Small-Utility-Scale PV Generation :

Concepts and Installation of Grid Connected PV Systems

NIUE, July 2009

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www. TECHNOSOL. de

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Presentation Outline

- PV- Potentials
- PV- Grid System Components
  - Basics
  - Solar Cells and Panels
  - Inverters
  - Generator Design
  - Mounting Concepts
  - Structural Analysis
- Alternative Supply Concepts

PV-Basics

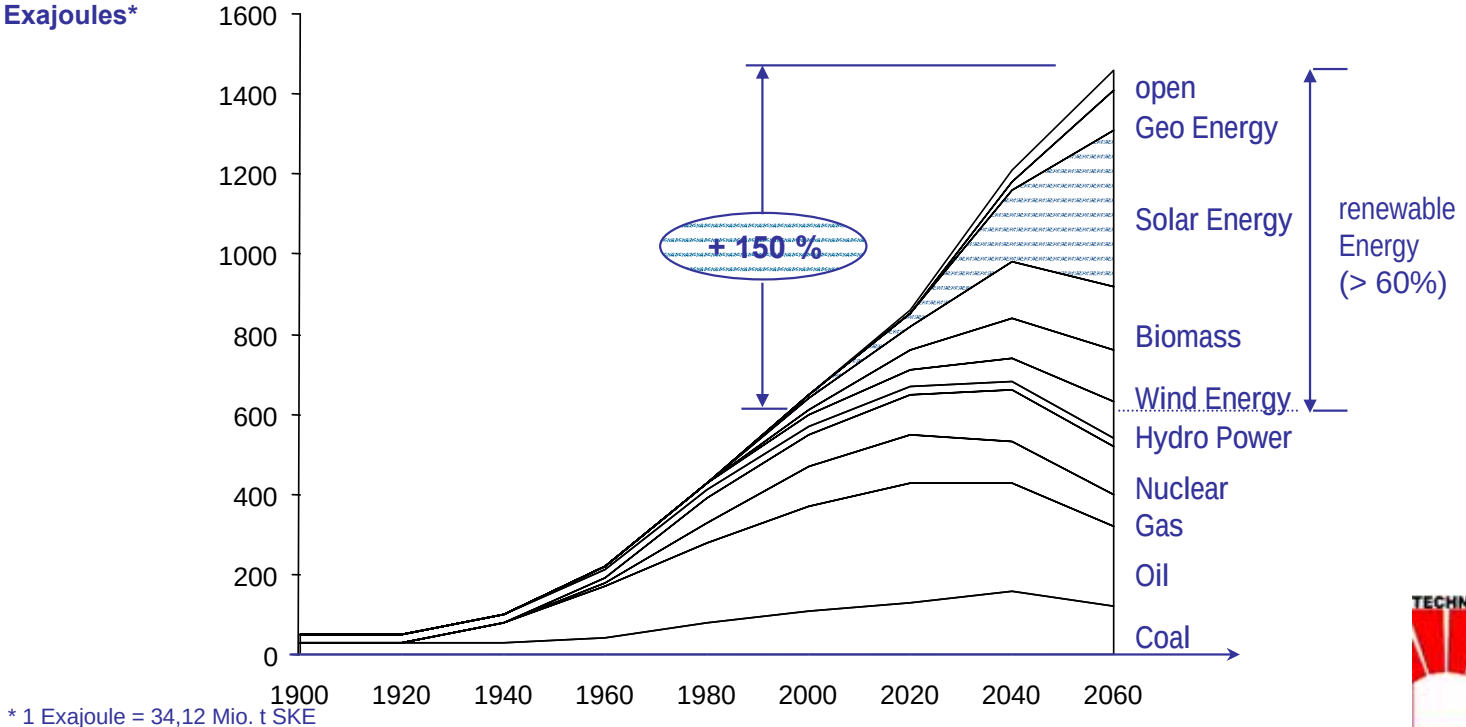
Solar Harvest

- The Sun gives 63,000 kW/m²
- Earth receives 1,360 W/m² = Solar Constant
- 1,000 W/m² reaches the ground at clear sky
- Direct Solar, also Wind, Water, Bio
- Heat emission converted thermally to 700 W/m²
- Light energy converted electrically to 100 W/m²

PV-Basics

World Electricity Consumption

Until 2060 demand will more than double, even at sustainable growth
Only considerable supply from renewable energy can cope.



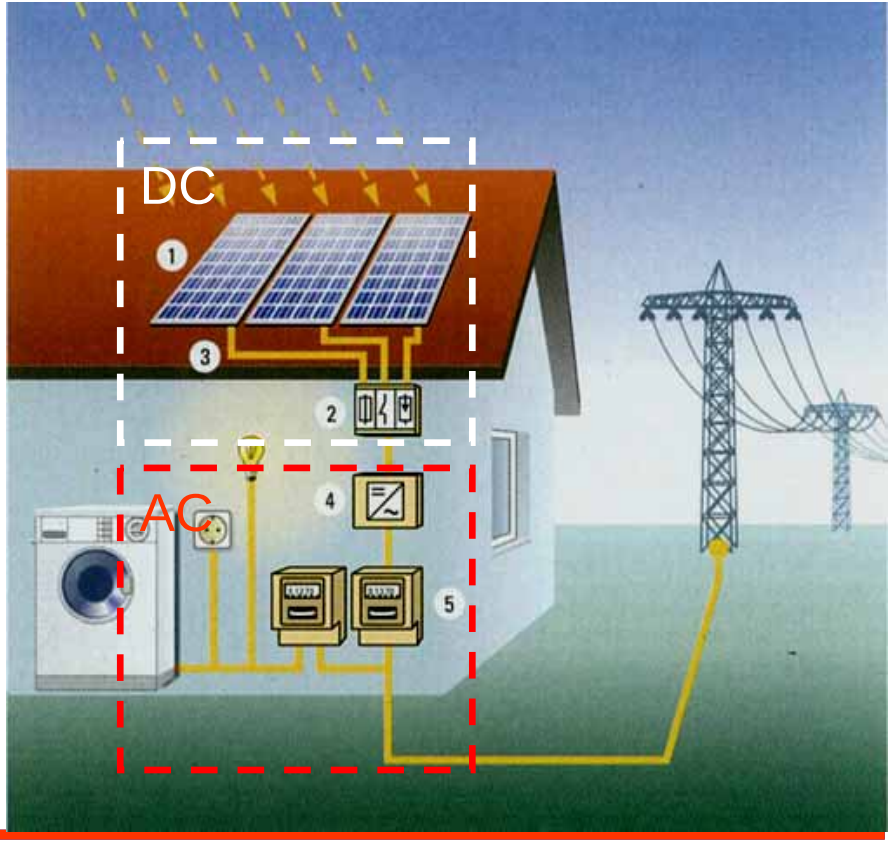
* 1 Exajoule = 34,12 Mio. t SKE

Source: Greenpeace, Wuppertal-Institut, Shell
11.July 2009

Grid Systems

Components

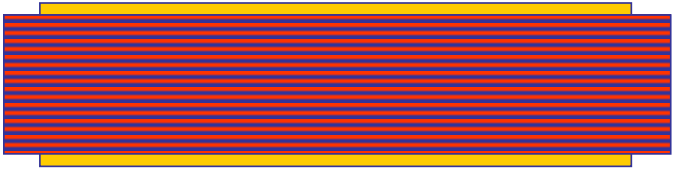
- (1) Solar Generator
- (2) Group box & wiring
- (3) Mounting structure
- (4) Inverter
- (5) Meter



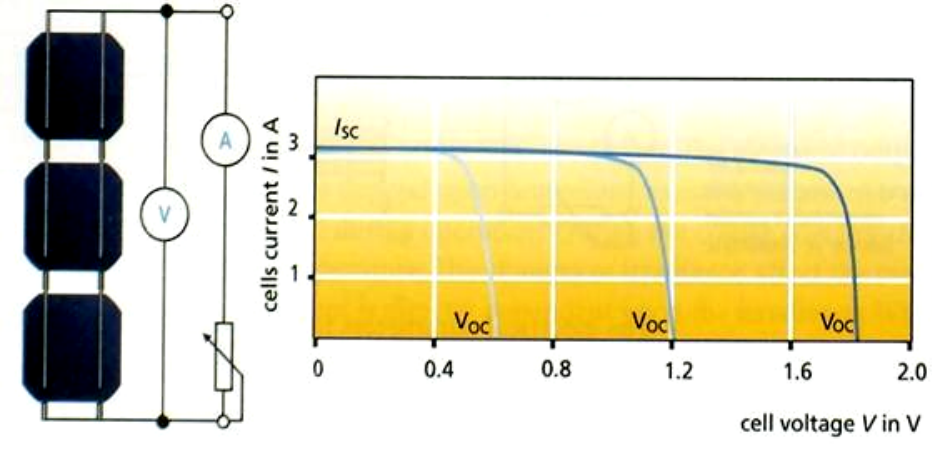
PV-Basics

Electricity Fundamentals

- Electricity is similar to **water in a hose** :
- **Current** is the flow
- **Voltage** is the pressure



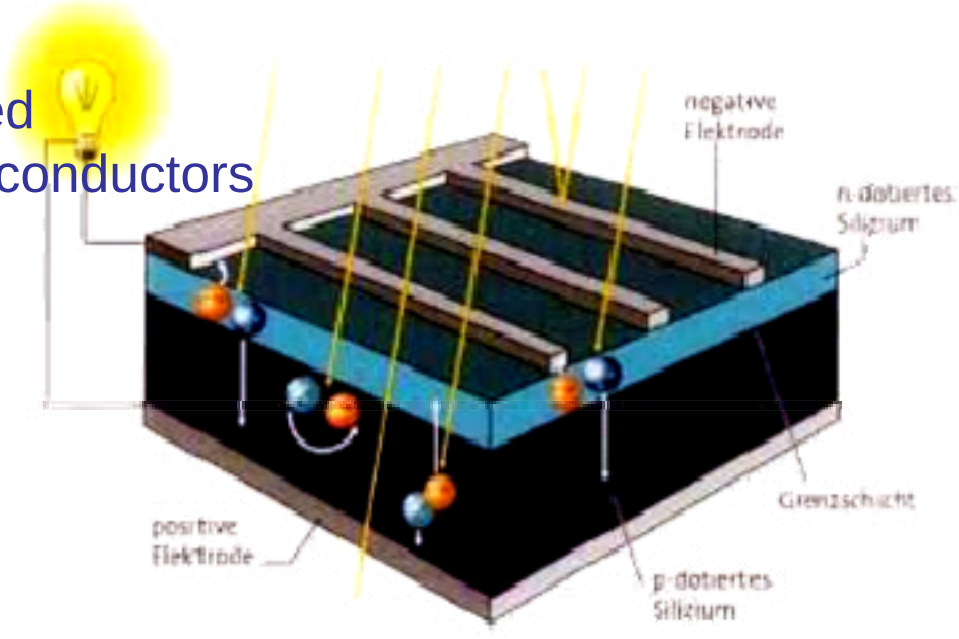
- Measure Voltage and Current for a Photovoltaic Cell



PV-Basics

The Photovoltaic Effect

- **Light Energy** separates charged electrons in semiconductors

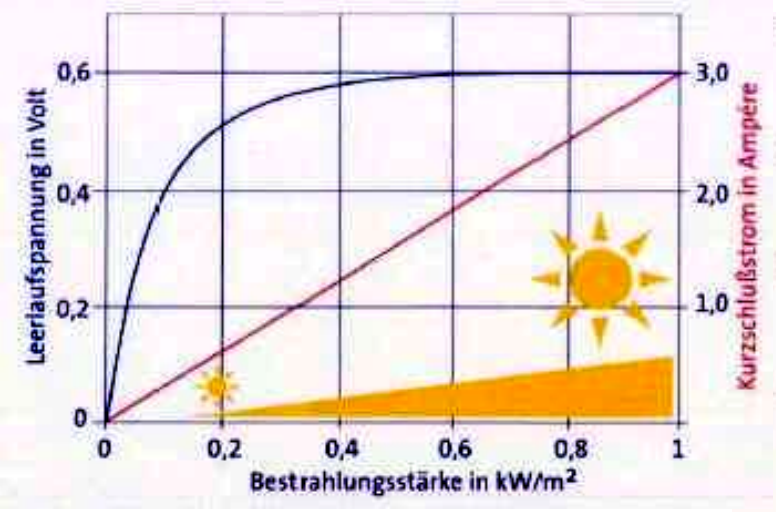


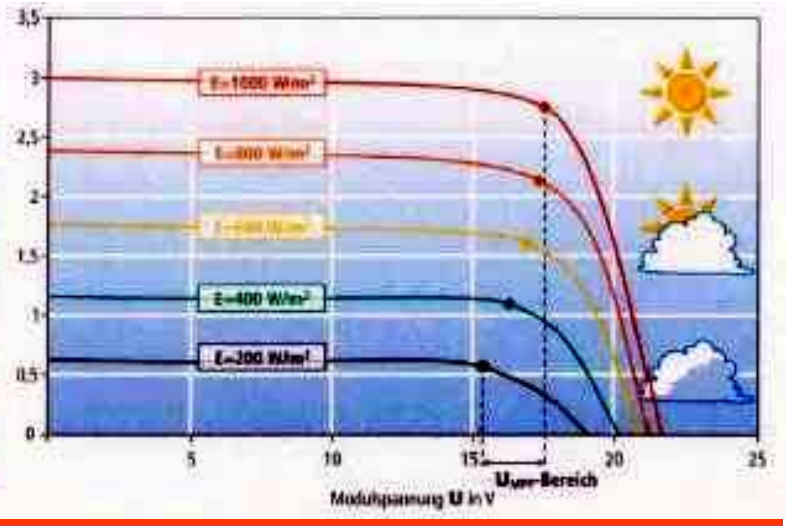
- **Depends on:**
  - Material
  - Light Intensity
  - Wavelength
  - Temperature

PV-Basics

Characteristics of Solar Cells

- Irradiation Effect on Solar Cell Current and Voltage

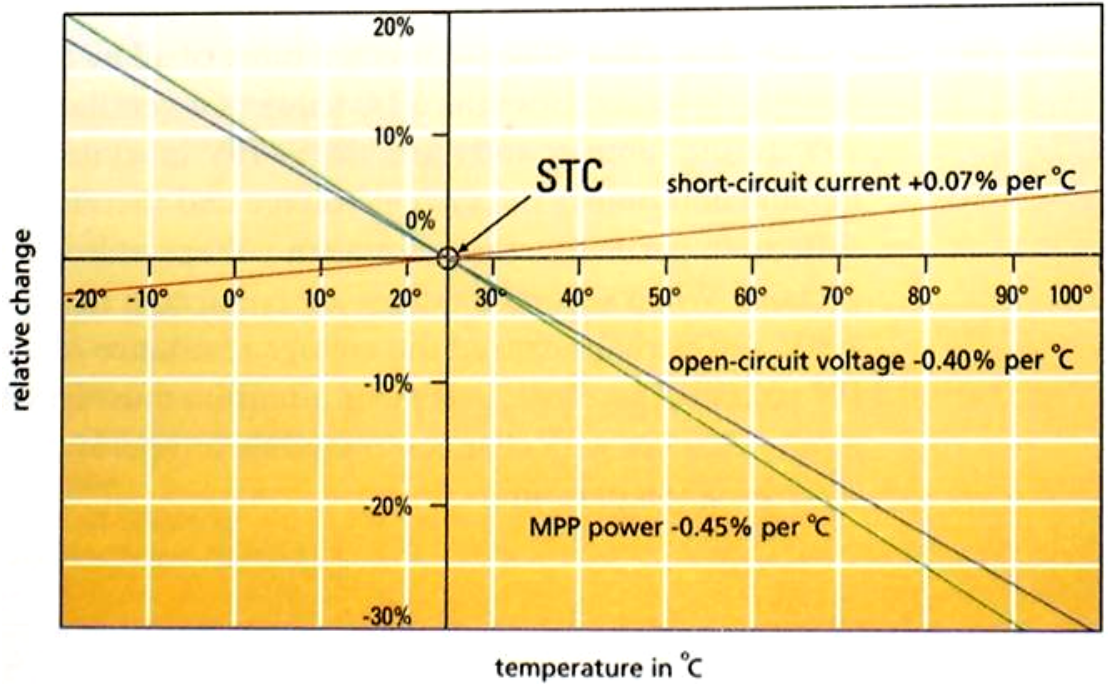




PV-Basics

Characteristics of Solar Cells

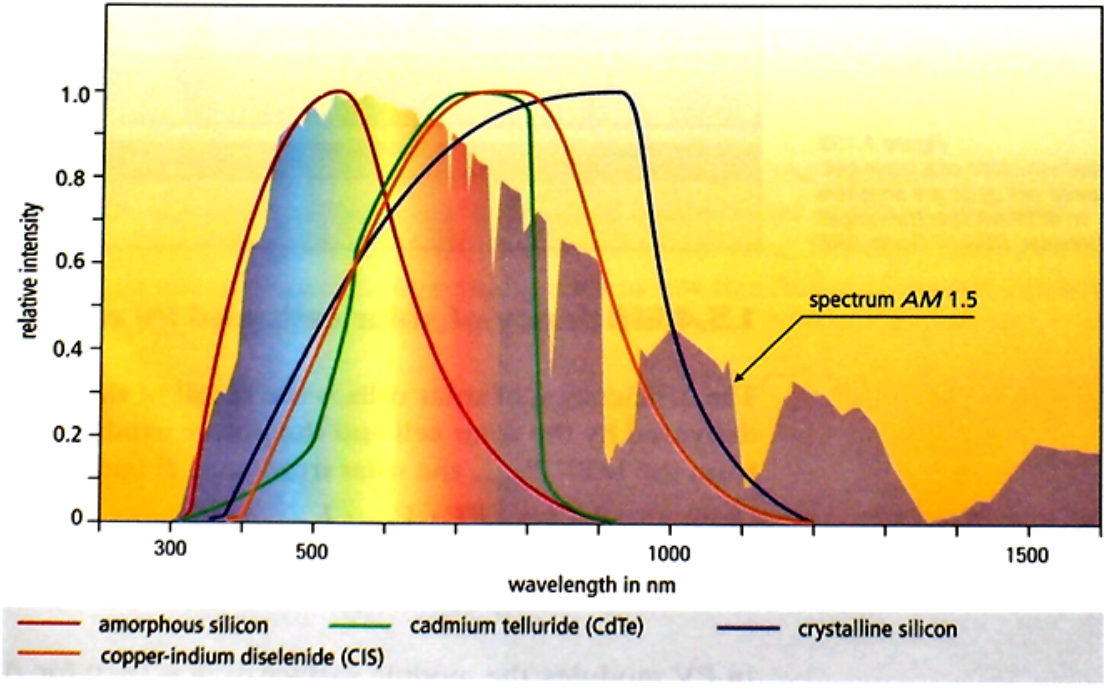
- Temperature effect on solar cells



PV-Basics

Characteristics of Solar Cells

- Light spectrum effect on solar cells

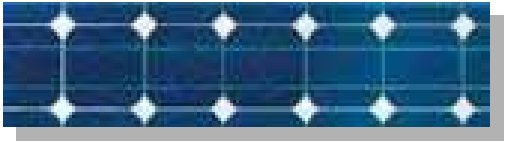


Grid Systems

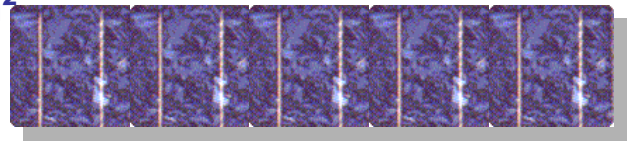
Power Density Solar Cells

Area use of different PV Cells :

- **Monocrystalline** 110-160 W/m²

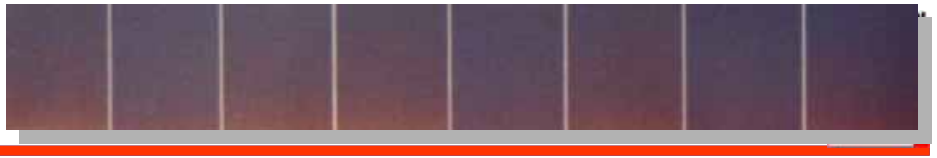


- **Polycrystalline** 100-140 W/m²



- **Thin-Film** 60-100 W/m²

- **Amorphous** 40-80 W/m²

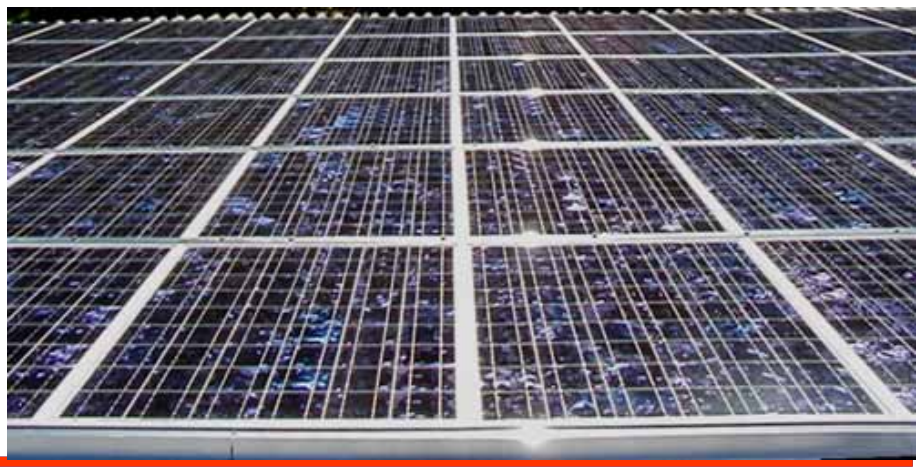


Grid Systems

Panel Selection

Crystalline Solar Panels

- Good results at ideal orientation
- High Power Densitiy
- Robust, low mounting cost
- Inverter
  - trafoless
  - compact



Grid Systems

Panel Selection

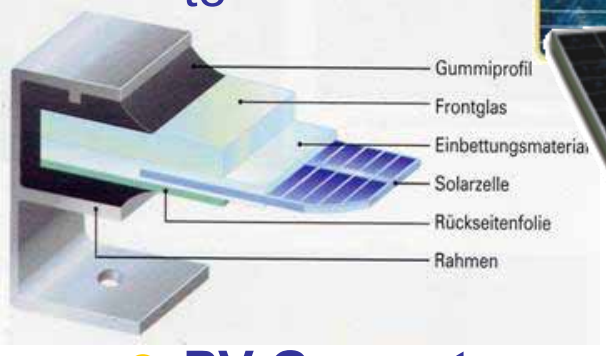
Thin-Film Solar Panels

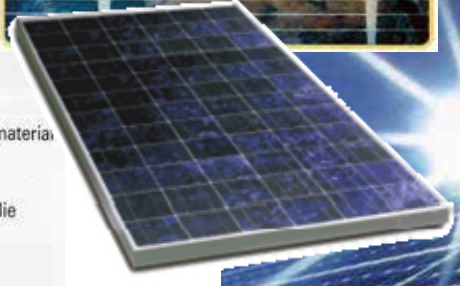
- Good at non-ideal orientation, larger surface
- More tolerant to temperature, partial shading
- Attractive cost
- Higher requirements to mounting, transformer

Grid Systems

Components of Solar Generator

- From
  Solar Cell
  to
- **Solar panel**
  to





- **PV Generator**

Grid Systems

Panel Parameters

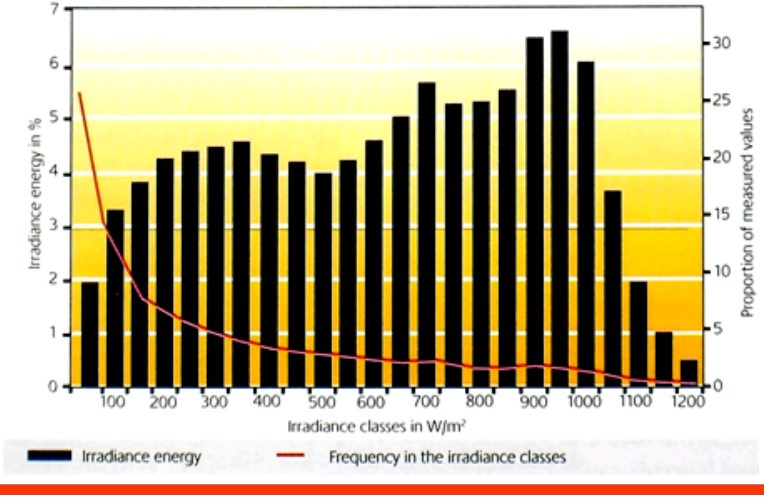
- Cost
- P_{MPP} [W_p]
- U / I_{MPP} [%/K]
- Certification IEC/UL (STC, noct)
- Power Density, Tolerance
- Construction: Glass, Alu, Encapsulation(EVA), Backside (Tedlar®), Connections (Multi-Contact®)
- Warranty (Product/Power)

Grid Systems

Inverters

- **Purpose**
  - Convert generator DC to grid AC
  - Protect generator and grid
  - Offer maximum conversion efficiency

Frequency distribution of input power



Grid Systems

Inverters

- **Performance**
  - Efficiency
  - MPP-Tracking
  - Power Range
  - Voltage Range
  - Max Voltage
  - Control
  - Grid Safety
  - Warranty

Grid Systems

Inverters

- **Concept**
  - String / parallel
  - Central / Stacked
  - Master / Slave
  - Multistring / Team
- **Design**
  - Transformer/less/HF
  - Connectors
  - Interface
  - Display
  - Protection
  - Cooling

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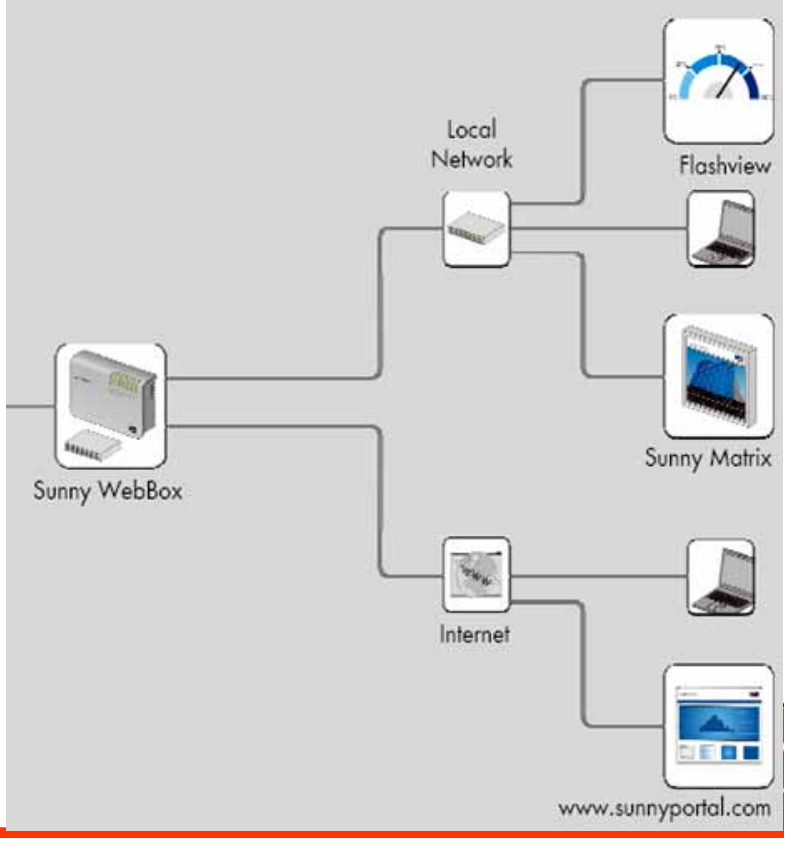
Grid Systems

Inverters

- **Communication**
  - Display LED,LCD,remote
  - PC-Interface
  - Data-Logger
  - Remote Sensing
  - Web-Upload
  - Remote Control and Diagnostics



Grid Systems

Inverters

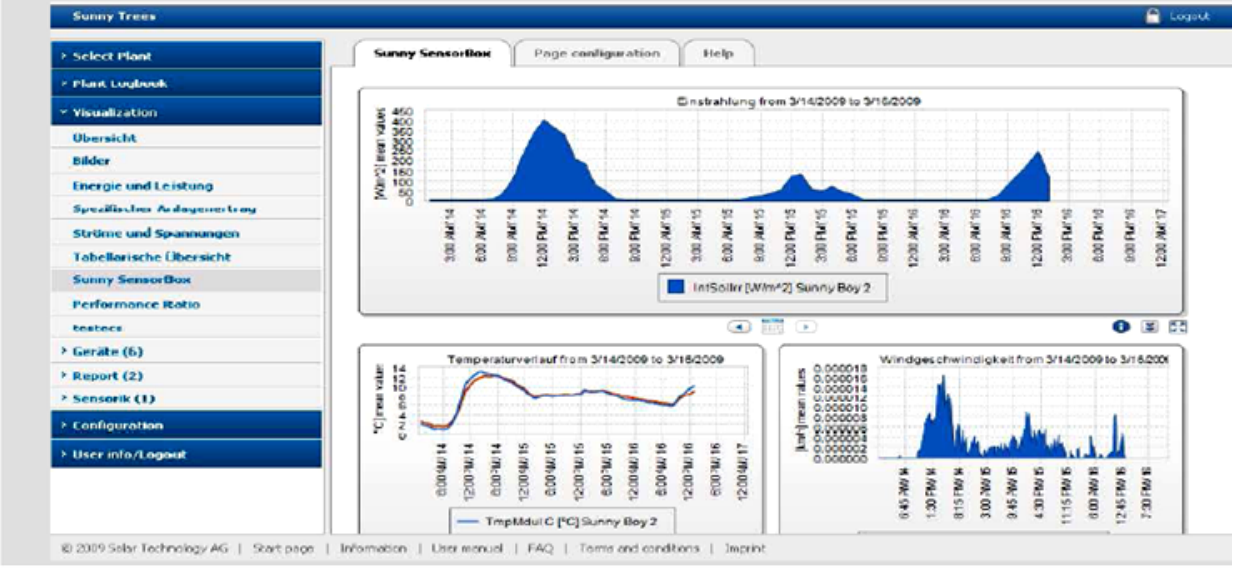
- **Monitoring**

Grid Systems

Inverters

- **Sensing**

Sunny SensorBox in Sunny Portal



Grid Systems

Design

- **Sizing Generator**
  - Available Area
  - Regulations
  - Panel Type
  - Customer´s Plan
- **Sizing Inverter**
  - Generator Power
  - String length
- **Sizing Components**
  - Mounting Structure
  - Wiring
  - Connection Boxes
  - Meter Cabinet
- **Cost Calculation**

Grid Systems

Generator Design

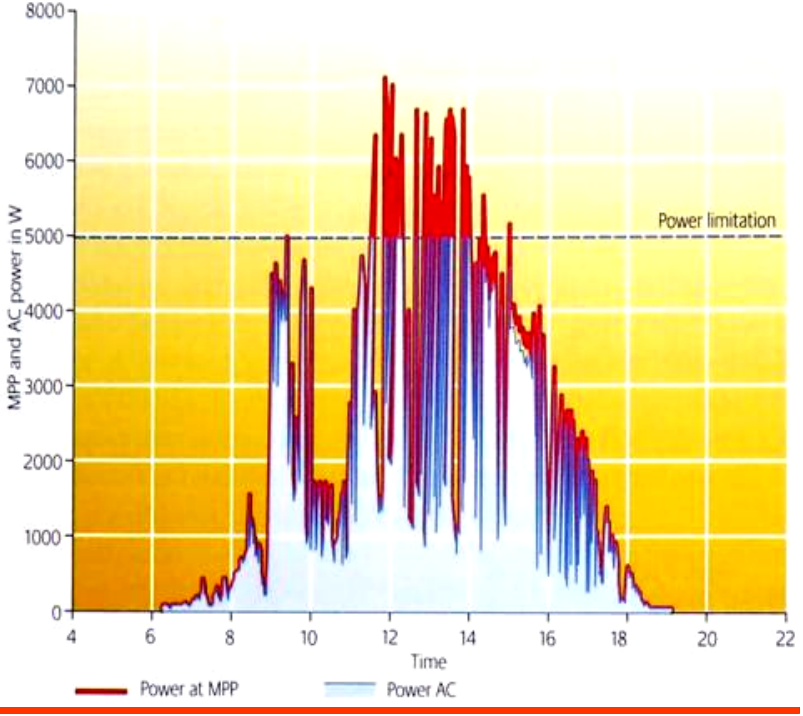
Solar Generator

- Panels are connected series/parallel to achieve certain Voltage/Current
- is specified to Power (Wp)
- Will not provide continuous power

Power Output

is dependend on

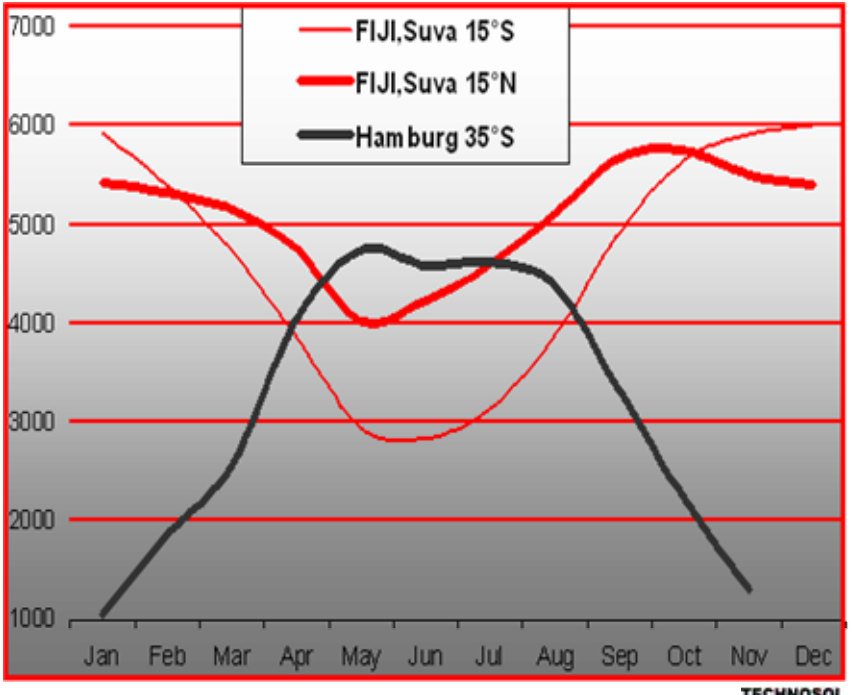
- Weather (Irradiation, Temperature)
- Inclination
- Shading
- Matching



Grid Systems

Generator Design

- Medium irradiation Fiji 5.070 (Hamburg 2.890) Wh/m²/day
- Annual receipt is Fiji 1.852 (Hamburg 1.132) kWh/m²/year
- Tilt, temperature, diffusion affect the solar harvest



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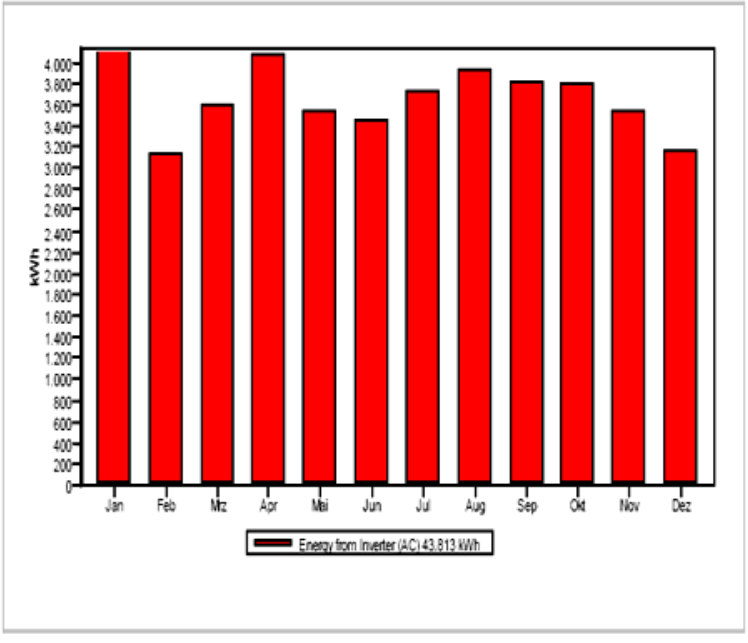
Grid Systems

Generator Design

- NIUE installations 2009

Location	*P [kWp]*	*E [MWh/a]*	*CO2 [t/a]*
Hospital	**30,6**	**43,8**	**38,7**
School	**20,4**	**28**	**24.7**
NPC	**1,7**	**2,3**	**2**
Total	**52,7**	**74,1**	**65,4**



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Grid Systems

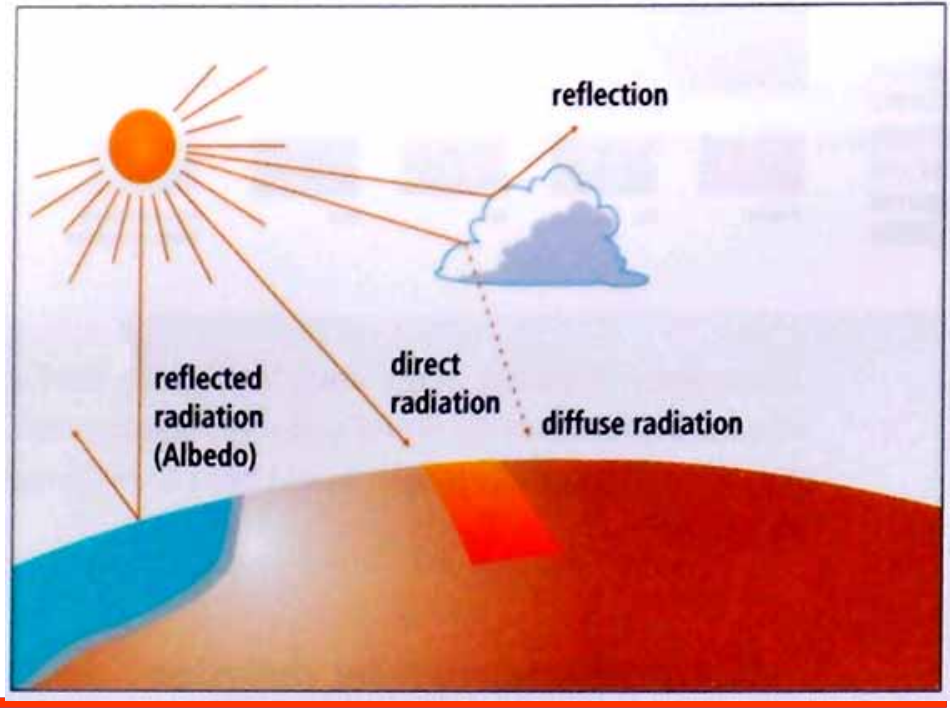
Generator Design

Irradiation

is affected by

- Sunshine-angle
- atmosphere
- reflection

- Optimum: Clear blue sky w/clouds, perpendicular on panel

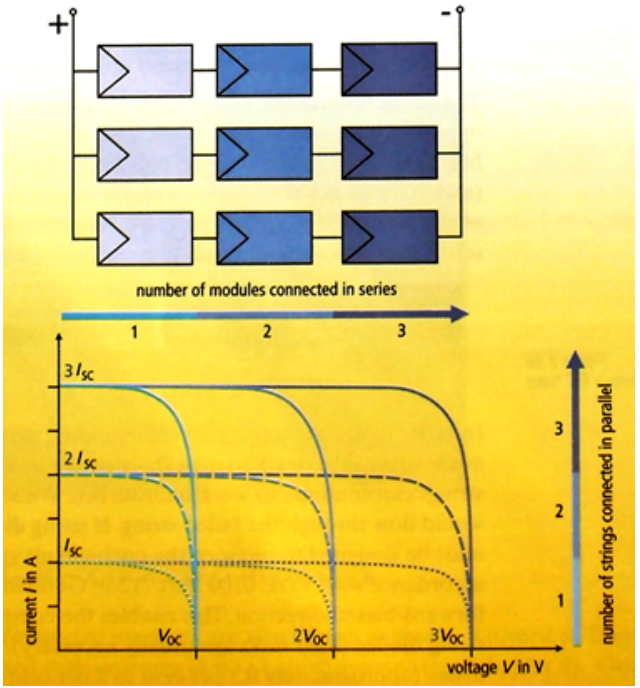


Grid Systems

Generator Design

Solar Generator

- Panels in series (STRING) give operating Voltage (limited by panel / inverter maximum values)
- Only identical panels in Series
- Strings in parallel determine max. Current (limited by inverter)
- Similar strings in parallel
- Observe polarity!

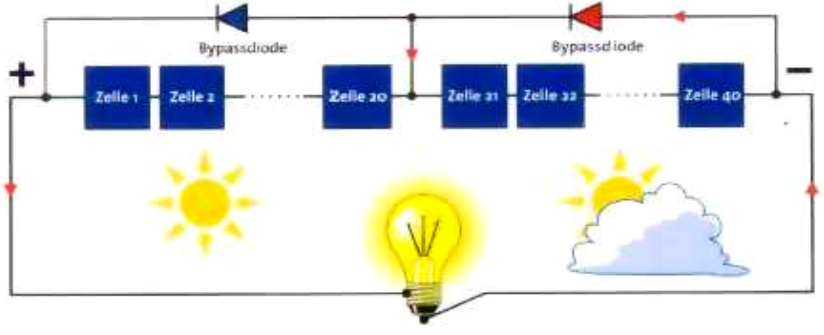


Grid Systems

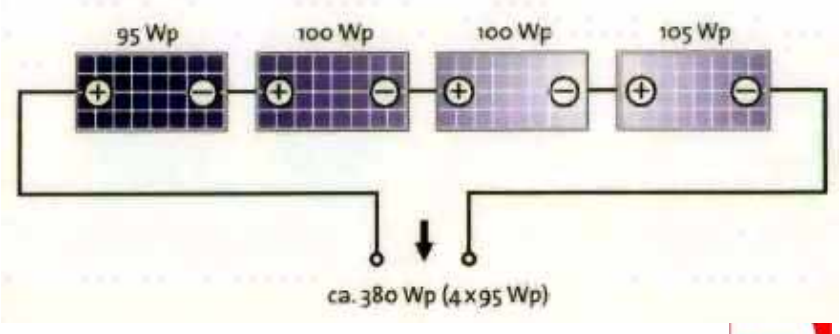
Generator Design

Disturbances

- **Panel:**
  Series-connection Cells
- Hot-Spot
- Bypass



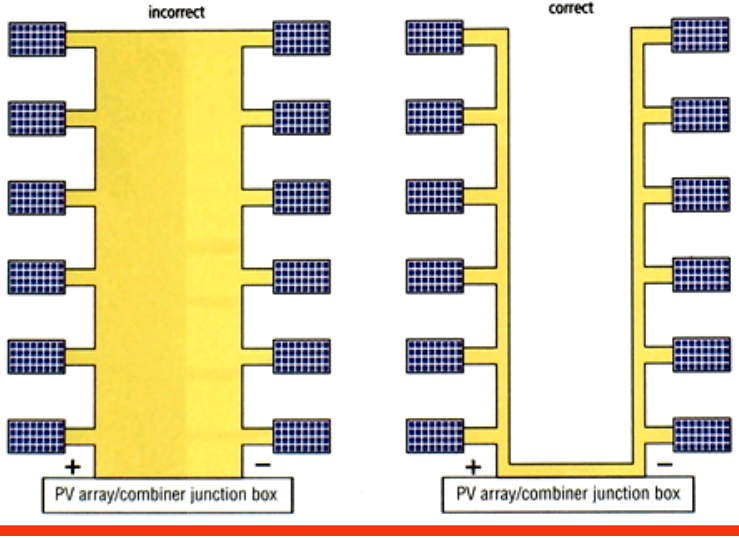
- **Generator:**
  Series-connection Panels
- Shading
- Matching



Grid Systems

Generator Design

- **Wiring**
  - Dimension from operating Voltage and maximum Current. Loss 1-3% $= 3{,}4 \times L_{[m]} \times I_{[A]} / (A_{[mm^2]} / U_{[V]})$
  - ClassII, UV resistance Cable
  - Durable DC connections
  - Observe Polarity!

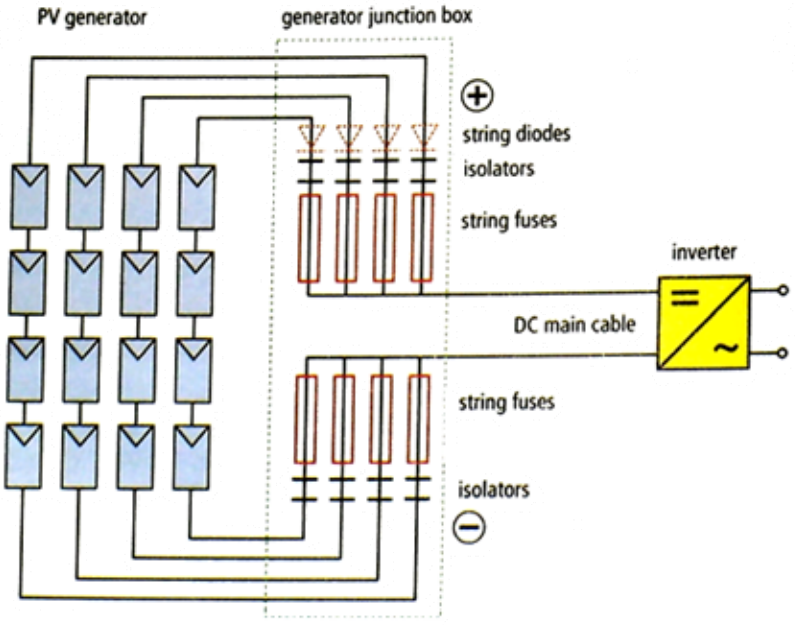


- **Protection**
  - Design shading areas
  - Keep cables short
  - Avoid Loop formation (induced voltage)

Grid Systems

Generator Design

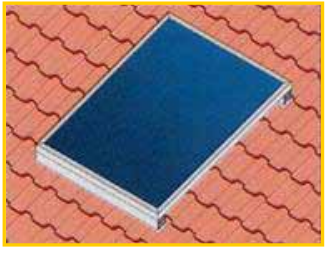
- **Protection**
  - **Surge Protection in Combiner Box, not standard**
  - **Lightning protection mostly unjustified, not standard**
  - **EMI protection mostly unjustified, not standard**



Grid Systems

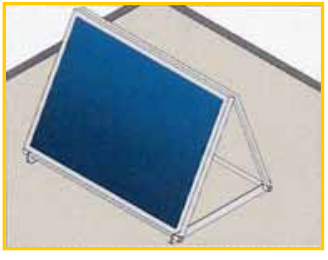
Mounting Concepts

- **On-Roof**
  standard



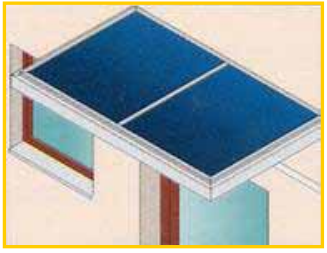
- **In-Roof**
  thermal

- **Tilted**
  good yield, wind sensitive



Architectural variations:

- **Shade**
  small



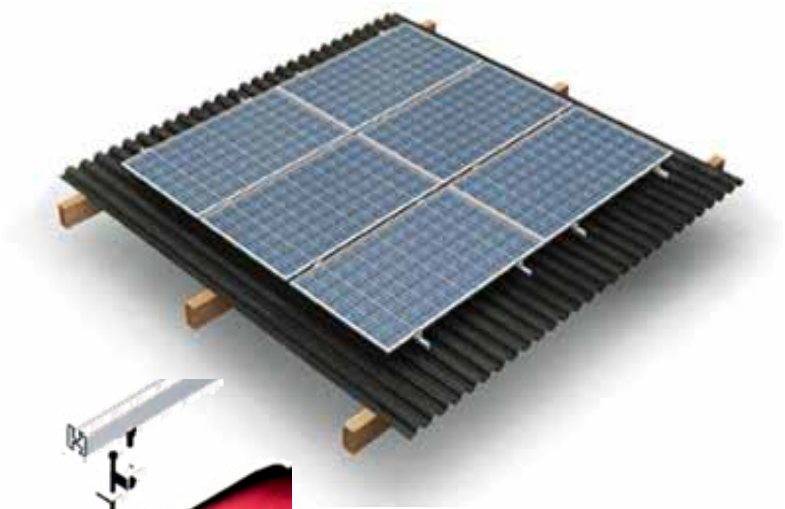
- **Full Roof**
  expensive, losses

- **Facade**
  reduced gains, expensive

Grid Systems

Generator Mounting

- **Purpose**
  - Fix panels securely in weather
  - Provide aeration for panels
  - Create a common Grounding



- **Rooftop Mounting**
  - Depends on roof orientation
  - Panels on rails
  - Support points in purlins
  - Non-corrosive material
  - Fast and safe mounting

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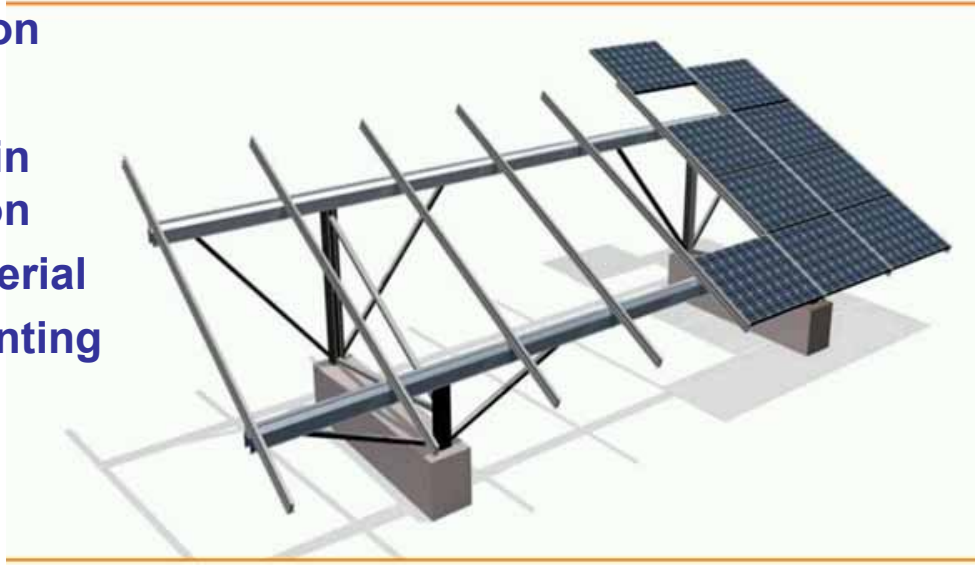
Grid Systems

Generator Mounting

- **Ground Mounting**
  - Optimum orientation
  - Panels on rails
  - Support structure in concrete foundation
  - Non-corrosive material
  - Fast and safe mounting



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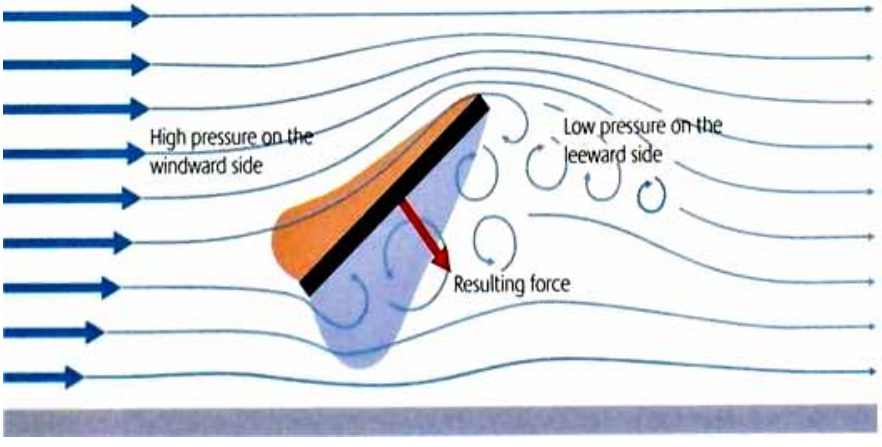
Grid Systems

Generator Mounting

- **Forces**
  on Array surface
- **All Mounts: Uplift**
- **Ground-Mount:**
  Plus wind-pressure
- **PV Panel 540 hPa**
  =5,4 kN/m² (IEC 61215)



	center	*rim*	*corner*
Lift force q :	**1,1 kN/m² at 30 m/s (3,05 kN/m² at 50 m/s)**		
Coefficient cp:	-1,20	-2,10	-2,40
Uplift ws=cp*q:	**-1,32 kN/m²**	**-2,31 kN/m²**	**-2,64 kN/m²**

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Grid Systems

Generator Mounting

- **Strength of a beam**

  $M_S = \sigma \times W$ [Ncm]

  W = D*H²/6 (rectangular)

  ex: 1400x271=379.400 Ncm

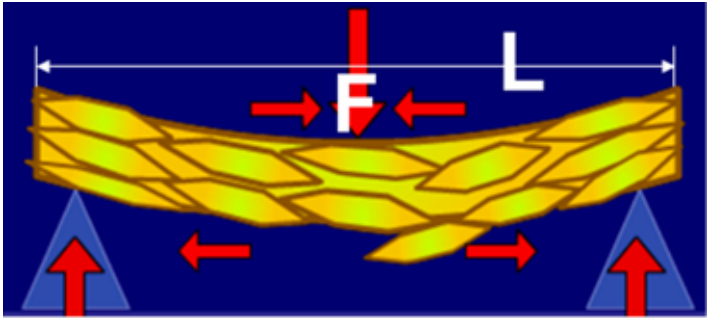
- **Load on a beam**

  $M_L = F \times L / 8$ [Ncm]

  ex: 5,4x2,74x5/6=12,33 kN x274/8=422.302 Ncm

- $M_L < M_S$

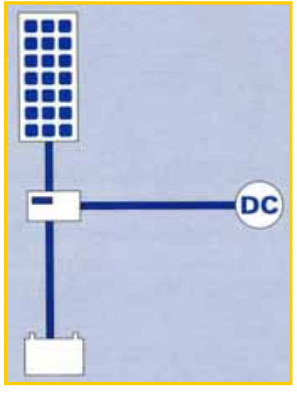
	Alu 6x4	*Wood 19x4,5*	*Wood 28,5x4,5*
σ N/cm²	16.000 - 20.000	1.400 - 3.000	1.400 - 3.000
Wx cm³	**7,8 / 15**	**271**	**610**

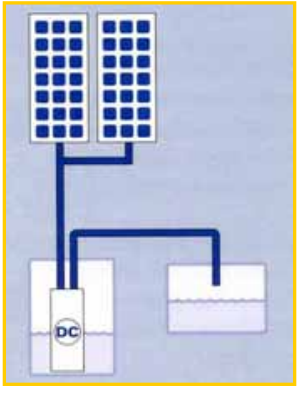


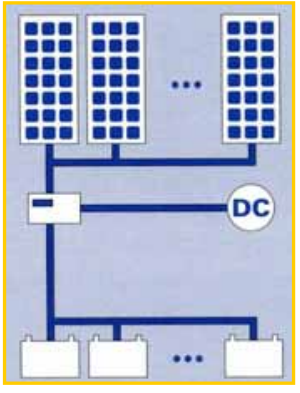
PV-Selections

Decentralized Applications

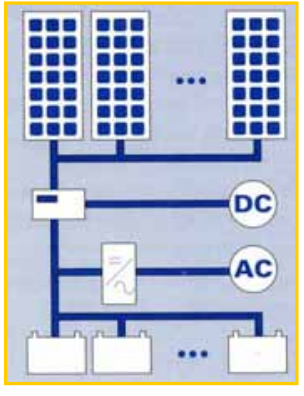
- **DC Systems:**
- Stand Alone System
- PV Pumping

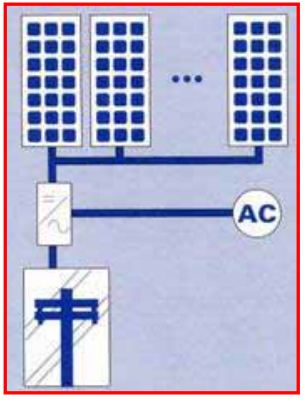


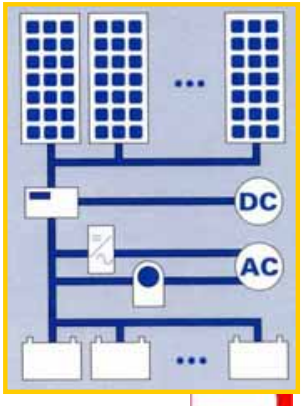




- **AC Systems:**
- AC/DC Supply
- Grid AC
- Hybrid System



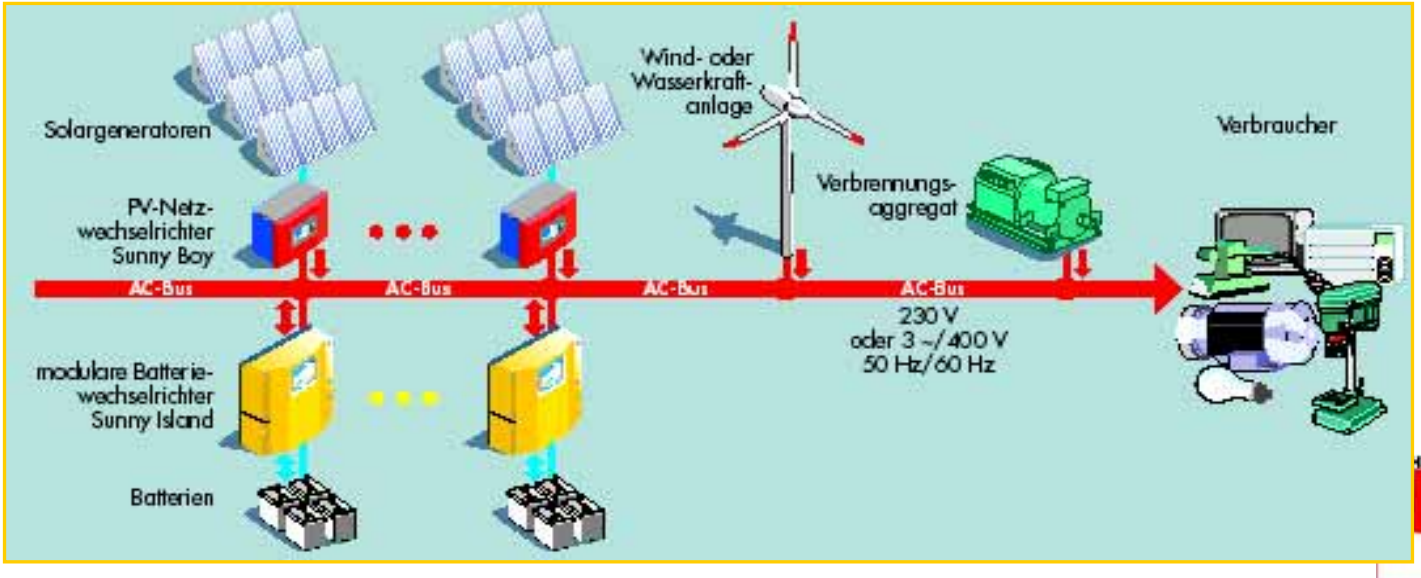




Mini-Grid

The AC-Bus

- Expandable (1- and 3-phase, parallel)
- Optimum battery life by smart battery-, load-, and grid management
- Comfortable Diagnosis (maintenance, remote sensing)



Mini-Grid

The AC-Bus

- Bi-directional battery-inverter
- Better quality than public grid
- Modular combination of PV / Wind / Dieselgenerators
- Simplified design of independent grid by coupling all components on the AC bus
- Applicable from single home to village size (3 to 100 kW)

Mini-Grid

Objectives for Hybrid Installations

- **Advantages of PV Hybrid:**
- **Peak Load** (seasonal supplement)
- **Independence**
  (grid failure, fuel shortage, genset breakdown)
- **Security** (backup, peak load, autonomy)
- **Grid Healing** (voltage drops, peak consumption)

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Mini-Grid

Combining Hybrid Components

- Analyse Consumption Profile
- Day / Night ratio = modelling helps
- High, lasting load =
  Motor Generators
- Short load peaks = Battery/Inverter
- Small, essential load = PV based

PV-Economics

German Support Program EEG

- Feed-in-Law
- Guaranteed purchase for 20 years at rates around 0,82 NZ$
- Privately owned, operated
- Safe Investment
- Inspired a PV boom over 1.000 MW/y
- Adopted in Spain, Italy, Greece ...
- Goal RE < 20% by 2020 attainable

PV-Economics

Support Alternatives

- **Tax Benefits** (e.g. Tax deductable investment)
- **Net metering** (only sell surplus)
- **Quota** (IPPs bid for concessions)

- **Comparison of the different RE Supply-Applications :**

Application	Lines	Energy	Battery	Subsidy	Service	Metering
Small Solar	no	medium	small	yes	provider	no
MiniGrid, single	**yes**	medium	yes	**no**	**user**	**no**
MiniGrid, multiple	**yes**	**more**	**yes, sorry**	yes	provider	**yes**
Grid-connected	**yes**	**full**	**no**	**no**	**user**	basic

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Thank You for Your Attention!