Design Requirements for a successful Solar Project

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Kai Ilham Klingenhagen Business Development APAC· juwi Group
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Content

juwi at a Glance

Organisation

- Founded in 1996 by Fred Jung and Matthias Willenbacher (juwi), pioneers for renewable energies with agricultural roots
- juwi AG is an owner-managed group of companies and not listed on the stock exchange

Total capacity

Around 3,000 megawatt (approx. 2,300 systems)

Annual energy output

Approx. 5.5 billion kilowatt-hours, corresponds to the annual power demand of around 1.5 million households

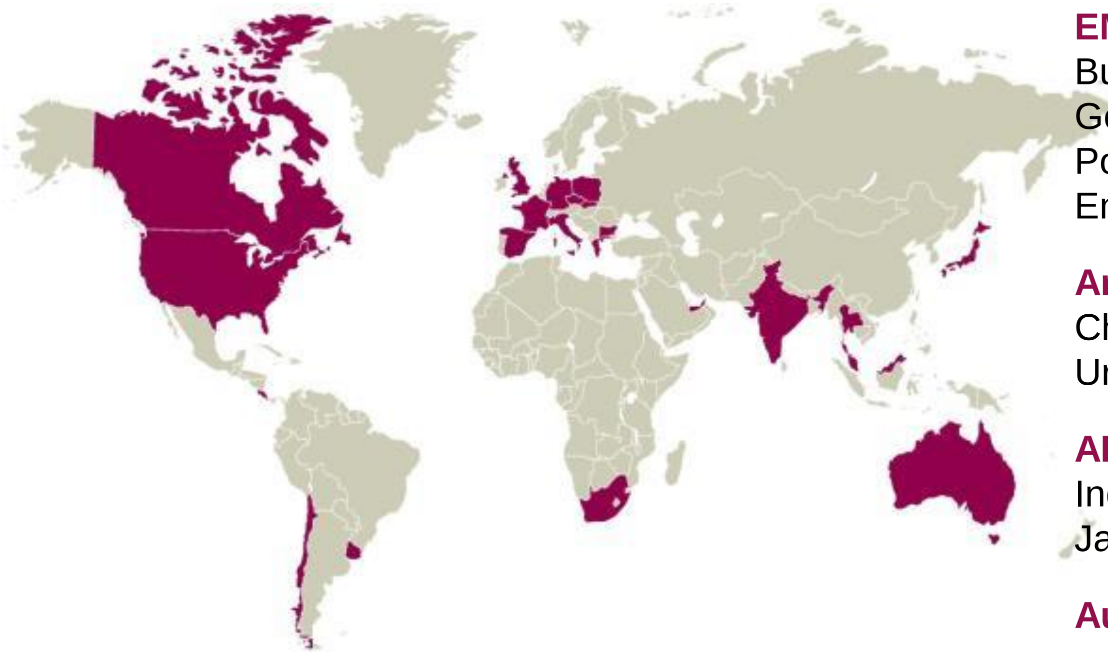
Investment volume (since 1996)

Approx. 5.9 billion Euro

Employees & turnover

- > 1,500 employees (worldwide)
- Approx. 1.0 billion Euro in 2012

International Offices, Project Locations and New Markets



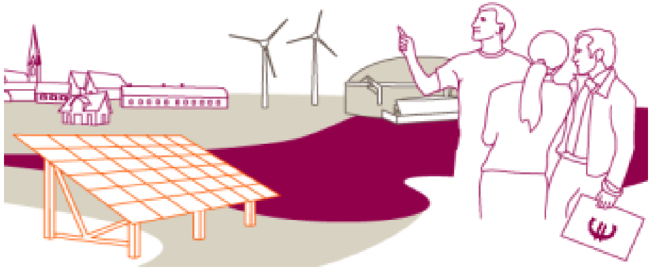
EMEA
Bulgaria, Czech Republic, France, Germany, Great Britain, Greece, Italy, Poland, South Africa, United Arab Emirates

Americas
Chile, Costa Rica, USA/Canada, Uruguay

APAC
India, Malaysia, Singapore, Thailand, Japan, Philippines

Australia

OUR PASSION - All about the Project



3,000 MW Wind & Solar projects completed

In more than 20 countries of which 5 are in Asia Pacific

Asia Pacific, more than 150 MWp completed

Thailand 61 MWp | Japan 5 x 1 MWp, Rajasthan 26.4 MWp, Gujarat 24 MWp | Malaysia 10 MWp

Japan 9 projects completed to date

Higo Otsu 1 MWp, Kyushu (Japan) | Bear 2, Rooftop, 1 MWp, completed Bear 1, Freefield, 1 MWp

Wind Power 2013: ~350 MW plus paper deals
Large Turbines & High Towers




Costa Rica, Germany, USA, Poland | 7.5 MW turbines & up to 145 m juwi ATS hybrid towers

juwi Asia Pacific 2014

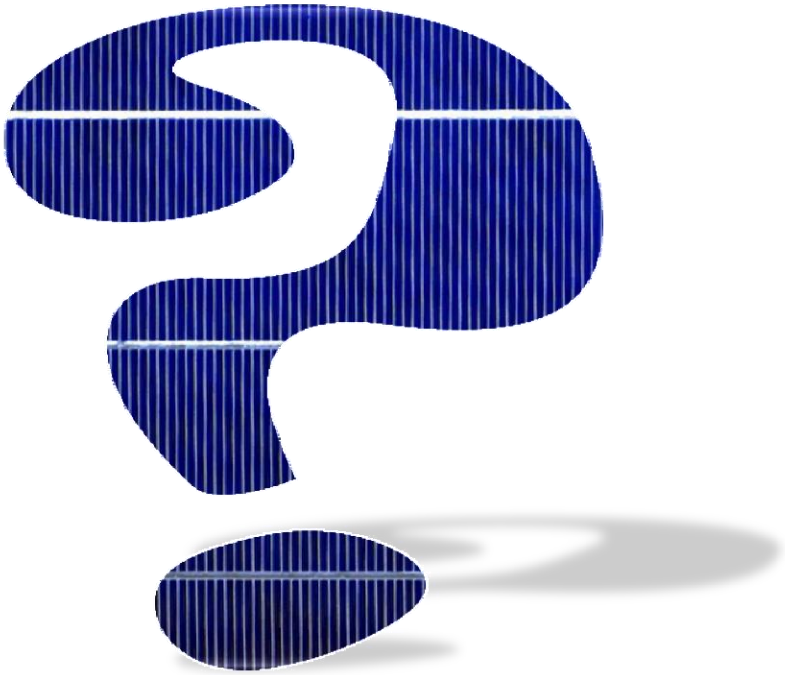
- >120 staff (Singapore, India, Japan, Thailand, Malaysia, Philippines)

- Regional Headquarter in Singapore

- Projects
  - India: 75 MW completed since 2011
  - Thailand: 61 MWp
  - Malaysia: 10 MW Carport
  - Japan: 9 projects with more than 10 MW completed
    + several MWp under construction
    >400 MW pipeline
  - Philippines: several MW projects in construction start
  - Taiwan: multiple rooftops since 2012

Why a good Design?

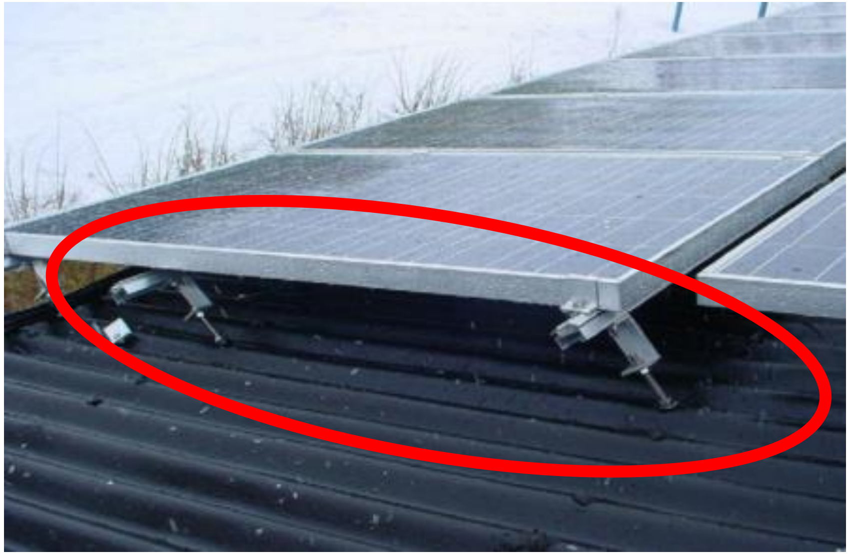
Why is a good Design the key for a successful project?



Why a good Design?
- A.: to avoid failure or lower generation

Shading objectives

Why a good Design?
- A.: to avoid failure accidents and loss or breakage




Wind Load and selection of Materials

Why a good Design?
- A.: to avoid burning cables or inverters

Design in Different Project Stages

Project Stages from early Development

Input Information

- Scouting for land
- Land identification & Selection
- Preliminary title search
- Signature of MOU with land owner
- Preliminary Utility response
- Local (PPA) application*
- Topographic Survey
- Irradiation review

Design Steps

1. **Yield (Irradiation) analysis**
2. **Grid capacity analysis**
3. **Grid interconnection requirements**
4. **Flood study**
5. **Soil testing and preliminary foundation**
6. **Selection of most optimal module angle**

Project Stages up to construction

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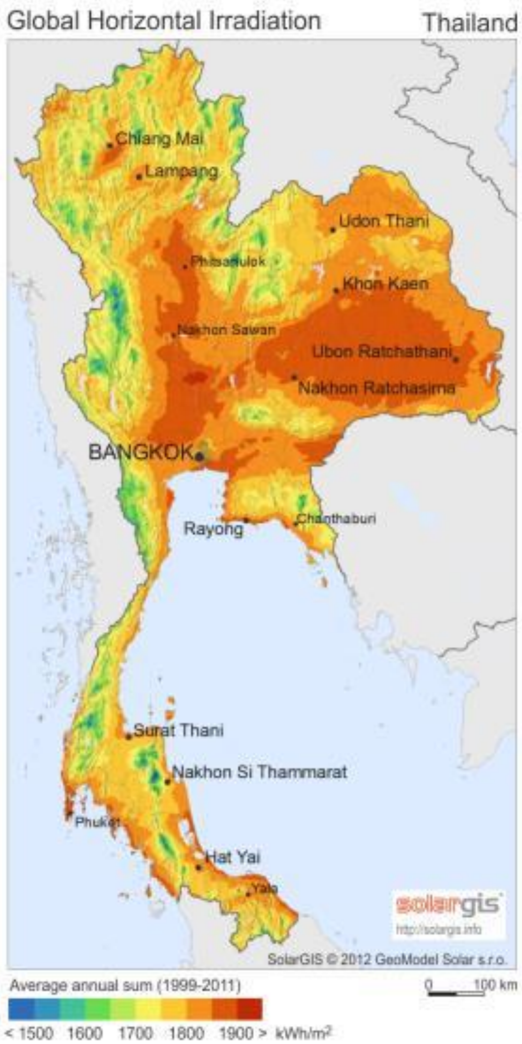
Input Information	Design Steps
- Component Preference - Useful Area - Environmental Disturbance - Grid Impact Study - Flood Studies	7. **Layout incl. Component evaluation** 8. **Shading Analysis (Near, Horizontal)** 9. **Inverter calculation** 10. **String Configuration** 11. **Losses** 12. **Yield Analysis** 13. **Detail Design stage calculation**

4. Basic Design

4.1. Yield Analysis
Available Irradiation

- To be evaluated after site selection, or in discussion with the available sites
- Available irradiation on several free sources in the internet, plus professional commercial databases
- Free sources can provide a first glim of expected Energy yield
- Available in kwh/m²



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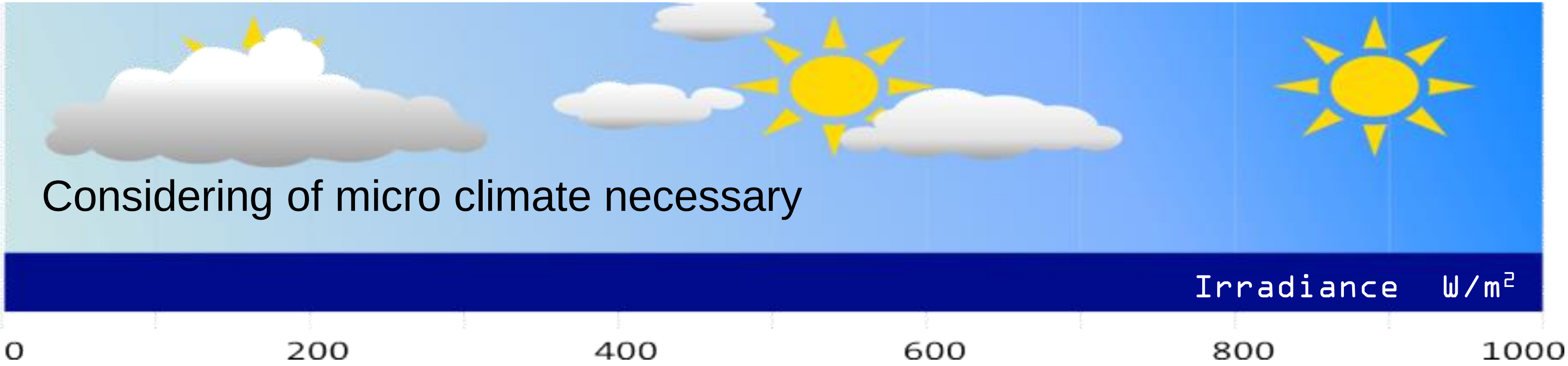
4.1. Yield Analysis
Available Irradiation



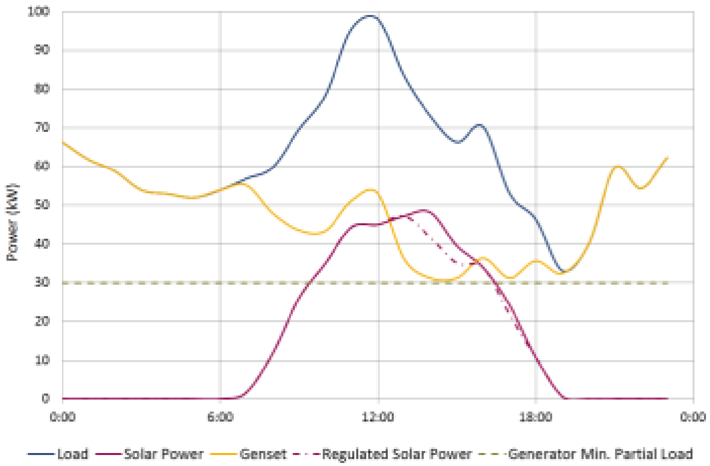
- The diffuse radiation and the direct radiation are the global radiation
- The intensity of the solar irradiance (W/m2) depends on local/global weather condition.
- Weather, Environmental conditions and ground reflection (albedo) having an direct effect on the diffuse fraction

Usual values for albedo

Urban situation	0.14 - 0.22
Grass	0.15 - 0.25
Fresh Grass	0.26
Fresh snow	0.82
Wet snow	0.55 - 0.75
Dry asphalt	0.09 - 0.15
Wet asphalt	0.18
Concrete	0.25 - 0.35
Red tiles	0.33
Aluminium	0.85
New galvanised steel	0.35
Very dirty galavanised stee	0.08

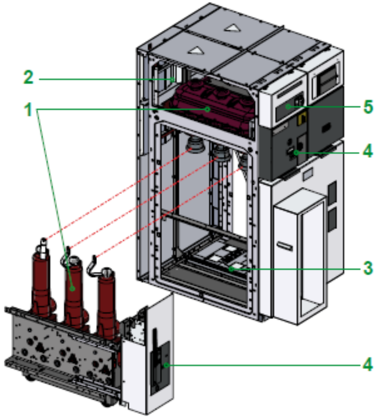
4.2. Grid Capacity Analysis

- Grid capacity needs to be discussed with local Utility or Grid Authority
- In Thailand to be discussed with PEA and MEA
- In certain Regions in Thailand already problematic to connect Solar Power to the Grid
- Weakest points are the Substations and the overload in the specific grid, if solar power would be connected, the request for regulation of the solar power plant is a must, which is a loss for the investment



4.3. Grid interconnection requirements

- **Requirements for the interconnections in Thailand are :**
  - Switchgear
    - Circuit breaker (Vacuum or SF_6 insulated) with 25kA (Isc)
    - Current transformer (Accuracy class : 5P20 or above)
    - Power Quality Meter (Profile Recording "RMS average, Min & Max every <u>10 mins</u> based on Std. EN 50160)
    - Others (Based on IEC standard or suppler list)



Pic. Source: Schneider Electric

4.3. Grid interconnection requirements

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- **Requirements for the interconnections in Thailand are :**
  - Grid Harmonization
    - Don’t allow VSPP to apply Automatic Reclosing Scheme
    - Synchronization done at Interconnection CB
    - Anti-Islanding shall be applied
    - Protective relay shall be coordinated with PEA’s system
    - Voltage level (± 5% for alarm , ± 10% for emergency)
    - Power Factor (0.9 lag thru 0.9 lead while injecting power > 10% Inverter capacity)
    - Power Frequency 50 Hz (49.5-50.5 Hz for alarm , 48.00-51.00 Hz for emergency)
    - Reverse DC current to grid (< 0.5% rated current of inverter)
    - Power quality meter shall be provided if inverter capacity is above 250 kW.
    - Etc. (Voltage Fluctuation, Harmonic Distortion)

4.3. Grid interconnection requirements

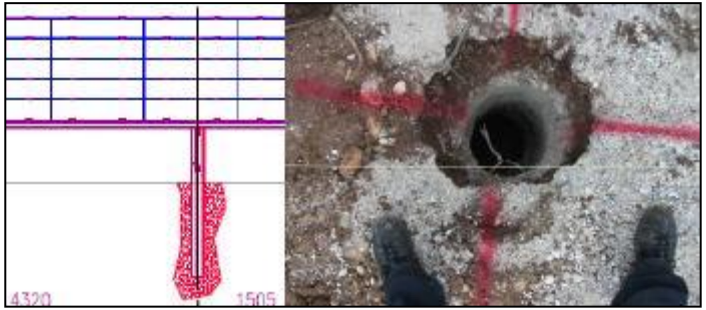
- **Requirements for the interconnections in Thailand are :**
  - Grid Protection for VSPP with 3 phase inverter connected to 22kV system
    - Under Voltage relay / Over Voltage relay (27/59)
    - Instantaneous O/C relay / IDMT O/C relay (50/51 & 50N/51N)
    - Frequency relay (81)
    - Synchronizing relay (25)
    - Anti-islanding protection
    - Remote control to disconnect the plant from grid shall be provided
      (if Total inverter capacity > 2MW or Transformer capacity >2MVA)

4.4. Flood Study

- A Flood study is crucial for the investment and can be the key changing point of a project to be feasible or not feasible
- Should be provided from local experts which includes the evaluation of local information, as well available Meteorological data and topographical maps
- The recommendation needs to be integrated in the civil design (drain design etc.)

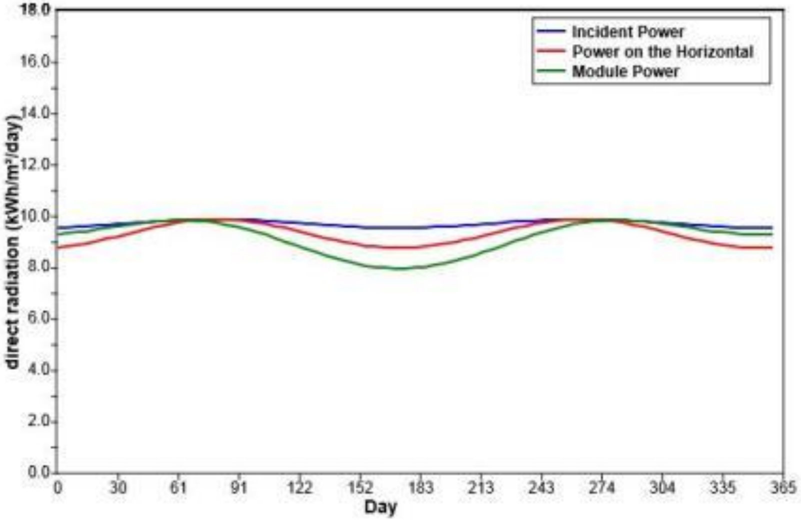
4.5. Soil Testing and preliminary foundation

- **Soil testing is done to evaluate the method of foundation**
- **Test's should include the following test's as a min:**
  - Field Investigation (Boring, Soil Resistivity, Seismic Down Hole)
  - Laboratory Test (Atterberg Limits, Chemical Analysis, Particle Size Anlysis)
  - Pullout Test

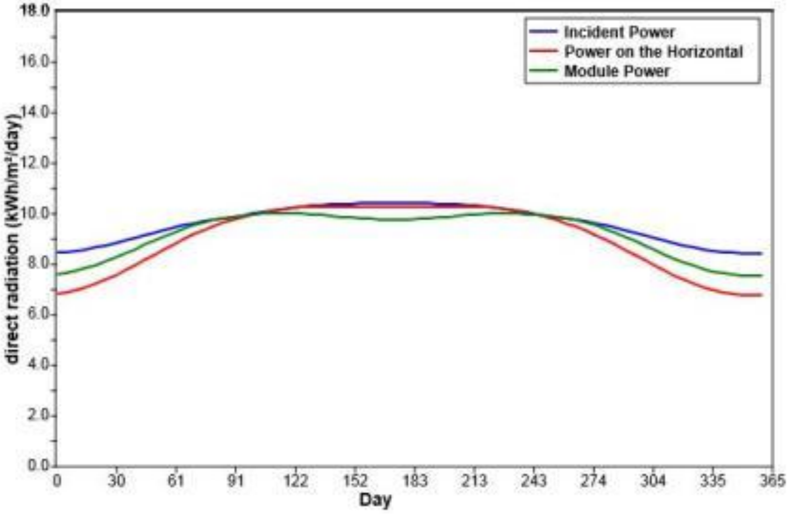


4.6. Module tilt angle

- Elevation of the Sun to the surface varies within 365 days of the year. The closer to the Ecuador, the lesser is the variation.



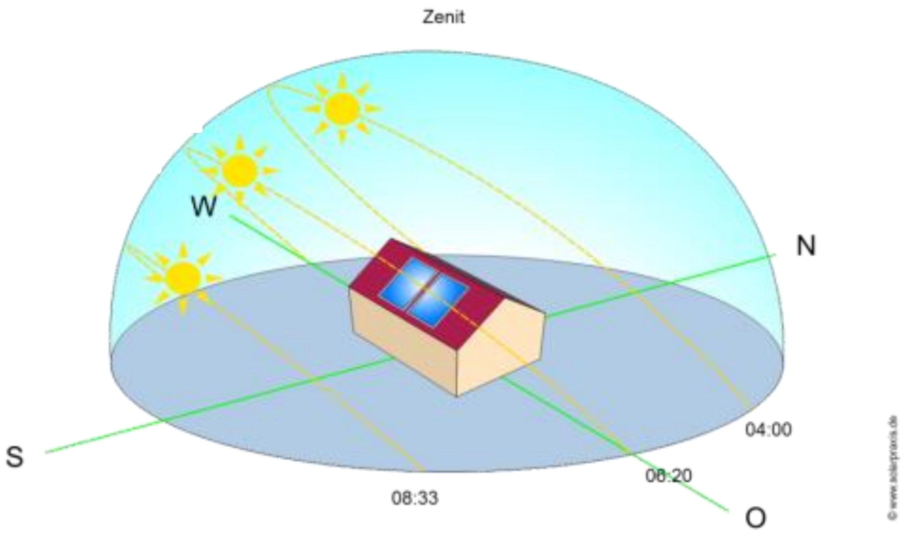
Module Angle = 10º
Location Jakarta



Module Angle = 10º
Location Bangkok

4.6. Module tilt angle

- Choosing the Module declination for the highest annual energy output
- **Easy Rules to Remember:**
- The higher the Latitude the greater the Module Angle
- Min. Angle of 10º for self cleaning purpose a must
- In Thailand most optimum between 10 and 20 degree



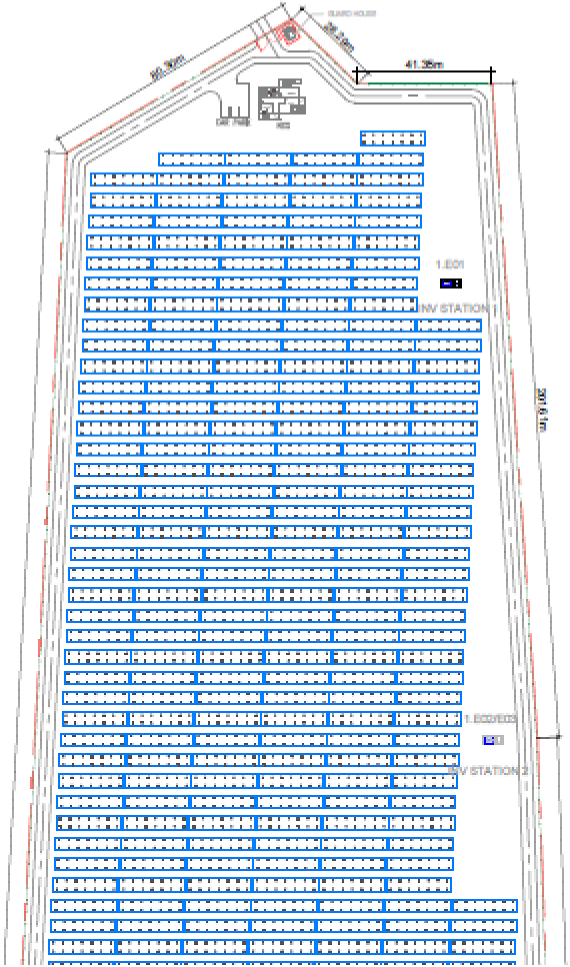
4.6. Module tilt angle

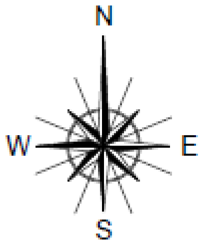
Azimuth

- Azimuth is the direction facing the Sun.
- Located in the Northern Hemisphere we choose 0º (means facing South)
- Located in the Southern Hemisphere we choose 180º (means facing North)
- Only on roof top installation, we would work with different Azimuth's

4.7. System Layout

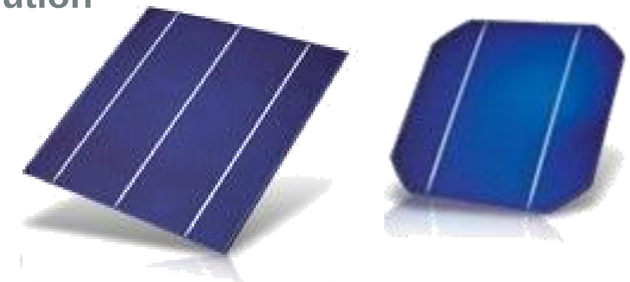
- Shape of the available land area
- Max AC Power which is required
- Row to Row distance
- Area’s of concerns
  - Outside shading objects
  - Inside Pont's and creeks
  - Possible Flood preventions





4.7. System Layout
Modules

- Choosing the most economical and technical suitable solution
- Monocrystalline, **Polycrystalline,** Thin film technology
- Must haves of Modules:
  - IEC tested 61215 and 61730
  - CE certified
  - PID test
  - Positive power tolerance
  - 3rd Party Performance test
  - Independence Factory test
  - Salt Water Resistance Test
  - 25 years linear performance warranty
  - Min. Temperature Coefficient
  - Reference Projects



- Qualified, IEC61215
- Safety tested, IEC61730
- Periodic Inspection
- Power controlled

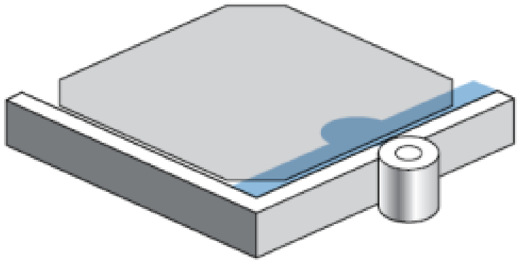
4.7. System Layout

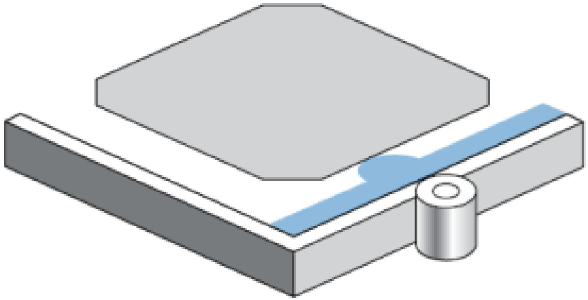
Modules

Module A efficiency xx 225 Mono: η_{Module} = 225 W / Module Area= 13.4%	Module B, efficiency 225Wp Mono: ηModule = 225W / Module Area= 13.7%
Cell efficiency 225 Mono: ηModule =3.75W/ Cell Area = 15.4%	

Module A performed better:

- **Module A, 225 Mono Yield: 1124.4kWh/kWp**
- **Module B, 225 Mono Yield: 1112.6kWh/kWp**





<u>4.7 System Layout</u>
Mounting Structure

- **The mounting structure (MS) needs to be designed according to**
  - Required standards (มยผ 1311-50 มาตรฐานการคำนวณแรงลมและการตอบสนองของอาคาร) and
  - Wind Loads (In Thailand reference range from 25 m/s to 29 m/s and TF =1.0 to 1.2)
  - Min. Galvanization thickness as required (harsh environmental conditions near the sea for e.g. requires a min of 80 µm galvanization thickness)

- **MS area available in Aluminum and Galvanized steel**
  - Galvanized Steel more cost effective
  - Different foundation available (depends on soil)
  - Min 10 years workmen ship guarantee
  - Wind loads of up to 250 km/h feasible

4.7 System Layout
Mounting Structure

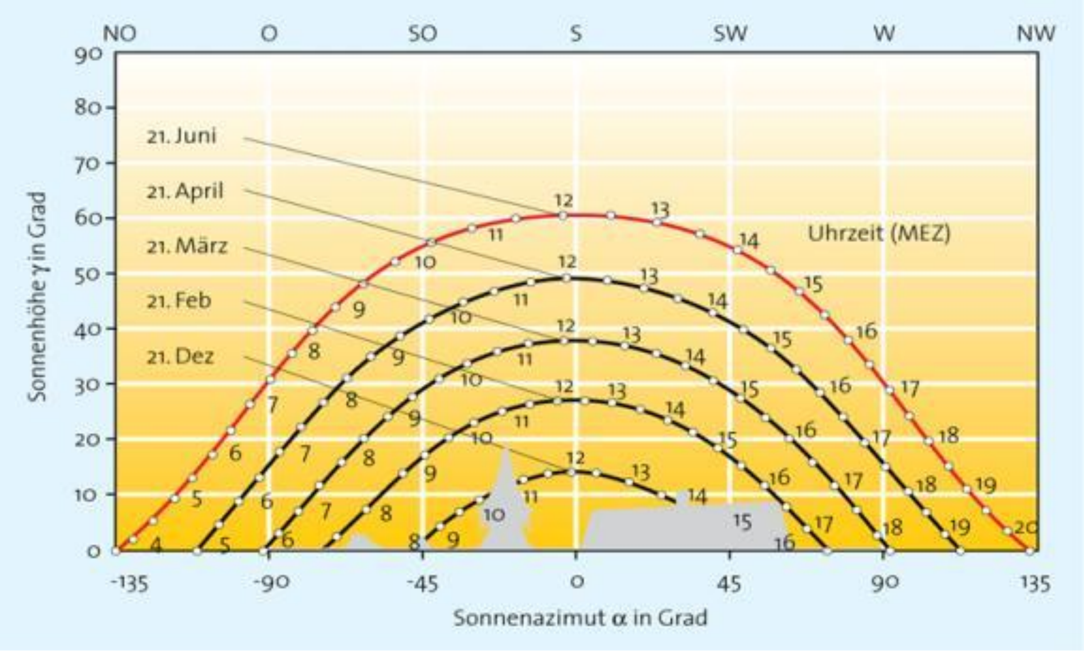
- Part of the MS is the selection of the correct foundation which depends on the soil condition



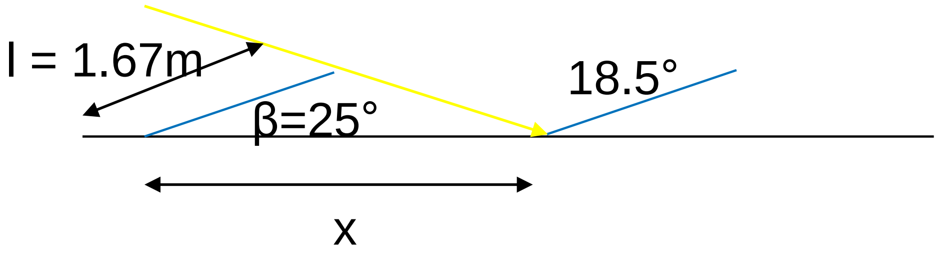

- Important information for the design stage is length and foundation
- One key for the right selection is cohesion and available machines/ tools

4.8. Shading Analysis

Horizontal shading



4.8. Shading Analysis
Near shading

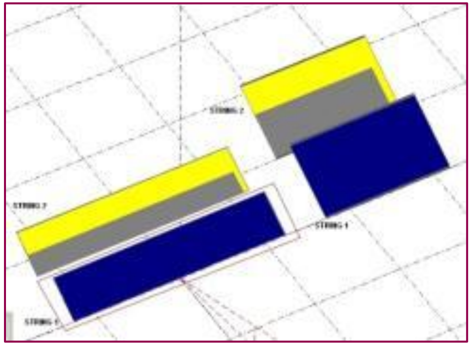


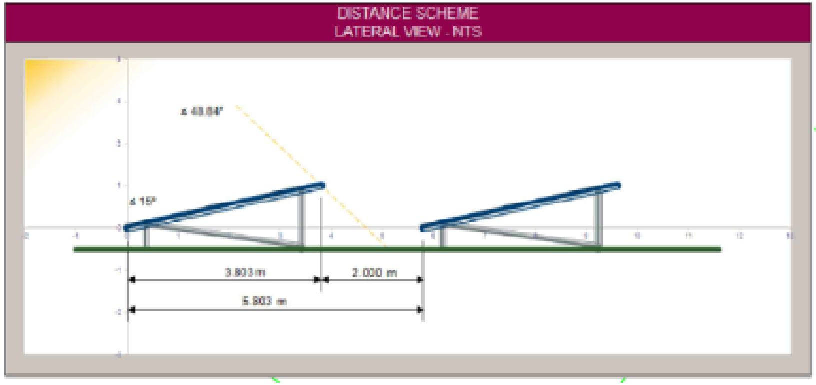
- Location: Freiburg, southern Germany (48 °N)
- We want that no shading occurs on noon at the 21st of December (shortest day)
- What angle does the sun have with the horizon on the 21st of December? (23.5°)
  90°- latitude-declination= sun angle
  90° - 48° - 23.5° = 18.5°
- What is the minimum distance x to guarantee that there is no shading on noon?
- X = l * (cos β + sin β / tan 18.5°)
- In general it is always a compromise: Optimizing!
- Software tools use optimize factors

4.8. Shading Analysis

General

- **Advance shading analysis with Simulation software possible as:**
  - String shading with the effect from row to row
  - Punctual shading
  - Horizontal shading
- **In Thailand the most efficient row to row should be around 2.5m**



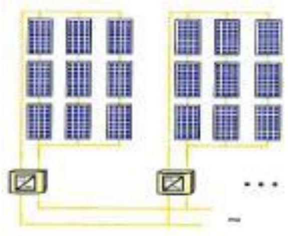


! Target: No shading on the day with lowest Sun evaluation at 12pm.

4.9. Inverter Calculation

Two possible inverter concepts are suitable for Solar Systems:

String Inverter



+ Omission of the PV String combiner/junction Box
+ Up to 1 MWp more cost efficient and if no Service is available
+ Reduction of the module DC cabling to series interconnection
+ Need less extra space
+ faster to repair or to exchange

Central Inverter

+ More cost efficient from >800 kWp
+ less additional mounting structure costs
+ less cabeling costs

4.9. Inverter Calculation

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Inverters with Transformers	Transformer less Inverters
• Does not need a neutral wire • HF-Technology is smaller and lighter → close to transformer-less devices • Less efficient compared to transformer less inverters	• Small • Light weight • More efficient

Inverters with single MPPT	Inverters with multi MPPT (Multi String Inverter)
• Inputs internally wired parallel • Lower cost • Requires: identical modules, string-lengths, orientation, shading, roof pitch	• Independent optimization of strings with different modules, string-lengths, orientation, shading, roof pitches • More expensive • Optional internal parallel wiring (depending on inverter)

4.9. Inverter Calculation

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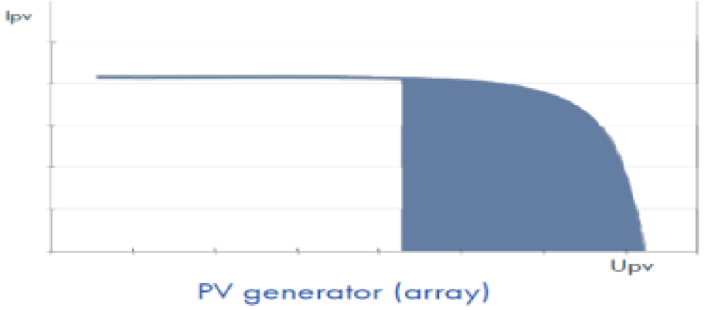
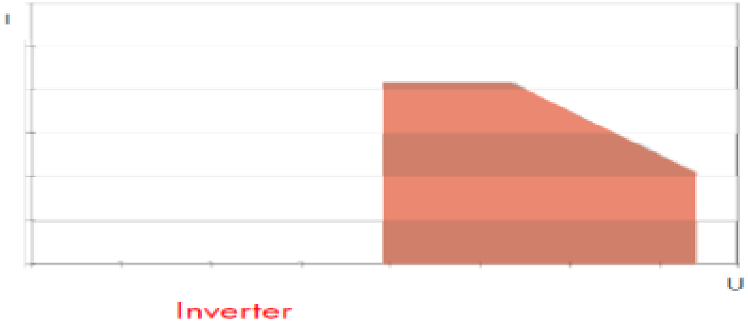
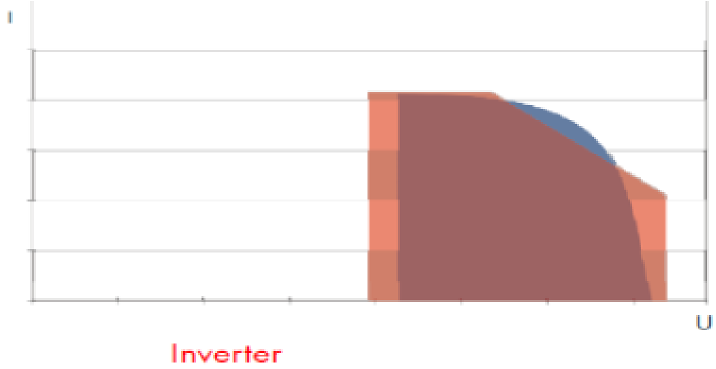
- High efficiency can only be achieved with high MPP voltage
- Maximize string length (limitation: Observe Open-Circuit voltage at lowest temperature in the region or use standard -10oC)
- Avoid MPP Voltages below 200V (e.g. Sunny Tripower have in built electronic String fuses which will only be activated for MPP voltage above 188V)
- Avoid shading as much as possible
- If shading exists, limit shading to one string or to one MPPT tracker (in case of using multi string inverters)

4.9. Inverter Calculation

Working Areas of PV Generator and Inverter







- The working areas of Inverter and PV generator array are not congruent
- Sizing of System is vital for effective and efficient plant design

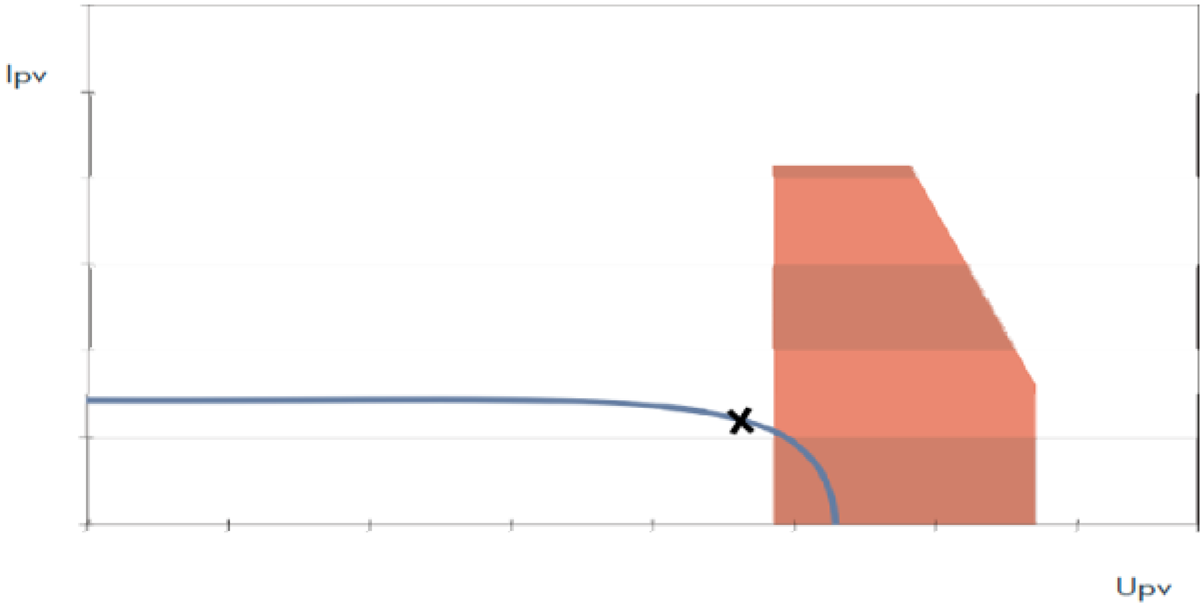
4.9. Inverter Calculation

Inverter and Plant Design

Design Criteria - Scenarios

Scenario 1: Low MPP Voltage

- **The PV generator has its MPP (maximum Power Point) below the Minimum Input Voltage of Inverter**



The Inverter remains in operation and feeds the power of the PV generator at the Minimum input voltage

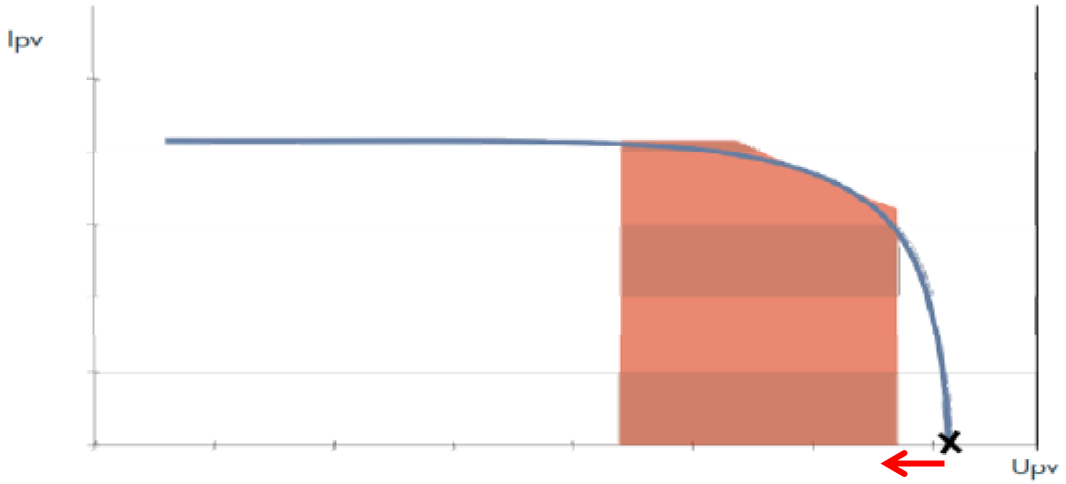
This can be avoided by sizing the PV array at high MPP Voltage range of Inverter

4.9. Inverter Calculation
Inverter and Plant Design

Design Criteria - Scenarios

Scenario 2: Large Open Circuit Voltage

- **The PV generator has an open circuit voltage that is higher than the maximum Input Voltage of Inverter**



Depending on intensity of Overvoltage and module temperature, the inverter may be damaged.

This can be avoided by sizing the PV array below the Maximum Input voltage of Inverter

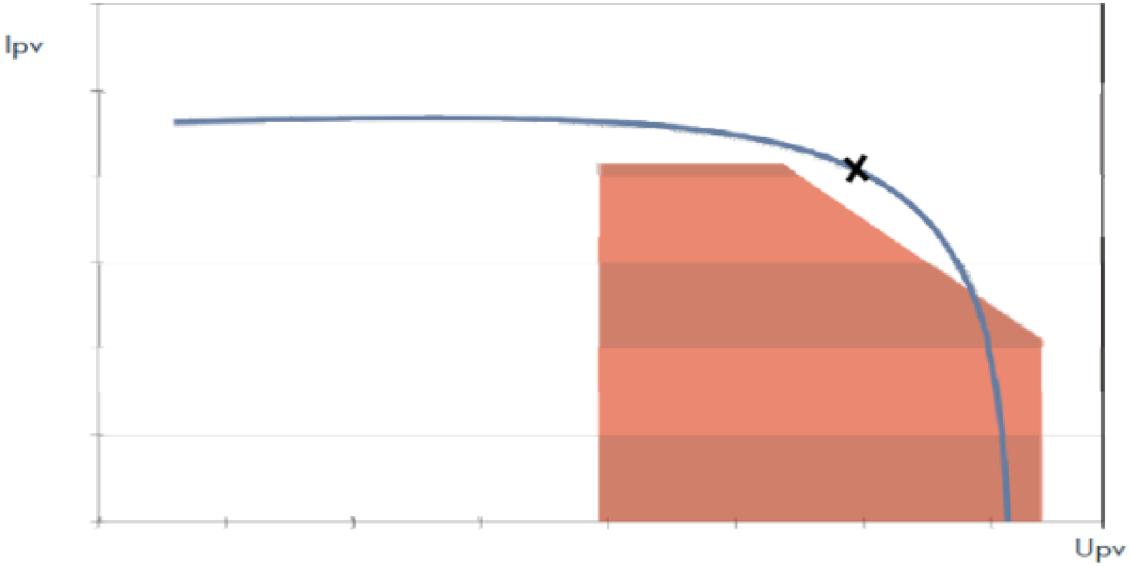
4.9. Inverter Calculation

Inverter and Plant Design

Design Criteria - Scenarios

Scenario 3: Current/Output Limitation

➢ **The PV generator could deliver higher power than the maximum power input of the inverter**

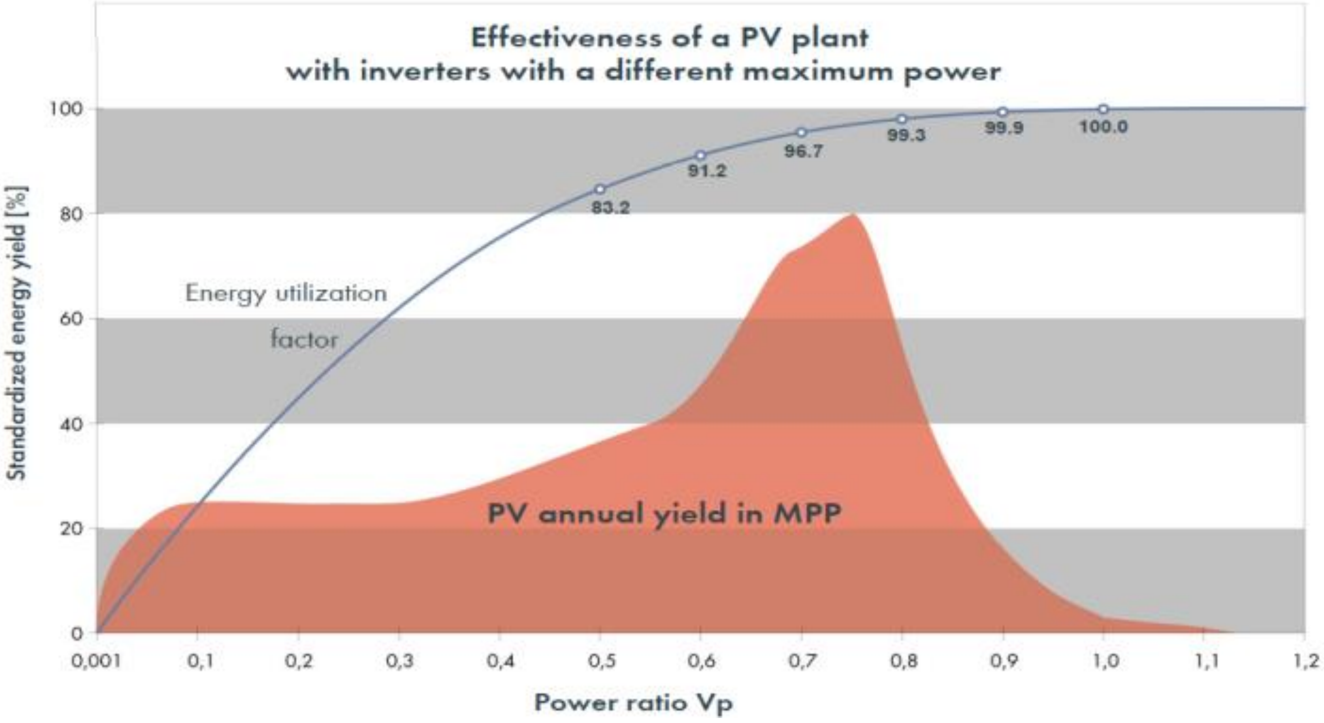


The Inverter remains in operation and feeds **its** maximum power on the grid

- Having a nominal Power ratio between PV Generator and Inverter is important.
- The excess power generated by PV will be lost if the Inverter is largely undersized.

4.9. Inverter Calculation
Inverter and Plant Design

Energy Utilization



For example for an undersized system with Power ratio of 0.7, the energy utilization factor will be 3-4% lower than the system with unity power ratio

4.9. Inverter Calculation
Inverter and Plant Design

Nominal Power Ratio Inverter – PV Array

- **For a well designed PV Plant, the power of the Inverter needs to match the power of the connected PV array**
- **The Nominal power ratio is the ratio of the power of the Inverter to the power of the connected PV Array**

$$\text{Nominal PV Ratio} = \frac{\text{Maximum Input Power of the Inverter}}{\text{Nominal Power of PV Array at STC*}}$$

*STC: Standard test Conditions

4.9. Inverter Calculation
Inverter and Plant Design, Example

- Inverter Selection eg. SMC10000TL

Scenario
Modules: SolarWorld SW 240 Poly

Required Plant Power: Approx. 10 kWp

String sizing
How to decide the optimum number of modules per String?

- Note down the temperature coefficient of the Modules SW240 Poly

THERMAL CHARACTERISTICS

NOCT	46 °C
TC I_{sc}	0.081 %/K
TC U_{oc}	-0.37 %/K
TC P_{mpp}	-0.45 %/K

PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

		SW 240
Maximum power	P_{max}	240 Wp
Open circuit voltage	U_{oc}	37.2 V
Maximum power point voltage	U_{mpp}	30.2 V
Short circuit current	I_{sc}	8.44 A
Maximum power point current	I_{mpp}	7.96 A

- Note down the MPPT voltage range, Maximum Voltage Range from the datasheet of the SMC10000TL

Technical data	Sunny Mini Central 10000TL
Input (DC)	
Max. DC power (@ cos φ = 1)	10350 W
Max. input voltage	700 V
MPP voltage range / rated input voltage	333 V – 500 V / 350 V
Min. input voltage / initial input voltage	333 V / 400 V
Max. input current	31 A
Max. input current per string	31 A
Number of independent MPP inputs / strings per MPP input	1 / 5

4.9. Inverter Calculation
Inverter and Plant Design

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- Note the maximum and minimum Ambient temperature reached at the site of installation

For Minimum temperature, Use -10ºC

- The Nominal Power ratio should not be lower than 90%, in certain case it is OK to max 80%

$$T_{cell.eff} = T_{amb.temp} + 25$$

Minimum Voltage of Module

Minimum Voltage occurs at maximum Ambient temperature

Module MPP Voltage = 30.2 V

Voltage coefficient = -0.37%/C

$$V_{mpp\_min} = V_{mpp\_STC} + (\Upsilon v \times (T_{cell.eff} - T_{STC})^{*} V_{mpp\_STC}$$

$$V_{mpp\_min} = 30.2 + (-0.0037x\ (70 - 25)^{*}\ 30.2\ .(\text{Assume } T_{amb.temp} = 45)$$

$$V_{mpp\_min} = 25.1717\ V$$

4.9. Inverter Calculation

Inverter and Plant Design

Maximum Voltage of Module

Maximum Voltage occurs at minimum Ambient temperature

Module Open Circuit Voltage = 37.2 V

Voltage coefficient = -0.37%/C

$V_{oc\_max} = V_{oc\_STC} + (ϒv \times (T_{cell.eff} - T_{STC})^{*} V_{oc\_STC}$

$V_{oc\_max} = 37.2 + (-0.0037 \times (-10 - 25)^{*} 37.2$.(Assume $T_{amb.temp} = -10$)

$V_{oc\_max} = 42.01$ V

N_{min} Per String = $\frac{V_{inv\_min}}{V_{mpp\_min}}$

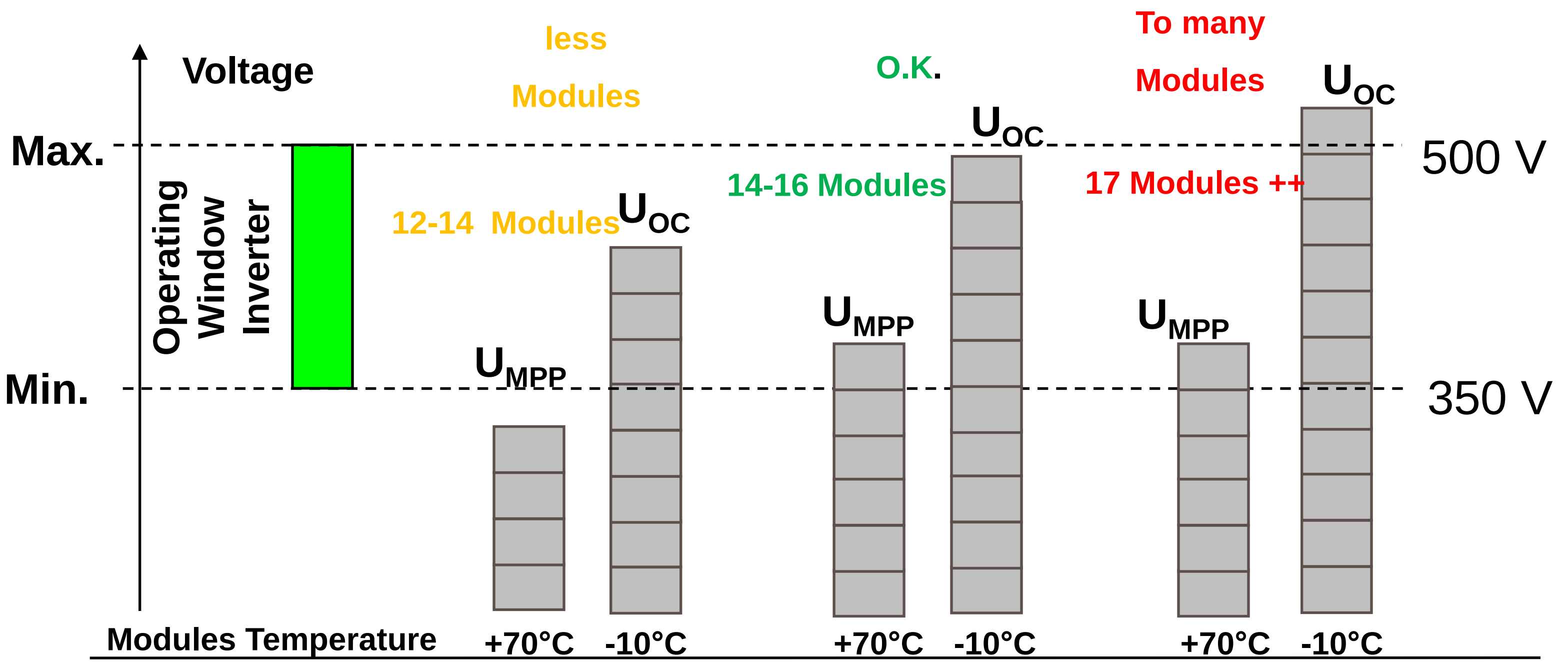
N_{max} Per String = $\frac{V_{inv\_max}}{V_{oc\_max}}$

N_{min} Per String = $\frac{350}{25.1717} = 13.9$

N_{max} Per String = $\frac{700}{42.01} = 16.65$

Therefore, Can place between 14-16 modules in a string

4.9. Inverter Calculation
Inverter and Plant Design



4.9. Inverter Calculation
Inverter and Plant Design

juwi

Specific Energy Yield: is expressed in kWh per kWp and is calculated as

$$\text{Specific Yield} = \frac{\text{System Energy output}}{\text{Rated output Power of System}}$$

If the performance of systems in different regions need to be compared, shading losses need to be eliminated from calculation for accurate comparison

Performance Ratio: is used to assess the installation quality.
The Performance Ratio provides a normalized basis so comparison of different types and sizes of PV systems can be undertaken.

$$\text{Performance Ratio} = \frac{\text{System Energy output}}{\text{Ideal Energy Output}}$$

Ideal Energy Output = Rated output Power of System x Insolation on Panel

4.9. Inverter Calculation
Inverter and Plant Design

Assuming 15 Modules in a string	
Rated String Power	= 3.6kWp
Therefore, number of strings required	= 3 x 3.6kWp = 10.8 kWp
Maximum String Current	= 8.44 A
Total Current Input to Inverter with 3 strings	= 25.32 A **OK**
Max Input Current limit of Inverter	= 31 A
Nominal Power Ratio	= 95% **OK**
If using 16 Modules in String,	
3 Strings per Inverter, Power	= 11.52kWp
Nominal Power Ratio	= 89% **NOT OK** (ok in regions with low irradiation and low specific yield)

Use 11kWp Inverter

4.9. Inverter Calculation
DC AC Ratio

A high DC/AC Ratio of 120% (which means more DC Power than AC power) are more cost effective.

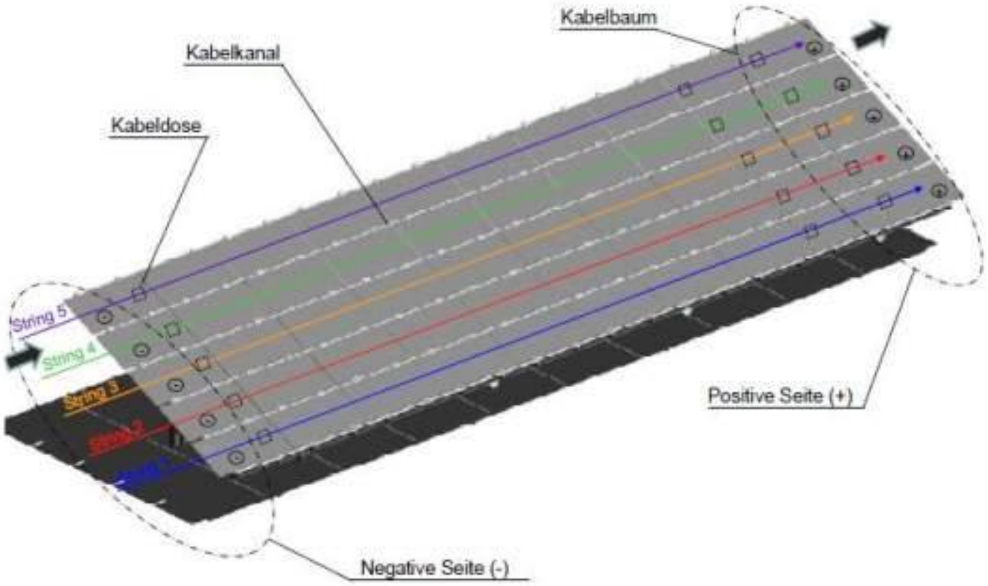
Keep in mind: High DC/AC ratio, means:

- **Higher losses**
- **Operating and max level Inverter operating Level**

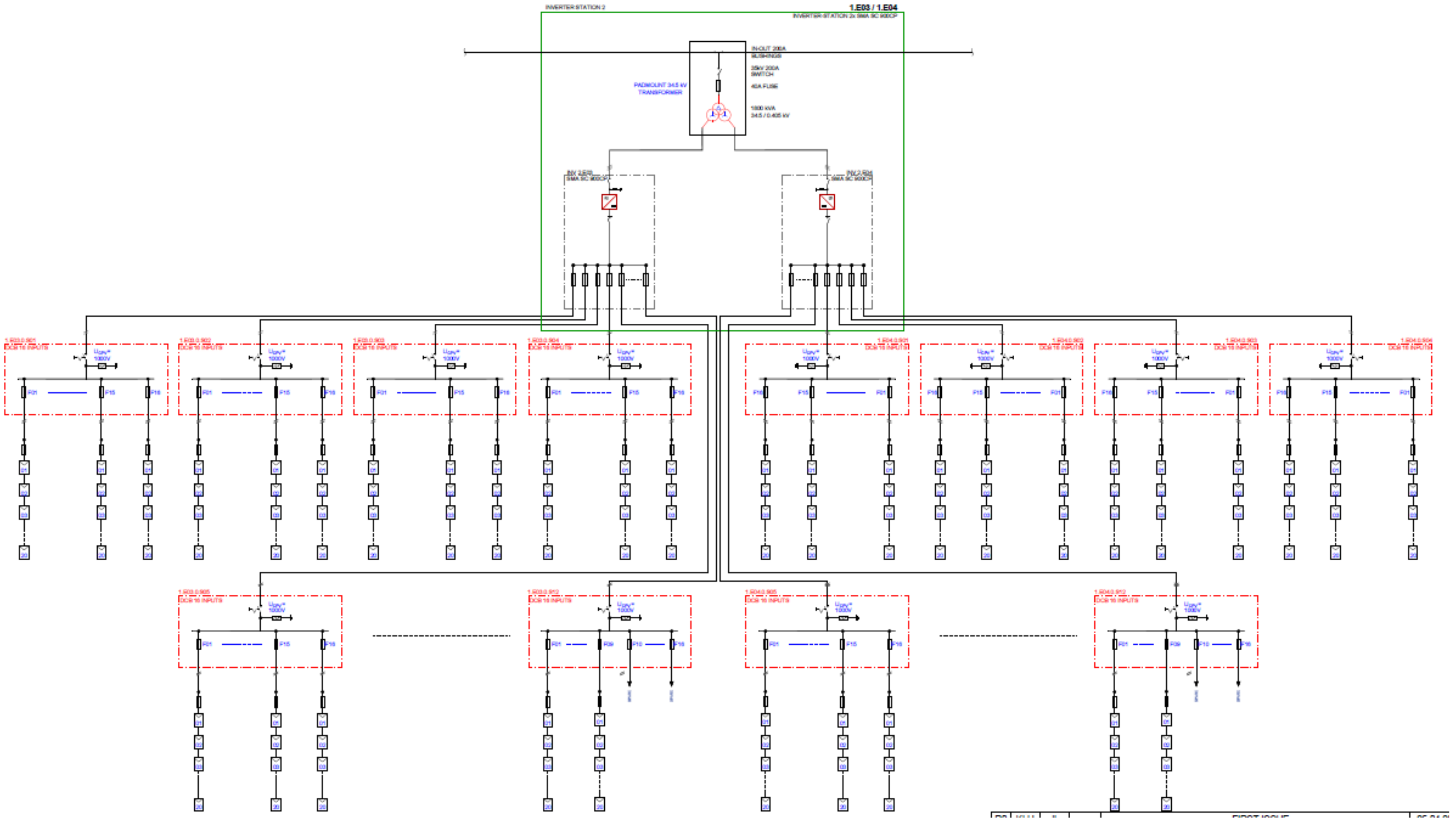
It is advisable to check the warranty conditions with Suppliers before going for the higher DC/AC Ratio

4.10. String configuration

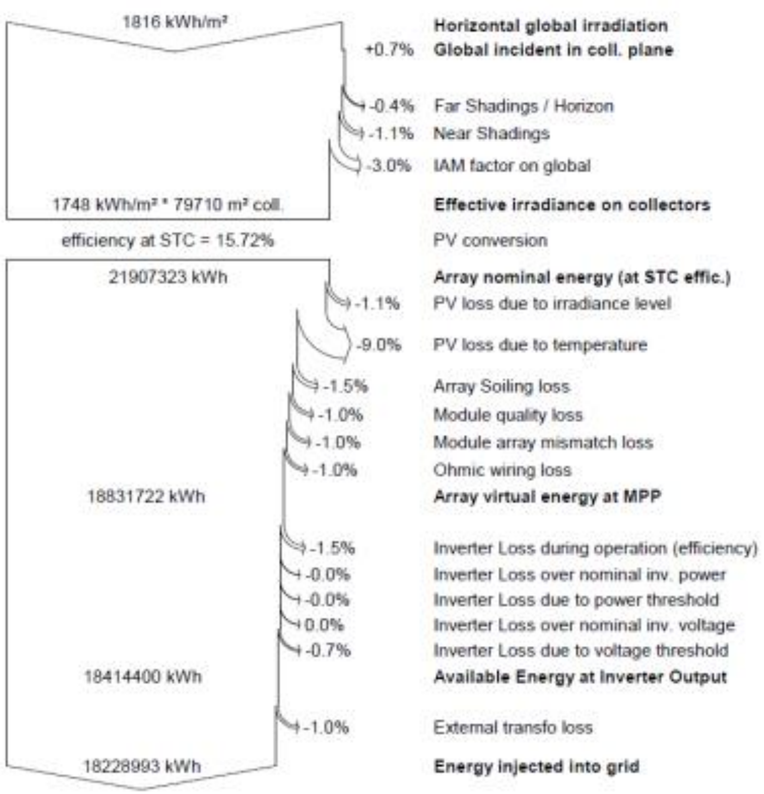
- String Configuration is based on the operating window and Module requirements.
- This is part of the Inverter sizing as well part of the preliminary wiring plan



4.10. String configuration
Electrical Design LV



4.11. Losses



Major losses occur due to:

- Module losses (high Temperature, through shading, irradiance level, array Soiling, quality loss)
- Inverter Losses (temperature, Module mismatching, voltage treshold)
- Cable losses (in total not more than 1.5%)
- Transformer operating losses

4.12. Yield Analysis Simulation

Necessary Input data

- **Site Info**
  - Metrological data
  - Irradiation, Sunshine hours
  - Temperature
- **PV System info**
  - Components
- **Geographic Position**
- **PV array characteristic**
- **Climate reference**

Shading Factor

IAM Factor on global

PV Loss due to Irridance Level

PV Thermal Loss

Soiling Loss

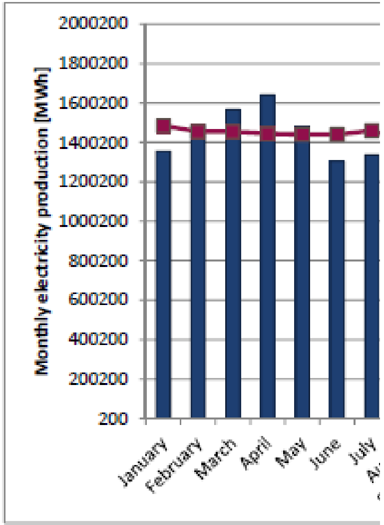
Inverter inefficiency

Ohmic Loss

Module Array Missmatch Loss

Plant Transformer Loss

Module quality Loss & Array mismatch



Year	Forecast Annual Generation
[No]	[kWh]
1	18007028
2	17880979
3	17755812
4	17631522
5	17508101
6	17385544
7	17263845
8	17142998
9	17022997
10	16903836
11	16785510
12	16668011
13	16551335
14	16435476
15	16320427
16	16206184
17	16092741
18	15980092
19	15868231
20	15757154

4.10. Detail Design Steps

Detail Design Steps before construction starts and include in general:

- Final Module Layout
- Cable Wiring, Cable Routing
- Single Line Diagram and Details
- Details (Grounding, Combiner Box, Inverter, Main Station, Fence, Roads, etc…..)
- Civil Plans
- Security Concepts
- Technical Calculation (AC cable, DC cable, Inverter Sizing, Road Work installation, etc..)
- Technical Specification

4. Simulation Software

Simulation Software
- Overview

Different Software's available from:

- **Free supplier:**
  - free but limited to the Manufacturer specifications
  - Best source from Inverter and Module Manufacturers (SMA, PowerOne, etc)

- **Professional Software:**
  - Use of customer metrological data or generated data as from METEONORM, or NASA
  - Optimized Module Angle and Azimuth selection
  - Shading simulation
  - Easy String configuration
  - Provides a nice print out useable for Proposal and documentation

Q & A

This is how a plant shall look like…

…in Thailand, India

… or anywhere in Asia Pacific

Thank You Very Much for Your Attention!

Kai Klingenhagen
Business Development ASIA Pacific,
Temp. Country Manager juwi Philippines Inc.

juwi Renewable Energies Private Limited
152 Beach Road, # 21-07 Gateway East,
Singapore 189721
Mob. +65 9199 0395
Fax. +49. (0)6732. 96 57-8541
kai.klingenhagen@juwi.com
www.juwi.com