


Figure 2. P(V) curves for an FS Series 3 PV Module with some cells entirely shaded. Shading occurred along the 600mm dimension. Circles denote maximum power points.

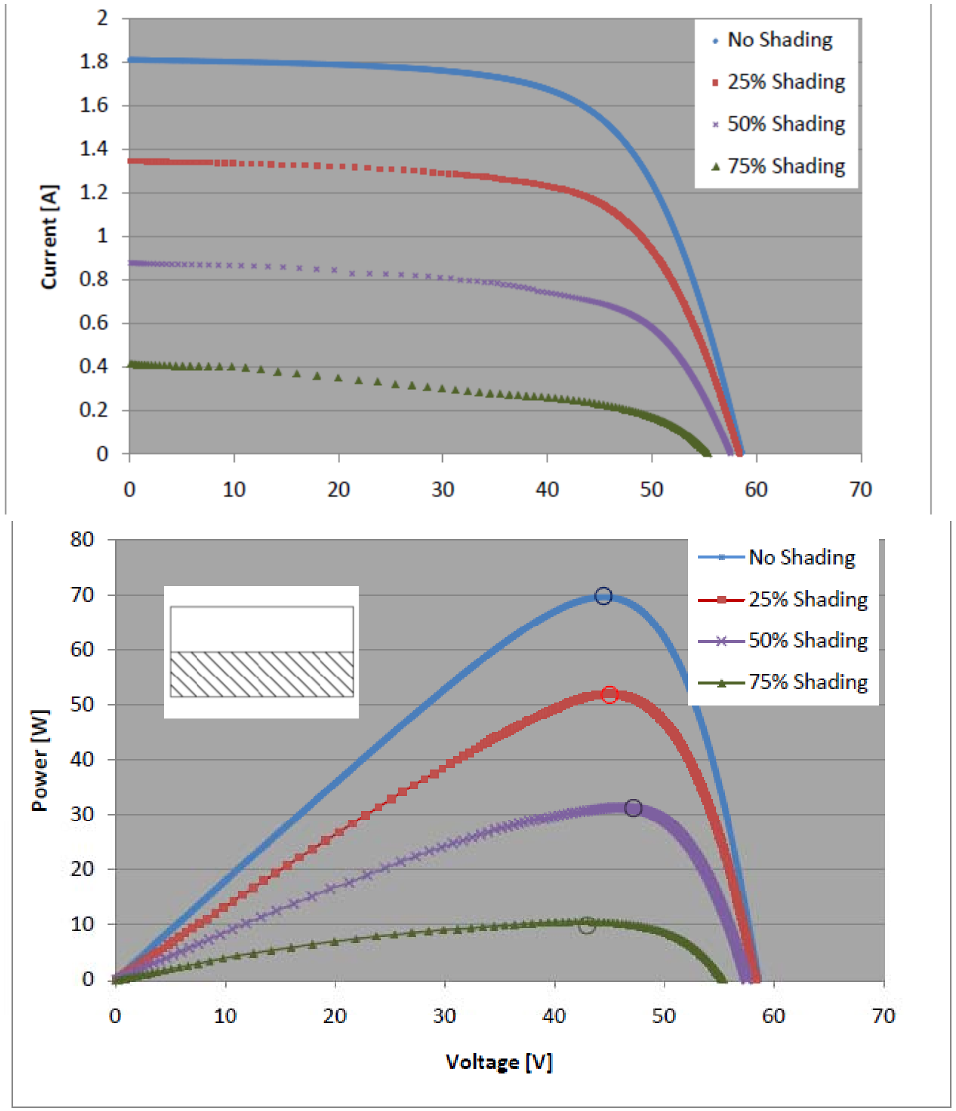
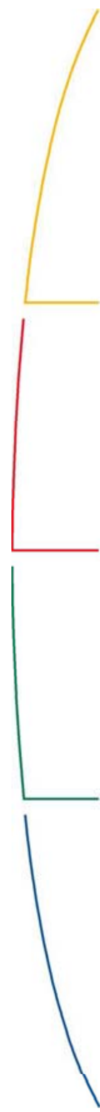


Figure 4. P(V) curves for FS Series 3 PV Module with all cells partially shaded along 1200mm dimension. Circles denote maximum power points.

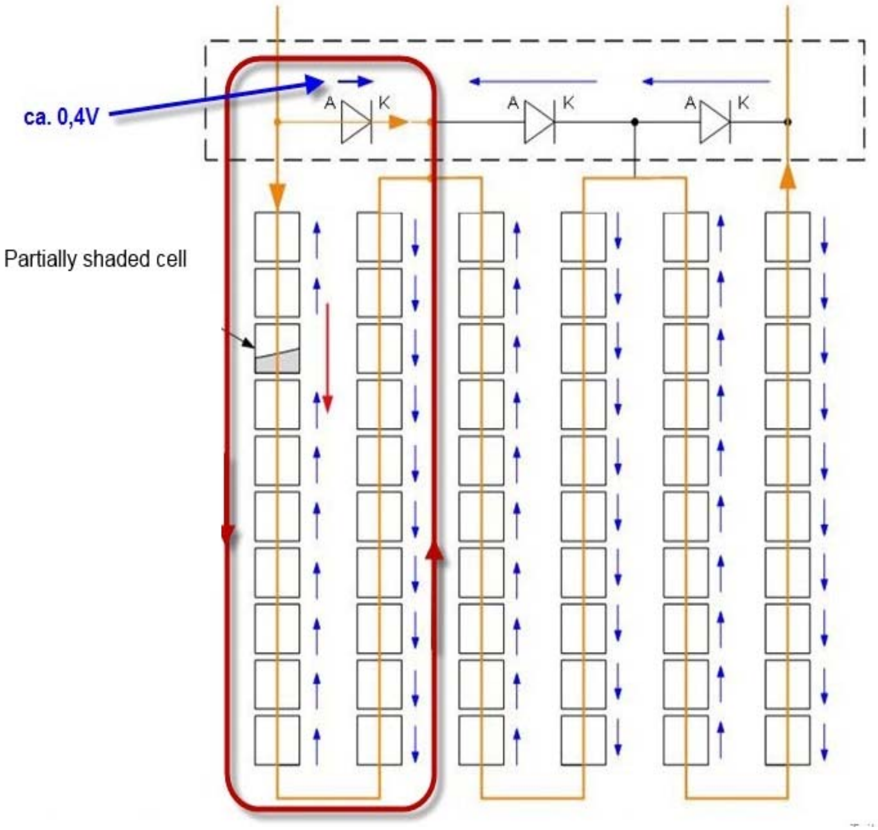


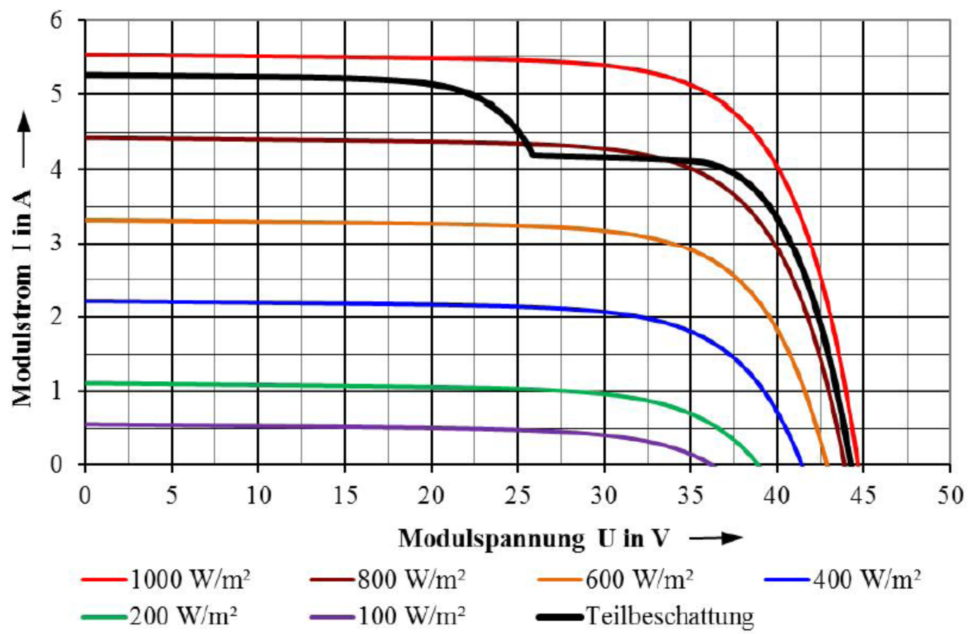
First Solar

FICHTNER

Module with cell shading

Shading of c-Si modules



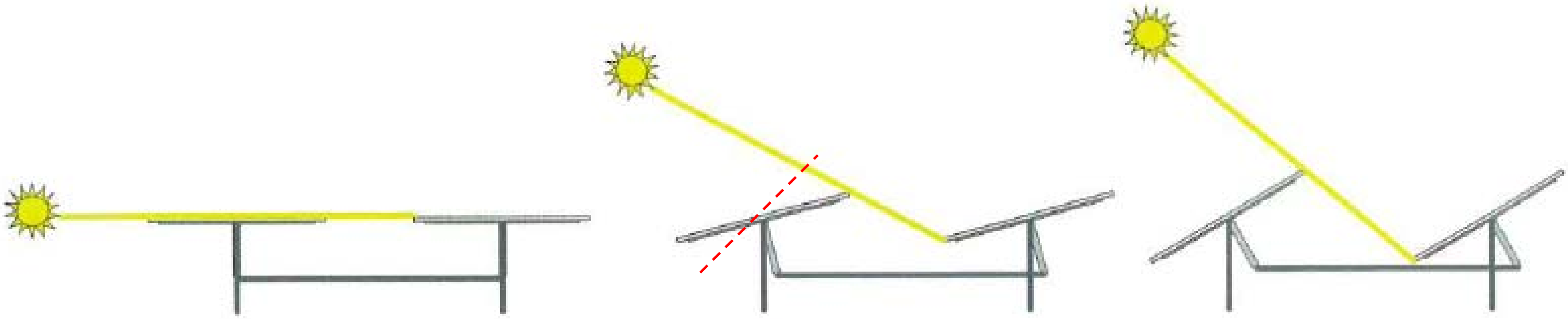


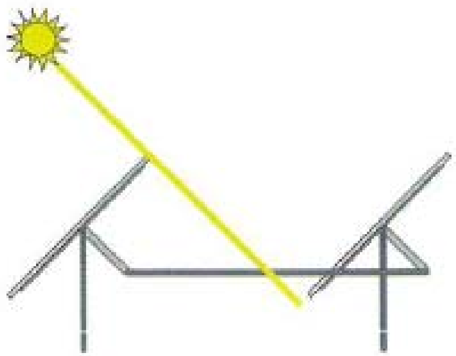
1-axis horizontal system: backtracking

Backtracking:

mutual (row-to-row shading) is prevented by backtracking operation. The module tilt is lowered to have un-shaded exposure of the modules to the light in the morning and evening hours.

Note: the PR will usually increase with backtracking due to lower irradiation.





Source: DGS, SunPower T0

Performance Ratio

$$PR = Y_{AC} / G_{TILT} * A_{1kW} * \eta_{STC}$$

Y_{AC} = specific AC electricity yield [kWh/kW_p]
G_{TILT} = total global solar irradiation sum on the tilted module plane [kWh/m²]
A_{1kW} = area of a 1 kWp PV module array [kW/m²]
η_{STC} = PV module efficiency at standard test conditions [%]

- Ratio for annual values of total AC energy to the theoretically available energy
  - Expression of the quality of the installation
  - PR represents the module performance that deviates from the STC together with the losses between module and inverter outlet
  - Often applied as basis for **performance guarantee**
- Alternative formula:

$$PR = \frac{Yield}{Irradiation}\frac{\frac{kWh}{kWp}}{\frac{kWh}{m^2}} \times 1000\,\frac{W}{m^2}$$

Performance Ratio

Exercise:

$$PR = \frac{Yield \frac{kWh}{kWp}}{Irradiation \frac{kWh}{m^2}} \times 1000 \frac{W}{m^2}$$

1) What is the Performance Ratio (PR) for a PV Plant with the following characteristics:

- Number of modules: 100 pcs.
- Nominal power: 300 Wp
- Irradiation on module: 1,500 kWh/m²x a (measured)
- Energy generated: 35,000 kWh (measured)

- Specific Yield = ________________

- PR = ________________

Performance Ratio

Performance ratio:

$$PR = \frac{Yield \frac{kWh}{kWp}}{Irradiation \frac{kWh}{m^2}} \times 1000 \frac{W}{m^2}$$

$$PR = \frac{\frac{35{,}000}{30} \frac{kWh}{kWp}}{1500 \frac{kWh}{m^2}} \times 1000 \frac{W}{m^2}$$

$$PR = \frac{1167 \frac{kWh}{kWp}}{1500 \frac{kWh}{m^2}} \times 1000 \frac{W}{m^2}$$

$$PR = 77.8\%$$

System:		
Module power	300	Wp
number of modules	100	pcs.
DC plant capacity	30	kWp
Irradiation:		
Irradiation GHI	1,470	kWh/m²
Irradiation POA	1,500	kWh/m²
Output		
Total Energy measured	35,000	kWh
Specific Yield	1,167	kWh/kWp
PR	**77.8%**	

Module inverter configuration

- Exercise

Enter the missing information.

Calulate the missing values

Module Data TRINA TSM PC/PA14		
	Unit	
Nominal Power	W	300
MPP voltage	V	
MPP current:	A	
open circuit voltage:	V	
short circuit current:	A	
temp. coeff. open circuit voltage	% / °C	
temp. coeff. Pmax	mV / °C	
allowed system voltage of module	V	
cells	-	

Calculation		
	Unit	
Temperature	°C	70
MPP Voltage	V	
Temperature	°C	50
MPP Voltage	V	
Temperature	°C	15
MPP Voltage	V	
Temperature	°C	-10
Open circuit voltage	V	

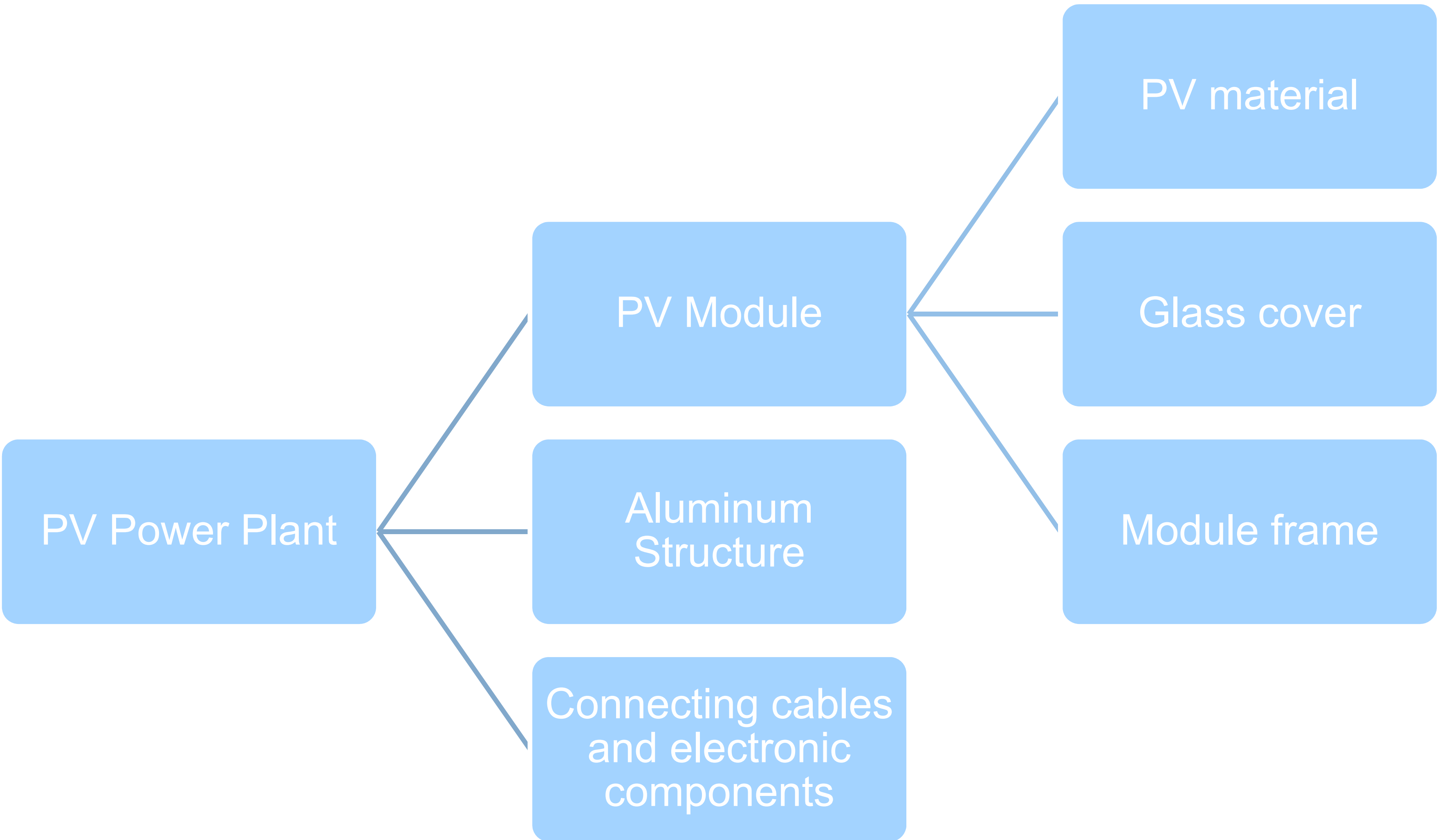
Module inverter configuration

results

Module Data TRINA TSM PC/PA14		
	Unit	
Nominal Power	W	300
MPP voltage	V	36.9
MPP current:	A	8.13
open circuit voltage:	V	45.3
short circuit current:	A	8.6
temp. coeff. open circuit voltage	% / °C	-0.33
temp. coeff. Pmax	% / °C	-0.44
allowed system voltage of module	V	1000
Number of cells	-	72

Calculation		
	Unit	
Temperature	°C	70
MPP Voltage	V	
Temperature	°C	50
MPP Voltage	V	
Temperature	°C	15
MPP Voltage	V	
Temperature	°C	-10
Open circuit voltage	V	

Module recycling



Module recycling – PV Cycle

- Established in 2007
- Responsible for modules recycling services in EU countries
- Pick up depends on the number of modules, recycling is free of charge.
- Only 1% of the collected modules so far are due to EOL, the rest is due to transport and installation damage
- The recycling is done by the modules manufacturers

Application Procedure

- Application Form and List of required documents
  - Direct contact to Fichtner Local Project Manager Artem Kharazyan (091-211 102)
  - Guidance, explanation, assistance on requirements and financing through GAF
  - Application Form, List of required documents also on Programme Homepage

www.gaf-re.am

funded by: BMZ Federal Ministry for Economic Cooperation and Development

Web:gaf-re.am

Project Office
V. Vagharshyan 20
Yerevan, Armenia
Tel: 091 - 211102
E-mail: asproject@bk.ru

Հայտ հարցաշար
մինչև 1 ՄՎտ հզորությամբ ֆոտովոլտաիկ էլեկտրակայանների համար
Application Form PV Power Plants up to 1 MW

Վերականգնվող էներգիայի զարգացման ծրագիր
Գերմանա-Հայկական հիմնադրամ (ԳՀՀ-ՎԷ) Փուլ III

Programme for the Promotion of Renewable Energies:
German-Armenian Renewable Energy Fund (GAF-RE) Phase III

Խնդրում ենք լրացնել սույն Հայտը և էլեկտրոնային տարբերակն ուղարկել asproject@bk.ru հասցեով, որը հնարավորություն կտա քննարկելու Ձեր դիմումը: Դուք կարող եք նաև Հայտը ուղարկել փոստով՝ ծրագրի գրասենյակ:

Please fill in this application questionnaire and submit it in an electronic form to asproject@bk.ru, which will guarantee the quickest way to get your application reviewed. Alternatively you can send it by mail to the Project office.

Հայտի ստացումը և քննարկումը կհաստատվի ԳՀՀ-ՎԷ ծրագիրը իրականացնող խմբի պատասխան նամակով: Եթե Ձեր ծրագիրը համապատասխանի ընտրության չափանիշներին, Ձեզ կտեղեկացնենք հաջորդ քայլերի մասին՝ Ձեր ընկերություն այցելելու և ավելի մանրամասն լրացուցիչ տեղեկություններ ստանալու վերաբերյալ:

GAF-RE FINANCING PROGRAMME - PV POWER PLANTS up to 1 MW
ԳՀՖ-ՎԷ մինչև 1 ՄՎտ ՖՎ էլեկտրակայանների ֆինանսավորման ծրագիր

Ստացված փաստաթղթերի ստուգման թերթ
Checklist of received documents

ՖՎ էլեկտրակայանի անվանումը / **Name of PV plant** ____________________

	Փաստաթղթի անվանում Name of document	Ստացված է Received	Մեկնաբա-նություններ Comments	Ստուգված է Checked	Մեկնաբանու-թյուններ/ դիտողություններ Comments/remarks
1	Հողակտորի սեփականաշնորհման վկայական/սերտիֆիկատ **Land privatization certificate**	☐		☐	
2	Տեղեկություն ՖՎ էլեկտրակայանի ընկերության/ սեփականատիրոջ մասին **Information about the PV plant Company / Owner**				
	Իրավաբանական անձի պետական գրանցման վկայական **Certificate of state registration of legal entity**	☐		☐	
	Տնօրենի գրանցման արձանագրություն **Director's registration protocol**	☐		☐	
	Հարկ վճարողի հաշվառման համարը **Taxpayer identification number**	☐		☐	
	Կանոնադրություն **Charter**	☐		☐	
3	ՖՎ էլ. կայանի կառուցման լիցենզիա **PV plant construction license**	☐		☐	
4	ՇՄԱԳ փորձաքննության եզրակացություն **Report on Environmental Impacts**	☐		☐	
5	Նախագծի փորձաքննության եզրակացություն **Report of the examination for the project**	☐		☐	
6	Գեոդեզիական հետազոտությունների հաշվետվություն **Topographic survey report**	☐		☐	
7	Երկրաբանական հետազոտությունների հաշվետվություն **Geotechnical study report**	☐		☐	