This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792059

goPV

June. 21st - 3rd Session

PV Systems – EGP (Marco Caramanna)

co-organized with Università di Catania

GLOBAL OPTIMIZATION OF INTEGRATED PHOTOVOLTAIC SYSTEM FOR LOW ELECTRICITY COST

PV Systems – Enel Green Power

Agenda

1. PV plant overview
2. Utility scale PV plant – Main equipments
3. Utility scale PV plant – Conceptual design
4. Utility scale PV plant – Layout

1. Solar PV Plant Overview

The importance of sun

99.98%

Earth energy coming from sun

7.32 TW

Global electricity installed capacity
2019-US-EIA

25827 TWh

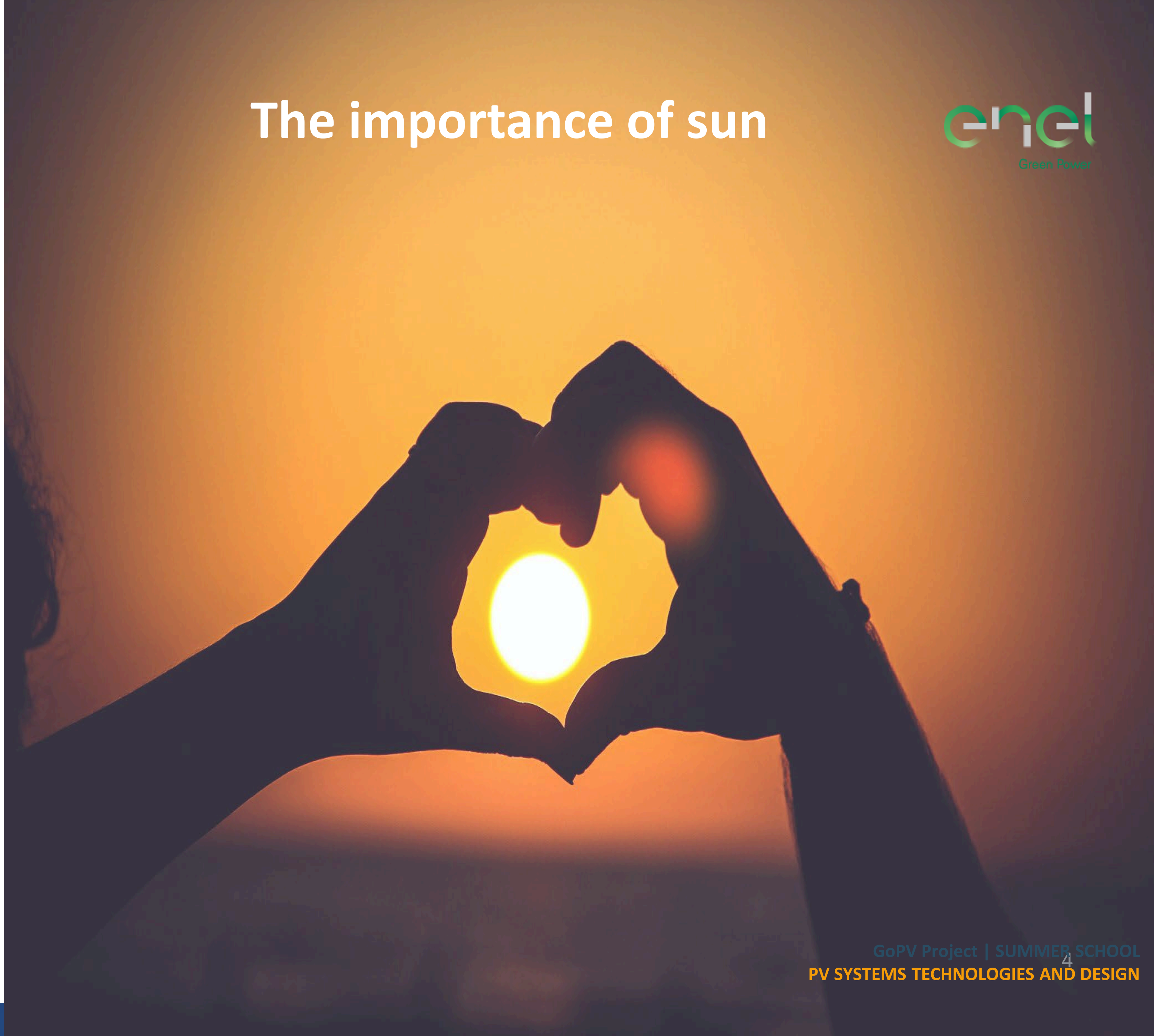
World electricity energy generation
2019-US-EIA

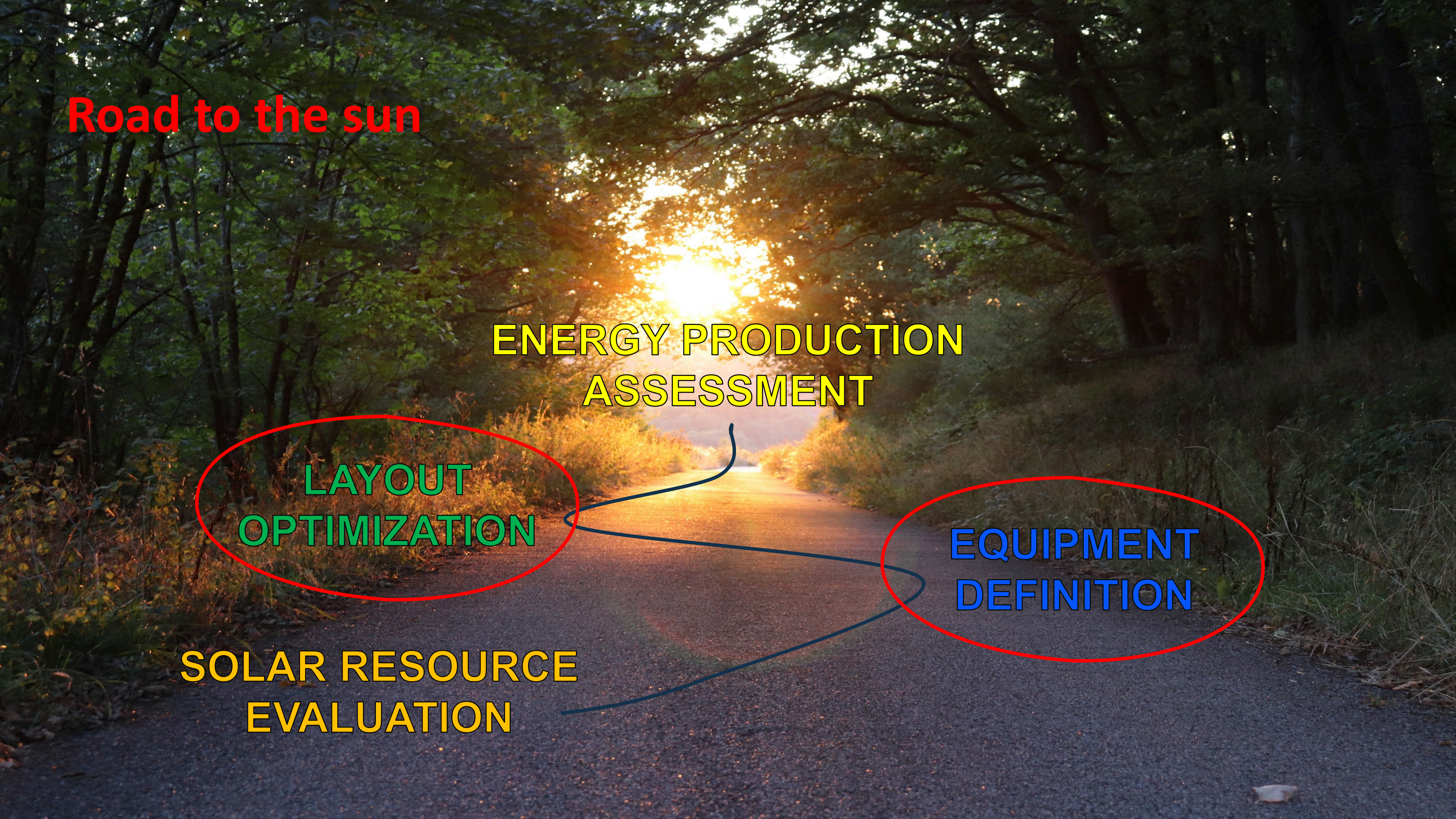
0.01%

Fraction of current world electricity capacity respect the solar resource (sun irradiance absorbed by earth = 90000 TW)

18 min

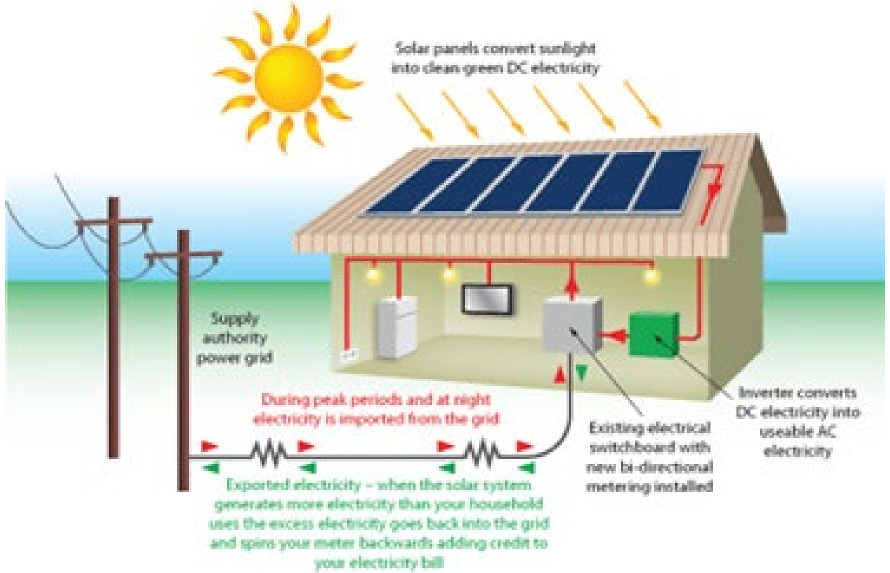
Time necessary to satisfy one year world's energy demand



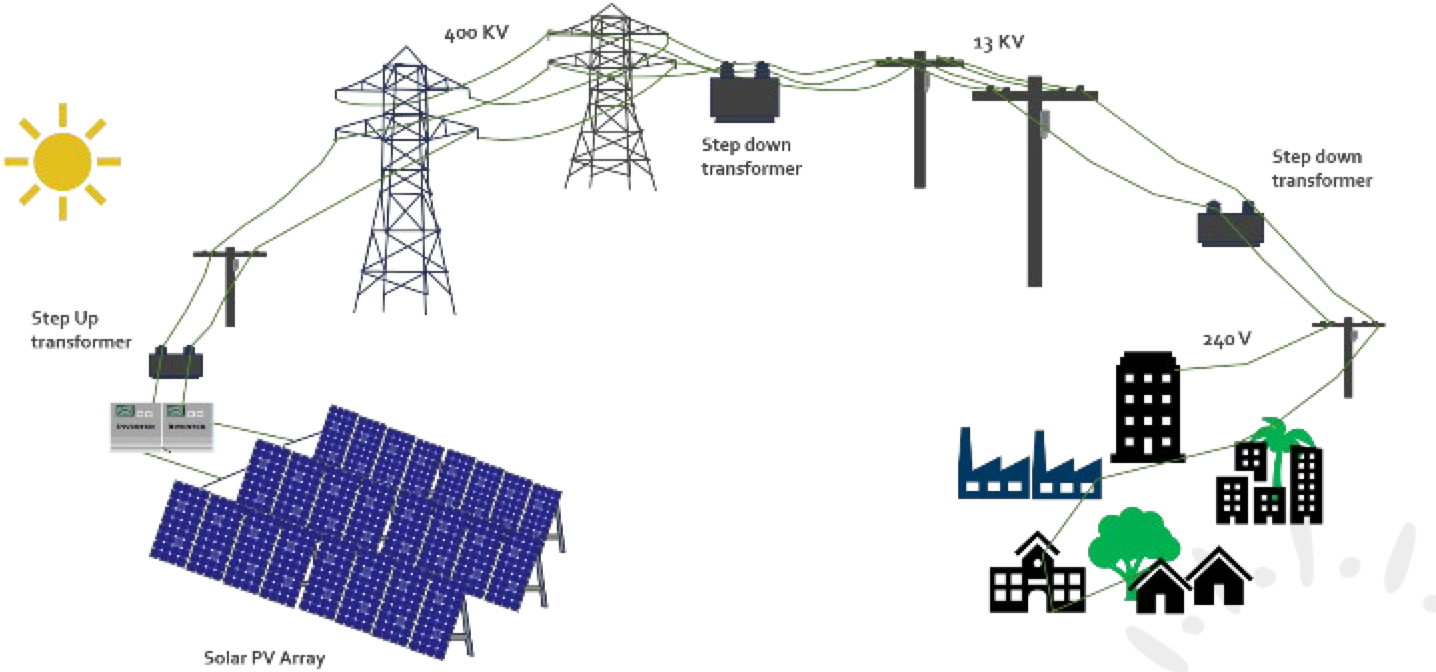

Road to the sun
ENERGY PRODUCTION ASSESSMENT
LAYOUT OPTIMIZATION
EQUIPMENT DEFINITION
SOLAR RESOURCE EVALUATION

Grid connected PV plant

Retail vs Utility scale



Retail PV plant



Utility scale PV plant

Grid connected PV plant

Utility scale

Utility scale PV plant

Introduction

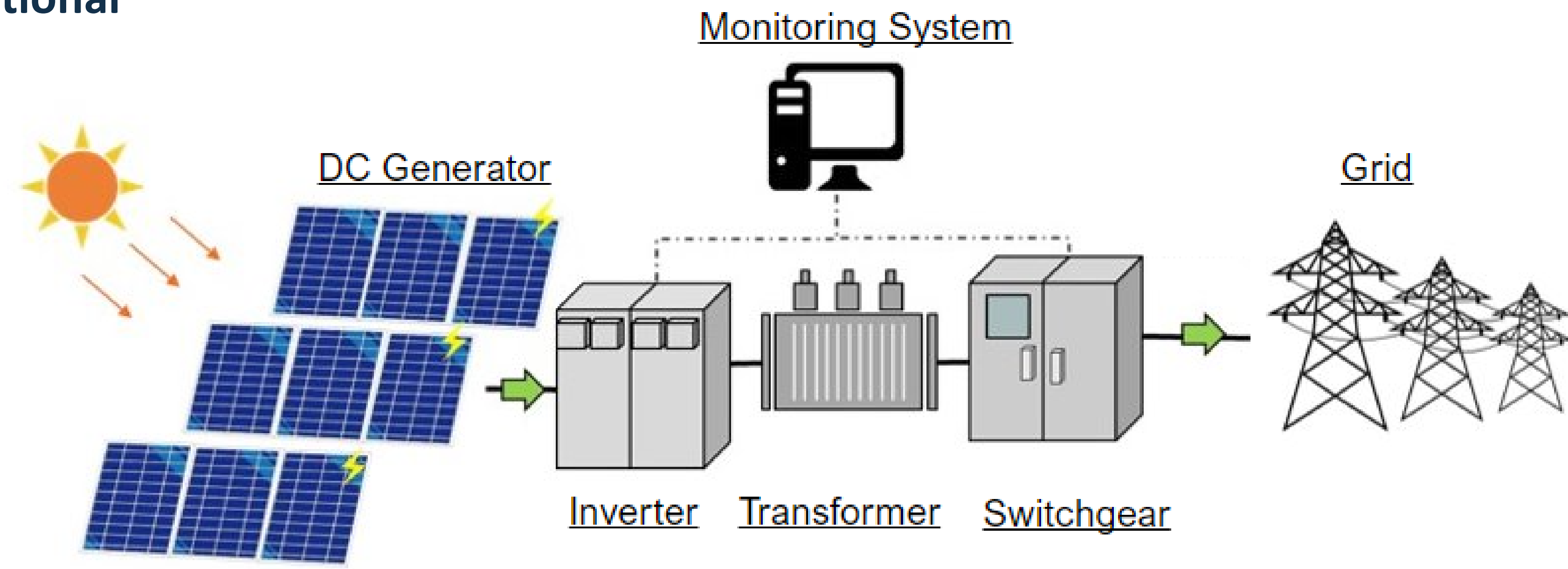
A utility-scale photovoltaic system (PV system) is designed to supply power into the National Electricity Grid.

Main components:

- **PV Modules**
- **Inverters**
- **Supporting Structures**

Other components (BoS):

- **DC & AC cables**
- **Monitoring system**
- **Substation**
- **Interconnection line**



2. Main equipments

2.1 PV modules

2.2 Structures

2.3 Inverters

Utility scale PV plant

Introduction

Modules
- Monofacial;
- Bifacial;

Structures
- Fixed;
- Tracker;

Inverters
- String;
- Centralized;

2. Main equipments

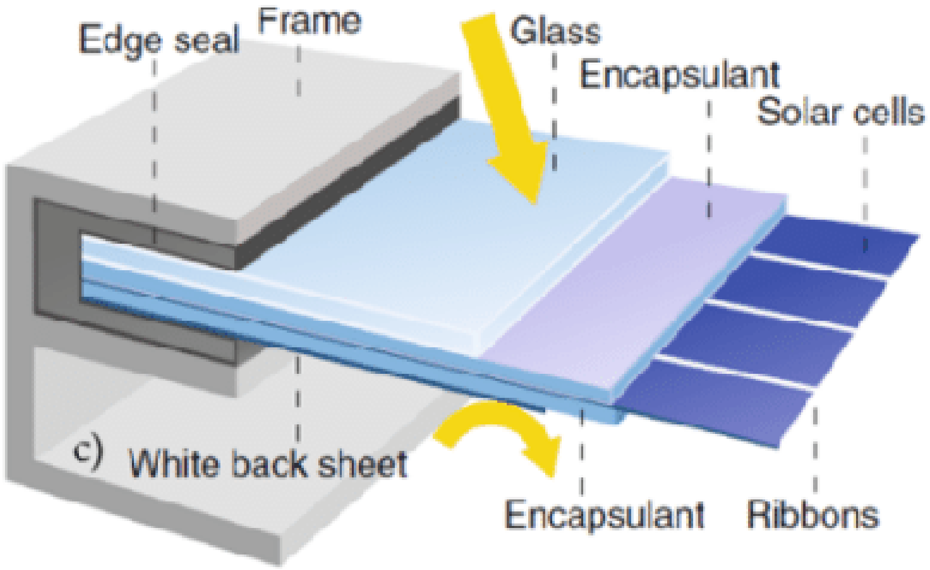
2.1 PV modules

2.2 Structures

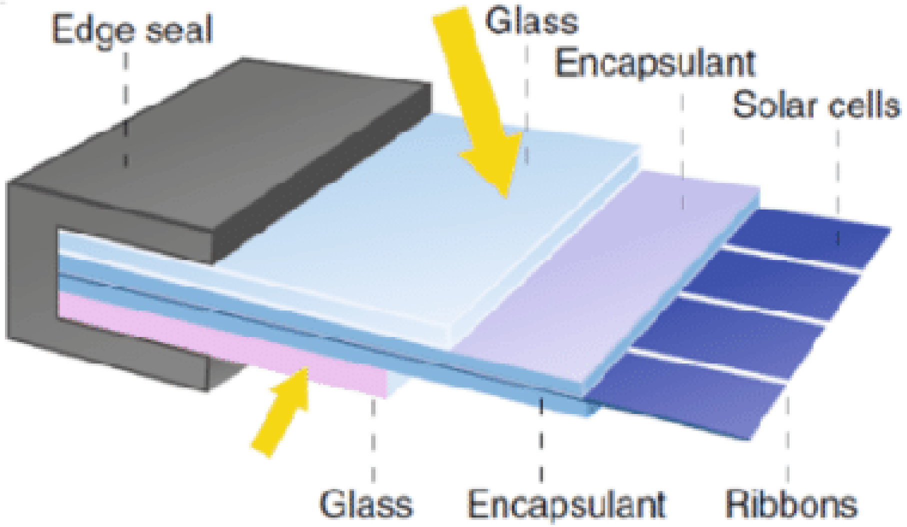
2.3 Inverters

PV modules
Main components

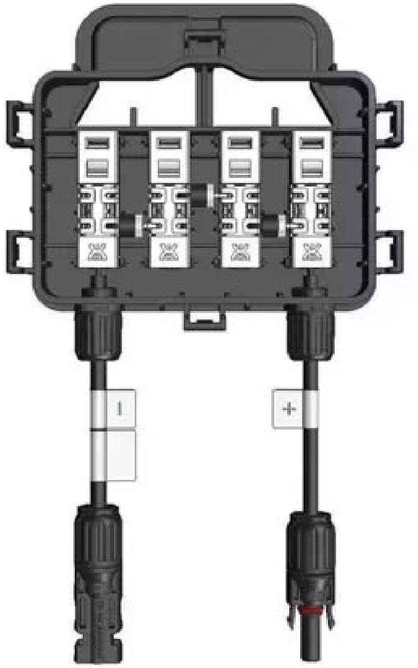
Monofacial



Bifacial

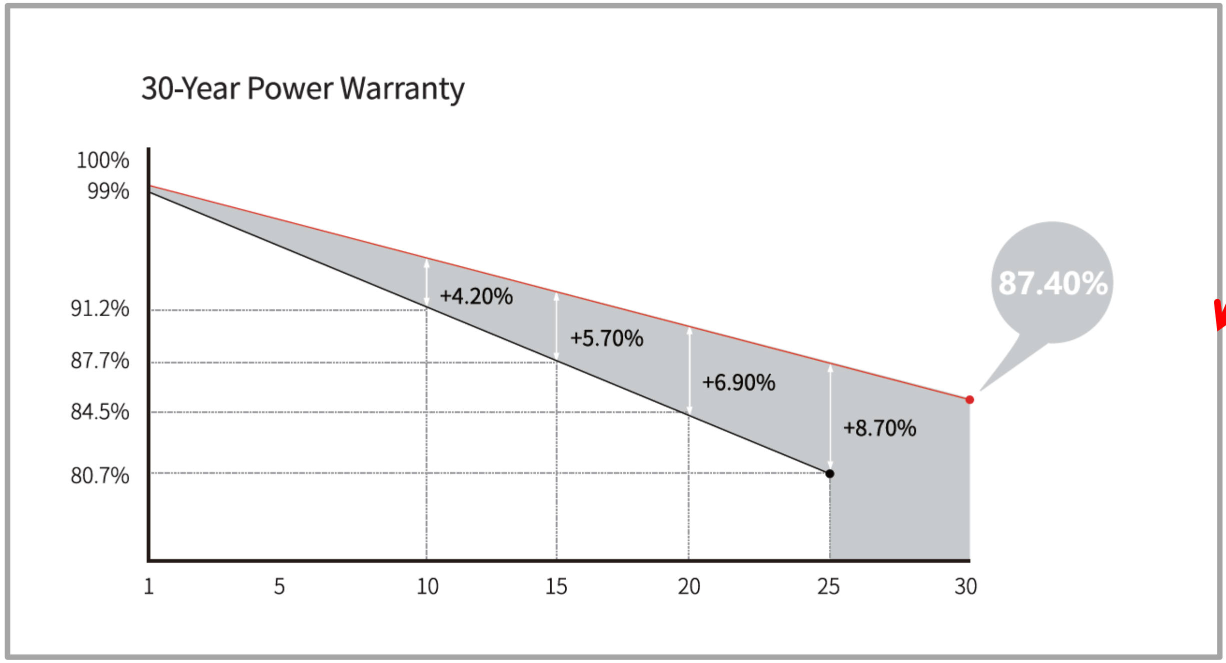


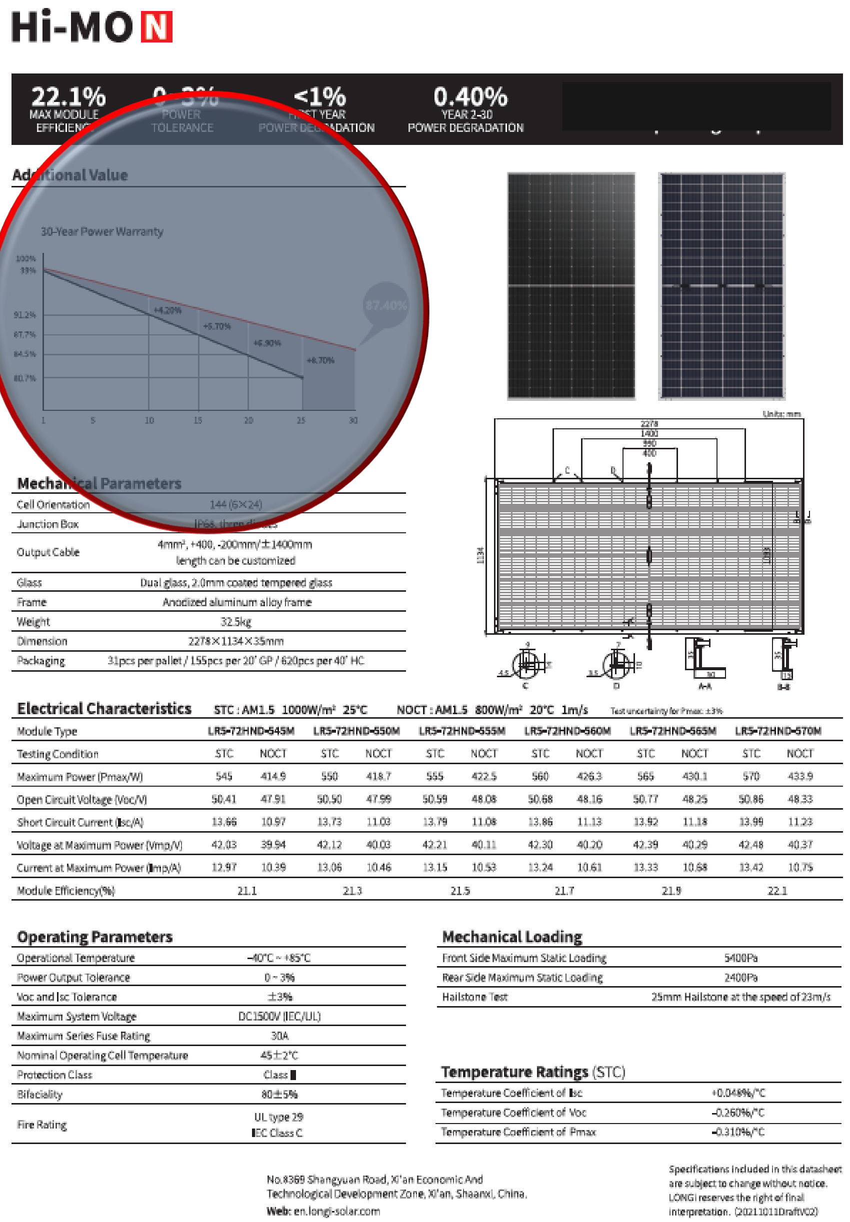
Junction box



PV modules

Datasheet overview - degradation





Hi-MO N

22.1%	0~3%	<1%	0.40%	
MAX MODULE EFFICIENCY	POWER TOLERANCE	FIRST YEAR POWER DEGRADATION	YEAR 2-30 POWER DEGRADATION	[redacted]

Additional Value

30-Year Power Warranty

Mechanical Parameters

Cell Orientation	144 (6×24)
Junction Box	IP68, three diodes
Output Cable	4mm², +400, -200mm/±1400mm length can be customized
Glass	Dual glass, 2.0mm coated tempered glass
Frame	Anodized aluminum alloy frame
Weight	32.5kg
Dimension	2278×1134×35mm
Packaging	31pcs per pallet / 155pcs per 20' GP / 620pcs per 40' HC

Electrical Characteristics STC : AM1.5 1000W/m² 25°C NOCT : AM1.5 800W/m² 20°C 1m/s Test uncertainty for Pmax: ±3%

Module Type	LR5-72HND-545M		LR5-72HND-550M		LR5-72HND-555M		LR5-72HND-560M		LR5-72HND-565M		LR5-72HND-570M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	545	414.9	550	418.7	555	422.5	560	426.3	565	430.1	570	433.9
Open Circuit Voltage (Voc/V)	50.41	47.91	50.50	47.99	50.59	48.08	50.68	48.16	50.77	48.25	50.86	48.33
Short Circuit Current (Isc/A)	13.66	10.97	13.73	11.03	13.79	11.08	13.86	11.13	13.92	11.18	13.99	11.23
Voltage at Maximum Power (Vmp/V)	42.03	39.94	42.12	40.03	42.21	40.11	42.30	40.20	42.39	40.29	42.48	40.37
Current at Maximum Power (Imp/A)	12.97	10.39	13.06	10.46	13.15	10.53	13.24	10.61	13.33	10.68	13.42	10.75
Module Efficiency(%)	21.1		21.3		21.5		21.7		21.9		22.1	

Operating Parameters

Operational Temperature	-40°C ~ +85°C
Power Output Tolerance	0 ~ 3%
Voc and Isc Tolerance	±3%
Maximum System Voltage	DC1500V (IEC/UL)
Maximum Series Fuse Rating	30A
Nominal Operating Cell Temperature	45±2°C
Protection Class	Class II
Bifaciality	80±5%
Fire Rating	UL type 29 IEC Class C

Mechanical Loading

Front Side Maximum Static Loading	5400Pa
Rear Side Maximum Static Loading	2400Pa
Hailstone Test	25mm Hailstone at the speed of 23m/s

Temperature Ratings (STC)

Temperature Coefficient of Isc	+0.048%/°C
Temperature Coefficient of Voc	-0.260%/°C
Temperature Coefficient of Pmax	-0.310%/°C

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Web: en.longi-solar.com

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PV modules

Datasheet overview – mechanical parameters

Mechanical Parameters

Cell Orientation	144 (6×24)
Junction Box	IP68, three diodes
Output Cable	$4mm^2$, +400, -200mm/±1400mm length can be customized
Glass	Dual glass, 2.0mm coated tempered glass
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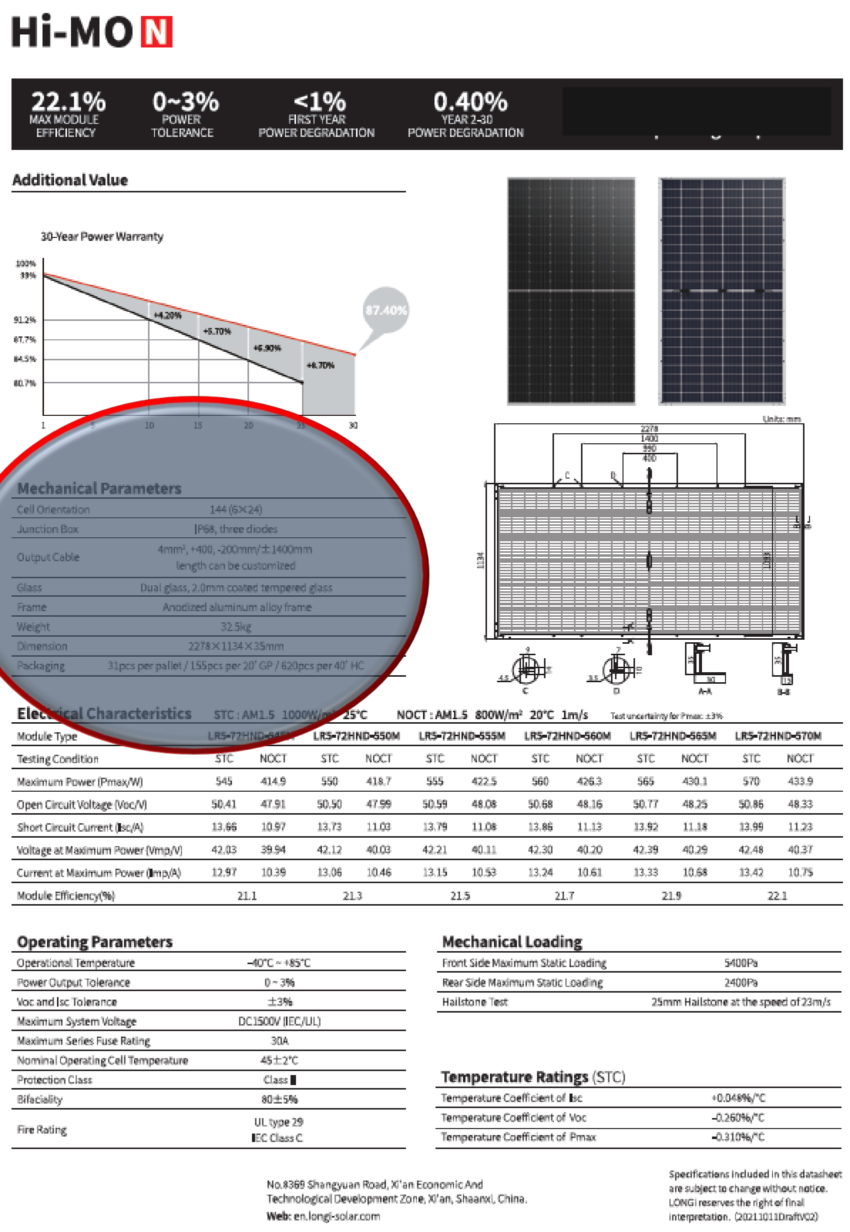

Hi-MO N

22.1% MAX MODULE EFFICIENCY | 0~3% POWER TOLERANCE | <1% FIRST YEAR POWER DEGRADATION | 0.40% YEAR 2-30 POWER DEGRADATION | [redacted]

Additional Value

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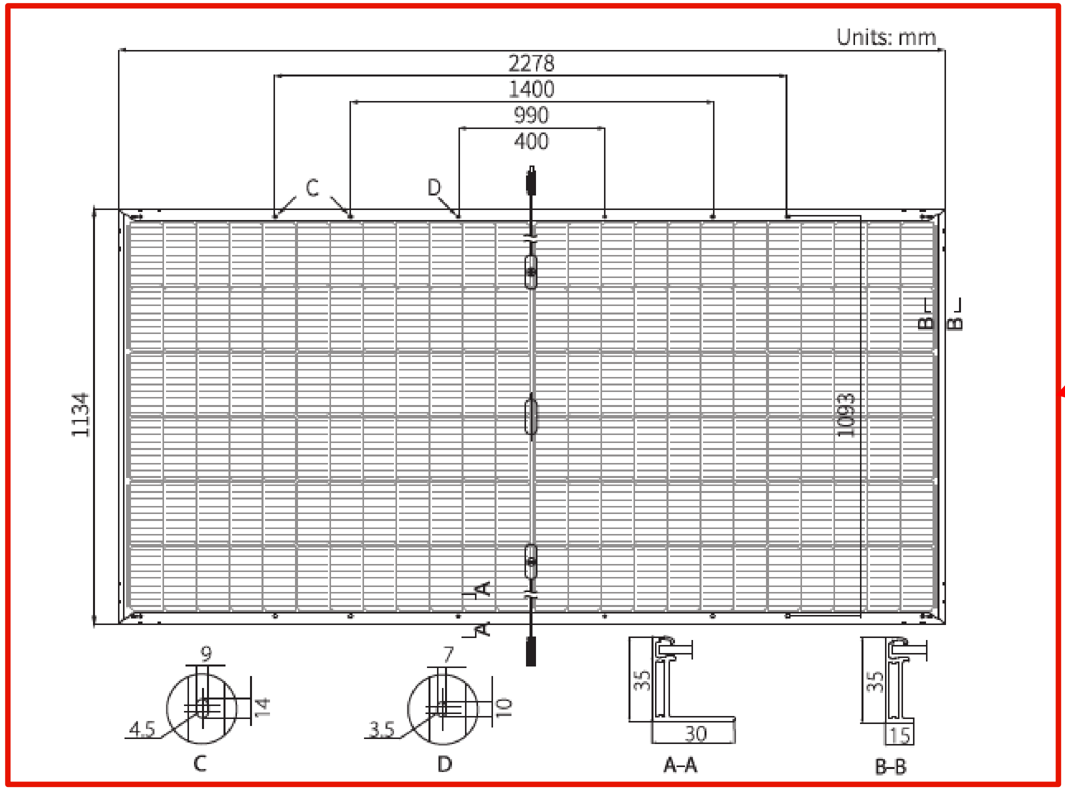
Green Power

PV modules

Datasheet overview – module drawing



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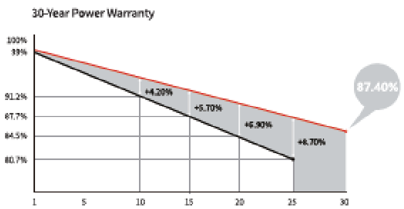

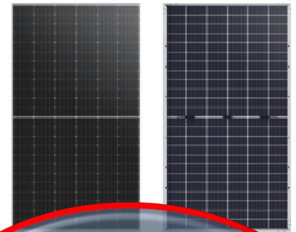

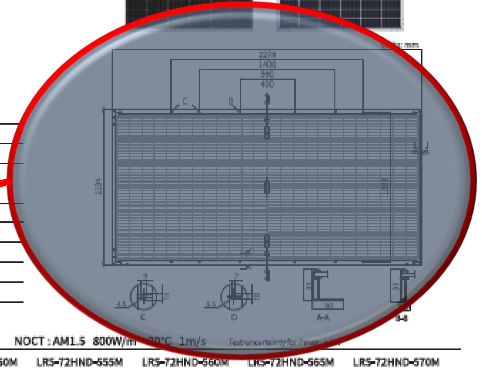

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PV modules

Datasheet overview – electrical and operating parameter

Electrical Characteristics

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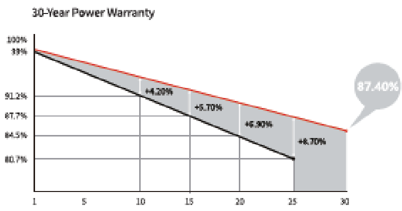

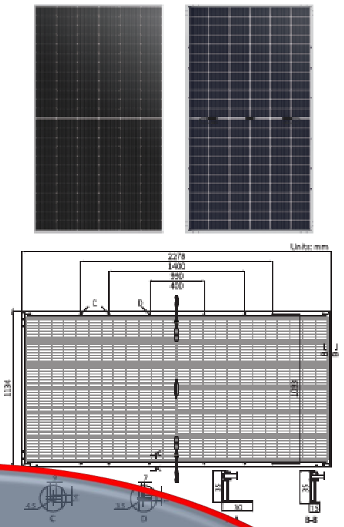

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2. Main equipments

2.1 PV modules

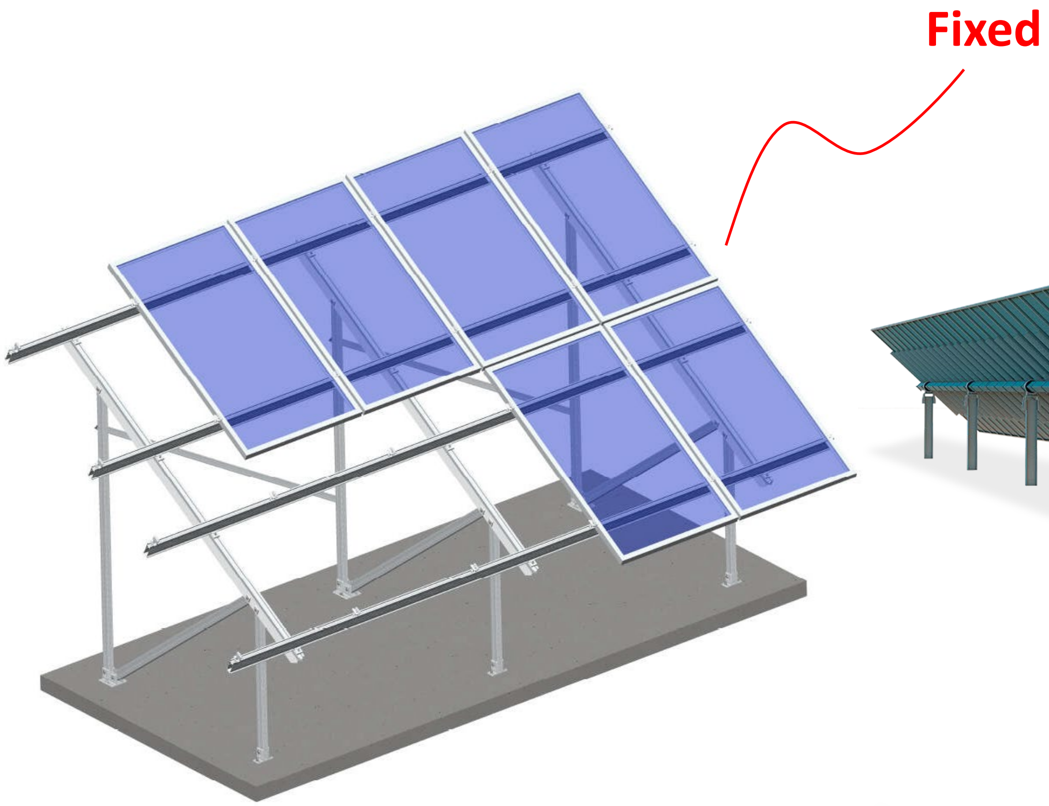
2.2 Structures

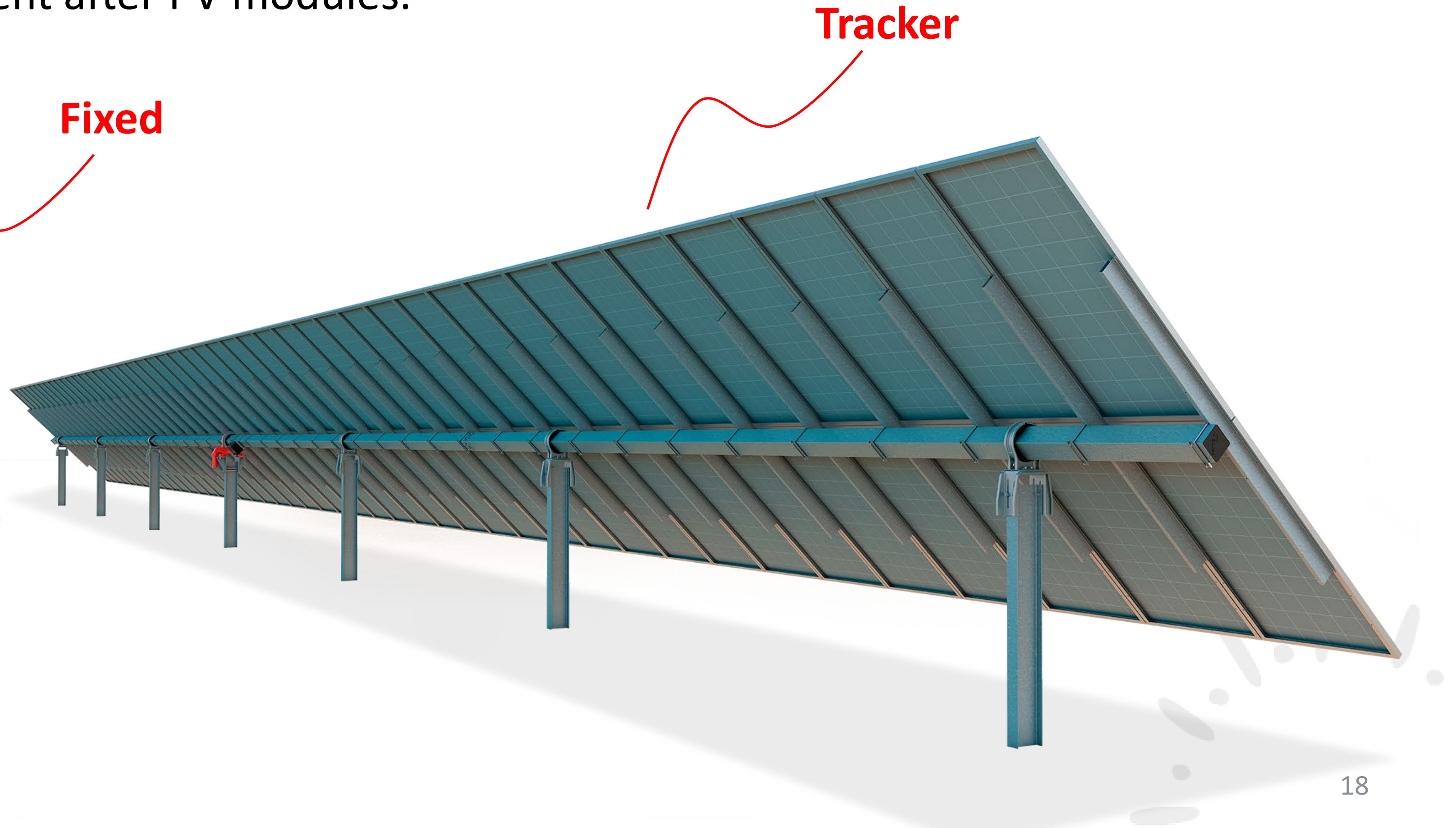
2.3 Inverters

PV structures

Definition

- One of the three main components within the PV plant.
- Second most expensive equipment after PV modules.

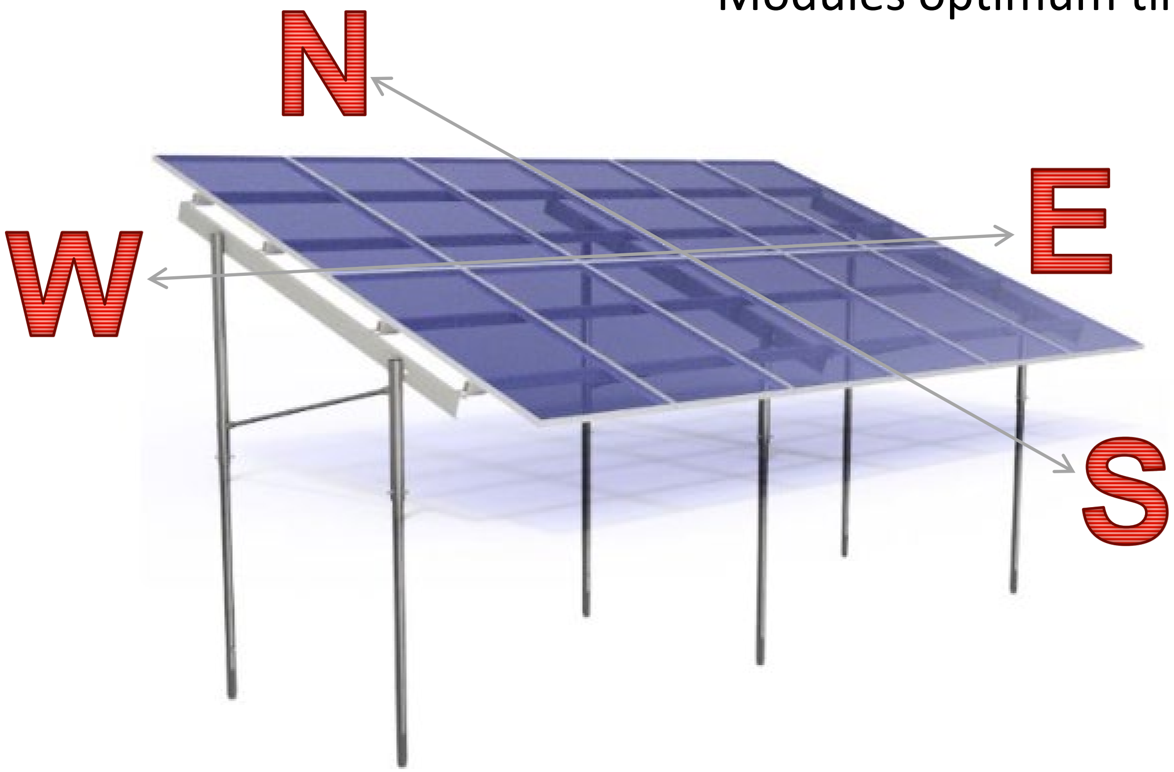




PV structures

Fixed

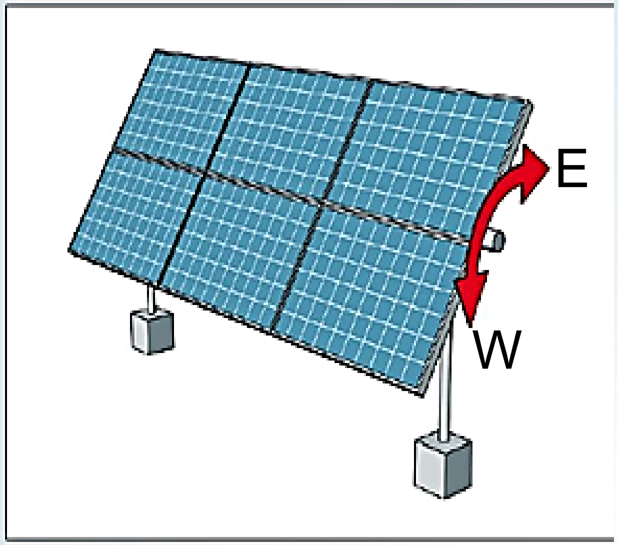
- Modules are positioned facing towards south/north.
- Modules optimum tilt is a function of latitude.



PV structures

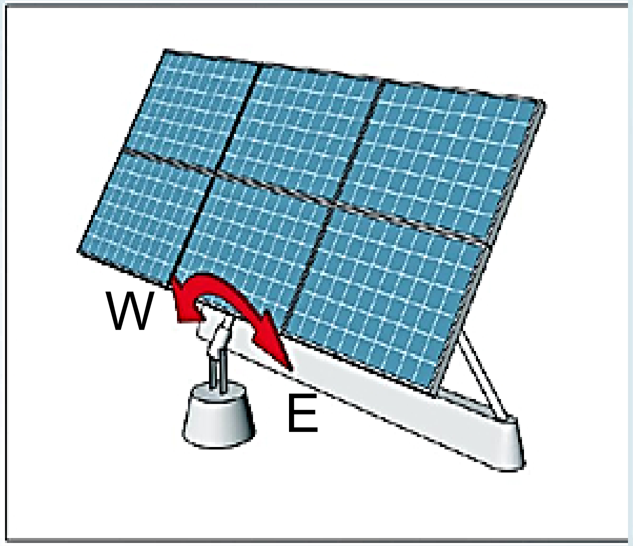
Tracker

A Solar Tracker is a device that orients PV modules towards the sun to **minimize the angle of incidence** between solar radiation and the PV modules.



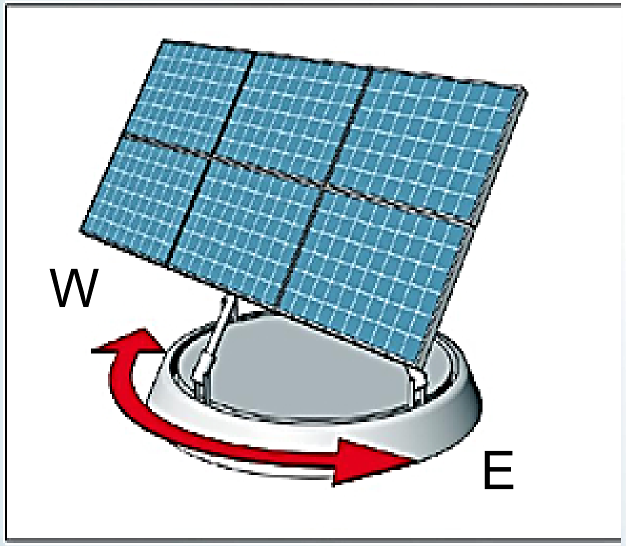
Horizontal single axis tracker

NS axis modules disposition
EW axis rotation



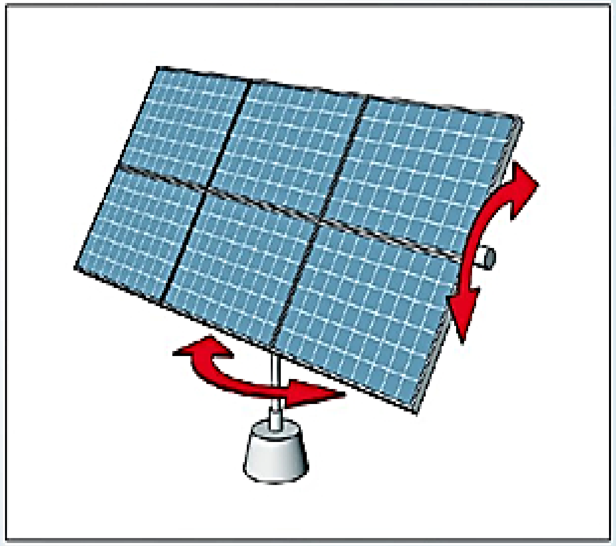
Tilted single axis tracker

S (N) Tilted modules disposition
EW rotation (tilt changing)



Azimuth tracker

S (N) Tilted modules disposition
Vertical axis rotation



Dual axis tracker

Rotation in all directions

PV structures

Horizontal single axis tracker

PV structures

Structures energy yield comparison

Fixed

- Easy installation (even with high slope);
- Low cost;
- Low-Medium performance.

Tracker EW axis

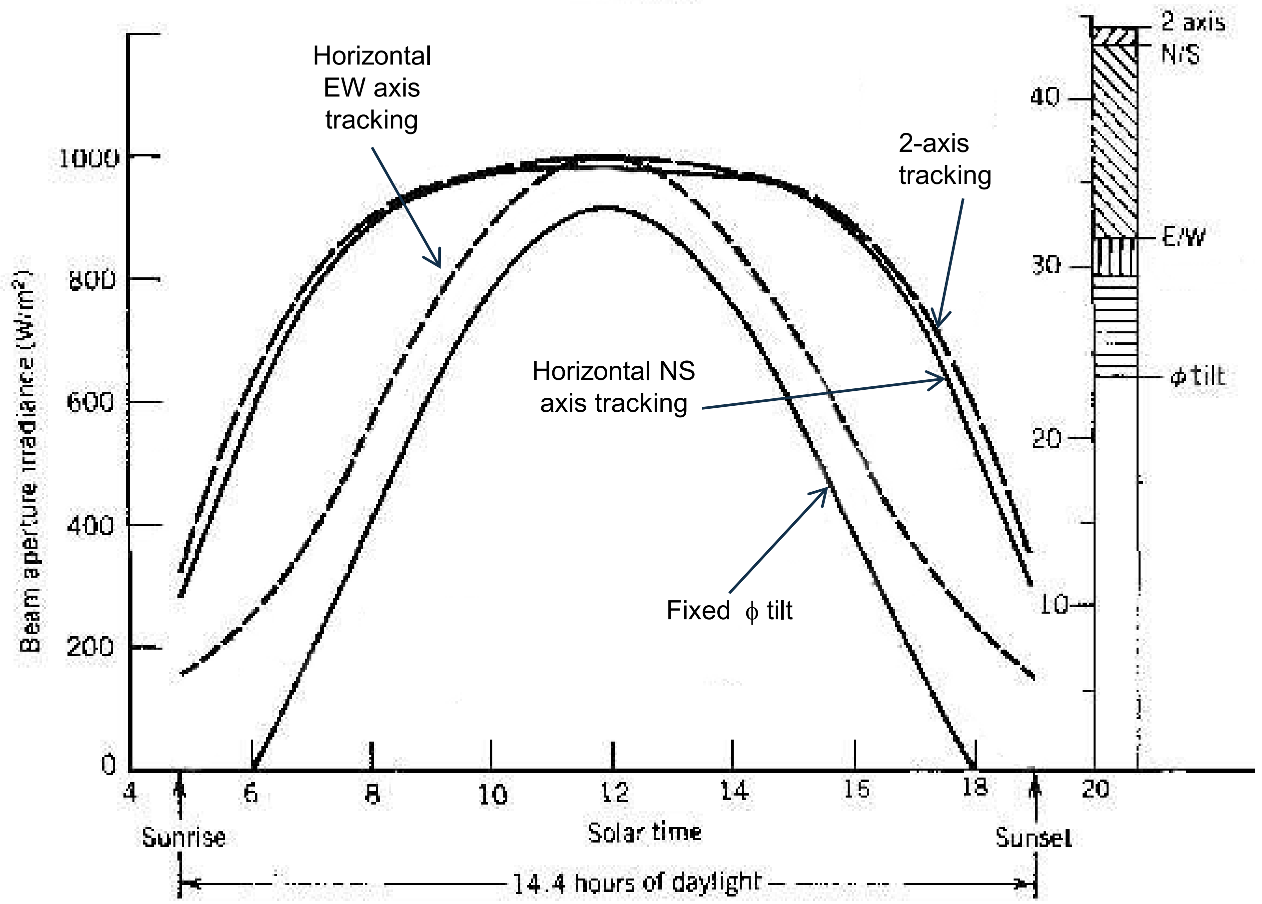
- Sun following in EW direction (fixed tilt);
- Low market development;
- Medium performance.

Tracker NS axis

- Sun following in EW direction;
- Cost competitive;
- Great performance.

Tracker 2-axis

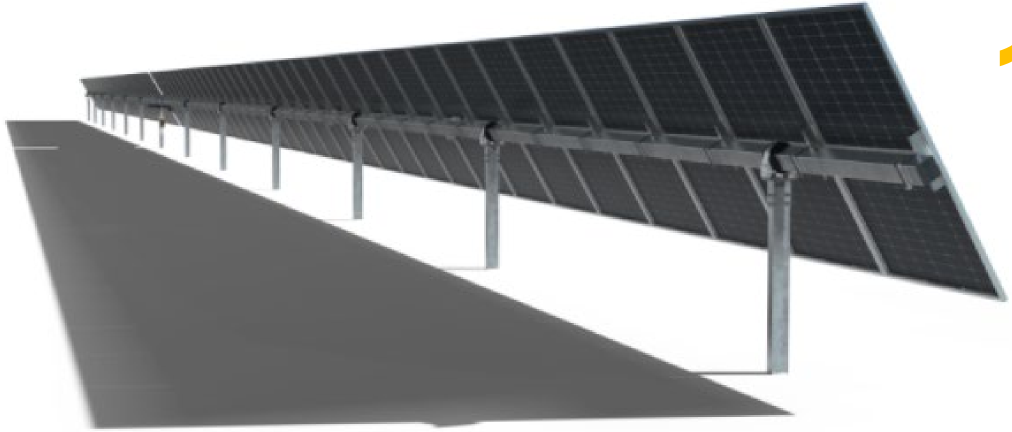
- Sun following in EW and NS direction;
- High costs;
- Best performance.



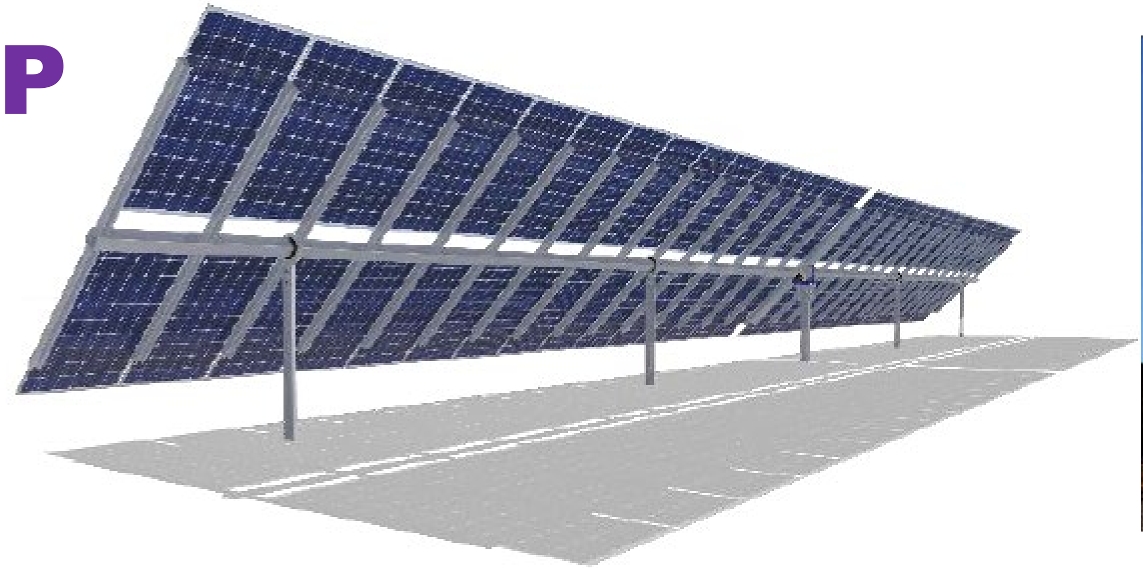
Horizontal single axis tracker

1P vs 2P

1P



2P



Horizontal single axis tracker

1P vs 2P

Single row

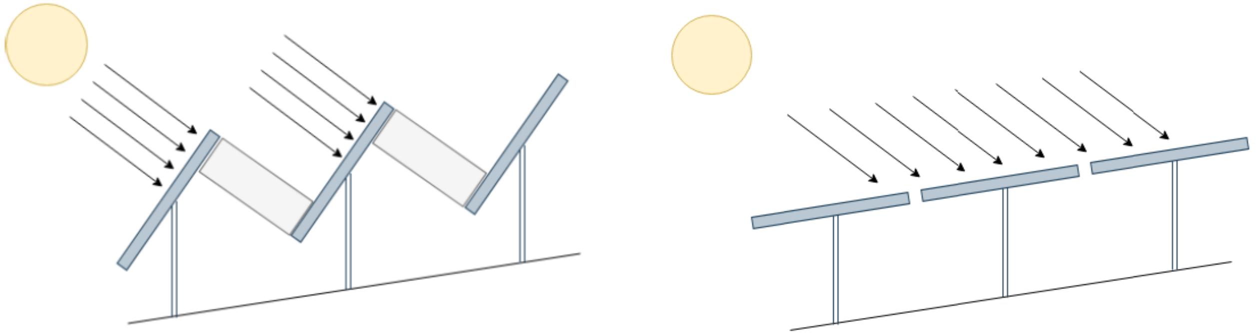
- 1 motor for each row

Multi row

- 1 motor for more rows

Horizontal single axis tracker

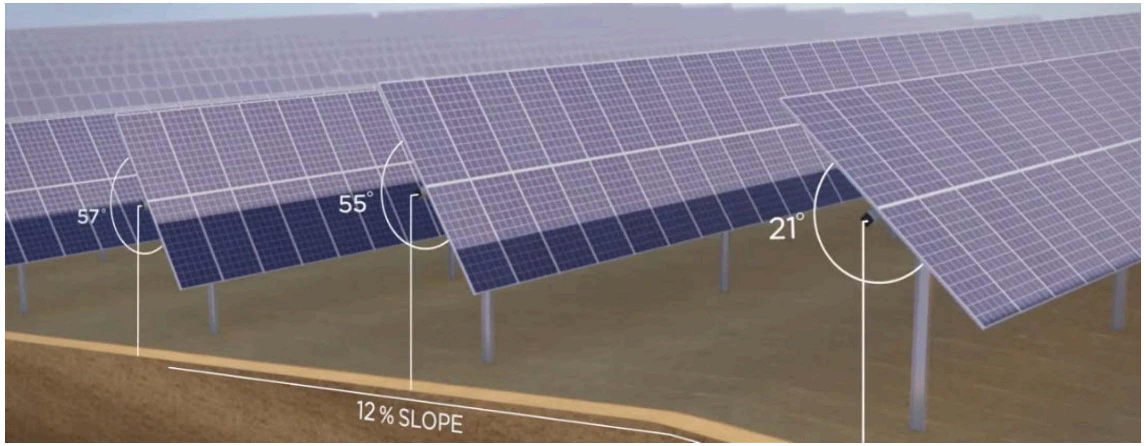
Backtracking

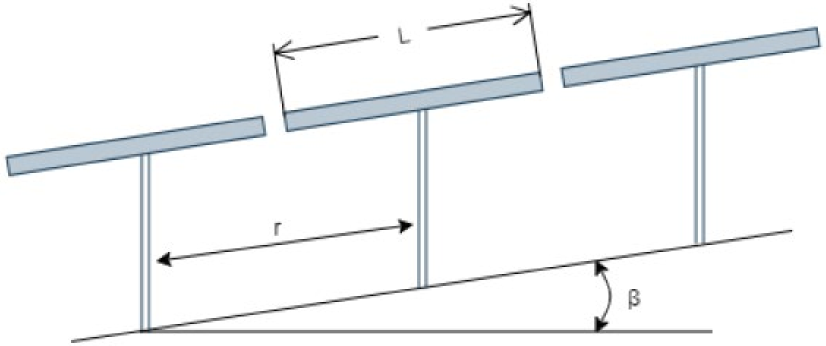


- ➢ Back-off algorithm to maximize the production and at the same time avoiding mutual shadowing.
- ➢ Begins in the maximum angle of movement and starts to minimize the tilt position to avoid shades until the night-time angle.

Input:

- PV module height (L);
- Spacing between trackers (r)
- Inclination west to east of the ground (β)
- Daytime and location.





2. Main equipments

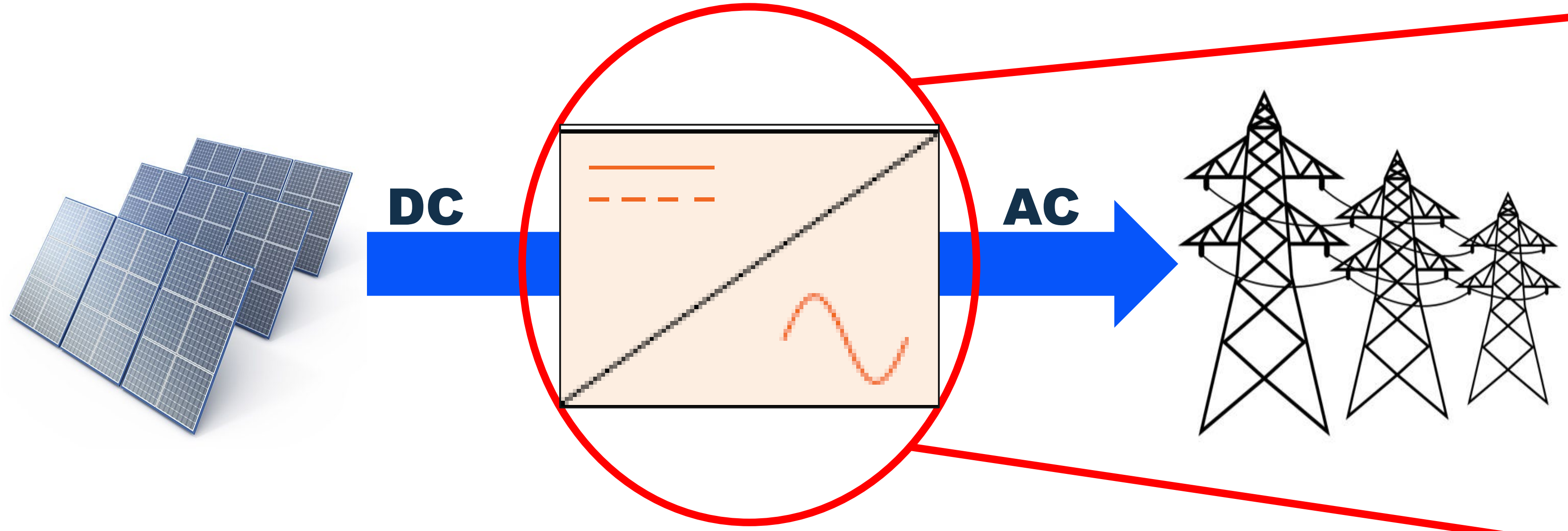
2.1 PV modules

2.2 Structures

2.3 Inverters

Inverter

Basics



Centralized inverter

String Inverter

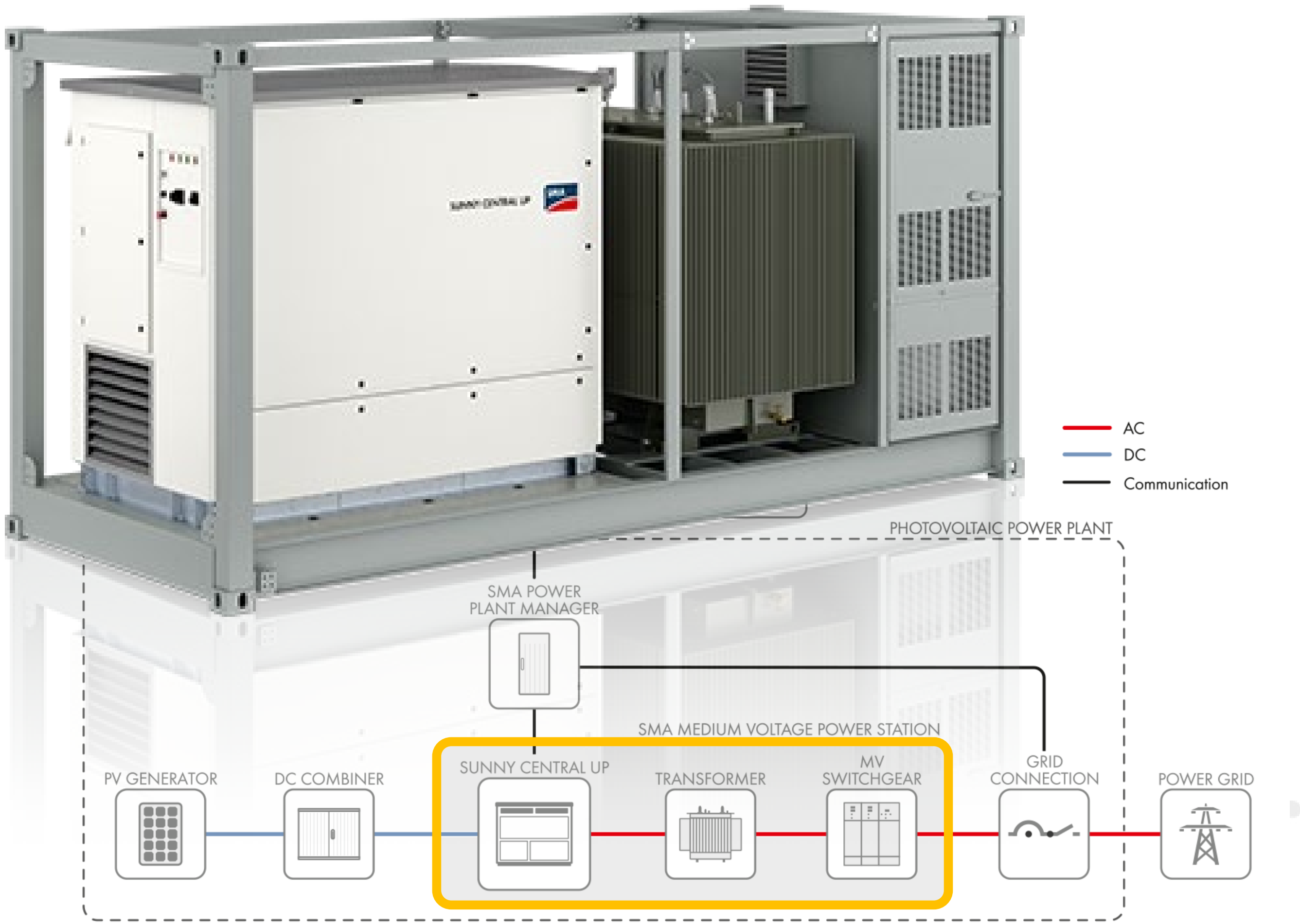
- Converts direct current (DC) into alternating current (AC);
- Maximize power output of solar array (MPPT);
- Interface with grid;

Inverter

Centralized inverter

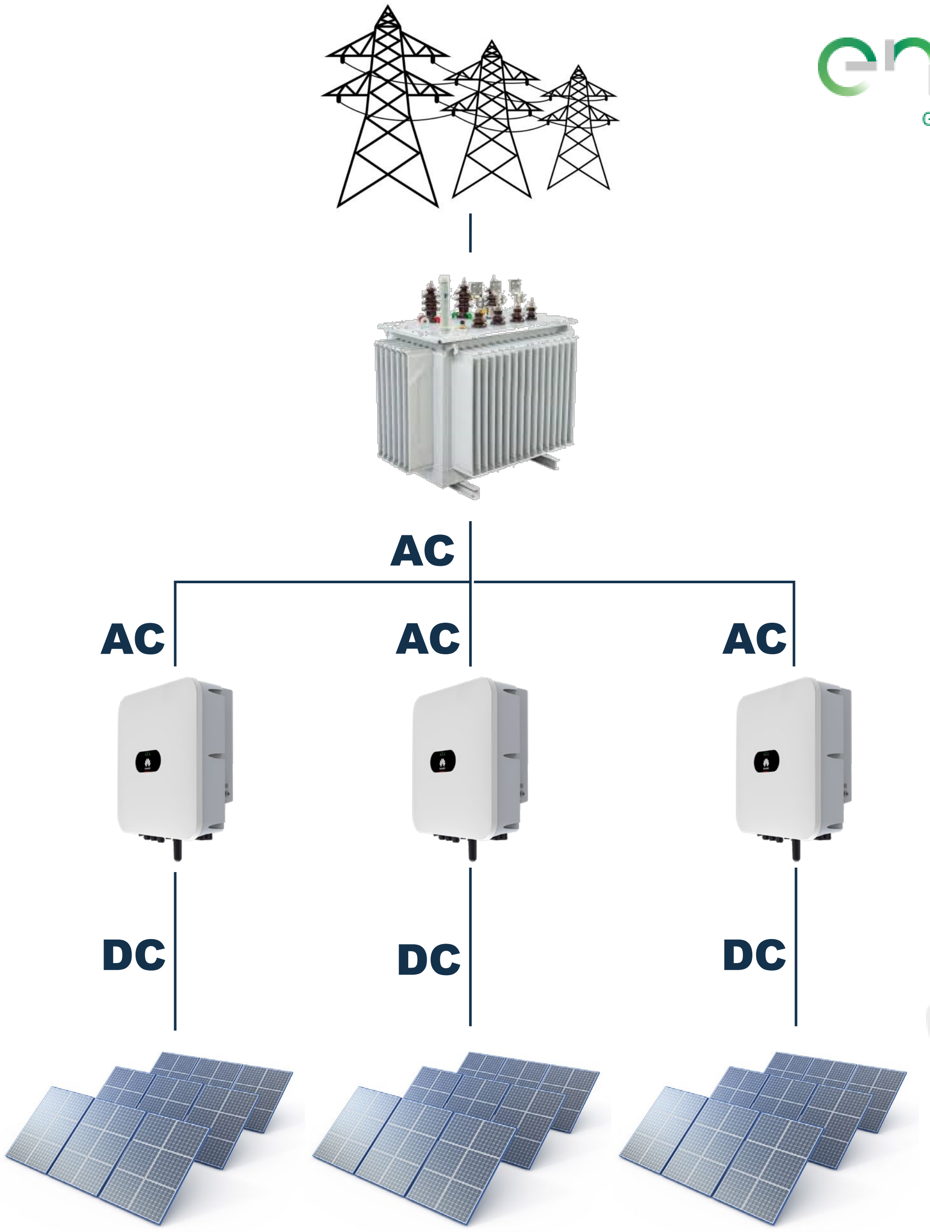
Power
Conversion
Unit

Inverter	LV/MV Transformer	Auxiliaries



Inverter

String inverter



Pros and cons:

- More inverter units → Higher costs
- MPPT per strings → Higher energy production
- Shorter DC cables → Lower costs
- Smaller units → Less production losses in case of failure

3. Conceptual design

3.1 Input definition

3.2 Configuration optimization

3.3 Output

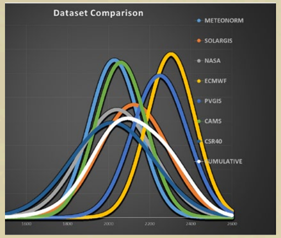
Road to the sun

Conceptual design

Green Power

Input

Meteo data selection



Constraints

Site

Project

Equipments

Module

Inverter

Structures

Configuration optimization

Batch energy simulations

Layout Research Algorithm

Layout and BoQ generator

Output

Solar Resource Energy Assessment

General Technical Specification

Bill of Quantities and Layout

3. Conceptual design

3.1 Input definition

3.2 Configuration optimization

3.3 Output

Equipments selection

Modules, inverters and structures

Modules
- **Monofacial**
- **Bifacial**

Structures
- **Fixed**
- **Tracker**

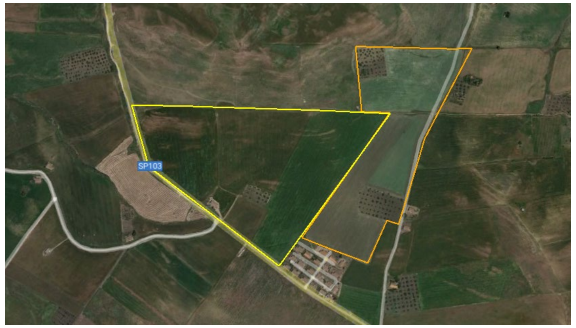
Inverters
- **String**
- **Centralized**

Input constraints

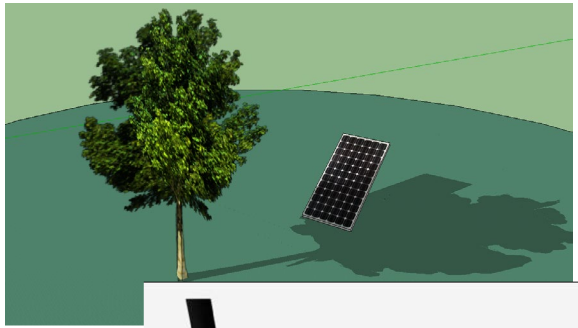
Site and projects constraints

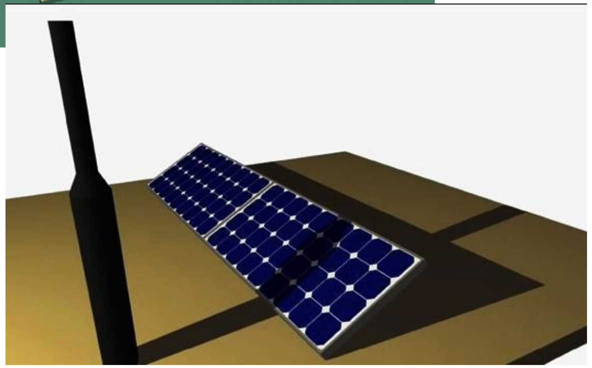
Site constraints

Land availability

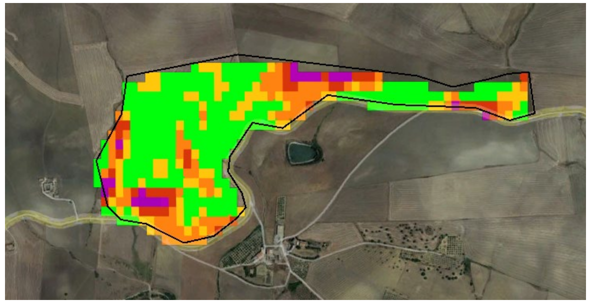


Shading Elements





Land orography



Project constraints

- **Time;**
- **Costs;**
- **Technical.**

3. Conceptual design

3.1 Input definition

3.2 Configuration optimization

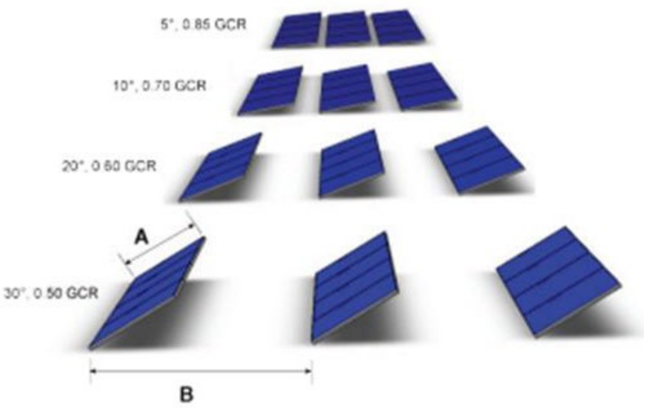
3.3 Output

Layout optimization

LCoE based

Ground Cover Ratio (GCR)

- Interdistance between structures



DC/AC selection

- Number of strings x inverter selection

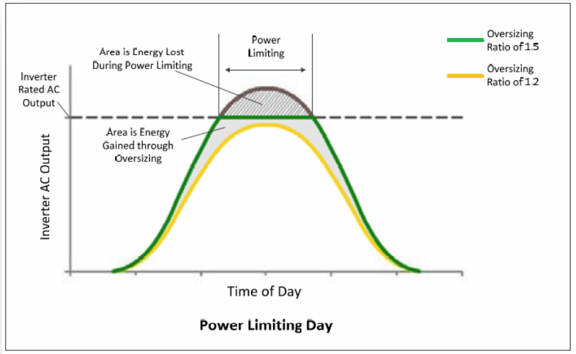


Figure 1a: Daily Production Profile Power Limiting Day

Levelized Cost of Energy (LCoE)

$$LCoE = \frac{Total\ cost\ over\ lifetime\ (capex + opex)}{Total\ energy\ produced\ over\ lifetime}$$

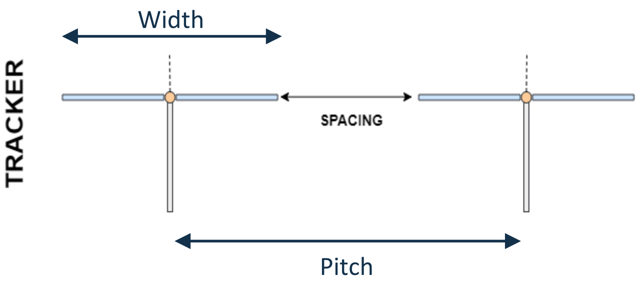
Layout optimization

Ground Cover Ratio (GCR)

$$GCR^{-1} = \text{Total area of the PV plant} / \text{Area occupied by modules}$$

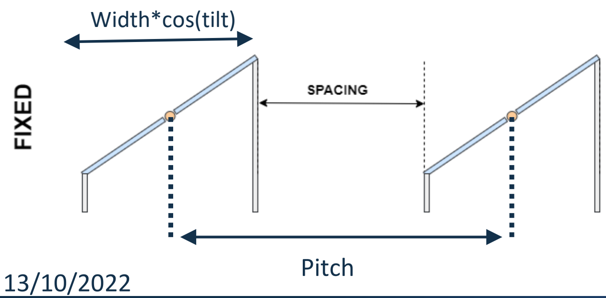
For NS axis tracking structures

$$GCR^{-1} = \frac{Pitch_{EW\ direction}}{Width_{EW\ direction}}$$

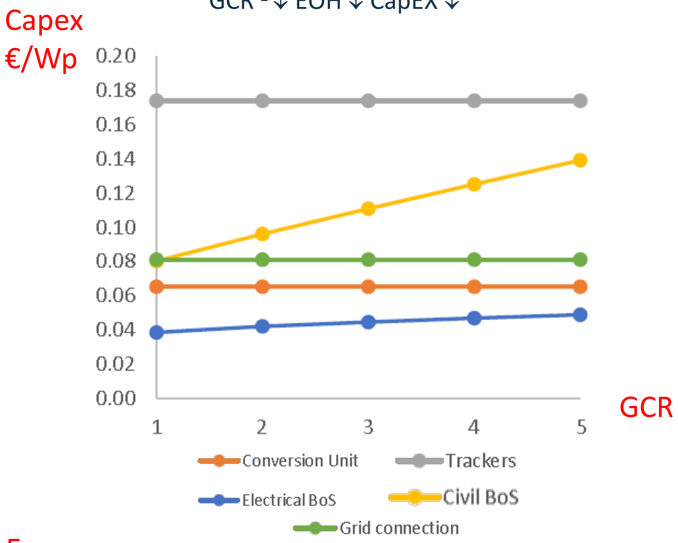


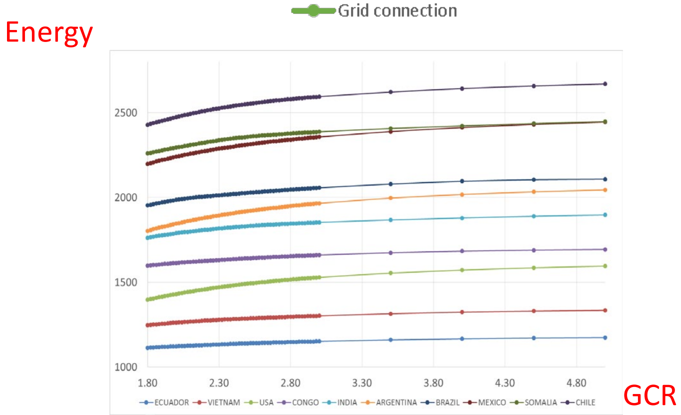
For fixed structures

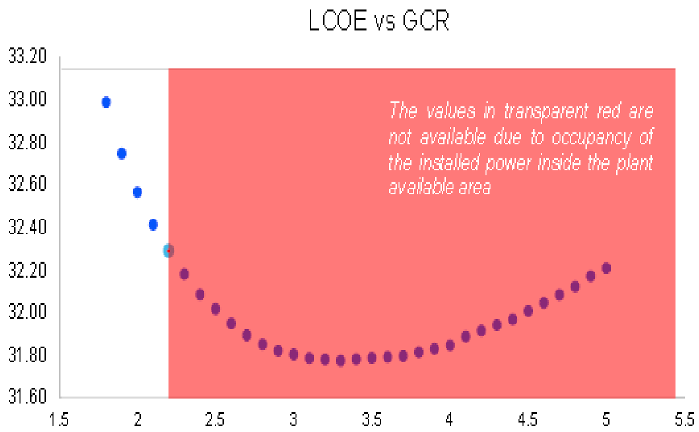
$$GCR^{-1} = \frac{Pitch_{NS\ direction}}{Width_{NS\ direction} * \cos(tilt)}$$



GCR^{-1} ↑ EOH ↑ CapEX ↑
GCR^{-1} ↓ EOH ↓ CapEX ↓

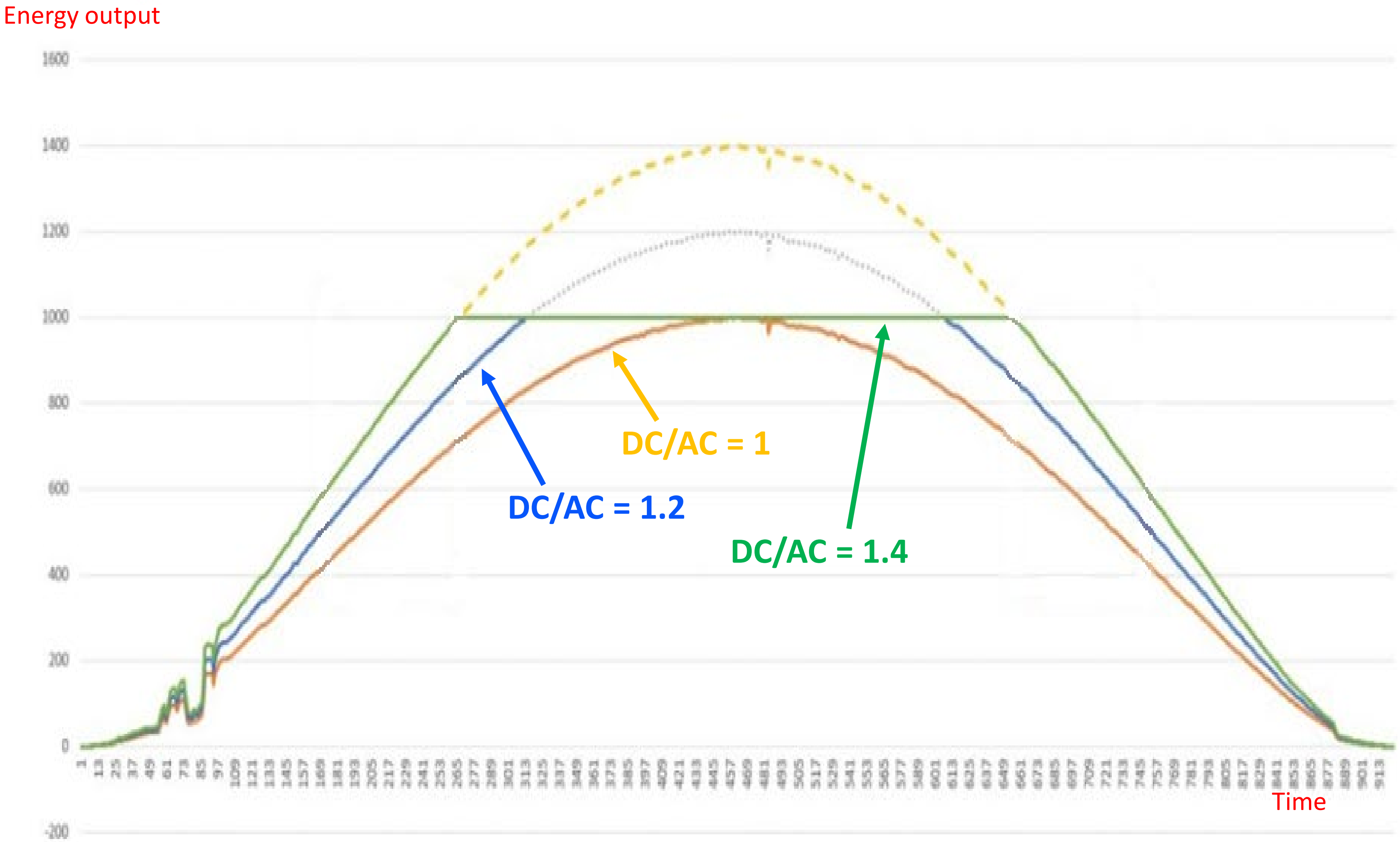






Layout optimization

DC/AC

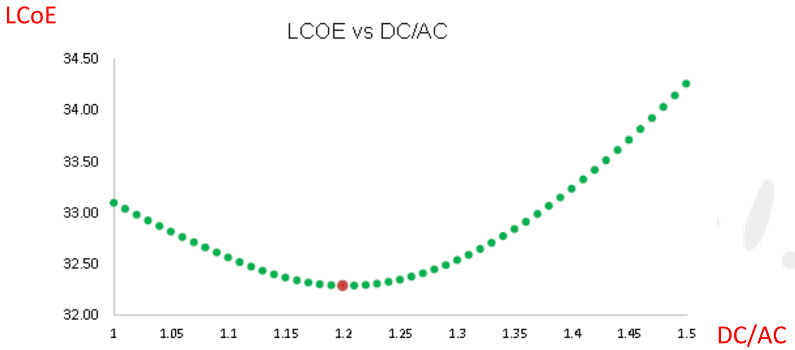


DC constant

- DC/AC ↑ → EOH ↓ Capex ↓
- DC/AC ↓ → EOH ↑ Capex ↑

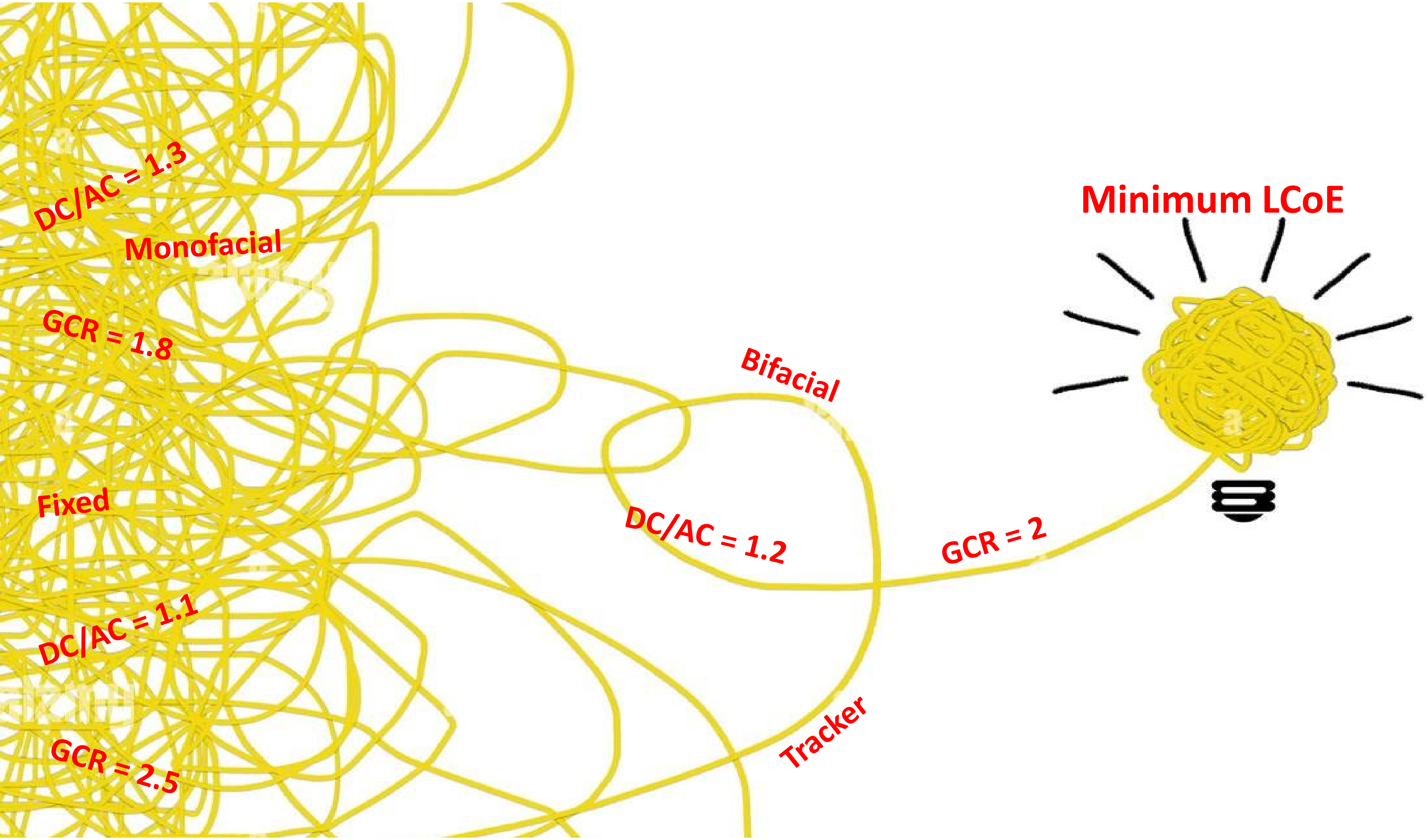
AC constant

- DC/AC ↑ → EOH ↑↓ Capex ↑
- DC/AC ↓ → EOH ↓↑ Capex ↓



Optimized Layout

Minimum LCoE



3. Conceptual design

3.1 Input definition

3.2 Configuration optimization

3.3 Output

Output

General Technical Specification (GTS)

Meteo data

Data
Maximum Yearly Solar Irradiance [W/m^2]
Minimum Air Temperature [°C]
Average Air Temperature [°C]
Maximum Air Temperature [°C]
Yearly Average Relative Humidity [%]
Yearly Rainfall rate [mm/year]
Yearly Average wind speed [m/s]
Yearly Max wind speed [m/s]
UV rays index threshold
DC Plant Capacity [MW_{dc}]
AC - Total Plant Inverters Capacity at 25°C [MVA]
# of CU COE simulation
Power Factor @ inverter level
Voltage MPPT Inverter range (min V - max V):
Max DC Voltage level (V):
Structrure Type
Tilt N/S/E/W (°):
Azimuth N/S (°):
Free spacing between structures in their maximum footprint position (NS for fixed or EW axis for tracker) [m]
Free spacing between structures in their maximum footprint position (EW for fixed or NS axis for tracker) [m]
Photovoltaic modules (monofacial and bifacial):
Total number of modules:
Electrical strings (# modules in series):
Maximum Imp (A)
Maximum modules string short circuit current Isc in operative condition (A)
Maximum modules string short circuit current Isc in operative condition (A) *3 hours average*

Electrical data

Layout data

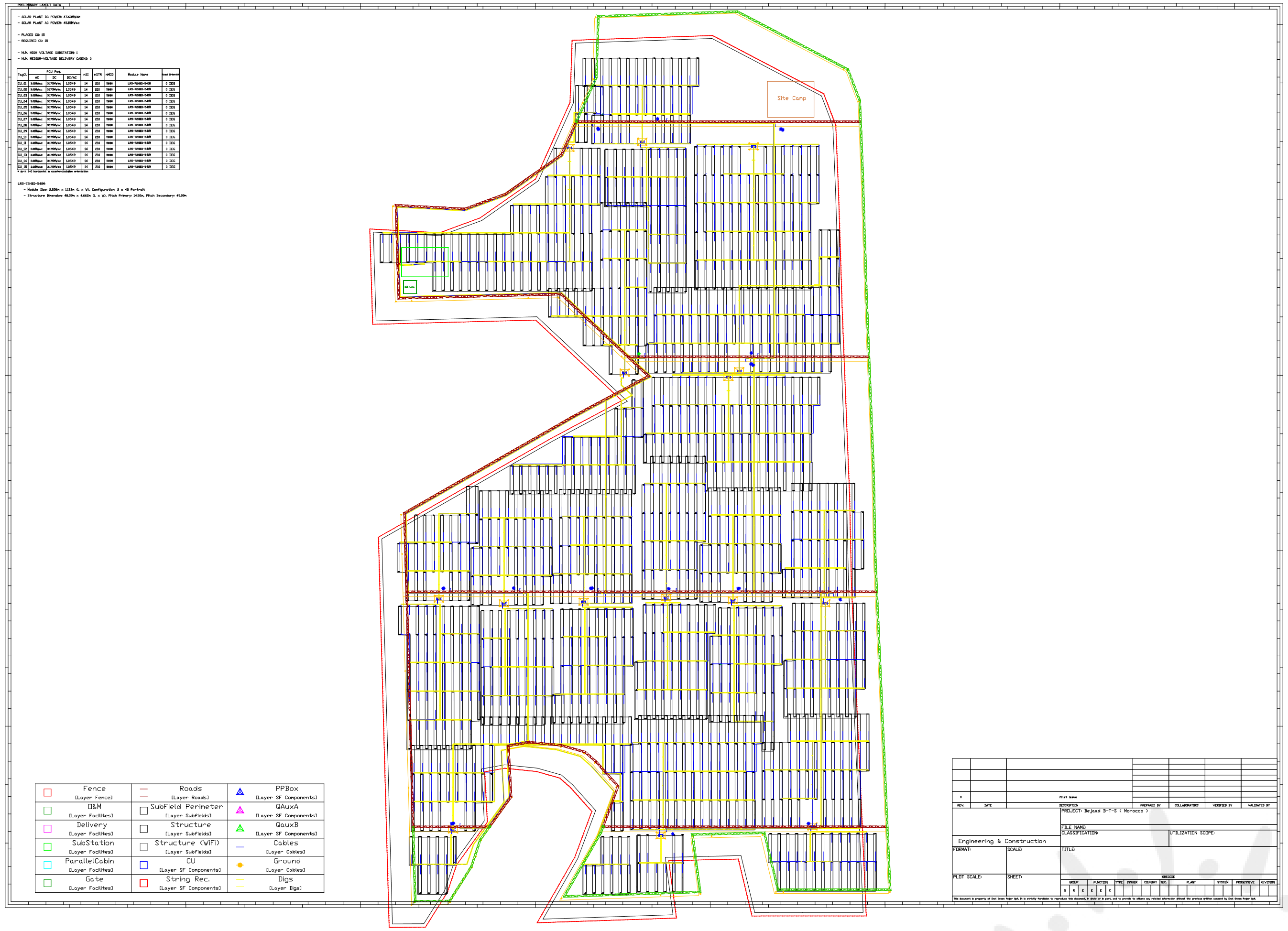
4. PV plant layout

PV layout

Basics

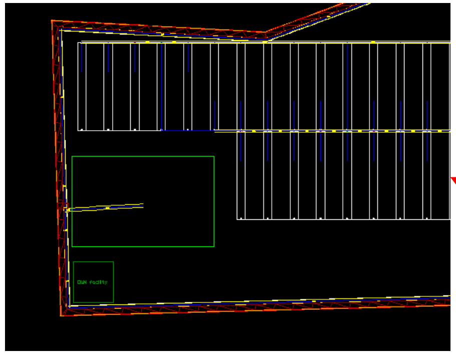
- The PV layout represent the PV plant and its components in the real spatial disposition

- Main elements:
  - Structures and module disposition
  - Electrical components and cabling
  - Roads, fences and facilities
  - Exclusion areas

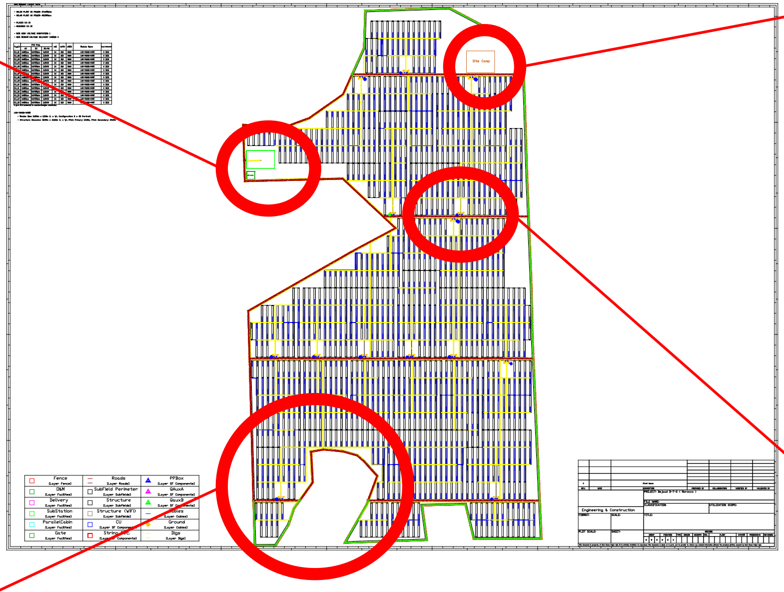


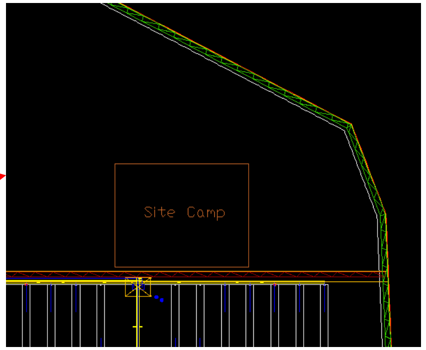
PV layout

Details



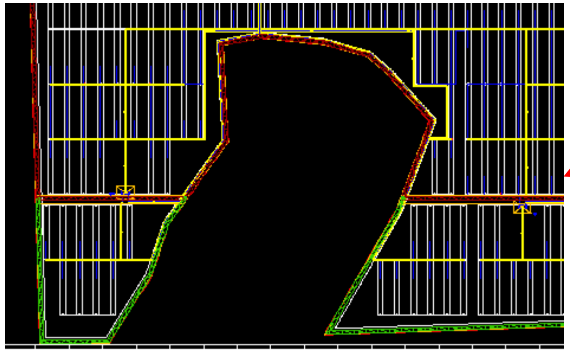
Step-Up station
O&M facility



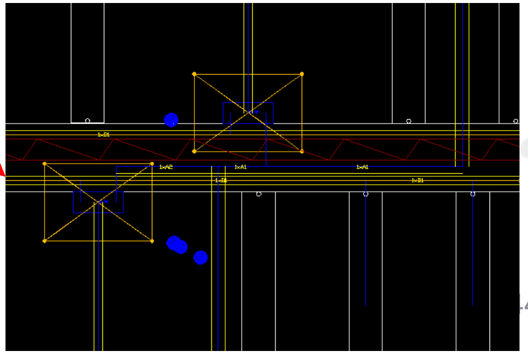


Site camp

Exclusion area
Fence



Internal roads
Transformation cabin
Cabling




Il sole brilla sempre, anche sopra le nuvole
The sun always shines above the clouds
El sol siempre brilla por encima de las nubes
Email: marco.caramanna@enel.com

GLOBAL OPTIMIZATION OF INTEGRATED PHOTOVOLTAIC SYSTEM FOR LOW ELECTRICITY COST

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792059

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