Report Technical Assistance Response Plan Algeria

September- November 2016

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Condor

Technical assistance on the design and construction of a ground-based photovoltaic plant of 1MWp rated capacity

Response plan first workshop
September 5, 6, 2016
UDES, CDER, Bou-Ismail, W. Tipaza, ALGERIA

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Abstract

This report provides the outcomes of the CTCN technical Assistance Response plan regarding the implementation including the EPC (Engineering, Procurement and Construction) for a 1 MW Photovoltaic facility in Boughezoul, Algeria.

This assistance plan was executed in two phases: In September, a 2-day inception workshop took place and in November a 3-day workshop focused on the concept design for a 1 MW installation and the associated full assistance plan for implementation, covering the EPC elements and analysing existing gaps in the implementation plan and offering options to close these gaps.

Contents

Summary

Algeria has defined Photovoltaic technology as one of the key technologies in its transition to a larger share of renewable energy in the energy mix in Algeria.
Algeria also wishes to build up technical and organisational know-how regarding the implementation of PV projects (at multi MW scale) , in order to execute EPC projects of this kind in-house (as opposed to a tendering process with supply from outside the country). Hence the Algerian request to CTCN to assist them in this scope of work that eventually will also benefit the own economy, for example through generating jobs. At this moment, the Ministry of Energy prepares a plan for implementation of 4 Gigawatt PV capacity in Algeria.

This report describes the concept design for a 1 MW installation and the associated full assistance plan for implementation, together with the identification of gaps for this implementation and the associated risks, with their corresponding mitigation measures.

1

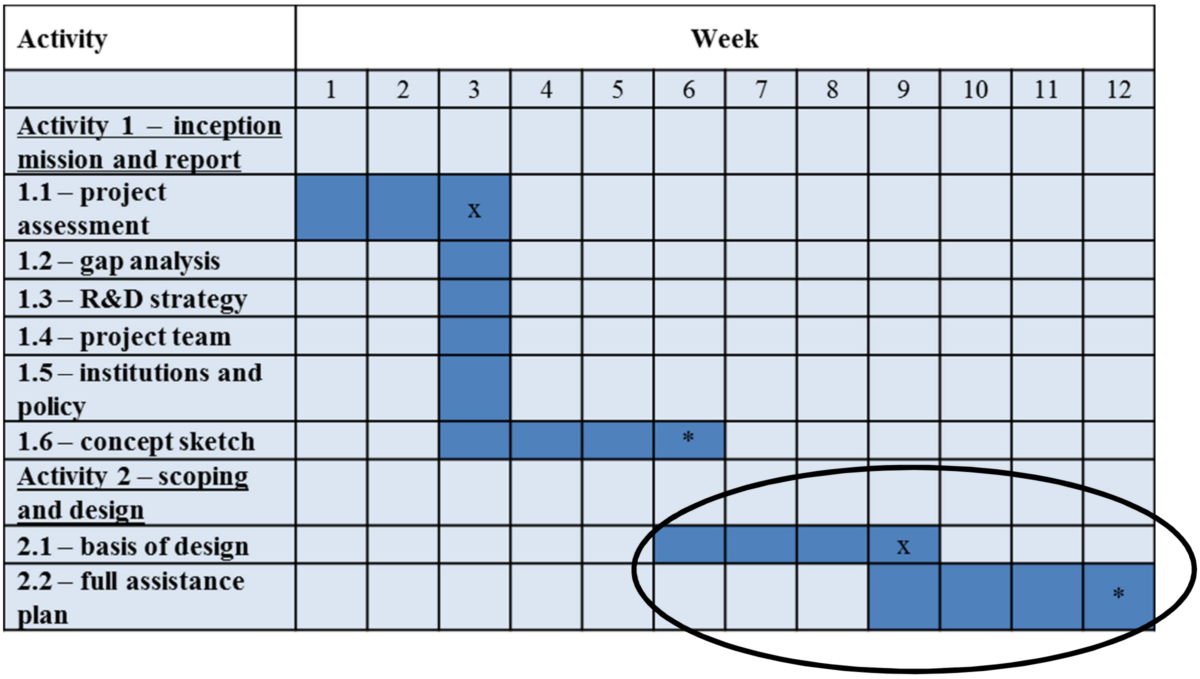
Introduction

Algeria has defined photovoltaic technology as one of the key technologies in its transition to a larger share of renewable energy in the energy mix in Algeria. This transition includes a target of 22GW of renewables in 2030.

Based on these ambitions, CDER, as one of the public institutions involved in the realisation of Algeria's renewable energy program, has identified the wish to realize a 1 MW photovoltaic power plant in the area of the new town Boughezoul (170 km south of Algiers). The realization of this 1 MW PV plant will act as a hands-on implementation model and learning vehicle.

Recently, the Algerian government has announced that it aims to issue a tender for the installation of 4 Giga Watt PV capacity. This plan will be publicised in January 2017. Therefore, the 1 MW EPC technical assistance plan fits perfectly in the overall ambitions regarding PV in Algeria, as the aim of the government is to include local companies and investors.

In September 2016 the inception workshop was conducted (activity 1 in figure 1); in this workshop the outline and elements of the technical assistance plan were discussed. The Full Assistance plan workshop (activity 2 in figure 1) was conducted in November 21-23, 2016, at the premises of CDER in Tipaza, Algeria.



Activity	Week											
	1	2	3	4	5	6	7	8	9	10	11	12
Activity 1 – inception mission and report												
1.1 – project assessment	■	■	■ x									
1.2 – gap analysis			■									
1.3 – R&D strategy			■									
1.4 – project team			■									
1.5 – institutions and policy			■									
1.6 – concept sketch			■	■	■	■ *						
Activity 2 – scoping and design												
2.1 – basis of design						■	■	■	■ x			
2.2 – full assistance plan									■	■	■	■ *

Figure 1: Project schedule technical Assistance plan

2

Workshop set-up and execution

2.1 Participants

The workshop participants included the following persons.

From Algeria:

List of participants in the second workshop with respective functions

N°	Name	Function	Affiliation
1.	KHELIF Messaoud	Researcher, Project Manager	CDER
2.	HADJ ARAB Amar	Senior Researcher, PV division director	
3.	HASSAINE Linda	Researcher, Team leader PV systems	
4.	SEMAOUI Smaïl	Researcher, Team leader PV systems	
5.	ABDELADIM Kamel	Researcher PV systems	
6.	BOUCHAKOUR Salim	Researcher PV systems	
7.	HADJIDJ Khaled	Production department manager	CONDOR
8.	SEBAA Bilal	Quality & control service	
9.	REBOULI Hassen	Studies and planning service	
10.	MAHRANE Aeloui	Senior researcher PV systems	UDES
11.	LAOUR Mohamed	Researcher PV systems	
12.	BENDIB Douadi	Researcher PV systems	

These participants from Algeria are also the persons that will be involved in the EPC implementation of the 1 MW PV plant.

For ECN:
Mr. Martin Spath, Senior consultant PV technology
Mr. Paul van den Oosterkamp, Senior energy Advisor and project manager for this CTCN assignment.

2.2 Workshop agenda

The agenda for the second workshop was conducted along the number of themes that were discussed with CDER in the inception workshop. These themes were concentrated on the EPC elements as well as phasing issues and the identification of gaps where technical assistance is most needed. We also discussed the risks assessment and the possible mitigation of these risks.

Day 1: Monday, November 21

Nr.	***Time***	***Subject***	***Lead***	***Remarks***
	09.00	Welcome, opening of workshop, coffee &tea	P.	
	09.15- 09.45	Introduction of participants	P.	
1	**10.00- 11.00**	**EPC overall plan**		
		• Objectives	M.	
		• Scope	P.	
		▪ Planning	P.	
2	**11.00 – 13.00**	**Detailed discussion on EPC plan elements**	M.	
		• Basis of design		
		• Basic Design		
	Lunch 13.00-14.00	•		
3	**13.00 – 15.00**	**Detailed discussion on EPC plan elements**	**M.**	
		• Grid connection		
		• Information from utility company		
	15.00 – 15.30	**Break**		
4	**15.30 -17.00**	**Detailed discussion on EPC plan elements**	P.	
		• Detailed design and Balance of System components		
		Q&A		
5	**17.00**	**Wrap-up of Day 1, outlook Day 2**		

Day 2: Tuesday, November 22

	Time	*Subject*	*Lead*	*Remarks*
6	**10.00 – 13.00**	**Detailed discussion on EPC plan elements**		
		Procurement		
		Site preparation		
		Installation of equipment		
		Commissioning and test runs		
	13.00 – 14.00	**Lunch**		
6	**14.00 – 17.00**	**Plant visit Condor (tentative)**		
8		(if yes, swap with the morning)		
		Wrap-up of Day 2, outlook Day 3		

Day 3: Wednesday, November 23

	Time	*Subject*	*Lead*	*Remarks*
6	**10.00 – 13.00**	**Risk assessment for EPC plan**		
		Confirmation of Objective		
		Which risks to exist in the execution of the EPC plan ?		
		What are the 2 most unwanted events to take place ?		
		Which mitigating measures can be thought of ?		
	13.00 – 14.00	**Lunch**		
6	**14.00 – 16.00**	**Detailed discussion on EPC plan elements**		
8		Finalization of gap identification		
		Preparing recommendations for CTCN		

3

Basic design of the 1 MW PV plant

3.1 Basic design considerations

The basic design is a very important step in the EPC process. The basic design determines the magnitude of all streams in the process (involving all material streams (input and output), for example water or steam, electricity . The basic design for the 1 MW PV plant is strongly related to the local irradiance from the sun, the available space, the estimated efficiency of the solar modules employed, the generated electricity per module over a year period and, as a result, the calculation of the number of modules to satisfy a required capacity.

Usually, a quick, back of the envelope calculation is made first. When the result is in the ballpark of the objective, a more detailed calculation is made using a detailed modelling tool such as PVSyst (see paragraph 3.3 for an explanation) in our case.

3.2 Quick estimate on sizing of the PV plant

In the workshop, the basic design steps were discussed and a first quick estimate was illustrated in a number of relatively simple steps:

Step 1. *Establish Peak sun hours for location*
→ Say 5 hrs.

Step2. *Multiply Peak sun hours with STC[1] irradiance of 1000 W/m^2*
→ 5hrs*1,000W/m^2= 5,000Wh/m^2 per day

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[1] STC = IEC (International Electrotechnical Commission) Standard Test Conditions (module temperature of25^{0}C and1000W/m^2 in-plane insolation, with AM 1.5 spectrum)

Step 3. *Establish Solar cell efficiency and calculate electricity power produced per m^2*
→ Say 20 % (0.20)
→5,000Wh/m^2 per day*0.20=1,000Wh/m^2 per day= 1kWh/m^2 per day, this is the electrical energy that can be produced per m^2 of module surface per day

Step 4 *Establish module surface area to calculate power production per module*
→ Say 1 module= 1.5 m^2
→1 Module produces 1.5m^2*1 kWh/m^2 per day =1.5 kWh/module per day
→This equals 365 days/year* 1.5 kWh/module per day = 547.5 kWh/module per year

Step 5 *Establish nameplate capacity of plant :*
→1.1MW nameplate capacity= 1,100,000 Wp= 1,100 kWp
→With 5 sun peak hours per day to give 1,100 kW*5h= 5,500 kWh/day
→This equals 5,500 kWh/day*365 days/year = 1,825,000 kWh/year
→This is 1,825 MWh/year (DC side)

Step 6 *Calculate amount of modules*:
→With derate factor of 0,77 : 0,77*1,825 = 1,404 MWh per year or 1,40 GWh/year (Note : 0.77 derate factor is NREL based and includes losses due to module contamination, degradation and mismatch, and losses in the electrical system)
→The amount of modules will be 1,825,000 kWh/547.5 kWh per module = 3,333 modules.

This production estimate and number of modules should be confirmed in the detailed design of the project, but serves as a ± 10 % estimate. And of course the estimated production in MWh should be compared to the projected demand.

3.3 PVSyst simulation

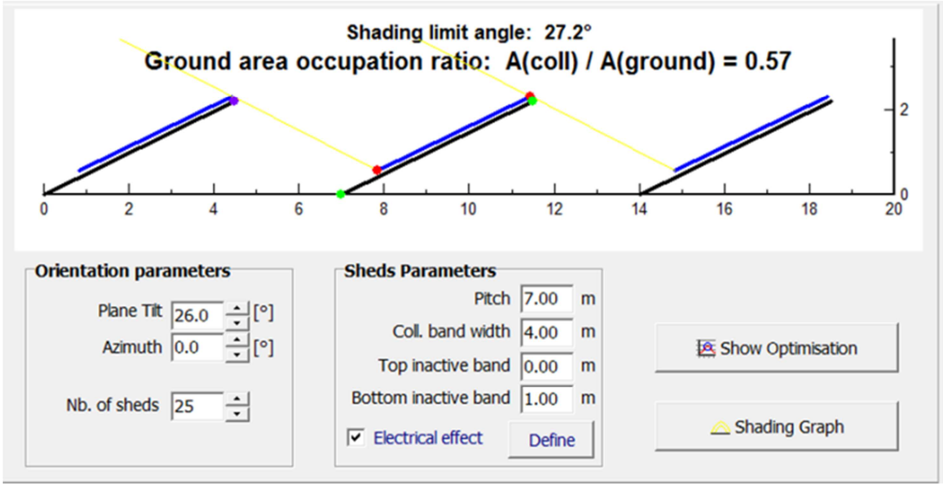
For a more detailed calculation of the production in MWh, a first simulation was made by Condor, using the PVsyst modelling tool (http://www.pvsyst.com/en/).

These simulations were based on the data sheet supplied of the CEM250-60 module, and the inverter has been taken from the PVsyst data base.

The results by Condor were checked by ECN. The Condor results show a production estimate of 2120 MWh/year (DC),and this result was also confirmed by ECN, using the Condor input settings.

ECN made two relevant corrections with regard to the Condor calculations:

a) The simulation performed by Condor has not taken into account the shading of modules by the shed in front (this is the rack with module in front of another module, this shed can provide shade to the back module; see figure 2 as illustration).



Shading limit angle: 27.2°

Ground area occupation ratio: A(coll) / A(ground) = 0.57

Orientation parameters

Plane Tilt 26.0 [°]

Azimuth 0.0 [°]

Nb. of sheds 25

Sheds Parameters

Pitch 7.00 m

Coll. band width 4.00 m

Top inactive band 0.00 m

Bottom inactive band 1.00 m

☑ Electrical effect Define

Figure 2: Shed and shading

b) With regard to the effect of cooling by wind flowing between the PV modules, the related heat transfer coefficient to take this cooling effect into consideration, has to be applied. To this end, Condor has calculated with a heat transfer coefficient U_c of 20.0 W/m^2K in the PVSyst model, using the 'semi-integrated' modules option. In practice, there will be more heat transfer from wind flowing between the modules; the PVsyst default value for U_c for a 'free mounted module' is 29.0 W/m^2K ,or, if wind speed is available, the suggested conservative value is: U_c = 25.0 W/m^2K.

ECN has modelled the influence of both shading and heat transfer. The results, together with the Condor simulations are given in figure 3.

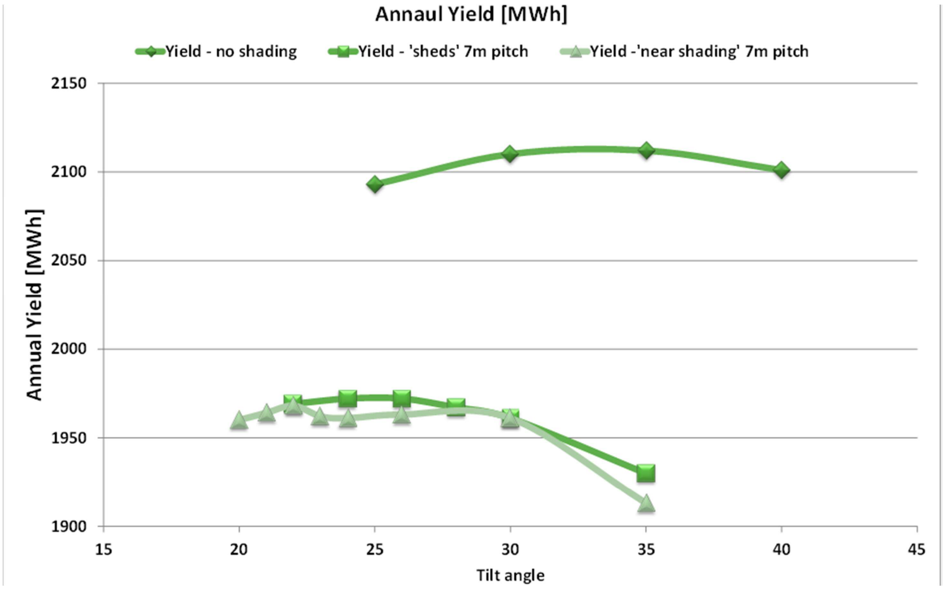


Figure 3: Results of simulations for unshaded and shaded systems as a function of tilt angle. The optimum tilt angle shifts to lower values when the shed shading is considered. Slightly different results are obtained when using the 'sheds' or the 'near shading – module strings' methods.

The ECN simulation results show a production value of about 1960 MWh/year, this is after the inverter, so AC electricity (the lower two lines in figure 3).

The full report on PVSyst simulation is provided in Annex A3.

4

Full assistance plan

4.1 EPC phases

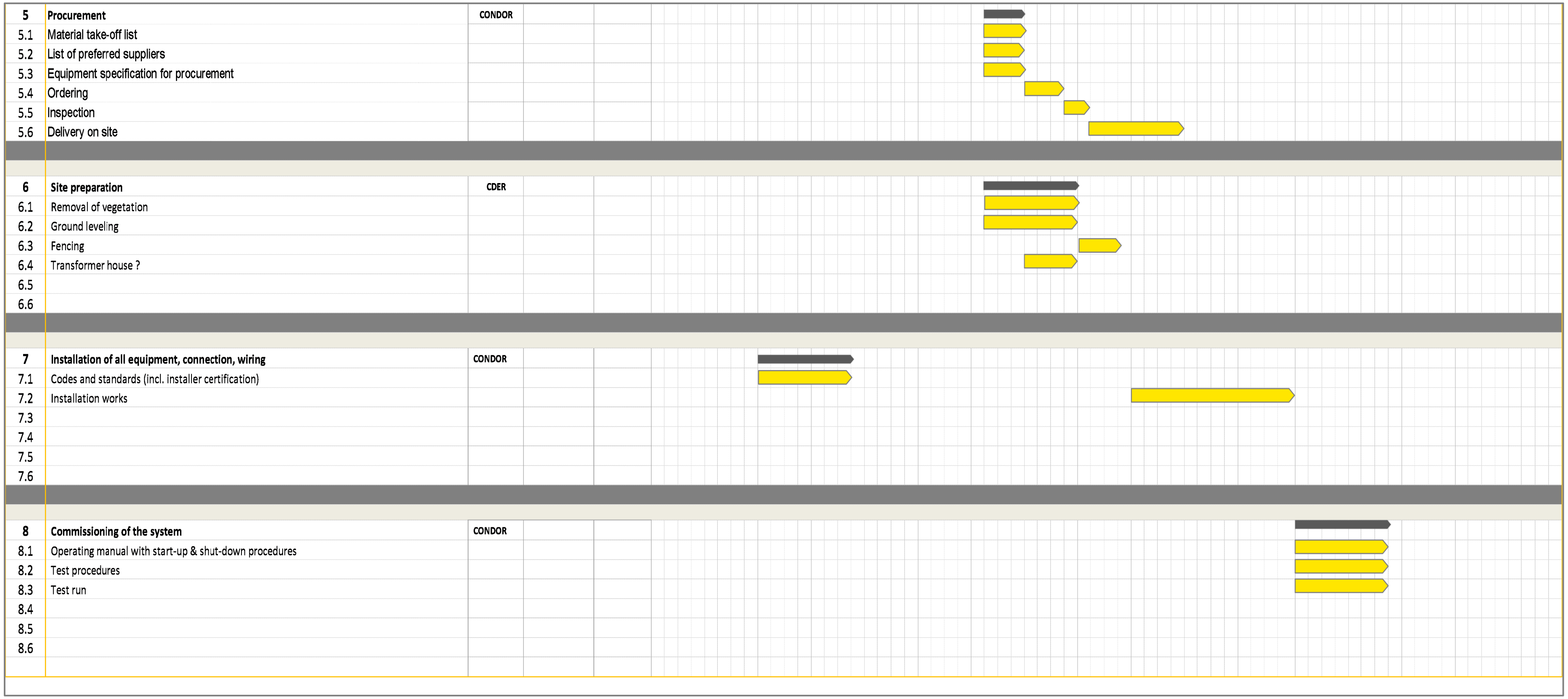
In the inception workshop in September, already the relevant tasks regarding the EPC implementation were defined:

Task nr.	Subject	Responsible actor	Support role
1	Basis of design : starting points to be confirmed	CDER	ECN
2	Basic design : functional specification, main components, output	CDER	ECN
3	Agree with stakeholders (utility company) about requirements for connection to the grid	CONDOR	
4	Detailed design (all equipment specifications, applicable codes & standards, test protocol)	CONDOR	CDER, ECN
5	Procurement	CONDOR	
6	Site preparation	CDER	
7	Installation of all equipment, connection, wiring	CONDOR	
8	Commissioning of the system	CONDOR, Utility company in Boughezoul	

These tasks were taken up in the second workshop to discuss in detail the content and the scope of each step. In the following paragraphs, the EPC tasks will be described, the related presentations are added in Appendix A2.

The EPC plan timeline, indicated in figure 4, is about 14 months. This EPC plan can be used as starting point for the detailed project plan.

N.	Phases of the EPC process	Main actor	Gap Yes/No ?	Support/Review Role
1	**Basis of design**	CDER		ECN
1.1	Location			
1.2	Area available, in m^2			
1.3	E- demand and profile (day-night, year)			
1.4	Applicable codes for safety and design			
1.5	Weather conditions (sunhours, wind, rain, duststorms, hurricanes)			
1.6	Irradiance data and temperature			
2	**Basic design : functional specification, main components, output**	CDER		ECN
2.1	Energy delivered to the grid (AC), In MWh/year			
2.2	Type of solar PV cells (mono or multi c-Si) , producer of cells			
2.3	Type of inverters: string, central ? In container ? Cooled ?			
2.4	Output of PVsyst: what will be used for basic design ?			
2.5	Control philosophy			
2.6	Applicable standards (IEC, etc.)			
3	**Grid connection**	CONDOR		
3.1	Agree with stakeholders (utility company) about requirements for connection to the grid			
3.2	Net characteristics (Voltage & frequency ranges, protection: current levels & critical times)			
3.3	Applicable safety rules and standards, net metering			
3.4	Grid drawing (feed-in location, main components, locations and types of generators and loads)			
3.5				
3.6				
4	**Detailed design (all equipment specifications, applicable codes & standards, test protocol)**	CONDOR		
4.1	Solar cells and modules			
4.3	Inverters, cabling, transformer(s) and protection equipment			
4.4	Racking and enclosures			
4.5	Applicable codes & standards			
4.6	Specification of layout and civil works			
4.7	Power management, (remote) SCADA, ICT system			



5	**Procurement**	CONDOR
5.1	Material take-off list	
5.2	List of preferred suppliers	
5.3	Equipment specification for procurement	
5.4	Ordering	
5.5	Inspection	
5.6	Delivery on site	
6	**Site preparation**	CDER
6.1	Removal of vegetation	
6.2	Ground leveling	
6.3	Fencing	
6.4	Transformer house ?	
6.5		
6.6		
7	**Installation of all equipment, connection, wiring**	CONDOR
7.1	Codes and standards (incl. installer certification)	
7.2	Installation works	
7.3		
7.4		
7.5		
7.6		
8	**Commissioning of the system**	CONDOR
8.1	Operating manual with start-up & shut-down procedures	
8.2	Test procedures	
8.3	Test run	
8.4		
8.5		
8.6		

Figure 4: EPC plan and timeline

4.2 Basis of design

The basis of design formulates the starting points and boundary conditions of the facility :

- In a separate document, and should include :
- Location (where ? Elevation ?)
- Area available, in m^2
- Electricity demand and profile (day-night, year)
- Applicable codes for safety and design
- Weather conditions (sun hours, wind, rain, dust, hurricanes)
- Irradiance data and ambient temperature (over the year)
- Production required (MWh per year)
- Type of system : grid connected or stand alone.

The basis of design was discussed as first relevant EPC task.

For this Task, CDER will be in the lead and ECN will support.

4.3 Basic design

The basic design will produce the functional specifications, the desired output and main components, to answer the question how many solar panels and other main components are required to satisfy the requested electricity to the grid (AC, in MWh/year):

- A 'back of the envelope' calculation to estimate nr. of modules
- A more detailed calculation tool like PVsyst to verify and to include the overall irradiance over the year and with regard to the position towards the sun (altitude and azimuth)
- Basic lay-out and electrical drawings, single line diagrams with main safety and control features
- Type of solar PV cells (mono or multi c-Si), requirement for supplier (tier1..)
- Type of inverters (central, string) In cooled environment (air conditioned container) ?
- Control philosophy (link with grid connection; who will be responsible for the operation of the PV plant ?)
- Applicable standards (IEC, etc.)

In chapter 3, the basic design with regard to the PV plant was already discussed. With regard to inverter choice, a preliminary choice for string inverters was made, as they strike a balance between a large central inverter and micro inverters (per module one inverter).

The basic design gives either information for specifications to suppliers or can be used for input to detailed design in-house (in the detailed engineering task of the EPC plan.

For the basic design task , it was concluded that this task will be led by CDER, with support from ECN.

4.4 Grid connection

The connection to the grid is a very important aspect of PV implementation.
The grid connection is a vital element in the realisation of the PV system and requires a very good communication with the grid authority, the organisation that resides over the electric grid.

For residential PV systems (placed on rooftops of housed and buildings) the grid connection is relatively simple:

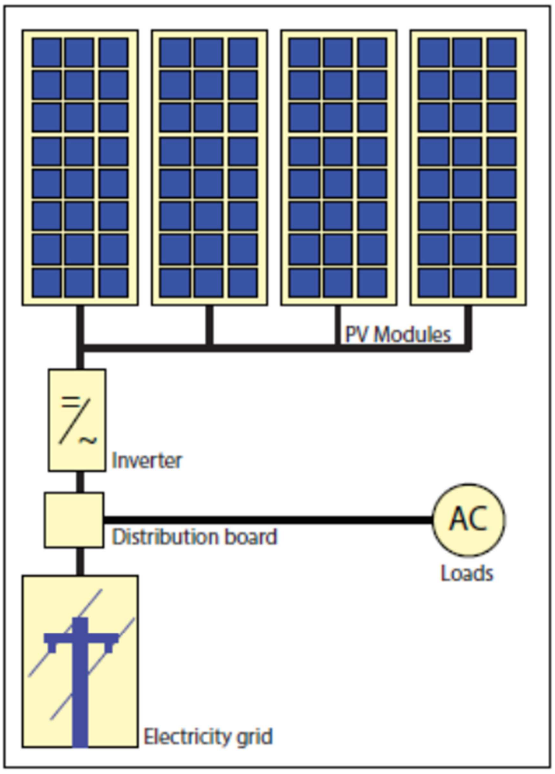


Figure 5: Residential PV system with grid connection.

(Source: Solar Energy, The physics and engineering of photovoltaic conversion systems, ISBN 978 1 906860 (2016))

For a large scale PV system, the grid connection is more complex, as more elements have to be checked, including the balancing and quality of the grid.

Typical characteristics of a grid connected PV system include:

- PV arrays connected to medium voltage grid through inverters and transformer station
- Both string inverters and central inverters are commonly used
- Dedicated SCADA system
- Possible use of local electricity storage for enhanced reliability and grid support.

A typical lay out of such a grid connected system is given in figure 6.

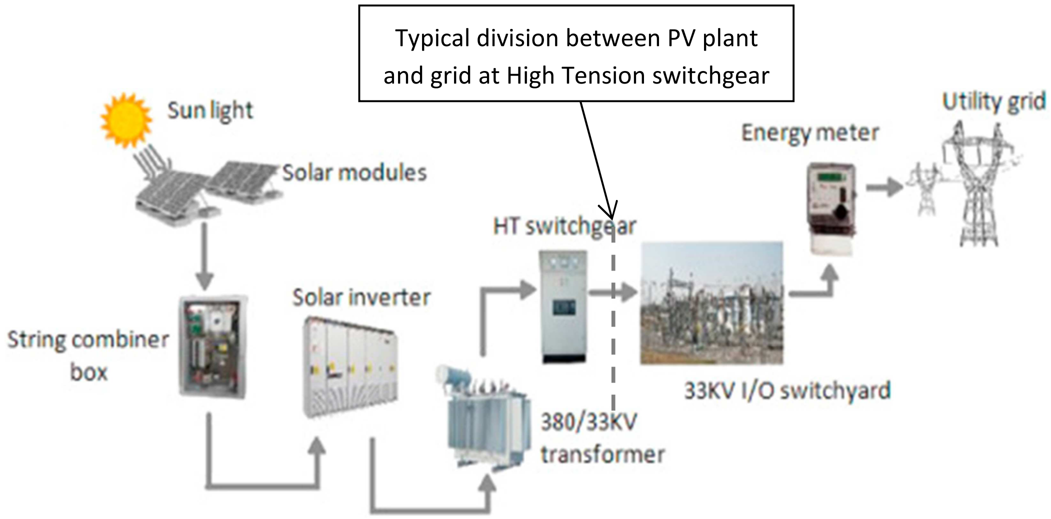

Typical division between PV plant and grid at High Tension switchgear

Figure 6: Typical grid connected system (source: B. Shiva Kumar, K. Sudhakar, Energy Reports 2015).

The *points of attention* for a grid connected PV system include:

- Array design: matching, cable efficiency, protection e.g. for partial shading, module failure
- Array and cables grounding, lightning protection, overload protection
- Quality of construction and installation
- Inverter (under)sizing (typ. about 90% of array peak power) can be economical
- Inverter protection & grid support: compliance to standards, tune settings to local conditions
- Connection to distribution grid: check / adjust control and protection settings, possible reinforcement (in communication with utility company).

In the process of grid connection, the various *voltage levels* have to be checked:

- DC collection grid
    - String voltages standardized at 1000 Volts
    - 1500 Volts will soon be standard: lower losses and about 30% higher inverter power rating
    - DC cabling to inverters not too long (V-loss, power loss)
- Inverter AC side voltage
- Inverters: At larger installations (kW .. MW level) 3-phase inverters are preferred, because of higher power density, longer lifetime and superior grid support capabilities

- AC voltage level are typically between 400V … 690V
- AC Connection point (grid tie-in point); depends on power rating and distance, but usually at medium voltage (MV), typically. 10 – 20kV. This requires a step-up transformer, but the inverters itself can be transformer-less -> lower losses
- Usually underground cables are more energy-efficient and reliable, than overhead lines (also depends on the overall power factor of the grid).

Required electrical equipment includes :

- Arrays / DC circuit
    - Array switches (for O&M purposes) and eventually series diodes, array fuses (protection)
    - Grounding and lightning protection of racks, cable ducts and equipment housings
    - Eventually measurement / monitoring equipment: electrical, irradiance, ambient temperature, wind speed
- AC circuit
    - Low Voltage load switches
    - Step-up transformer
    - Medium Voltage switches and circuit breakers
    - Larger installations may require parallel transformers, busses and distribution feeders for redundancy.
    - On-load tap changer or and/other means to control the Medium Voltage. Possibly adjustment of control and protection settings in the distribution system may be needed.

Regarding the electrical set-up of the PV system with regard to protection the following items are relevant:

- String diodes
    - Consider in case of partial shading
- Grounding
    - Layout and calculations
    - Ground fault detection
- Lightning protection
    - Based on calculations
- AC and DC switches to de-energize system for O&M purposes
- Safety
- Fire protection inverter, transformer & breakers
- Fencing and access route: Consider safety as well as replacement of large equipment (e.g. crane for transformers

Regarding the actual tie-in of the PV system into the grid, it is important to assess the feed-in location and route, with possible existing distribution stations, switching stations or distribution lines or cables, as well as the distance of the cable connection to the PV plant and what obstacles does it need to cross, e.g. critical infrastructure?

Also here, a discussion with the grid authority is required. Figure 7 illustrates the Grid tie-in at the Dutch island of Statia (Dutch Caribbean)

Figure 7: 2MWp PV system installation for STUCO (Statia, Dutch Caribbean, source: ECN)

Other elements that have to be investigated in relation to the grid connection include :

- Can the PV cabling be connected to an empty or new switch bay? Does it need a new distribution station or an extension?
- In case of a single failure in the distribution grid, can the power be rerouted though another (redundant) feeder? Does this need additional switchgear?
- Is there communication available or possible to a central control room?
- Do the feed-in point or the nearby other distribution stations have voltage control? If feeding in intermittent PV power leads to voltage fluctuations in the grid, this may be required
- Do Voltage settings in the grid might need adjustment ?

For example, an OLTC (= On Load Step Changer) may be used to control voltage in the grid. Figure 8 below shows a distribution feeder with the grid entry point at the upper left to which several households are connected with PV systems. During daytime the voltage over the distribution feeder increases with the distance to the grid entry point due to the feed-in of power from the PV systems. The low OLTC voltage setting prevents overvoltage at the end of the feeder. At night-time the voltage decreases with the distance to the grid entry point due to the household power demand. Then the high OLTC set point and the voltage regulator halfway keep the distribution feeder voltage in between safe operation limits. Besides, PV inverters can also contribute to the voltage regulation by controlling the reactive current, even at night-time.

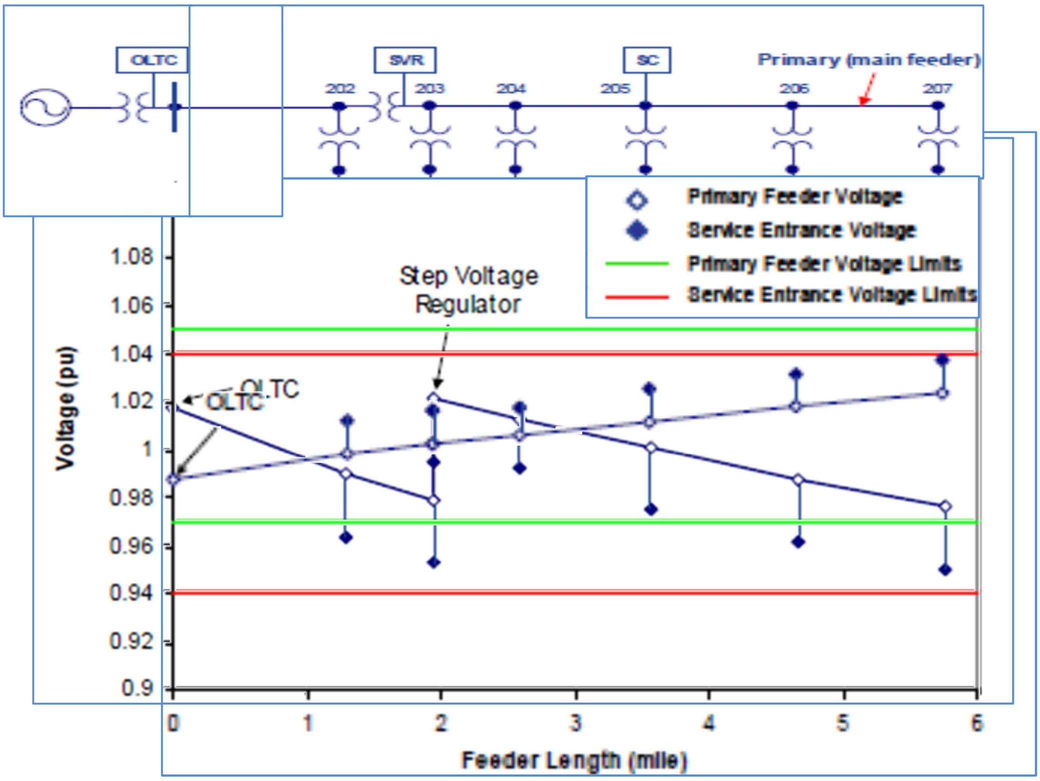


Figure 8: Voltage regulation with PV penetration in the grid

For the grid connection, it is crucial to obtain information from the grid authority, this information includes :

- Grid connection:
  - Application procedure, requirements
  - Permits, lead times
  - Connection fees, transport tariffs
  - Services provided by utility, e.g. metering, communication
  - Commissioning procedure
  - Grounding requirements (e.g. earthed neutral at either LV or MV side)
- Grid operation characteristics
  - Voltage setting and variations
  - Voltage quality, background harmonics

    - Typical load variations
    - In case of fossil power plants: minimum production level, ramp-up/down rates
    - Protection equipment and characteristics (current levels and response times)
- Compliance to (inter)national grid codes may include:
    - Reactive power limits/settings, e.g. fixed power factor or active voltage support
    - Frequency support needed, e.g. ramp rate limitation or reserve power for balancing?
    - Low- voltage ride through capability
    - Harmonics injection limits
    - Monitoring requirements
- Grid control / supervision / O&M
    - Possible integration with existing SCADA system, may require ICT upgrade
    - Service panel (on-site / remote location) for O&M purposes, and fault diagnosis
    - Current practice and experience, possible needs for O&M training

Finally, many different requirements do exist for connecting and operating PV systems (and other intermittent distributed renewable generation), of which several public documents are available, for example:

https://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0ahUKEwjQp8_Us-LQAhUEVywKHUadDeMQFgg9MAQ&url=https%3A%2F%2Fwww.iea.org%2Fmedia%2Ftraining%2Fpresentations%2Frenewableenergytrainingforlatinamerica2015%2FSession10MichaelCoddingtonNREL.pdf&usg=AFQjCNHEEAzINIV68KFAJbEV9xSbdEaDpQ
and:

https://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwilt8nTtOLQAhUEiywKHRHYCT0QFggaMAA&url=http%3A%2F%2Fwww.nerc.com%2Ffiles%2F2012_IVGTF_Task_1-3.pdf&usg=AFQjCNGLn6hNsvAiF6ozkFLU58ILbGQlnA&bvm=bv.140496471,d.bGg

For the task on grid integration, Condor will be in the lead.

4.5 Detailed design

In the EPC process, the detailed design is the phase to decide to either manufacture the equipment in-house (in that case the detailed design has to be done in-house as well) or to purchase equipment on the market, based upon the equipment specification.

In the detailed design task, also the applicable standards for design and for safety have to be listed. The following items are focus of the detailed design of the 1 MW PV plant:

- Solar cells and modules

- Inverters, cabling, transformer(s) and protection and safety equipment
- Racking for solar modules and enclosures
- Applicable codes & standards
- Specification of layout and civil works
- Power management, (remote) SCADA, ICT system.

For this EPC task, Condor is in the lead and CDER, ECN are in a support role.

4.5.1 Applicable codes & standards

The applicable codes & standards in relation to the design and implementation of a 1 MW PV system include:

- Cables : TüV 2PfG1169 or UL 4703 (1000V)
- DC connectors : TüV – IEC 50521
- PV modules : IEC 61215, IEC 61730
- Inverters :
    - UL 1741
    - IEC 68-2-68/EN 60068-2-68 (dust testing).

4.5.2 Inverters

Inverters are a key equipment item in the PV system. Figure 9 provides an overview of the different inverter systems available.

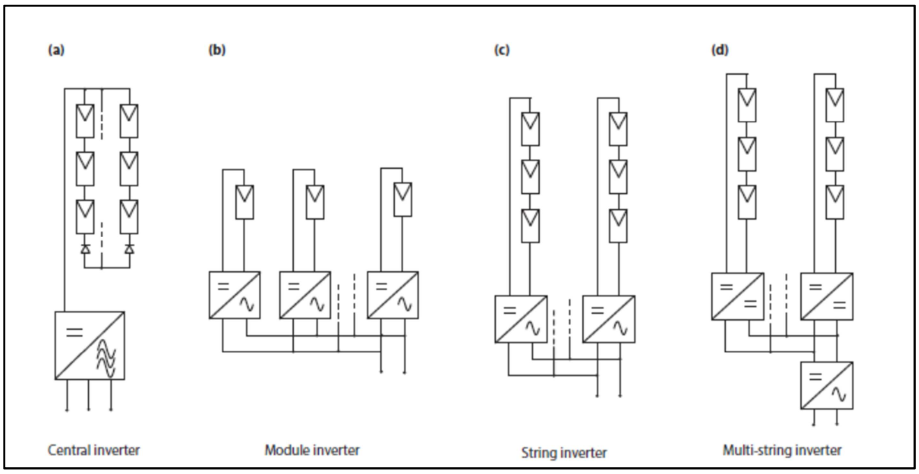


Figure 9: Different system architecture employed in PV systems (source : Solar Energy, The physics and engineering of photovoltaic conversion systems, ISBN 978 1 906860 (2016)

In the current 1 MW PV system, a choice was made for string inverters; these combine the advantage of central and micro (module) inverter. Inverters may also contain a DC-DC conversion and MPPT (Maximum Power Point Tracking). It was also decided that 24 PV modules per string would offer the most cost effective solution. These string inverters offer also the possibility to monitoring of data per string. Note: Larger string inverters often have enough capacity to connect several strings in parallel, sometimes with individual MPPTs per DC input.

Although many inverters have an IP rating that allows for outdoor mounting, proper enclosure, possibly with air conditioning, is important to improve their reliability and efficiency (i.e. to prevent de-rated operation at high temperatures).

For this subtask, Condor is in the lead.

4.5.3 Safety equipment and safety procedures

In the PV system, following safety equipment is required:
- Switches (automatic and manual), circuit breakers
- Personal safety equipment.

Regarding procedures, an operating manual with operating procedures, procedures for start –up and shutdown and a HAZOP (Hazard and Operability analysis) procedure are part of this. The HAZOP procedure is usually performed after finalization of the detailed design.

For this subtask, Condor is in the lead, with support from ECN and CDER.

4.5.4 Cabling and conduits

For cabling and conduits, the following elements are relevant :

- Different colour conventions of wiring for AC and DC
- DC cables must be certified up to 1 kV
- And should be coated with UV resistant material, as they are exposed to solar radiation
- Check/ calculate cable lengths and size (mm^2)
- Check all cable connections (commissioning stage)
- Conduits for housing of the PV wires.

For this subtask, Condor is in the lead, with support from ECN and CDER.

4.5.5 Racking and fencing

Racking requirements and standards in relation to wind or hurricanes. A study on soil conditions may be necessary to determine the best way to fix the racks and enclosures. Fencing of the facility is required for protection, prevention of vandalism.

These items are usually bought on the market, while often local companies are involved for construction activities.

For this subtask, Condor is in the lead, with support from ECN and CDER.

4.5.6 Power management system (PMS)

The power management system (PMS) supervises the supply and demand side and decides on the increase or decrease of power supply sources and, if applicable, energy storage devices. The PMS typically consists of :

- SCADA (supervisory control and data acquisition system) for monitoring, controlling
- To be integrated in Power Management system of Utility Company
- To be supported by ICT system (data storage, communication)

Also the control and monitoring of the PV plant has to be integrated in the PMS.
This task has also to be interfaced with the utility provider.

For this subtask, Condor is in the lead, but the local utility/ grid authority should be strongly involved.

4.6 Procurement

Once the detailed design is finalised, all equipment specifications are available and procurement can be initiated. The flowing items are relevant with regard to procurement:

- Material take-off list (all cabling, connectors, instruments to be prepared.
- List of preferred suppliers (e.g. tier 1 : Tier-1 companies are direct suppliers to OEMs. The term is especially common in the automobile industry and refers to major suppliers of parts to OEMs).
- Equipment specifications of all equipment items for procurement
- Ordering with selected vendors (supply contracts, delivery time, pricing)
- Inspection before shipping (FAT, factory acceptance test)
- Delivery of equipment and materials on site.

For this EPC task, Condor is in the lead and CDER, ECN are in a support role

4.7 Site preparation

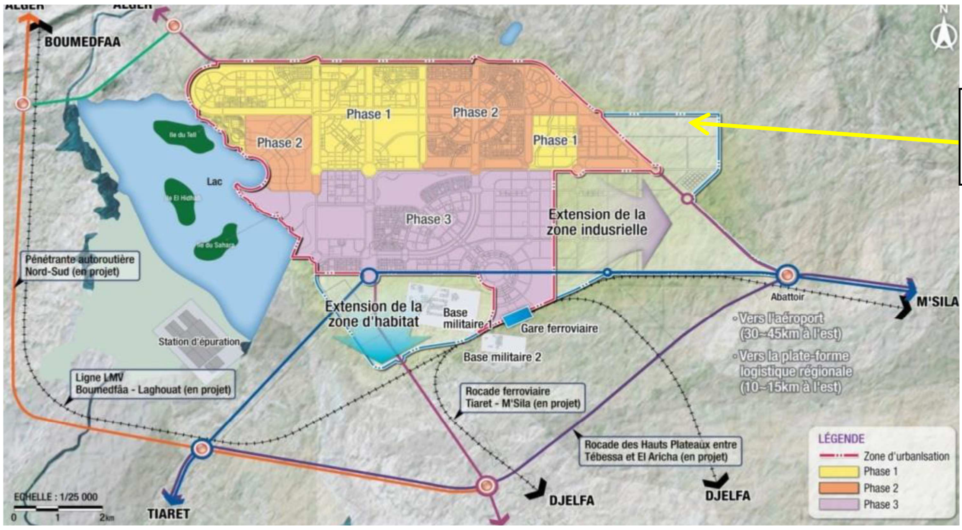
The site may have to be prepared for installation of a solar field, activities that are common include :

- Removal of vegetation, equalizing
- Possibly, a study of the soil characteristics
- Trenching and foundation construction (e.g. piles)
- Minimizing land disturbance
- Separate housing for transformer, eventual inverters

Figure 10 - 12 give a lay-out view of the new town project in Boughezoul of which realization is under way.

Projected project site in Boughezoul

Figure 10: site for 1 MW PV plant at Boughezoul



1 MW project location

Figure 11: Detailed view of location

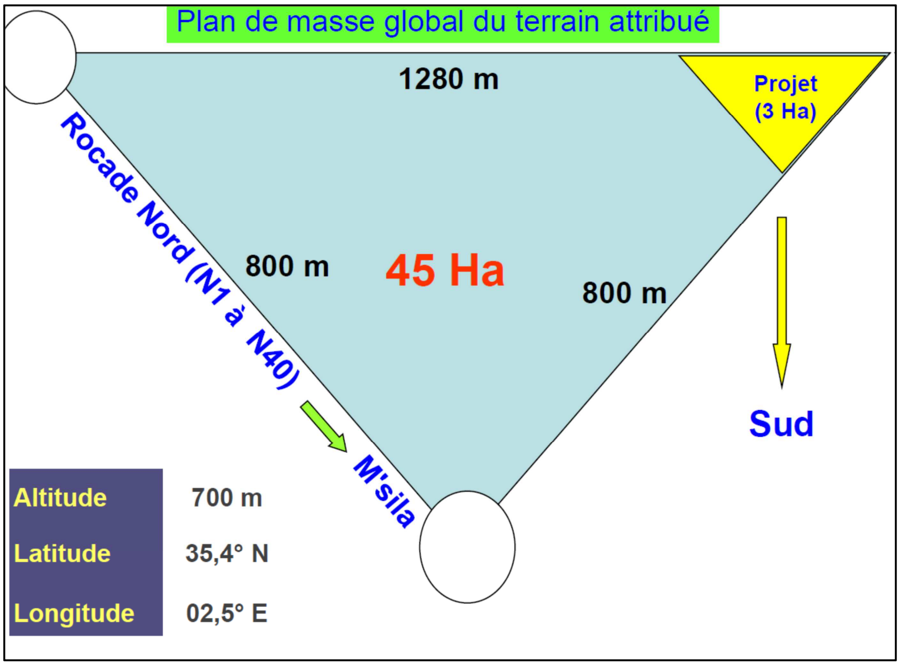


Figure 12: Site location and size data.

Base on the discussions , it was decided to have rectangular set-up of the solar modules, these modules can be poisoned in the 45 ha plot as desired.
The grid infrastructure in Boughezoul includes two 30kV middle voltage lines.

Condor is in the lead of the activities in relation to site preparation.

4.8 Installation of equipment

Installation of equipment is preferably by licensed installation companies and will include the mounting of all solar modules in the racks, installing inverters, possibly in a separate room or container, connection of all wiring on DC side and AC side.
A good reference regarding PV system installation is available on the NREL website (www.nrel.gov).

Condor is in the lead of this activity.

4.9 Commissioning and start-up

Once the installation of all equipment is finalized, the commissioning and start-up of the PV plant can be made. For this, next to the instructions of equipment suppliers, a test plan has to be made, based on applicable standards such as IEC-62446 and IEC -62346.
AC circuits to be tested based on IEC-60364-6.

A good reference regarding PV system operations and maintenance is available on the NREL website (www.nrel.gov).

Condor is in the lead of this activity, CDER and ECN are in a support role

4.10 Risk assessment

The risk assessment is useful, as we can, in advance, investigate the risks and the corresponding mitigating measures. The risk assessment was done with the EPC project team present and was done to answer the following questions:

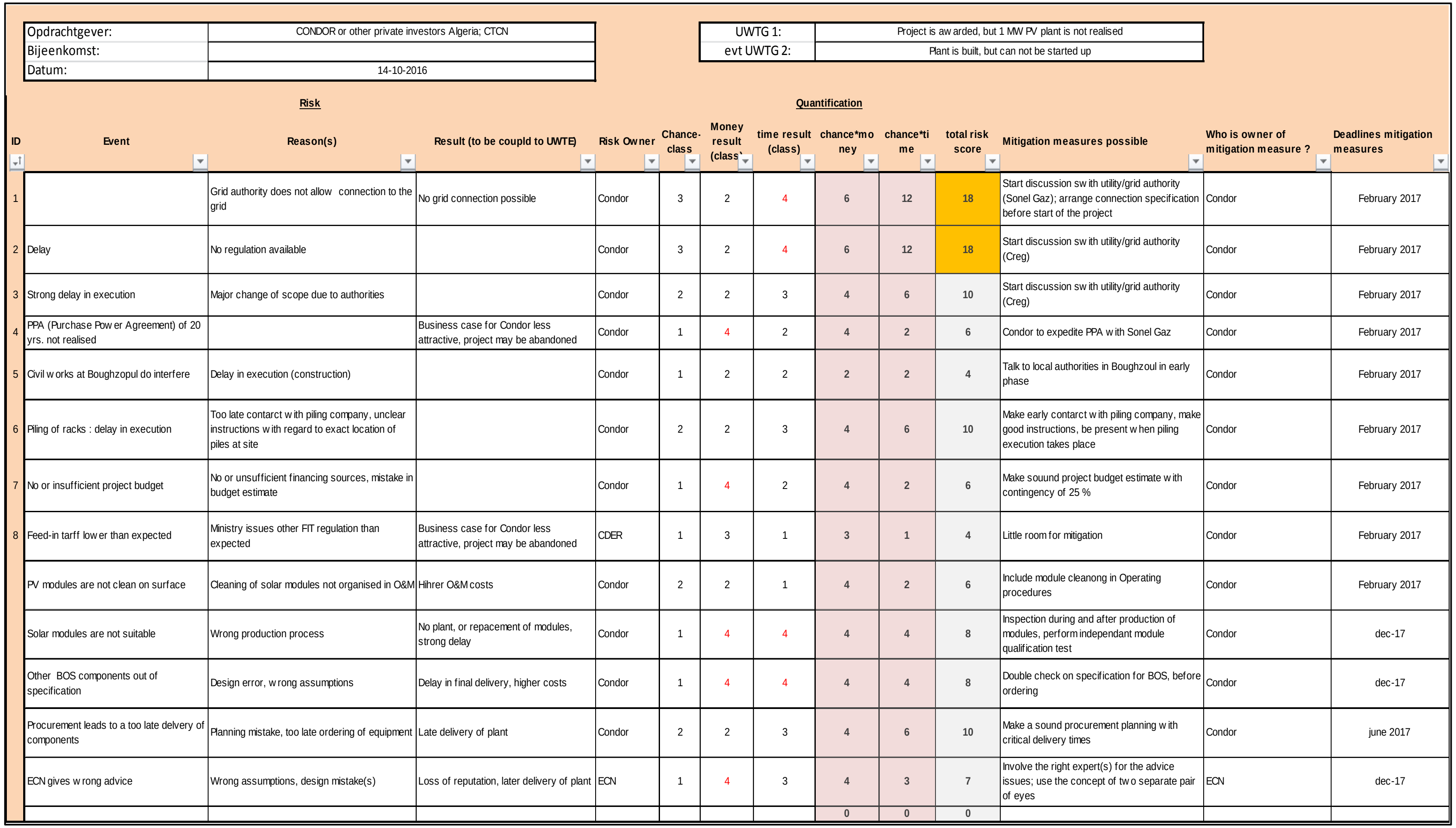
- What are the risks in this EPC project?
- In relation the aim of the project?
- Can we rank the risks on importance?
- Can we determine measures to reduce risks?

In figure 13, the process of risk assessment is illustrated, this scheme has been used in the workshop to identify the most relevant risks.

Figure 13: Risk assessment process

In the session on risk assessment, we determined the risks and listed those in Table 1.

Table 1: Risk assessment results



Opdrachtgever:	CONDOR or other private investors Algeria; CTCN
Bijeenkomst:	
Datum:	14-10-2016

UWTG 1:	Project is awarded, but 1 MW PV plant is not realised
evt UWTG 2:	Plant is built, but can not be started up

		Risk					Quantification						
ID	Event	Reason(s)	Result (to be coupld to UWTE)	Risk Owner	Chance-class	Money result (class)	time result (class)	chance*money	chance*time	total risk score	Mitigation measures possible	Who is owner of mitigation measure ?	Deadlines mitigation measures
1		Grid authority does not allow connection to the grid	No grid connection possible	Condor	3	2	4	6	12	18	Start discussion with utility/grid authority (Sonel Gaz); arrange connection specification before start of the project	Condor	February 2017
2	Delay	No regulation available		Condor	3	2	4	6	12	18	Start discussion with utility/grid authority (Creg)	Condor	February 2017
3	Strong delay in execution	Major change of scope due to authorities		Condor	2	2	3	4	6	10	Start discussion with utility/grid authority (Creg)	Condor	February 2017
4	PPA (Purchase Power Agreement) of 20 yrs. not realised		Business case for Condor less attractive, project may be abandoned	Condor	1	4	2	4	2	6	Condor to expedite PPA with Sonel Gaz	Condor	February 2017
5	Civil works at Boughzopul do interfere	Delay in execution (construction)		Condor	1	2	2	2	2	4	Talk to local authorities in Boughzoul in early phase	Condor	February 2017
6	Piling of racks : delay in execution	Too late contarct with piling company, unclear instructions with regard to exact location of piles at site		Condor	2	2	3	4	6	10	Make early contarct with piling company, make good instructions, be present when piling execution takes place	Condor	February 2017
7	No or insufficient project budget	No or unsufficient financing sources, mistake in budget estimate		Condor	1	4	2	4	2	6	Make souund project budget estimate with contingency of 25 %	Condor	February 2017
8	Feed-in tarff lower than expected	Ministry issues other FIT regulation than expected	Business case for Condor less attractive, project may be abandoned	CDER	1	3	1	3	1	4	Little room for mitigation	Condor	February 2017
	PV modules are not clean on surface	Cleaning of solar modules not organised in O&M	Hihrer O&M costs	Condor	2	2	1	4	2	6	Include module cleanong in Operating procedures	Condor	February 2017
	Solar modules are not suitable	Wrong production process	No plant, or repacement of modules, strong delay	Condor	1	4	4	4	4	8	Inspection during and after production of modules, perform independant module qualification test	Condor	dec-17
	Other BOS components out of specification	Design error, wrong assumptions	Delay in final delivery, higher costs	Condor	1	4	4	4	4	8	Double check on specification for BOS, before ordering	Condor	dec-17
	Procurement leads to a too late delvery of components	Planning mistake, too late ordering of equipment	Late delivery of plant	Condor	2	2	3	4	6	10	Make a sound procurement planning with critical delivery times	Condor	june 2017
	ECN gives wrong advice	Wrong assumptions, design mistake(s)	Loss of reputation, later delivery of plant	ECN	1	4	3	4	3	7	Involve the right expert(s) for the advice issues; use the concept of two separate pair of eyes	ECN	dec-17
								0	0	0			

In this table ,we conclude that the most critical risk is related to the subject of grid connection and regulation (score of 18) ; hence, a good interaction with the authorities (Sonelgaz, CREG (Cadre Authorisations et Energies Renouvelables) are required, on a short notice, to clear the situation regarding grid connection, before the EPC project can start. It should also be investigated, whether Sonelgaz would be prepared to be a partner in the EPC project, as this will automatically guarantee their involvement. Furthermore, some risks are present with a score of 10, this risks can be mitigated with a sound planning.

4.11 Questions to grid authority

In the workshop, we defined the relevant questions to the grid authority, these questions will help to realise the conditions for grid connection of the PV plant:

a) Questions related to grid connection :
  - Which regulation regarding grid connection is applicable or is foreseen in the next year ?
  - Which application procedure is applicable
  - Do we apply for a permit, if so, what is the lead time ?
  - Are connection fees or transport fees applicable ?
  - What services will be provided by Sonelgaz utility, e.g. metering, communication ?
  - Are there requirements with regard to commissioning in Commissioning procedure
  - What are the grounding requirements (earthed neutral at either LV or MV side) ?

b) Questions regarding compliance to (inter)national grid codes :
  - What are the Reactive power limits/settings, e.g. fixed power factor or active voltage support
  - Which frequency support is needed, e.g. ramp rate limitation or reserve power for balancing?
  - Low- voltage ride through capability ?
  - Harmonics injection limits ?
  - Monitoring requirements ?

c) Questions regarding grid control / supervision / O&M
  - Will the PV plant be integrated with existing SCADA system, may require ICT upgrade
  - A Service panel (on-site / remote location) for O&M purposes and fault diagnosis
  - is foreseen, can this be integrated in existing system?
  - Is an ICT upgrade required for communication or data storage?
  - Is there a needs for O&M training?

4.12 Gap analysis

In the last session of the EPC plan, the existing gaps were defined for the different EPC steps. In Table 2, these gaps are listed per task, together with the associated action, were needed, to close the gap.

N.	Phases of the EPC process	Main actor	Gap Yes/No ?	Support/ Review Role	Action
1	**Basis of design**	CDER		ECN	
1.1	Location		N		
1.2	Area available, in m^2		N		
1.3	E- demand and profile (day-night, year)		Y		Meeting with SonelGaz
1.4	Applicable codes for safety and design		Y		Meeting with CREG; list existing international codes
1.5	Weather conditions (sunhours, wind, rain, duststorms, hurricanes)		N		Algerian weather authorities
1.6	Irradiance data and temperature		N		PV syst GIS data
2	**Basic design : functional specification, main components, output**	CDER		ECN	
2.1	Energy delivered to the grid (AC), In MWh/year		N		
2.2	Type of solar PV cells (mono or multi c-Si) , producer of cells		N		
2.3	Type of inverters: string, central ? In container ? Cooled ?		N		
2.4	Output of PVsyst: what will be used for basic design ?		N		
2.5	Control philosophy		N		
2.6	Applicable standards (IEC, etc.)		Y		Meeting with CREG; list existing international codes
3	**Grid connection**	CONDOR			
3.1	Agree with stakeholders (utility company) about requirements for connection to the grid		Y		Meeting with Sonelgaz
3.2	Net characteristics (Voltage & frequency ranges, protection: current levels & critical times)		Y		Meeting with Sonelgaz
3.3	Applicable safety rules and standards, net metering		Y		Meeting with Sonelgaz
3.4	Grid drawing (feed-in location, main components, locations and types of generators and loads)		Y		Meeting with Sonelgaz
4	**Detailed design (all equipment specifications, applicable codes & standards, test protocol)**	CONDOR		CDER, ECN	
4.1	Solar cells and modules		N		
4.3	Inverters, cabling, transformer(s) and protection equipment		Y		Meeting with Sonelgaz
4.4	Racking and enclosures		N		
4.5	Applicable codes & standards		Y		Meeting with CREG; list existing international codes
4.6	Specification of layout and civil works		Y		Meet with local authority in Boughzoul
4.7	Power management, (remote) SCADA, ICT system				
5	**Procurement**	CONDOR			
5.1	Material take-off list		N		
5.2	List of preferred suppliers		N		
5.3	Equipment specification for procurement		N		
5.4	Ordering		N		
5.5	Inspection		N		
5.6	Delivery on site		N		
6	**Site preparation**	CDER			
6.1	Removal of vegetation		N		
6.2	Ground leveling		N		
6.3	Fencing		N		
6.4	Transformer house ?		N		
7	**Installation of all equipment, connection, wiring**	CONDOR			
7.1	Codes and standards (incl. installer certification)		Y		Meeting with CREG; list existing international codes
7.2	Installation works		Y		
8	**Commissioning of the system**	CONDOR		CDER, ECN	
8.1	Operating manual with start-up & shut-down procedures		Y		
8.2	Test procedures		Y		
8.3	Test run		Y		

Table 2: Gap analysis for EPC process tasks

5

Conclusions of the workshops

Based on the two workshops, we present the following conclusions.

1. A meeting with the grid authority and the utility in Boughezoul (Sonelgaz) has to take place in order to assess the aspects regarding grid connection. This meeting should be organised in the next two months, ahead of the formal start of the EPC project. Prior to these meetings, a question list has to be prepared.
2. A meeting with CREG has to take place, to define the existing regulation regarding PV connection to the grid.
3. A sound project budget should be made, based upon the existing EPC plan, with expenses per task for man-hours and out of pocket costs (capex cost) for hardware equipment. The project budget should contain a contingency of at least 25 % for unforeseen expenses and inaccurate estimates.
4. Condor would like assistance on a financial model suitable to calculate a project budget. ECN will provide this financial model, suitable to make the project budget.

Condor will investigate local companies that can execute activities in site preparation and piling plus installation of racks for solar modules.

6

Questions and answers

During the workshop, several questions emerged. Some of these questions were addressed at the spot, but some other questions, together with the appropriate answer are listed here.

Q1 : Wat is PID?
Answer : PID refers to Potential Induced Degradation of cells or modules. In PV systems that have a transformer-less inverter, no galvanic separation between the DC- and the AC-parts of the system is given. Because of this lack of galvanic isolation, a potential of -500 V or more between the PV modules and the ground can occur, which can lead to potential induced degradation (PID).

There is a lot of literature on this subject, most relevant articles have been forwarded to Condor.

Q2: Is there a recommended procedure for inverter testing? And which institution(s) in Europe execute(s) these type of tests ?
Answer :
A clear overview of PV inverter standards can be found for example at:
http://sinovoltaics.com/learning-center/certifications/certifications-solar-inverters/
From IEC standards for PV grid connected systems can be found on the Technical Committee TC82 site:
http://www.iec.ch/dyn/www/f?p=103:22:3351958516333::::FSP_ORG_ID,FSP_LANG_ID:1276,25

An example of a PV Inverter test protocol is available from California Energy Commission at: https://pvpmc.sandia.gov/modeling-steps/dc-to-ac-conversion/cec-inverter-test-protocol/
This is part of a broader PV Performance modelling Collaborative from SANDIA labs: https://pvpmc.sandia.gov/

A large number of testing labs promote their services. A directory can be found at: http://www.enfsolar.com/directory/service/certification

Q3 : What cable size on DC side will be required ?

Answer:

The cable sizing is done to strike a good balance against cable size and voltage drop, and also to have a cable size that prevents overheating or fire.

A correct formula for calculating the voltage drop in cabling is taken from:

http://photovoltaic-software.com/DC_AC_drop_voltage_energy_losses_calculator.php:

The Voltage drop is given by the following formula :

$$\Delta V = b\left(\rho_1 \frac{L}{S}\cos\varphi + \lambda\, L \sin\varphi\right) \times I_B$$

Where :

U : Voltage of the DC or AC system (V)

This is phase-phase voltage for 3-phase system; phase-neutral voltage for single-phase system.

Example : For western European countries a 3-phase circuit will usually have a voltage of 400 V, and single-phase 230V; In North America, a typical three-phase system voltage is 208 volts and single phase voltage is 120 volts.

NB: for DC voltage drop in photovoltaic system, the voltage of the system is U = U_{mpp} of one panel x number of panels in a serie.

ΔU : voltage drop in Volt (V)
b : length cable factor, b=2 for single phase wiring, b=1 for three-phased wiring.
ρ1 : resistivity of the material conductor, 0.023 for copper and 0.037 for aluminum (ambient temperature = 25°C) in ohm.mm²/m.
L : simple length of the cable (distance between the source and the appliance), in meters (m).
S : cross section of the cable in mm²
Cos ϕ : power factor, Cos ϕ = 1 for pure resistive load, Cos ϕ< 1 for inductive charge, (usually 0.8).
λ : reactance per length unit (default value 0.00008 ohm/m)
Sin ϕ : sinus (acos(cos ϕ)).
I_B : current in Ampere (A)

NB : For DC circuit, cos ϕ=1, so sin ϕ=0.

An online cable sizing tool is available at :

http://www.solar-wind.co.uk/cable-sizing-DC-cables.html.

7

Conclusions and recommendations

In this chapter, we present the conclusions of the Technical Assistance carried out in Algeria.

1. The technical Assistance could not have been better planned, as Algeria is facing a very ambitious implementation plan regarding solar energy.
2. In January 2017 , the Ministry of Energy will announce a tender for the implementation of 4 gigawatts of solar PV.
3. The executed Technical Assistance Plan provides a roadmap for the EPC (Engineering, Procurement and Construction) of a 1 MW solar PV plant in a new town, Boughezoul and could serve as a pilot project to involve the Algerian industry and knowledge centres in the realisation of the Solar PV ambition of Algeria.
4. In this way, the local economy in Algeria could play a relevant role in this transition.
5. A team of experts in Algeria has been formed , able to execute the EPC plan for a 1 MW PV plant.
6. For this plan, Condor, as local industry, will play a pivotal role. Next, support and guidance from CDER and ECN is recommended for the EPC execution of this project.
7. CTCN can play a catalysing role in the realization of this EPC project.

Appendix A. Presentations

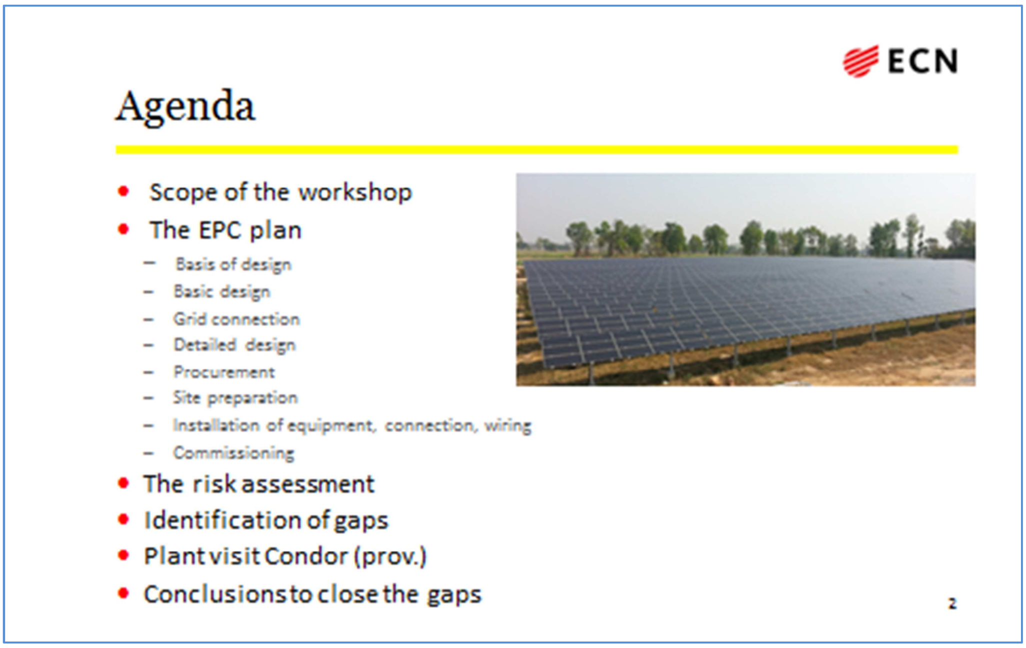
A.1. Presentations EPC plan

Full Assistance Plan 1 MW PV solar plant
in Bordj-Bou-Arreridj , Algeria

Paul van den Oosterkamp, Martin Spath,
Edwin Wiggelinkhuizen
ECN
Full Assistance workshop CTCN Response
plan, CDER, Tipaza, Algeria

21-23 November 2016

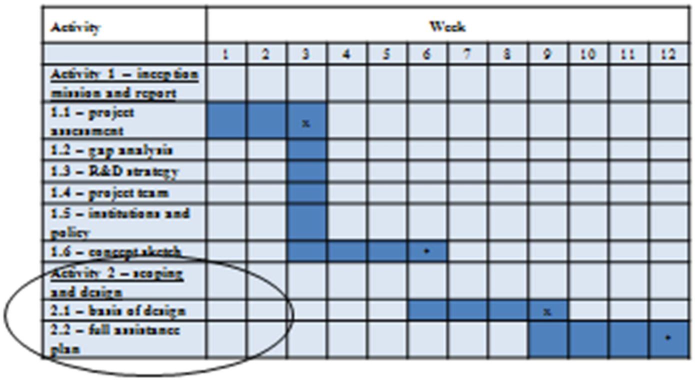
www.ecn.nl



Agenda

- Scope of the workshop
- The EPC plan
  - Basis of design
  - Basic design
  - Grid connection
  - Detailed design
  - Procurement
  - Site preparation
  - Installation of equipment, connection, wiring
  - Commissioning
- The risk assessment
- Identification of gaps
- Plant visit Condor (prov.)
- Conclusions to close the gaps

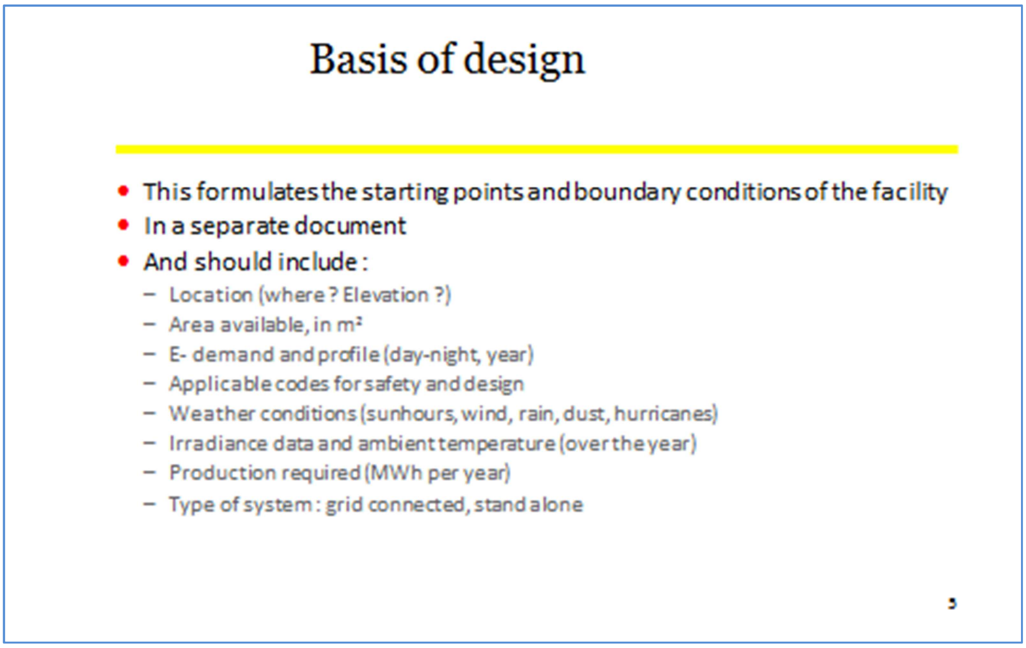
Scope of the second workshop



Activity	Week											
	1	2	3	4	5	6	7	8	9	10	11	12
Activity 1 – inception mission and report												
1.1 – project assessment	■	■	x									
1.2 – gap analysis			■									
1.3 – R&D strategy			■									
1.4 – project team			■									
1.5 – institutions and policy			■									
1.6 – concept sketch			■	■	■	•						
Activity 2 – scoping and design												
2.1 – basis of design						■	■	■	x			
2.2 – full assistance plan									■	■	■	•

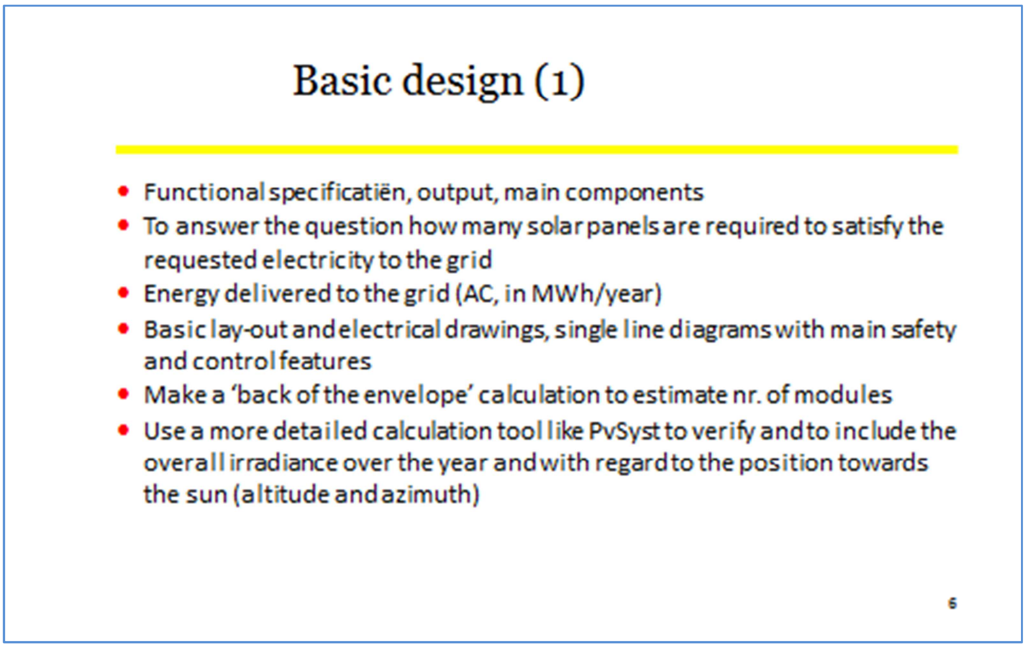
The EPC plan

- Basis discussed in inception workshop
- Worked out in more detail
- To be fine-tuned and finalized in this workshop, in an interactive mode



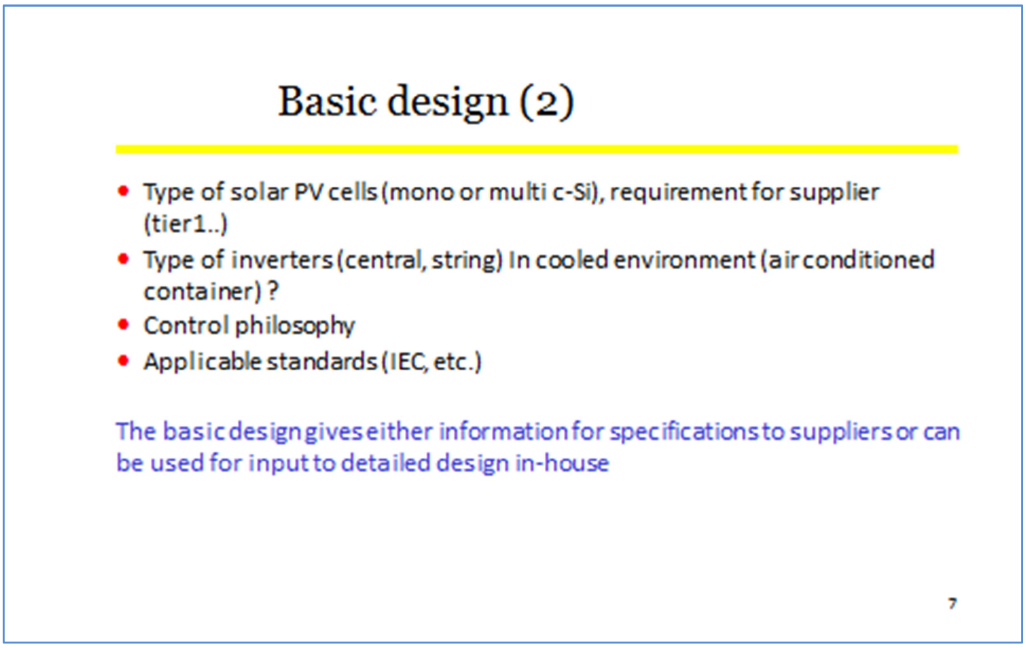
Basis of design

- This formulates the starting points and boundary conditions of the facility
- In a separate document
- And should include :
  - Location (where ? Elevation ?)
  - Area available, in m²
  - E- demand and profile (day-night, year)
  - Applicable codes for safety and design
  - Weather conditions (sunhours, wind, rain, dust, hurricanes)
  - Irradiance data and ambient temperature (over the year)
  - Production required (MWh per year)
  - Type of system : grid connected, stand alone



Basic design (1)

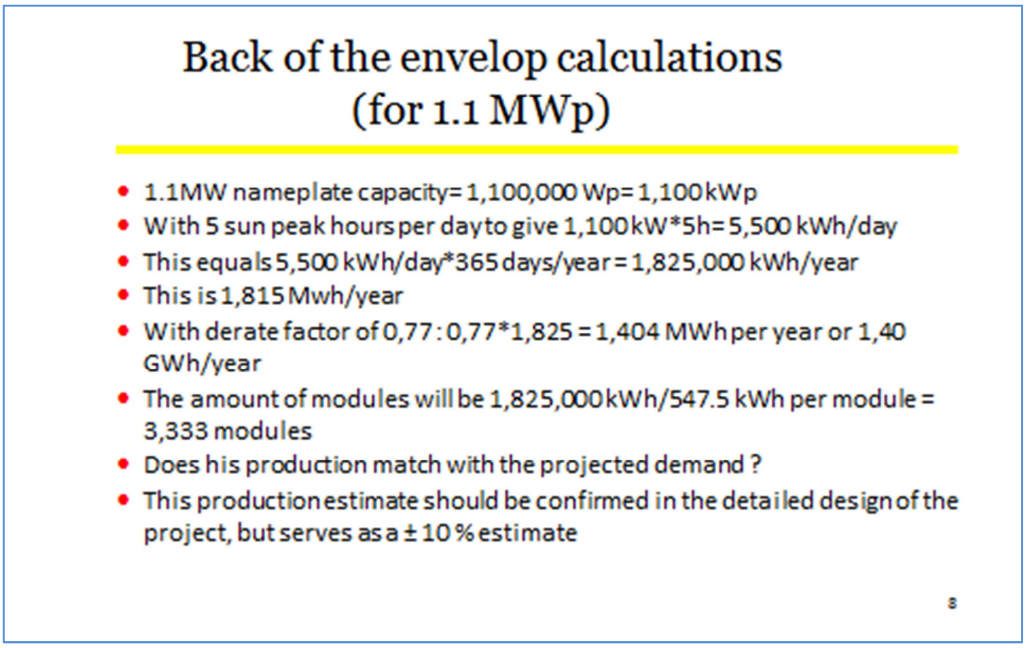
- Functional specificatiën, output, main components
- To answer the question how many solar panels are required to satisfy the requested electricity to the grid
- Energy delivered to the grid (AC, in MWh/year)
- Basic lay-out and electrical drawings, single line diagrams with main safety and control features
- Make a ‘back of the envelope’ calculation to estimate nr. of modules
- Use a more detailed calculation tool like PvSyst to verify and to include the overall irradiance over the year and with regard to the position towards the sun (altitude and azimuth)



Basic design (2)

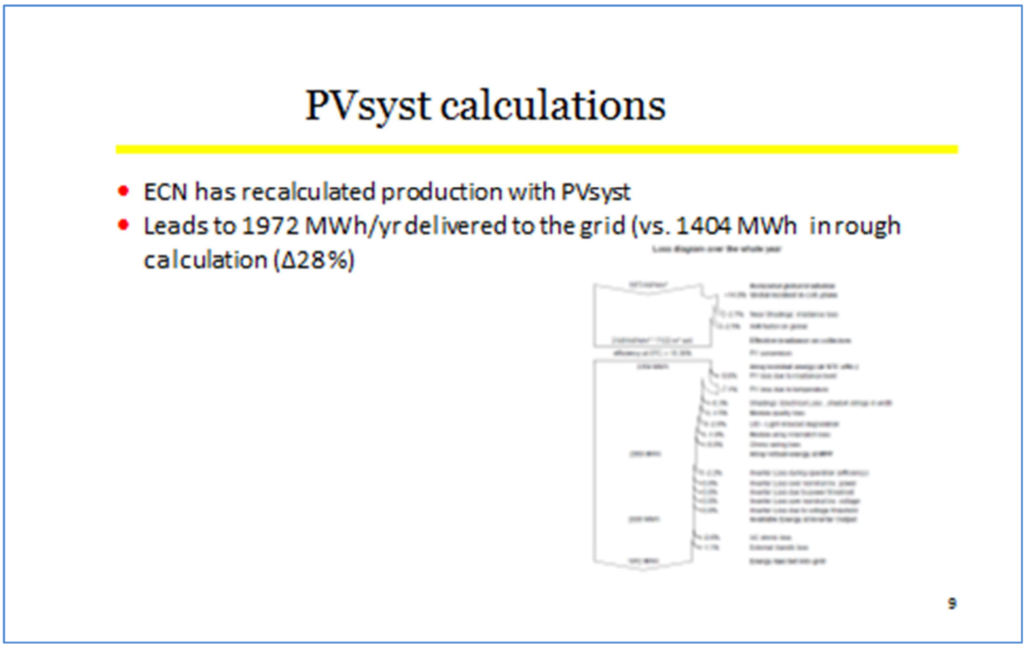
- Type of solar PV cells (mono or multi c-Si), requirement for supplier (tier1..)
- Type of inverters (central, string) In cooled environment (air conditioned container) ?
- Control philosophy
- Applicable standards (IEC, etc.)

The basic design gives either information for specifications to suppliers or can be used for input to detailed design in-house



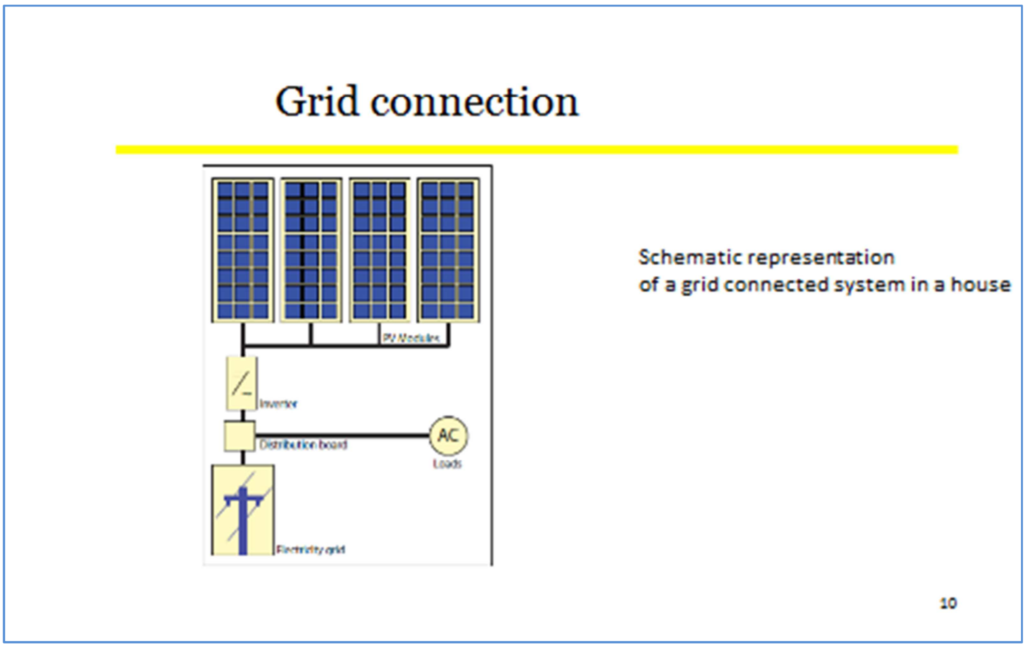
Back of the envelop calculations (for 1.1 MWp)

- 1.1MW nameplate capacity= 1,100,000 Wp= 1,100 kWp
- With 5 sun peak hours per day to give 1,100 kW*5h= 5,500 kWh/day
- This equals 5,500 kWh/day*365 days/year = 1,825,000 kWh/year
- This is 1,815 Mwh/year
- With derate factor of 0,77 : 0,77*1,825 = 1,404 MWh per year or 1,40 GWh/year
- The amount of modules will be 1,825,000 kWh/547.5 kWh per module = 3,333 modules
- Does his production match with the projected demand ?
- This production estimate should be confirmed in the detailed design of the project, but serves as a ± 10 % estimate



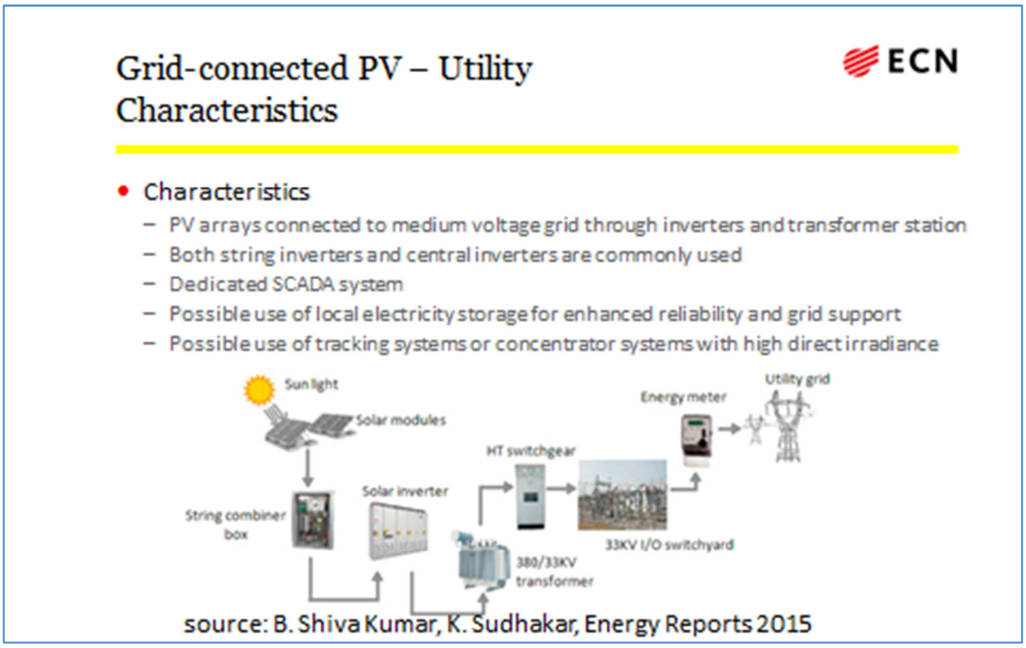
PVsyst calculations

- ECN has recalculated production with PVsyst
- Leads to 1972 MWh/yr delivered to the grid (vs. 1404 MWh in rough calculation (Δ28%)



Grid connection

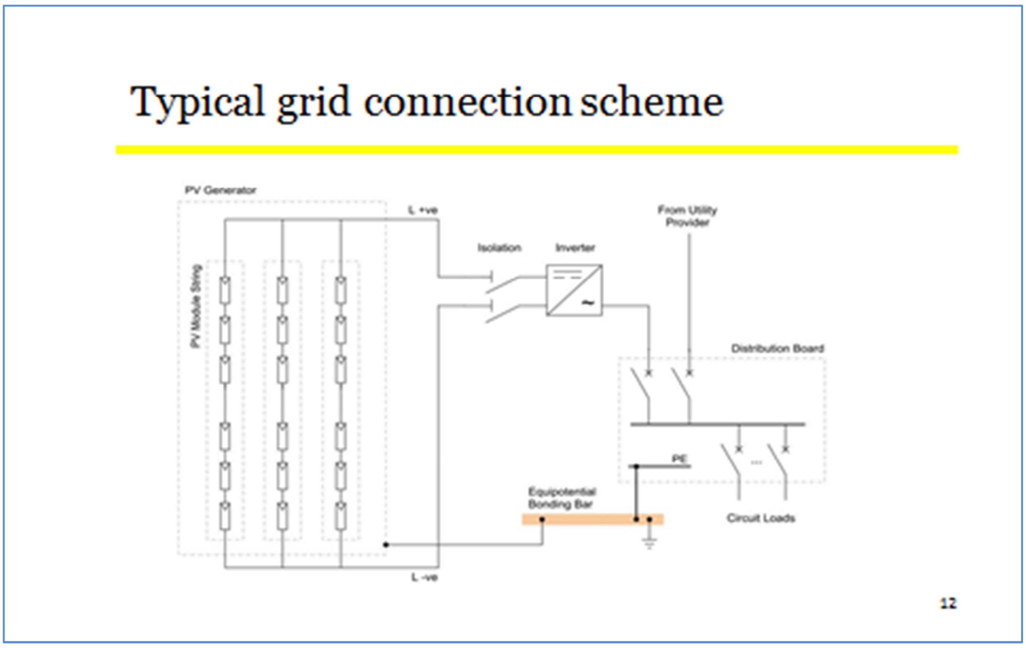
Schematic representation
of a grid connected system in a house



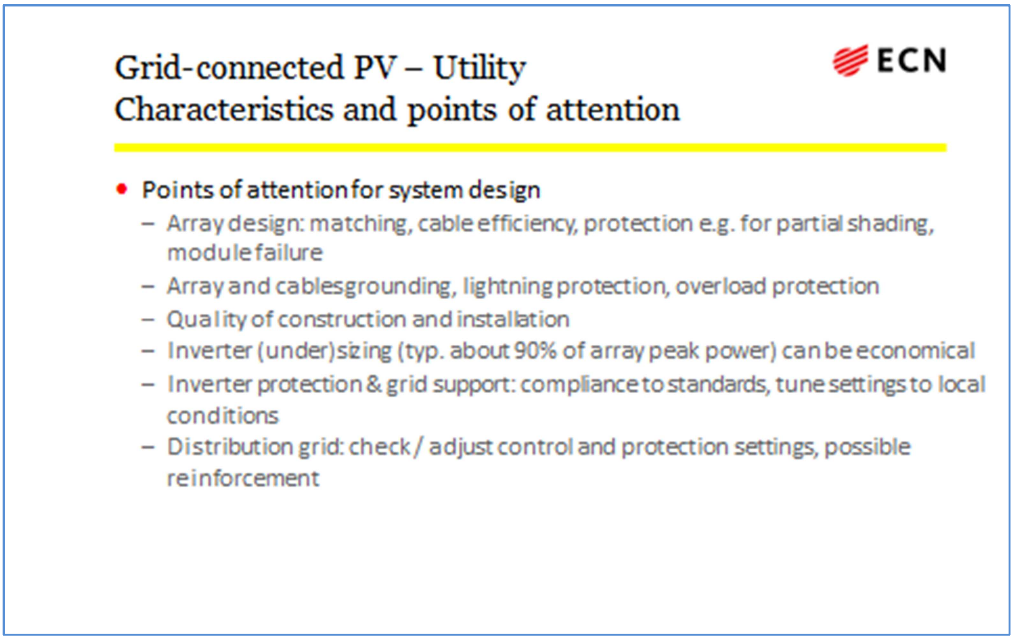
Grid-connected PV – Utility Characteristics

- Characteristics
  - PV arrays connected to medium voltage grid through inverters and transformer station
  - Both string inverters and central inverters are commonly used
  - Dedicated SCADA system
  - Possible use of local electricity storage for enhanced reliability and grid support
  - Possible use of tracking systems or concentrator systems with high direct irradiance

source: B. Shiva Kumar, K. Sudhakar, Energy Reports 2015

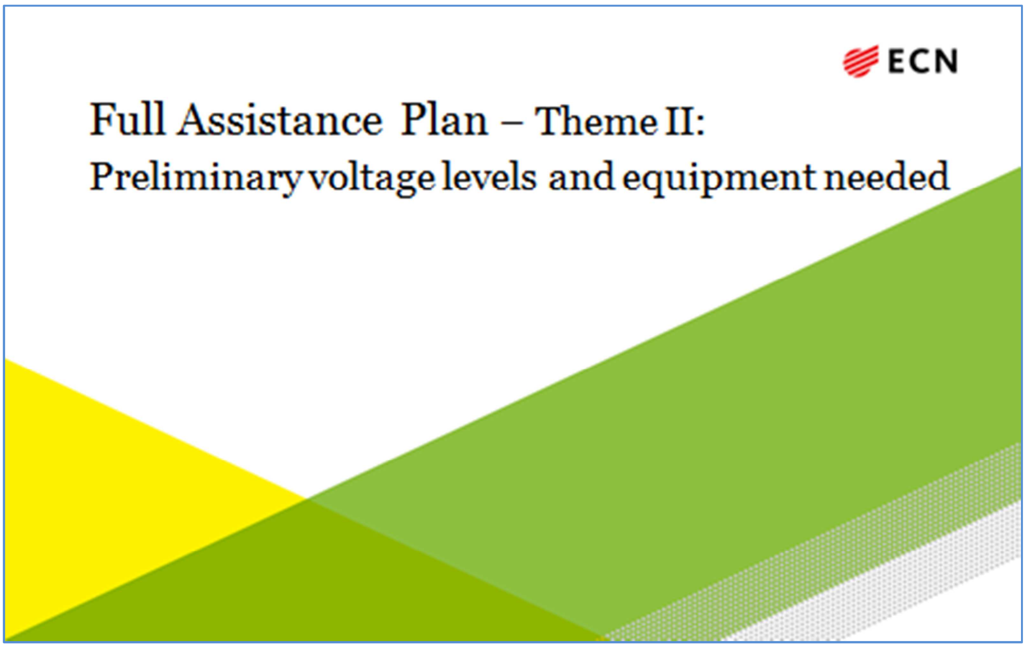


Typical grid connection scheme

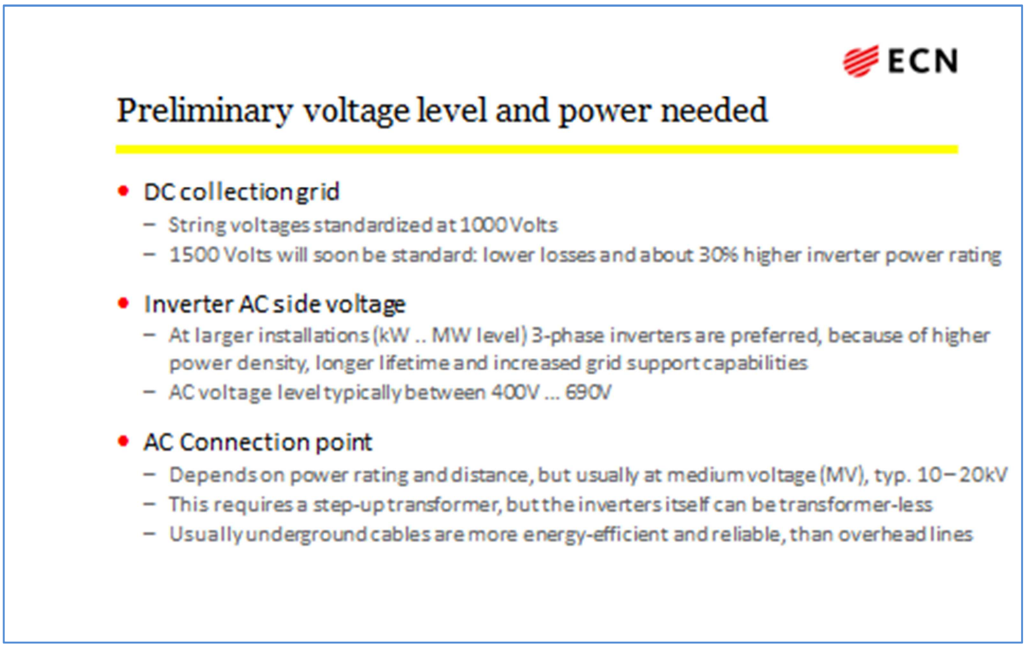


Grid-connected PV – Utility
Characteristics and points of attention

- Points of attention for system design
  - Array design: matching, cable efficiency, protection e.g. for partial shading, module failure
  - Array and cables grounding, lightning protection, overload protection
  - Quality of construction and installation
  - Inverter (under)sizing (typ. about 90% of array peak power) can be economical
  - Inverter protection & grid support: compliance to standards, tune settings to local conditions
  - Distribution grid: check / adjust control and protection settings, possible reinforcement



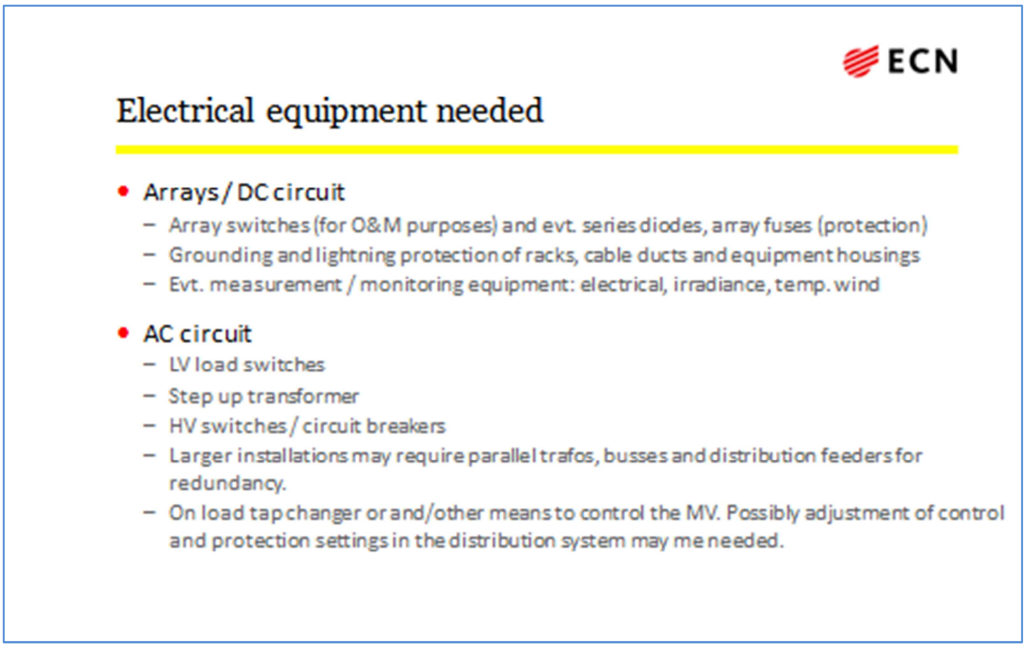
Full Assistance Plan – Theme II:
Preliminary voltage levels and equipment needed



ECN

Preliminary voltage level and power needed

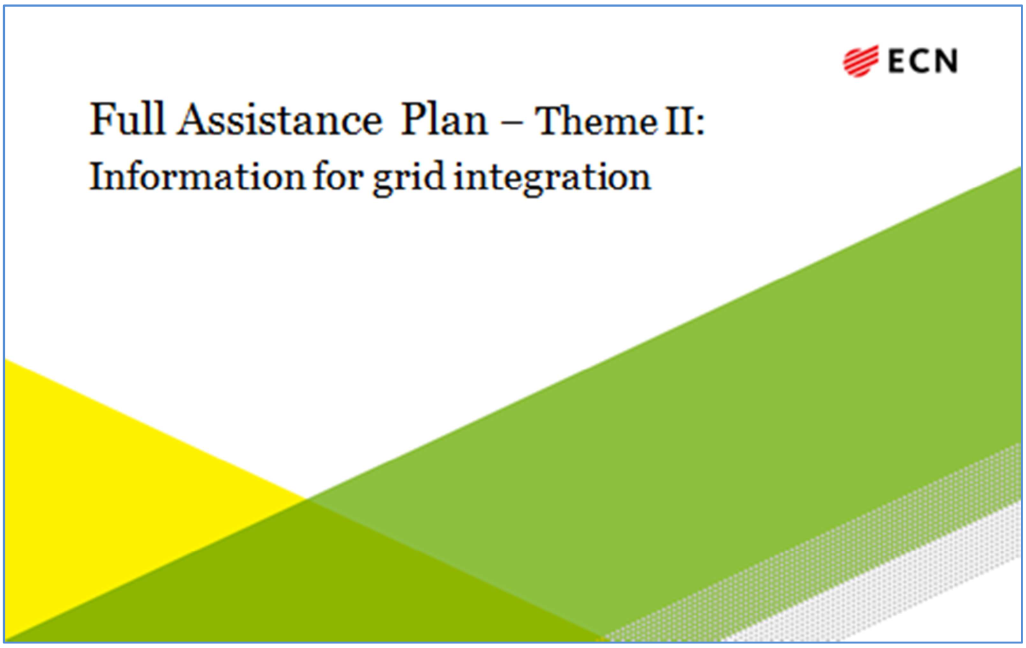
- DC collection grid
  - String voltages standardized at 1000 Volts
  - 1500 Volts will soon be standard: lower losses and about 30% higher inverter power rating
- Inverter AC side voltage
  - At larger installations (kW .. MW level) 3-phase inverters are preferred, because of higher power density, longer lifetime and increased grid support capabilities
  - AC voltage level typically between 400V … 690V
- AC Connection point
  - Depends on power rating and distance, but usually at medium voltage (MV), typ. 10 – 20kV
  - This requires a step-up transformer, but the inverters itself can be transformer-less
  - Usually underground cables are more energy-efficient and reliable, than overhead lines



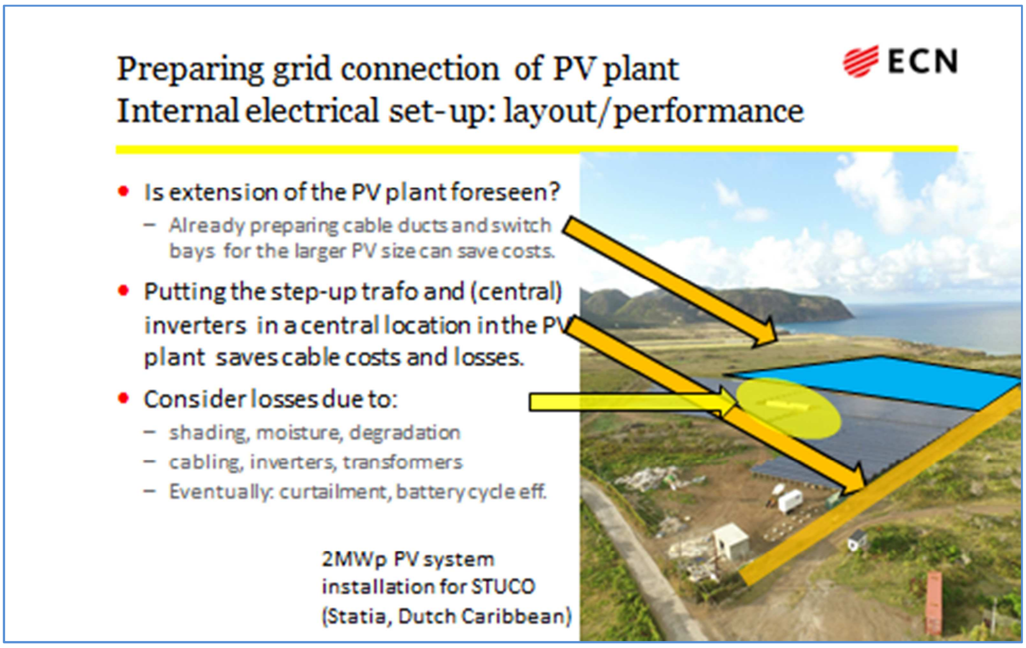
ECN

Electrical equipment needed

- Arrays / DC circuit
  - Array switches (for O&M purposes) and evt. series diodes, array fuses (protection)
  - Grounding and lightning protection of racks, cable ducts and equipment housings
  - Evt. measurement / monitoring equipment: electrical, irradiance, temp. wind
- AC circuit
  - LV load switches
  - Step up transformer
  - HV switches / circuit breakers
  - Larger installations may require parallel trafos, busses and distribution feeders for redundancy.
  - On load tap changer or and/other means to control the MV. Possibly adjustment of control and protection settings in the distribution system may me needed.



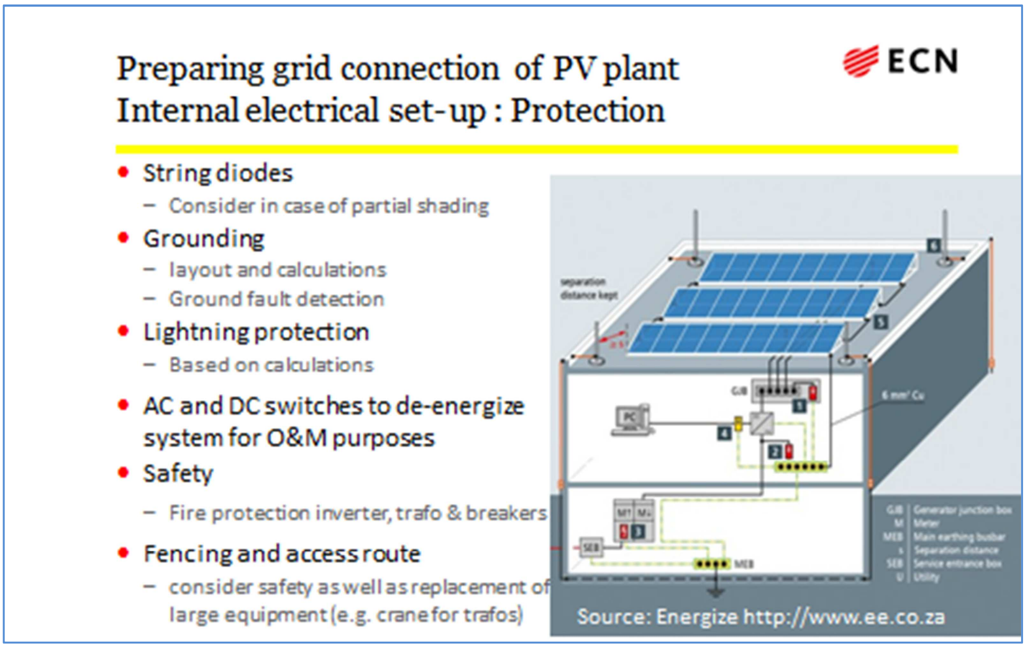
Full Assistance Plan – Theme II:
Information for grid integration



Preparing grid connection of PV plant
Internal electrical set-up: layout/performance

- Is extension of the PV plant foreseen?
  - Already preparing cable ducts and switch bays for the larger PV size can save costs.
- Putting the step-up trafo and (central) inverters in a central location in the PV plant saves cable costs and losses.
- Consider losses due to:
  - shading, moisture, degradation
  - cabling, inverters, transformers
  - Eventually: curtailment, battery cycle eff.

2MWp PV system
installation for STUCO
(Statia, Dutch Caribbean)



Preparing grid connection of PV plant
Internal electrical set-up : Protection

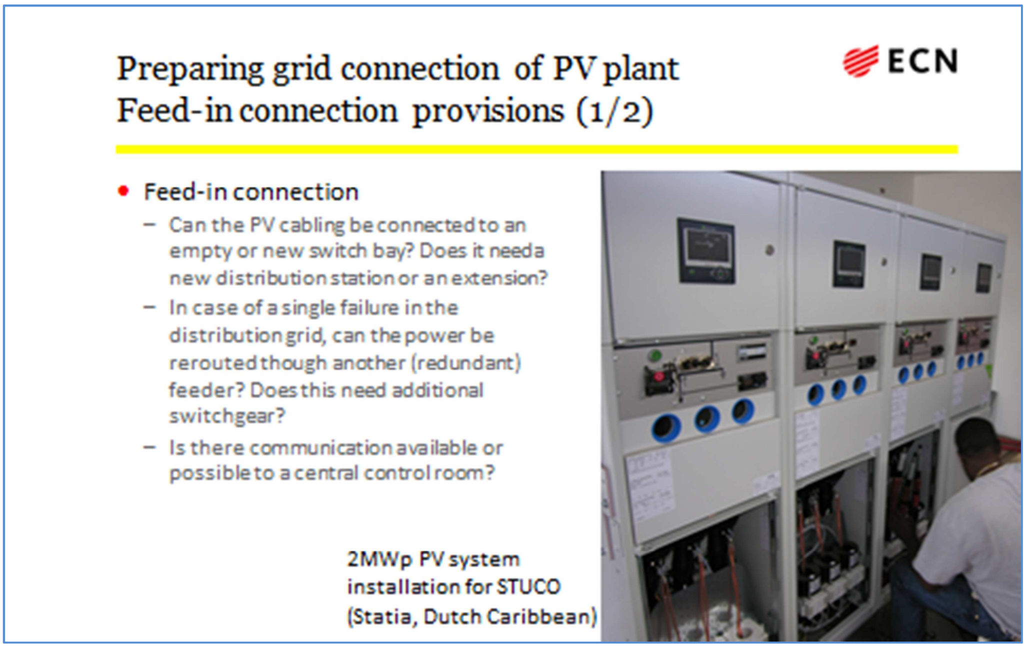
- String diodes
  - Consider in case of partial shading
- Grounding
  - layout and calculations
  - Ground fault detection
- Lightning protection
  - Based on calculations
- AC and DC switches to de-energize system for O&M purposes
- Safety
  - Fire protection inverter, trafo & breakers
- Fencing and access route
  - consider safety as well as replacement of large equipment (e.g. crane for trafos)

Source: Energize http://www.ee.co.za

Preparing grid connection of PV plant
Feed-in location access

- Feed-in location and route
  - Which nearby distribution stations, switching stations or distribution lines or cables exist
  - what is the distance of the cable connection to the PV plant and what obstacles does it need to cross, e.g. critical infrastructure?

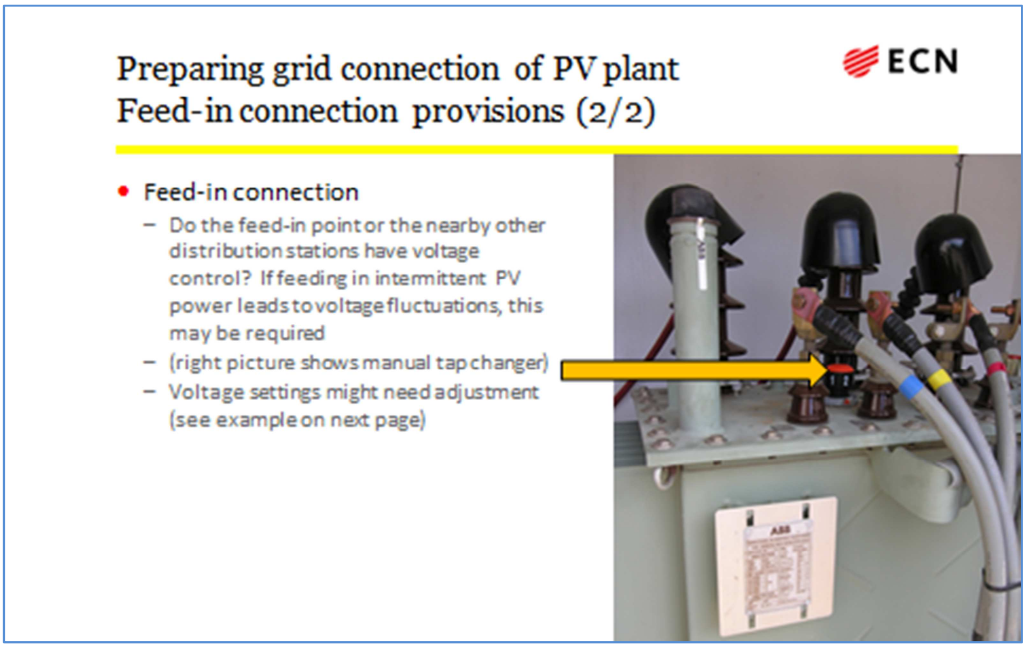
2MWp PV system installation for STUCO (Statia, Dutch Caribbean)



Preparing grid connection of PV plant Feed-in connection provisions (1/2)

- Feed-in connection
  - Can the PV cabling be connected to an empty or new switch bay? Does it needa new distribution station or an extension?
  - In case of a single failure in the distribution grid, can the power be rerouted though another (redundant) feeder? Does this need additional switchgear?
  - Is there communication available or possible to a central control room?

2MWp PV system
installation for STUCO
(Statia, Dutch Caribbean)



Preparing grid connection of PV plant Feed-in connection provisions (2/2)

- Feed-in connection
  - Do the feed-in point or the nearby other distribution stations have voltage control? If feeding in intermittent PV power leads to voltage fluctuations, this may be required
  - (right picture shows manual tap changer)
  - Voltage settings might need adjustment (see example on next page)

Preparing grid connection of PV plant
Example: Distribution feeder voltage control

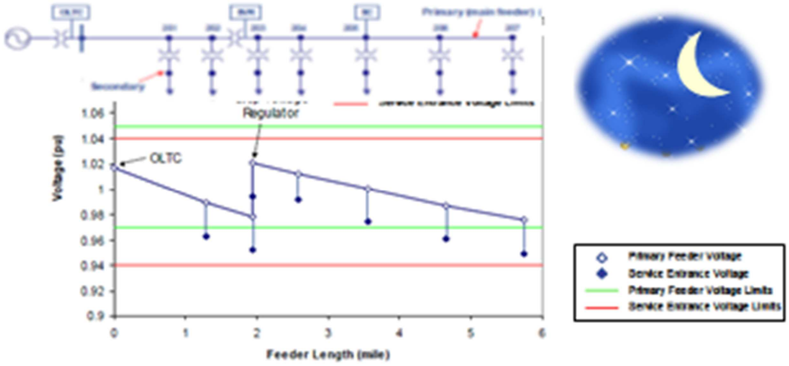
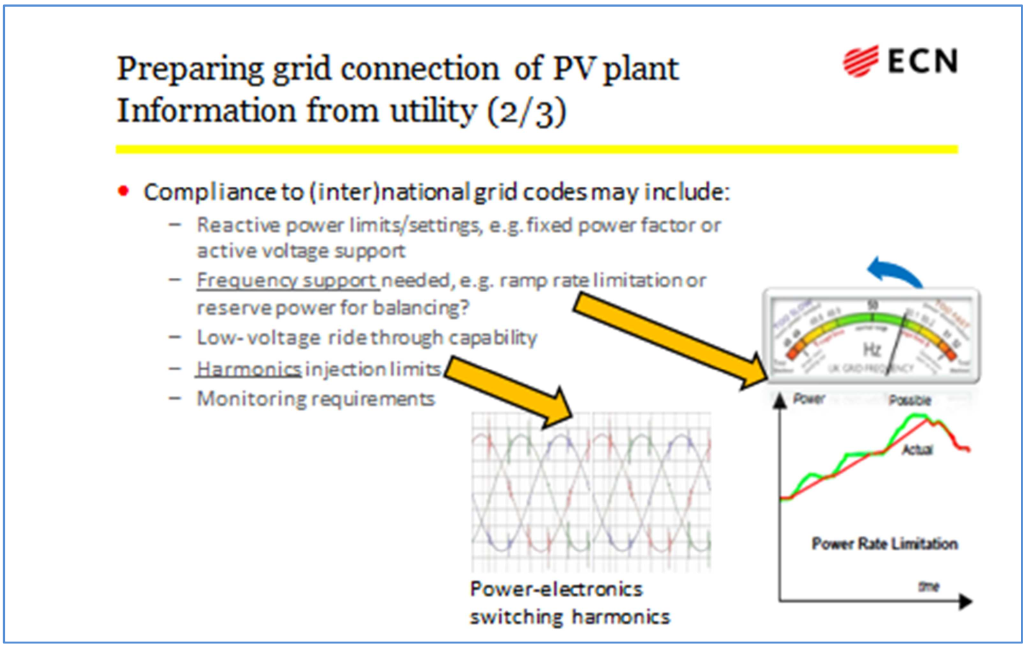


Figure 16. 50% PV penetration voltage profile: peak load with SVR

Source:,E.Liu, J. Babic, NREL 2008

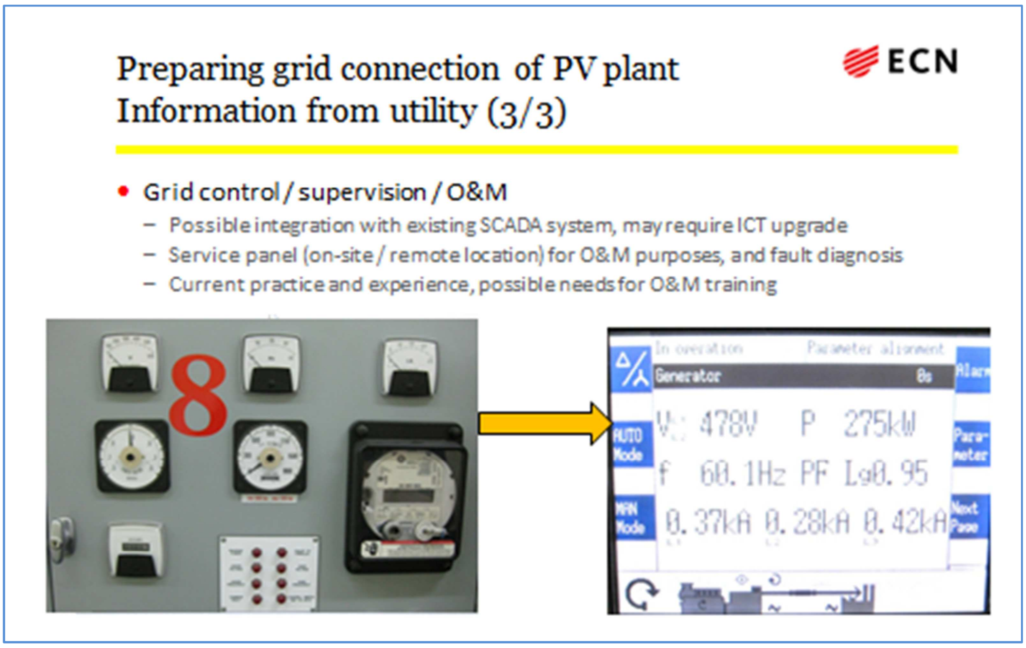
Preparing grid connection of PV plant
Information from utility (1/3)

- Grid connection
  - Application procedure, requirements
  - Permits, lead times
  - Connection fees, transport tariffs
  - Services provided by utility, e.g. metering, communication
  - Commissioning procedure
  - Grounding requirements (e.g. earthed neutral at either LV or MV side)
- Grid operation characteristics
  - Voltage setting and variations
  - Voltage quality, background harmonics
  - Typical load variations
  - In case of fossil power plants: minimum production level, ramp-up/down rates
  - Protection equipment and characteristics (current levels and response times)



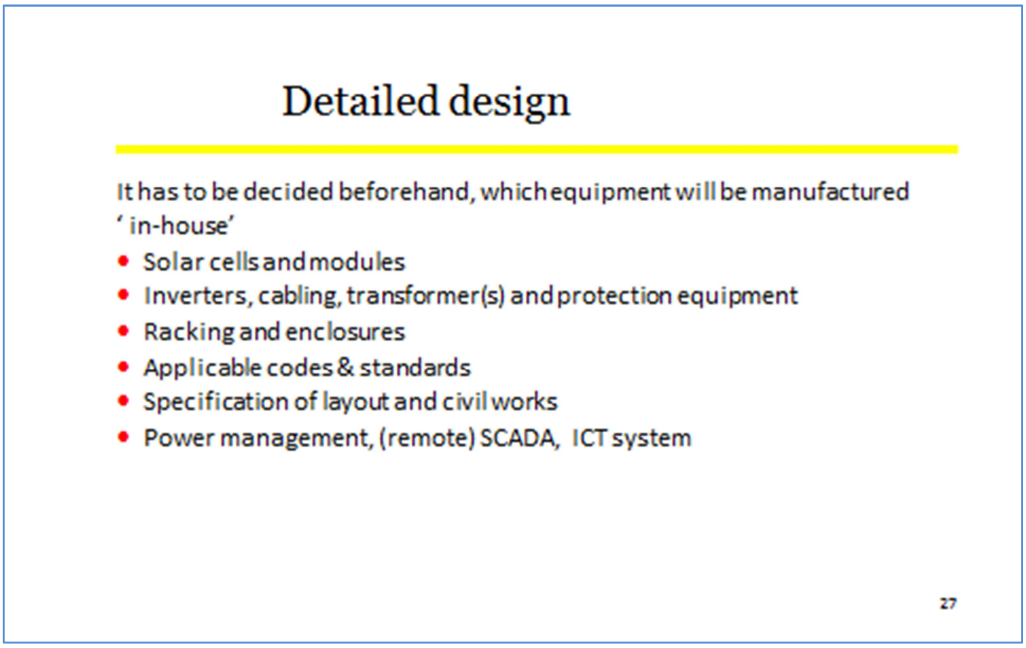
Preparing grid connection of PV plant Information from utility (2/3)

- Compliance to (inter)national grid codes may include:
  - Reactive power limits/settings, e.g. fixed power factor or active voltage support
  - Frequency support needed, e.g. ramp rate limitation or reserve power for balancing?
  - Low-voltage ride through capability
  - Harmonics injection limits
  - Monitoring requirements



Preparing grid connection of PV plant Information from utility (3/3)

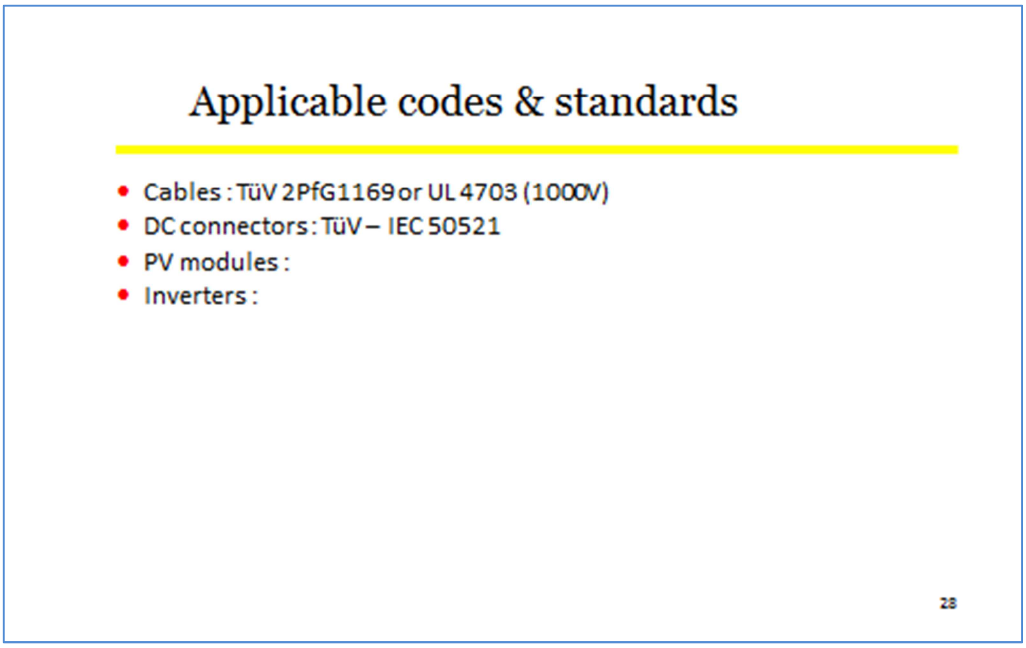
- Grid control / supervision / O&M
  - Possible integration with existing SCADA system, may require ICT upgrade
  - Service panel (on-site / remote location) for O&M purposes, and fault diagnosis
  - Current practice and experience, possible needs for O&M training



Detailed design

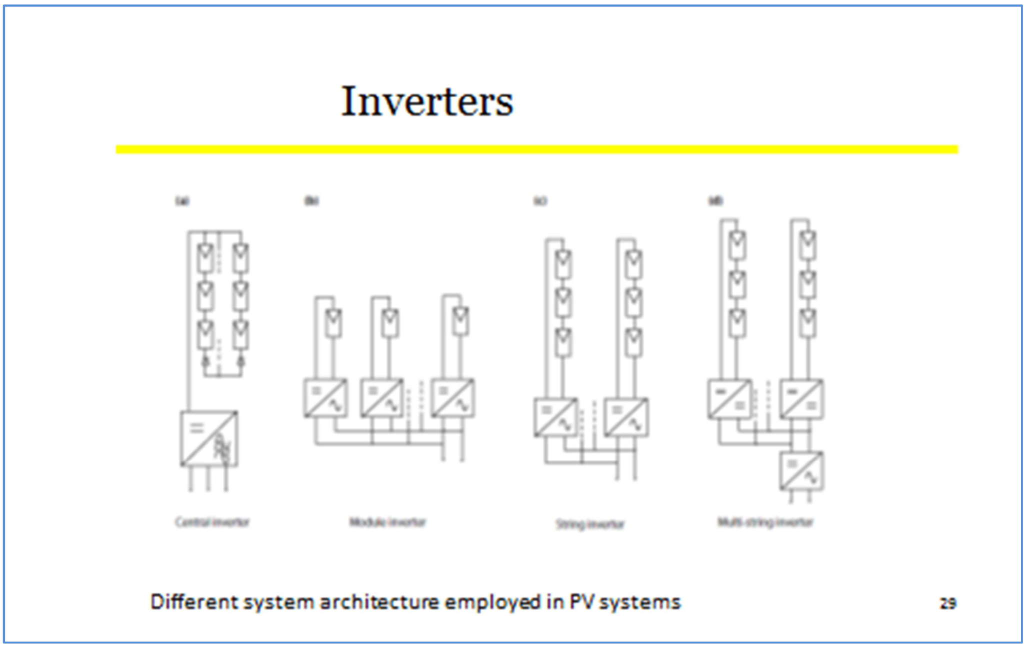
It has to be decided beforehand, which equipment will be manufactured ‘ in-house’

- Solar cells and modules
- Inverters, cabling, transformer(s) and protection equipment
- Racking and enclosures
- Applicable codes & standards
- Specification of layout and civil works
- Power management, (remote) SCADA, ICT system



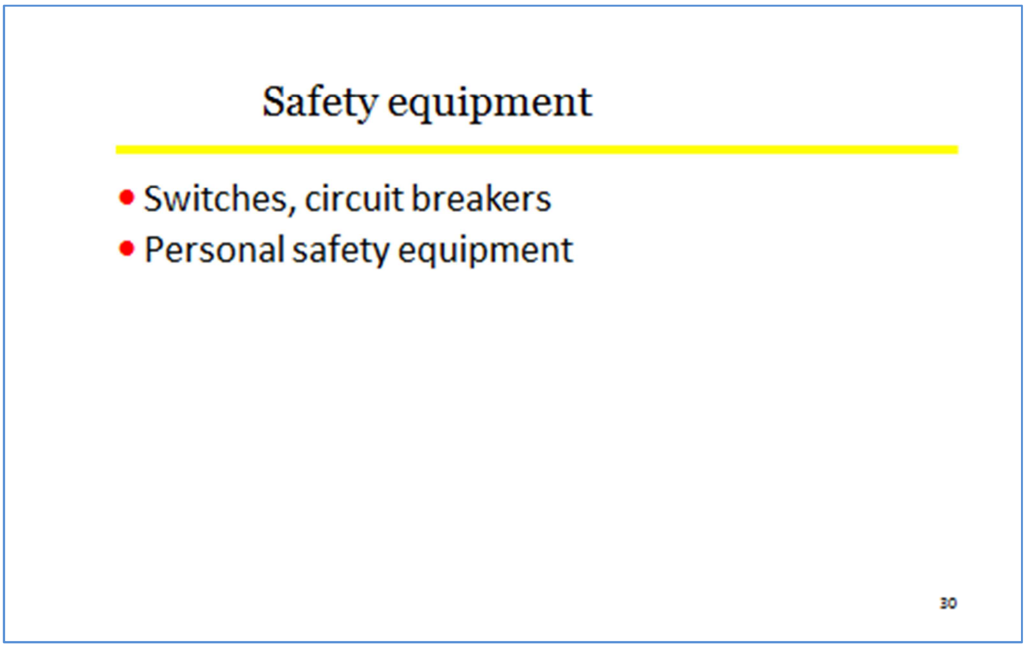
Applicable codes & standards

- Cables : TüV 2PfG1169 or UL 4703 (1000V)
- DC connectors : TüV – IEC 50521
- PV modules :
- Inverters :



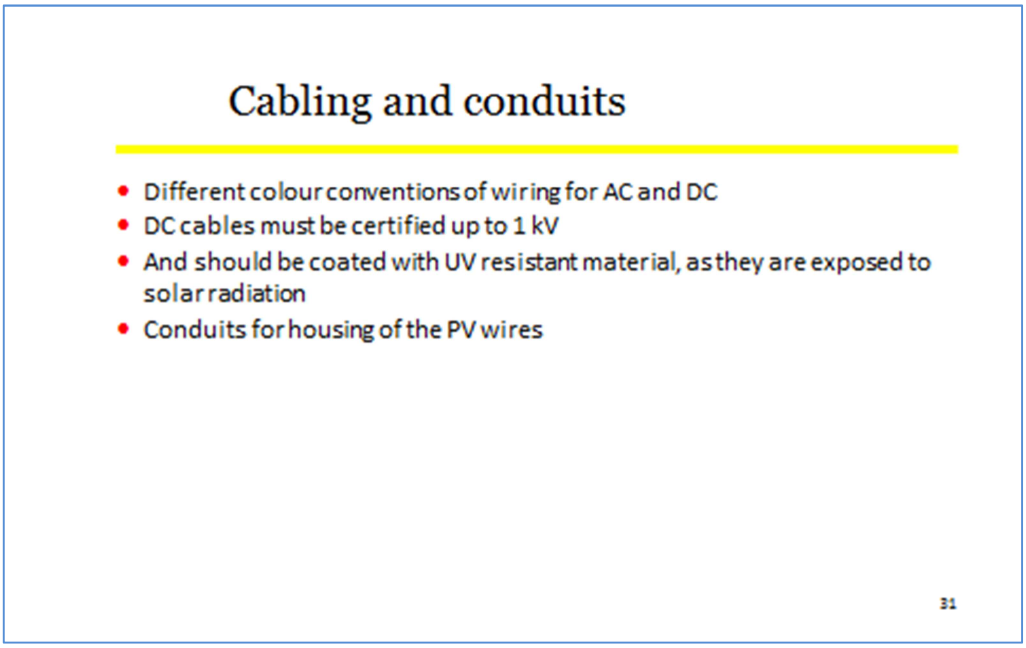
Inverters

Different system architecture employed in PV systems



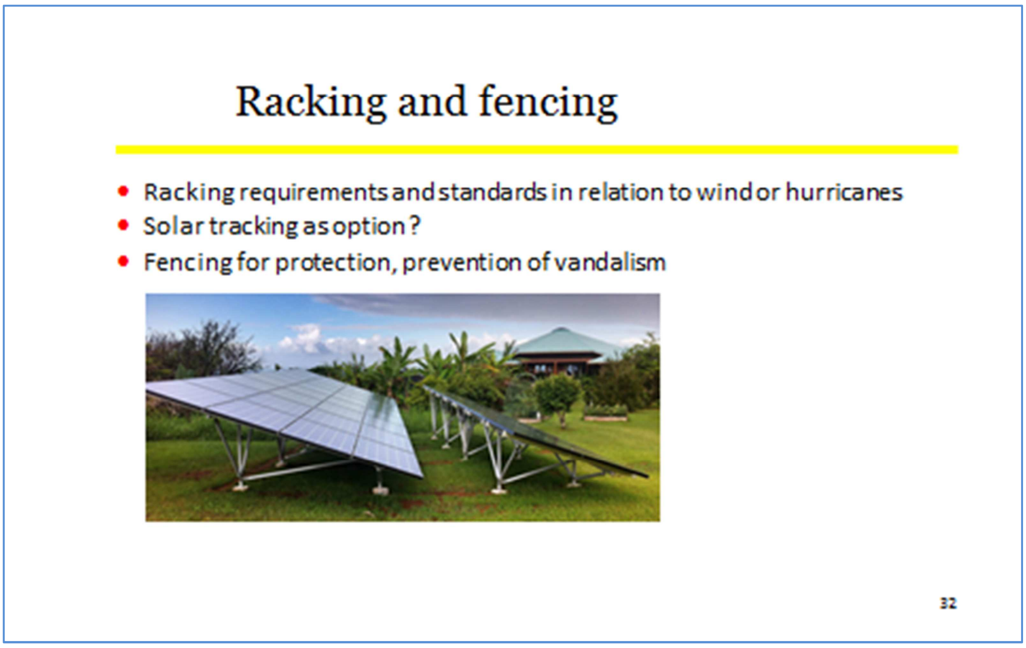
Safety equipment

- Switches, circuit breakers
- Personal safety equipment



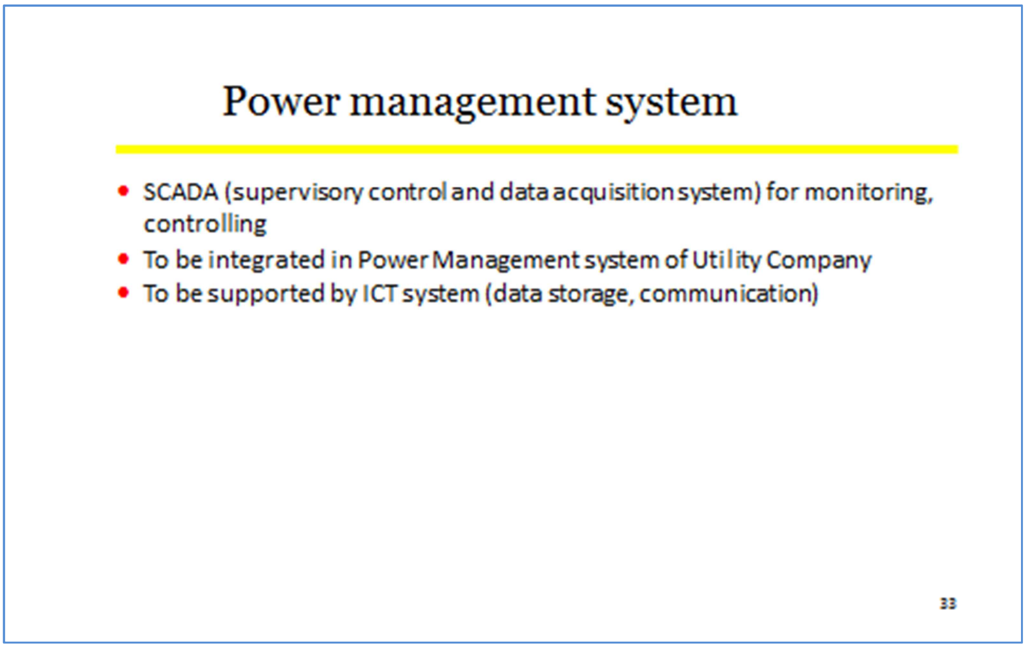
Cabling and conduits

- Different colour conventions of wiring for AC and DC
- DC cables must be certified up to 1 kV
- And should be coated with UV resistant material, as they are exposed to solar radiation
- Conduits for housing of the PV wires



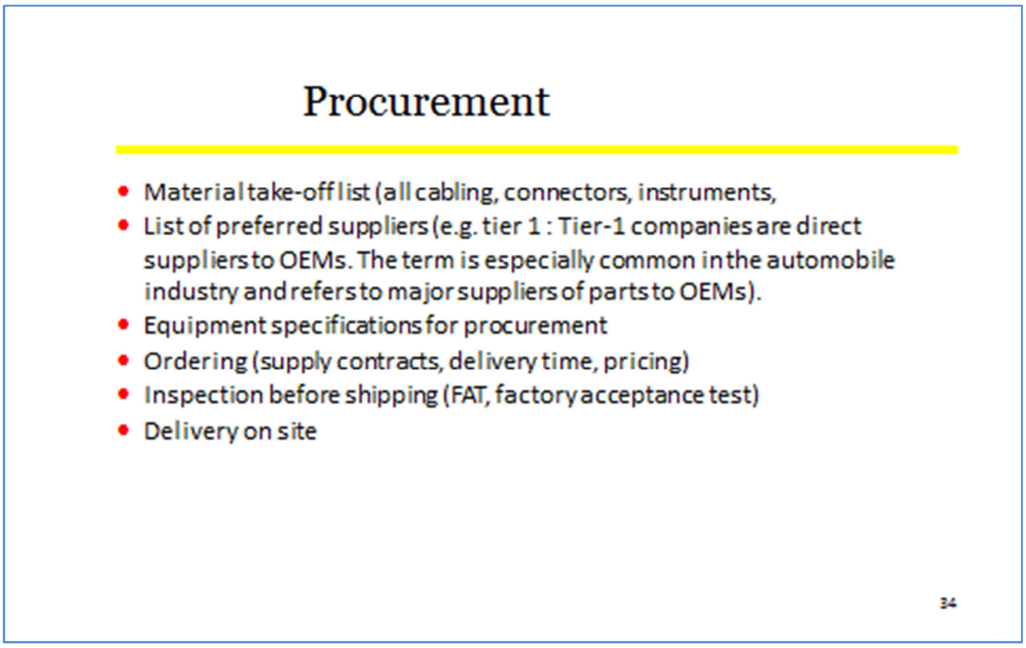
Racking and fencing

- Racking requirements and standards in relation to wind or hurricanes
- Solar tracking as option ?
- Fencing for protection, prevention of vandalism



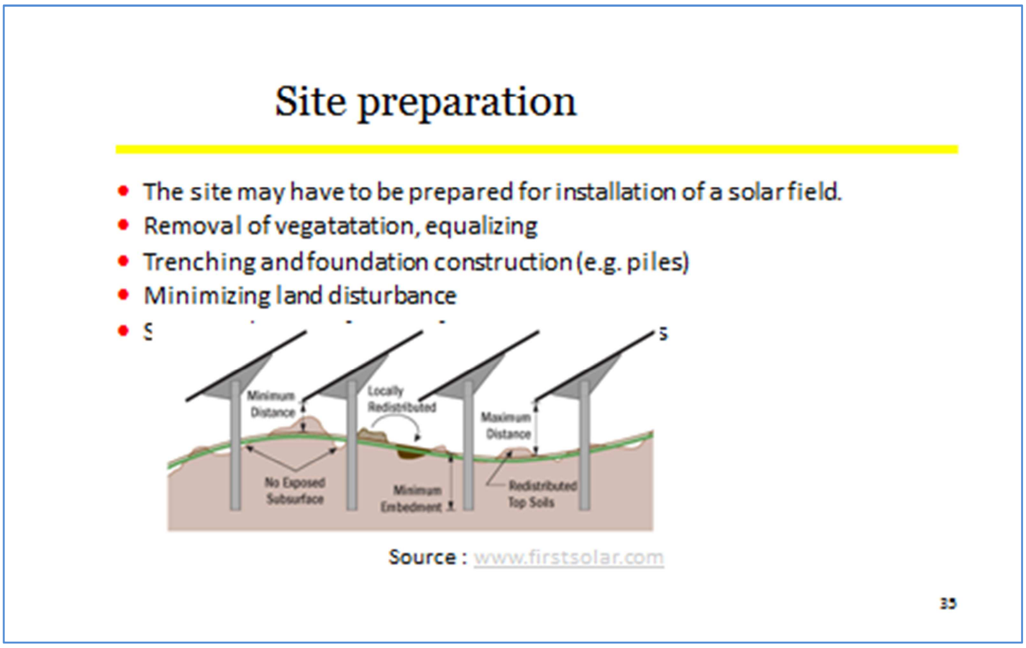
Power management system

- SCADA (supervisory control and data acquisition system) for monitoring, controlling
- To be integrated in Power Management system of Utility Company
- To be supported by ICT system (data storage, communication)



Procurement

- Material take-off list (all cabling, connectors, instruments,
- List of preferred suppliers (e.g. tier 1 : Tier-1 companies are direct suppliers to OEMs. The term is especially common in the automobile industry and refers to major suppliers of parts to OEMs).
- Equipment specifications for procurement
- Ordering (supply contracts, delivery time, pricing)
- Inspection before shipping (FAT, factory acceptance test)
- Delivery on site



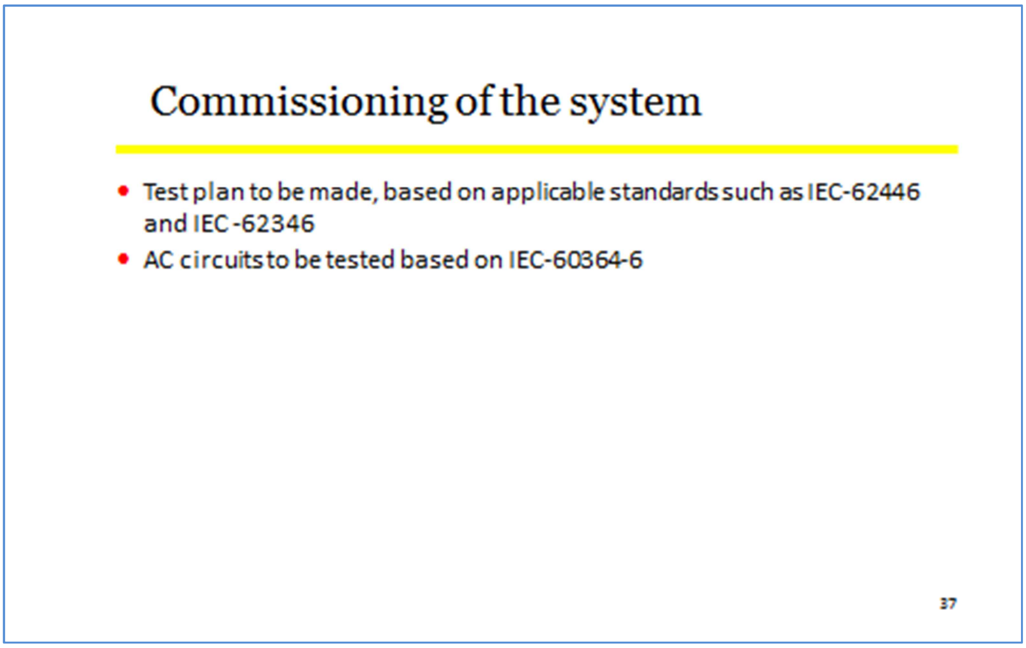
Site preparation

- The site may have to be prepared for installation of a solar field.
- Removal of vegatatation, equalizing
- Trenching and foundation construction (e.g. piles)
- Minimizing land disturbance
- S s

Source : www.firstsolar.com

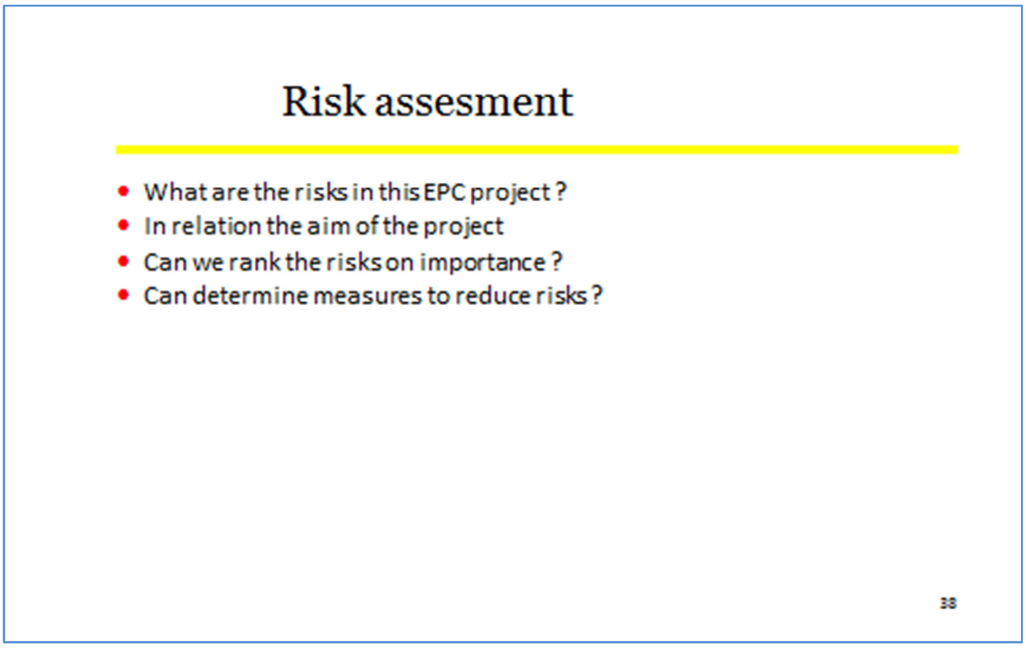
Installation of equipment, connections, wiring (cabling)

- Preferably by licensed installation companies



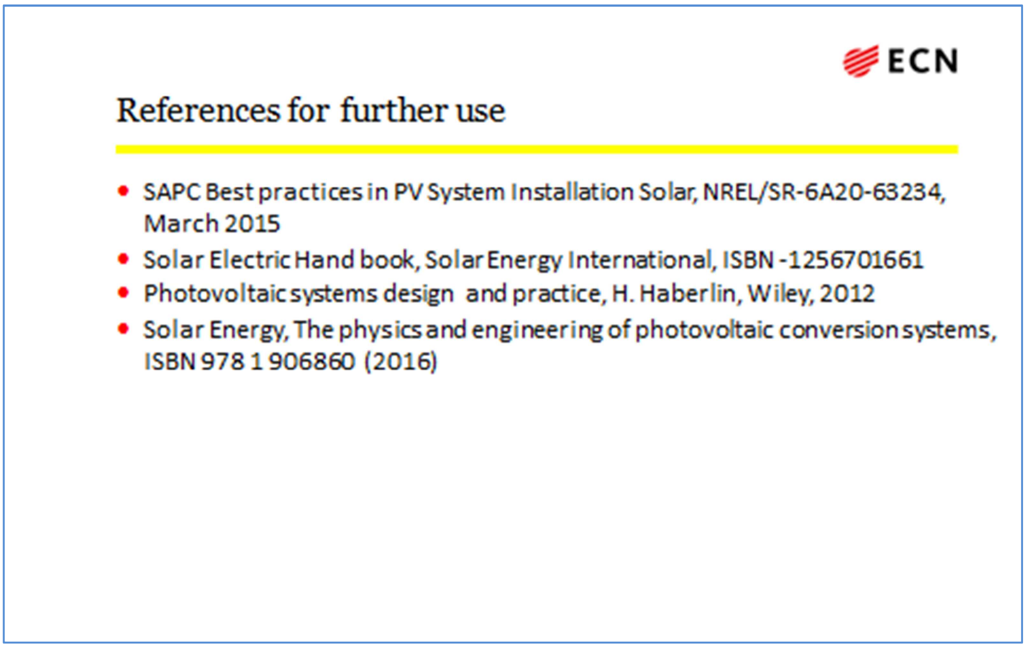
Commissioning of the system

- Test plan to be made, based on applicable standards such as IEC-62446 and IEC -62346
- AC circuits to be tested based on IEC-60364-6



Risk assesment

- What are the risks in this EPC project ?
- In relation the aim of the project
- Can we rank the risks on importance ?
- Can determine measures to reduce risks ?

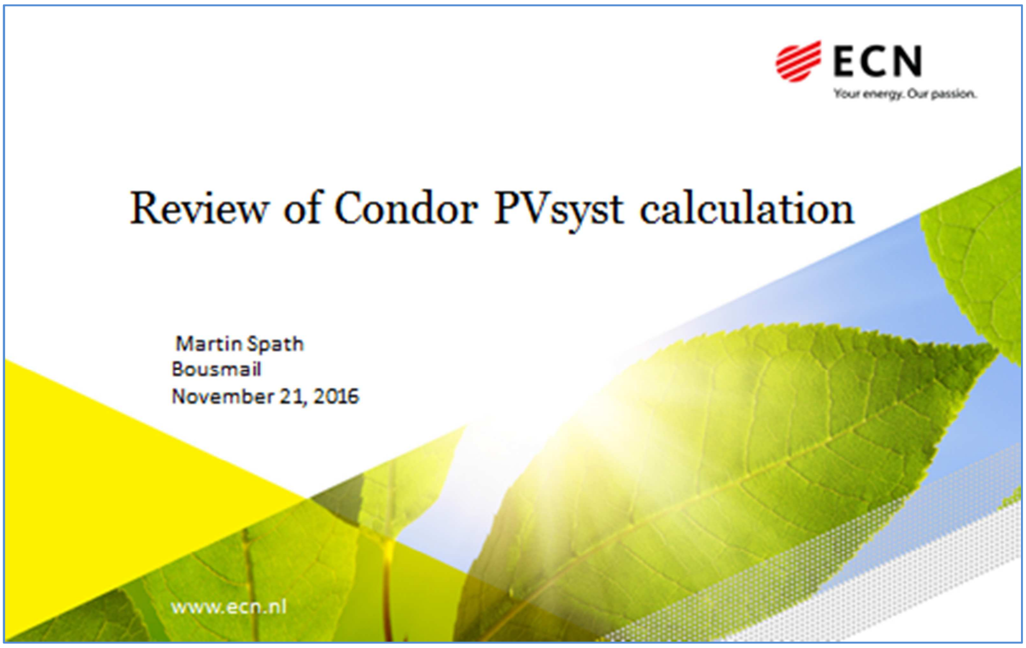


ECN

References for further use

- SAPC Best practices in PV System Installation Solar, NREL/SR-6A20-63234, March 2015
- Solar Electric Hand book, Solar Energy International, ISBN -1256701661
- Photovoltaic systems design and practice, H. Haberlin, Wiley, 2012
- Solar Energy, The physics and engineering of photovoltaic conversion systems, ISBN 978 1 906860 (2016)

A.2. Presentation PVsyst model

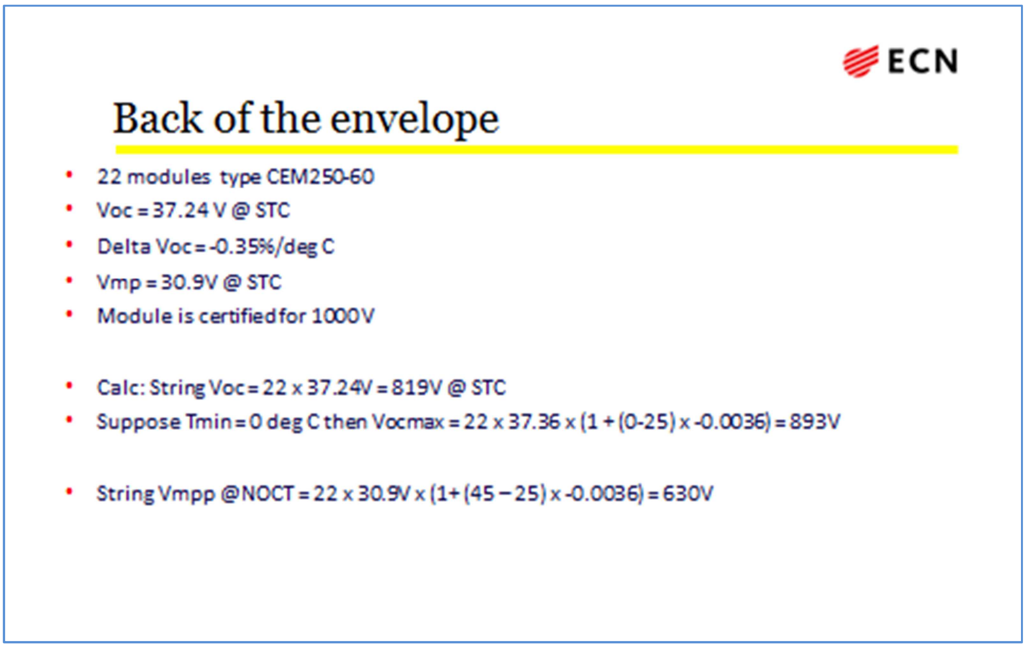


ECN
Your energy. Our passion.

Review of Condor PVsyst calculation

Martin Spath
Bousmail
November 21, 2016

www.ecn.nl



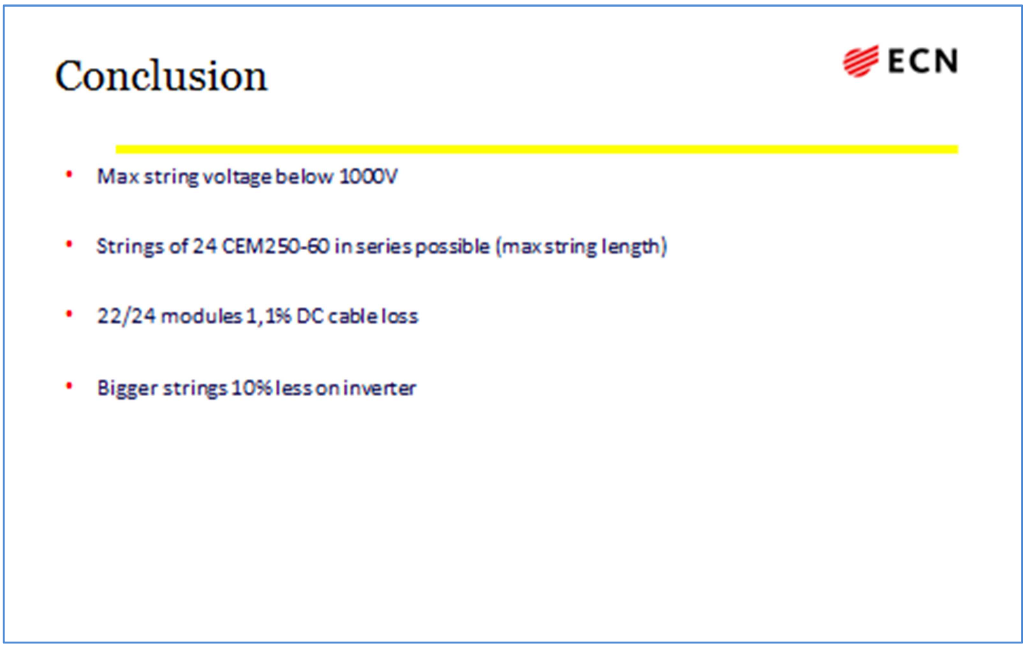
ECN

Back of the envelope

- 22 modules type CEM250-60
- Voc = 37.24 V @ STC
- Delta Voc = -0.35%/deg C
- Vmp = 30.9V @ STC
- Module is certified for 1000V

- Calc: String Voc = 22 x 37.24V = 819V @ STC
- Suppose Tmin = 0 deg C then Vocmax = 22 x 37.36 x (1 + (0-25) x -0.0036) = 893V

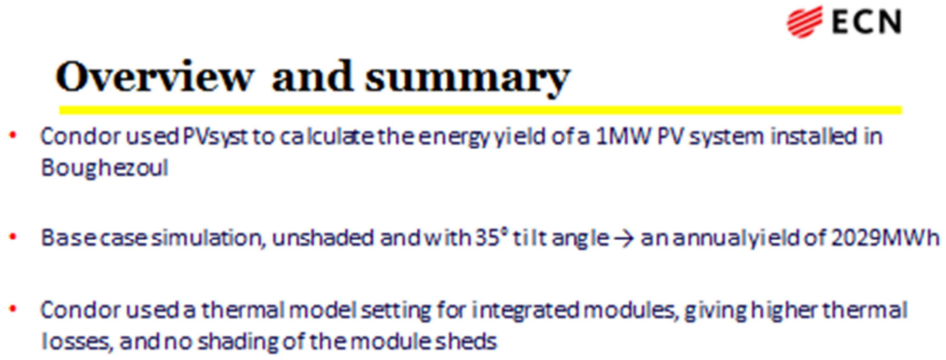
- String Vmpp @NOCT = 22 x 30.9V x (1+ (45 – 25) x -0.0036) = 630V



Conclusion

ECN

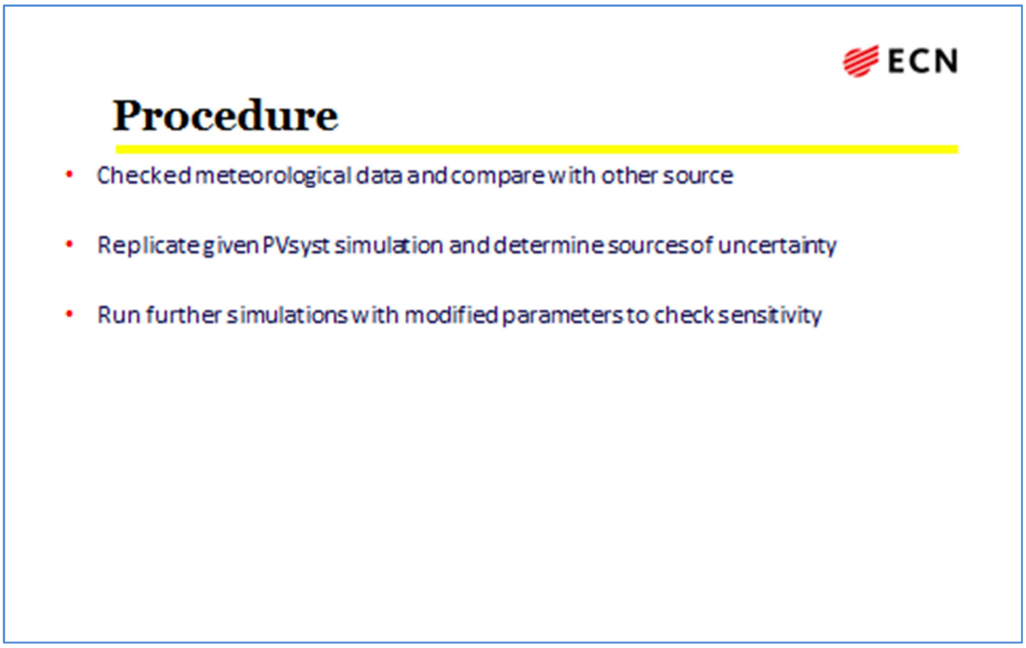
- Max string voltage below 1000V
- Strings of 24 CEM250-60 in series possible (max string length)
- 22/24 modules 1,1% DC cable loss
- Bigger strings 10% less on inverter



ECN

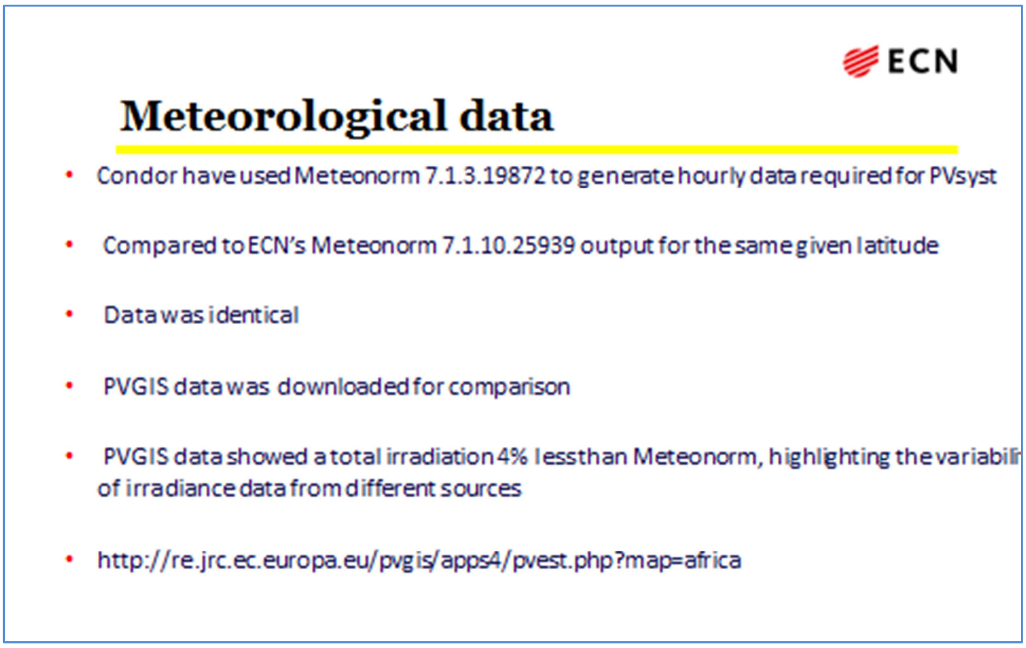
Overview and summary

- Condor used PVsyst to calculate the energy yield of a 1MW PV system installed in Boughezoul
- Base case simulation, unshaded and with 35° tilt angle → an annual yield of 2029MWh
- Condor used a thermal model setting for integrated modules, giving higher thermal losses, and no shading of the module sheds



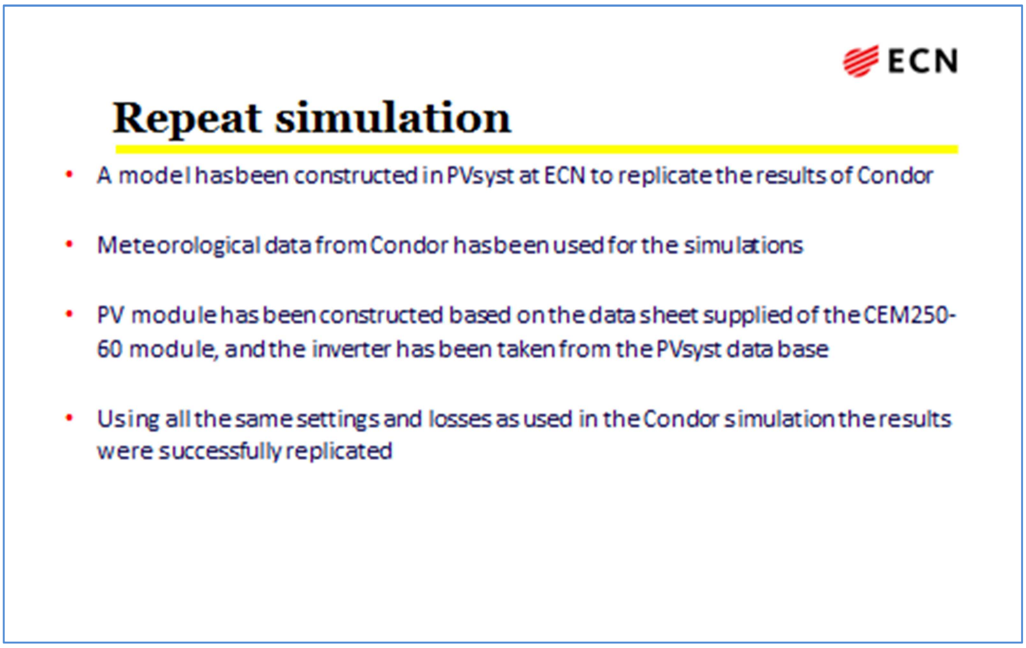
Procedure

- Checked meteorological data and compare with other source
- Replicate given PVsyst simulation and determine sources of uncertainty
- Run further simulations with modified parameters to check sensitivity



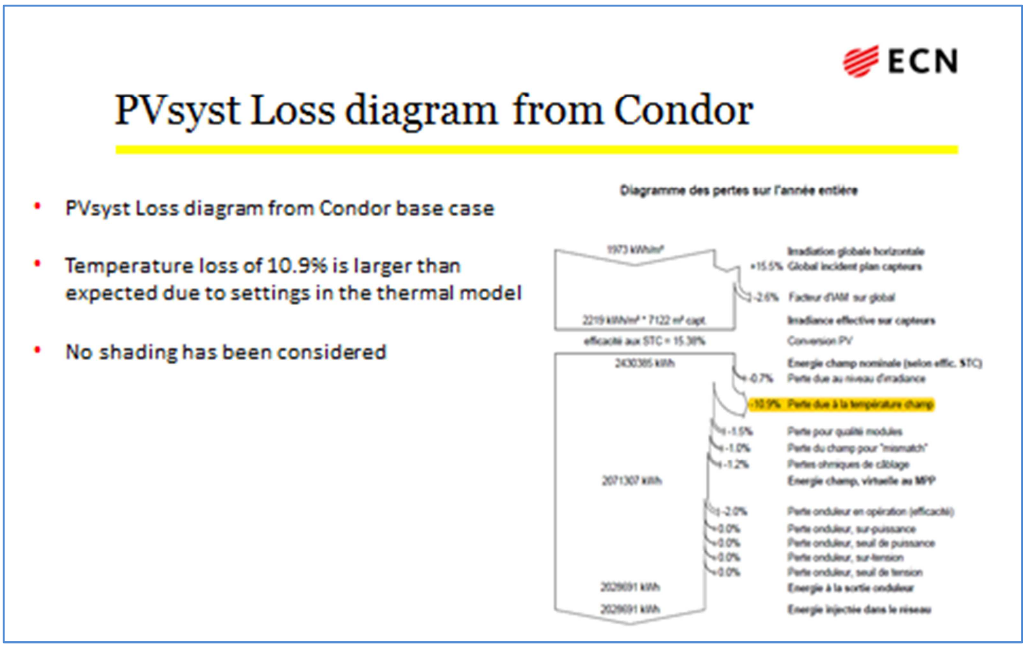
Meteorological data

- Condor have used Meteonorm 7.1.3.19872 to generate hourly data required for PVsyst
- Compared to ECN's Meteonorm 7.1.10.25939 output for the same given latitude
- Data was identical
- PVGIS data was downloaded for comparison
- PVGIS data showed a total irradiation 4% less than Meteonorm, highlighting the variabili of irradiance data from different sources
- http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa



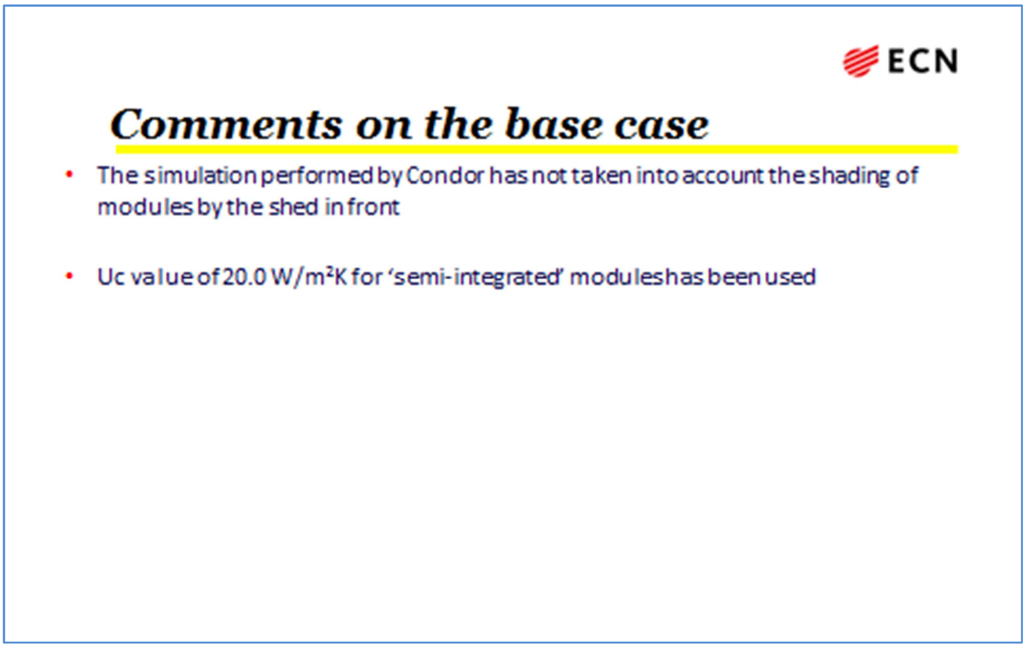
Repeat simulation

- A model has been constructed in PVsyst at ECN to replicate the results of Condor
- Meteorological data from Condor has been used for the simulations
- PV module has been constructed based on the data sheet supplied of the CEM250-60 module, and the inverter has been taken from the PVsyst data base
- Using all the same settings and losses as used in the Condor simulation the results were successfully replicated



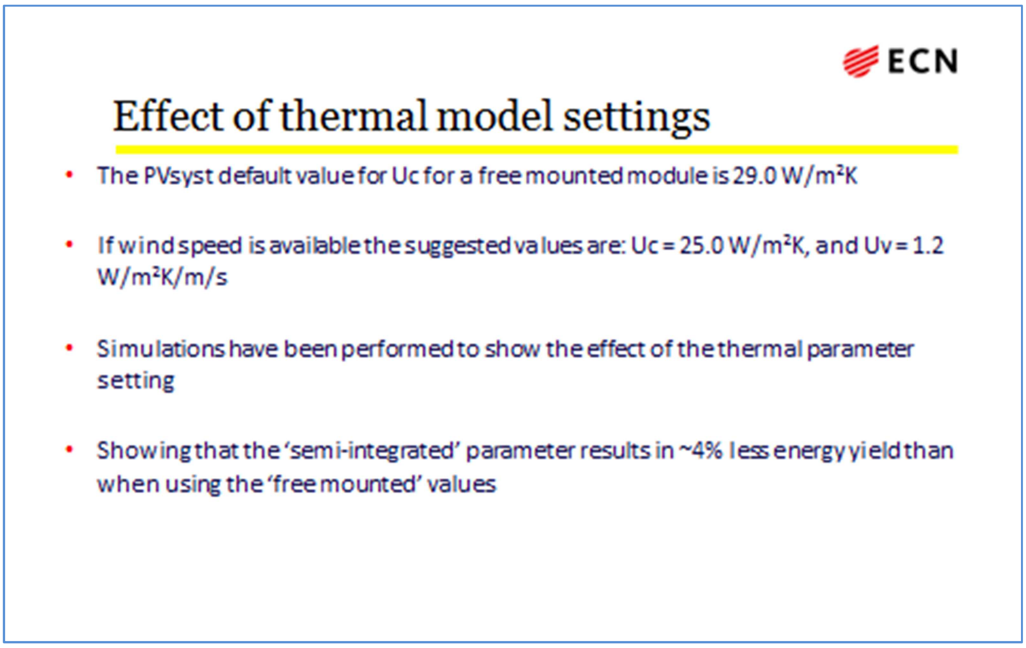
PVsyst Loss diagram from Condor

- PVsyst Loss diagram from Condor base case
- Temperature loss of 10.9% is larger than expected due to settings in the thermal model
- No shading has been considered



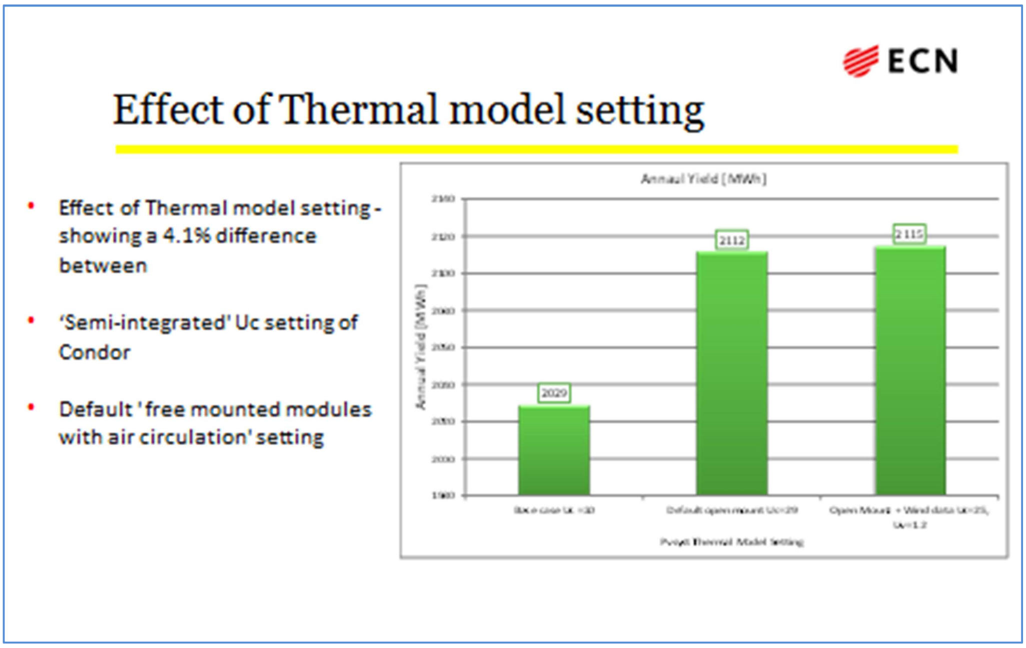
Comments on the base case

- The simulation performed by Condor has not taken into account the shading of modules by the shed in front
- Uc value of 20.0 W/m²K for 'semi-integrated' modules has been used



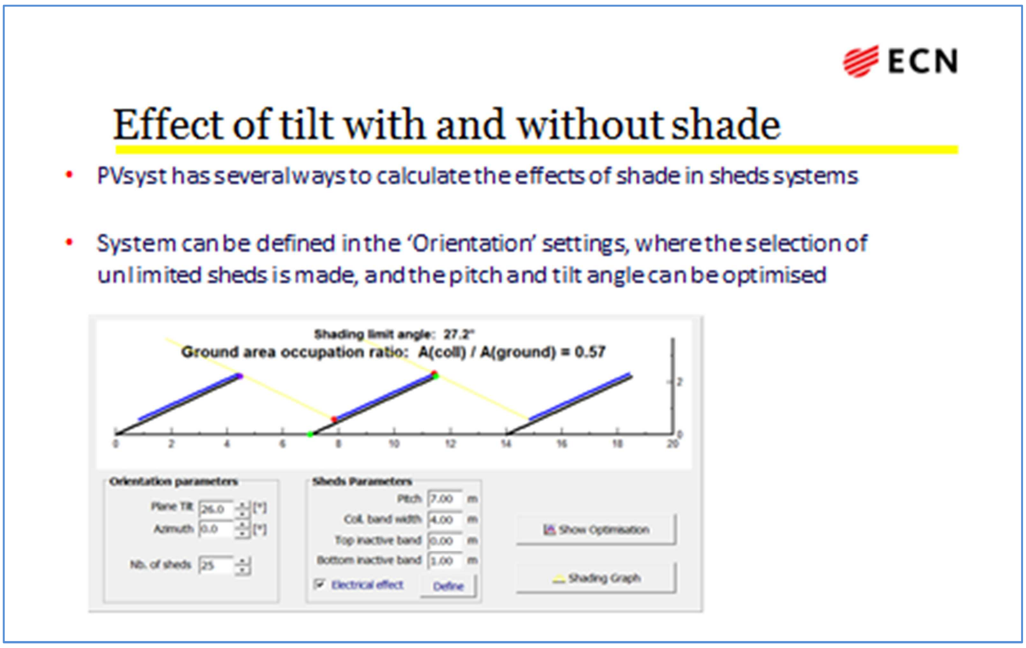
Effect of thermal model settings

- The PVsyst default value for Uc for a free mounted module is 29.0 W/m²K
- If wind speed is available the suggested values are: Uc = 25.0 W/m²K, and Uv = 1.2 W/m²K/m/s
- Simulations have been performed to show the effect of the thermal parameter setting
- Showing that the 'semi-integrated' parameter results in ~4% less energy yield than when using the 'free mounted' values



Effect of Thermal model setting

- Effect of Thermal model setting - showing a 4.1% difference between
- 'Semi-integrated' Uc setting of Condor
- Default 'free mounted modules with air circulation' setting



Effect of tilt with and without shade

- PVsyst has several ways to calculate the effects of shade in sheds systems
- System can be defined in the 'Orientation' settings, where the selection of unlimited sheds is made, and the pitch and tilt angle can be optimised

Shading limit angle: 27.2°

Ground area occupation ratio: A(coll) / A(ground) = 0.57

Orientation parameters

Plane Tilt 26.0 [°]

Azimuth 0.0 [°]

Nb. of sheds 25

Sheds Parameters

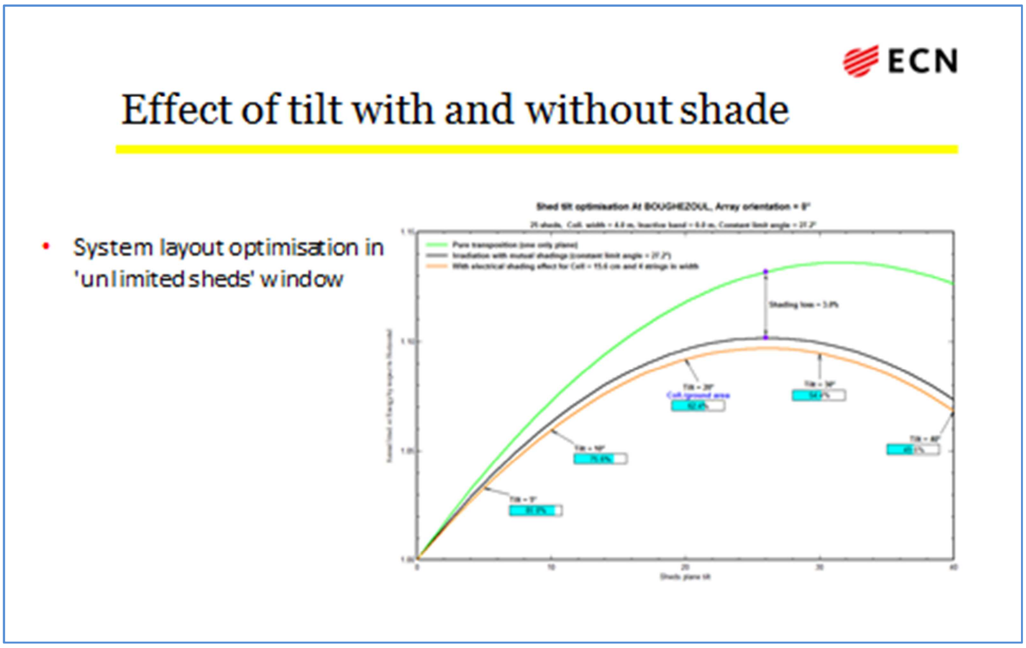
Pitch 7.00 m

Coll. band width 4.00 m

Top inactive band 0.00 m

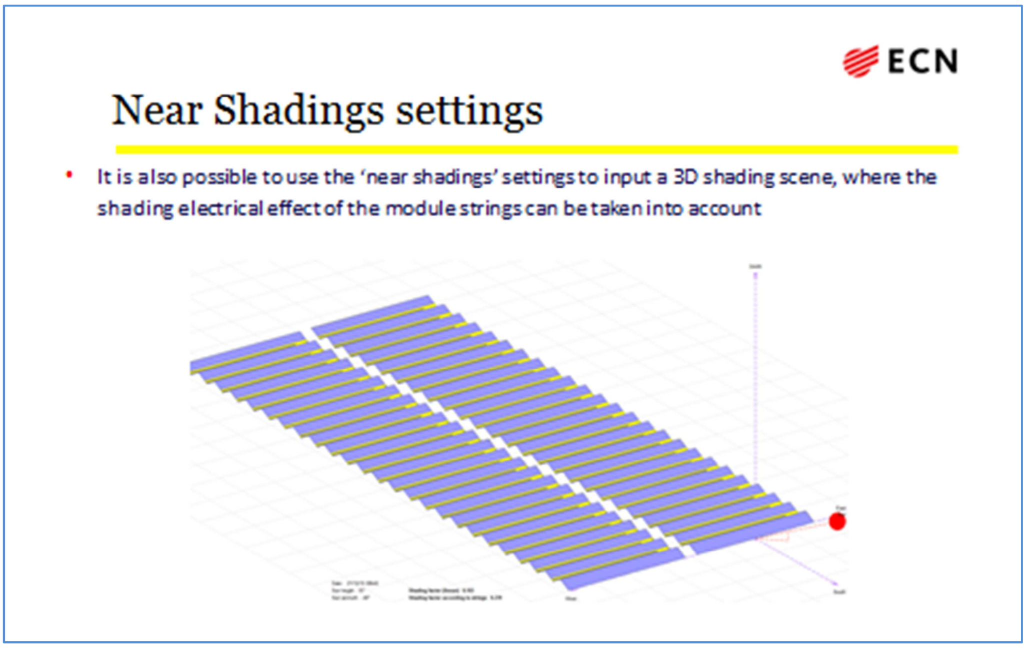
Bottom inactive band 1.00 m

☑ Electrical effect



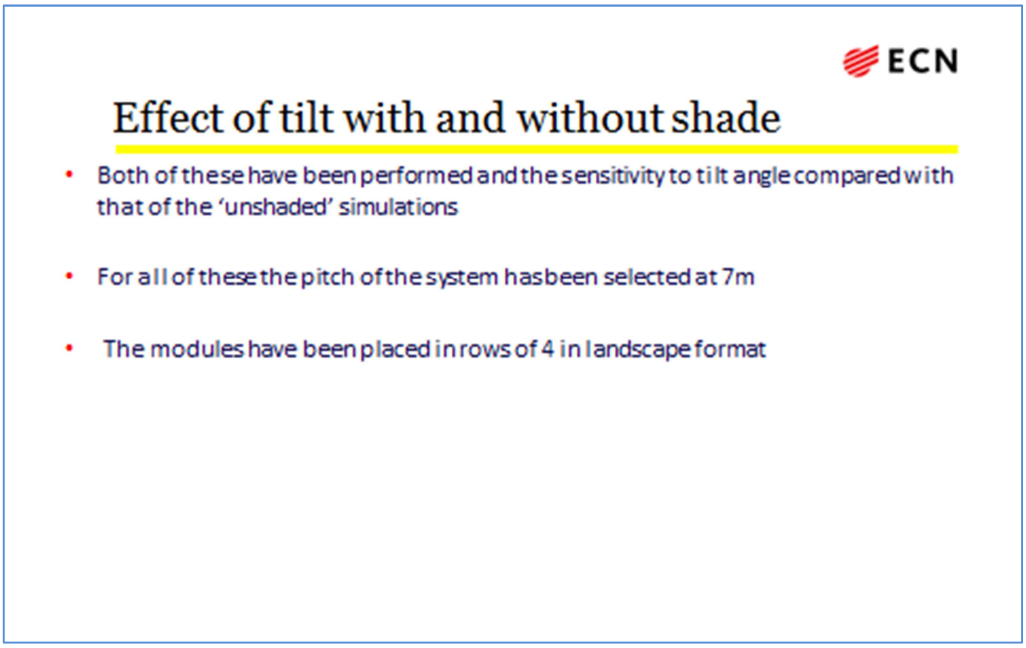
Effect of tilt with and without shade

- System layout optimisation in 'unlimited sheds' window



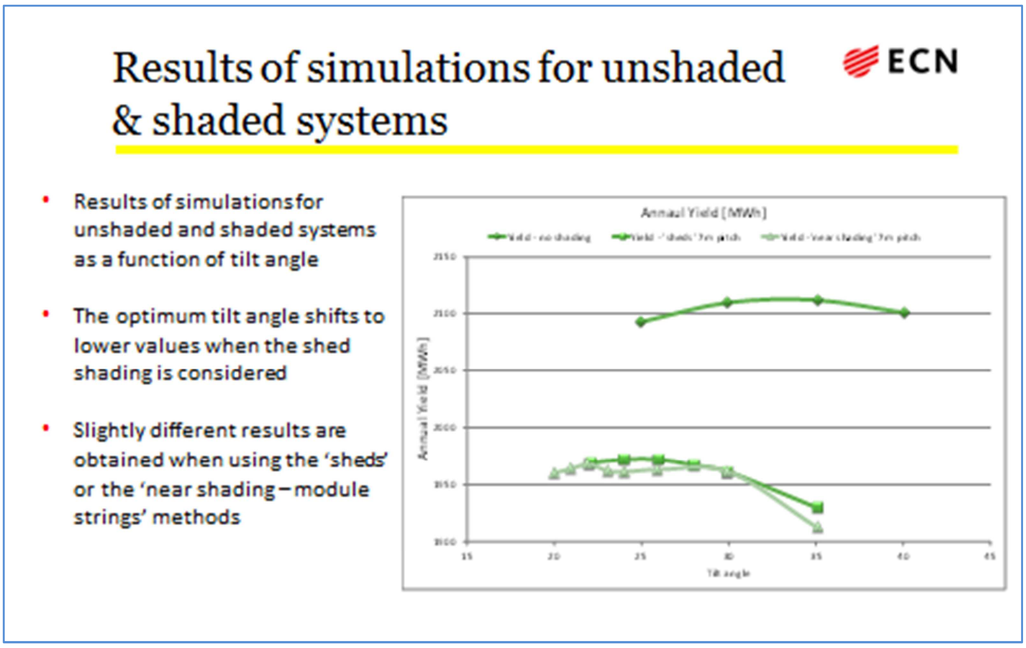
Near Shadings settings

- It is also possible to use the 'near shadings' settings to input a 3D shading scene, where the shading electrical effect of the module strings can be taken into account



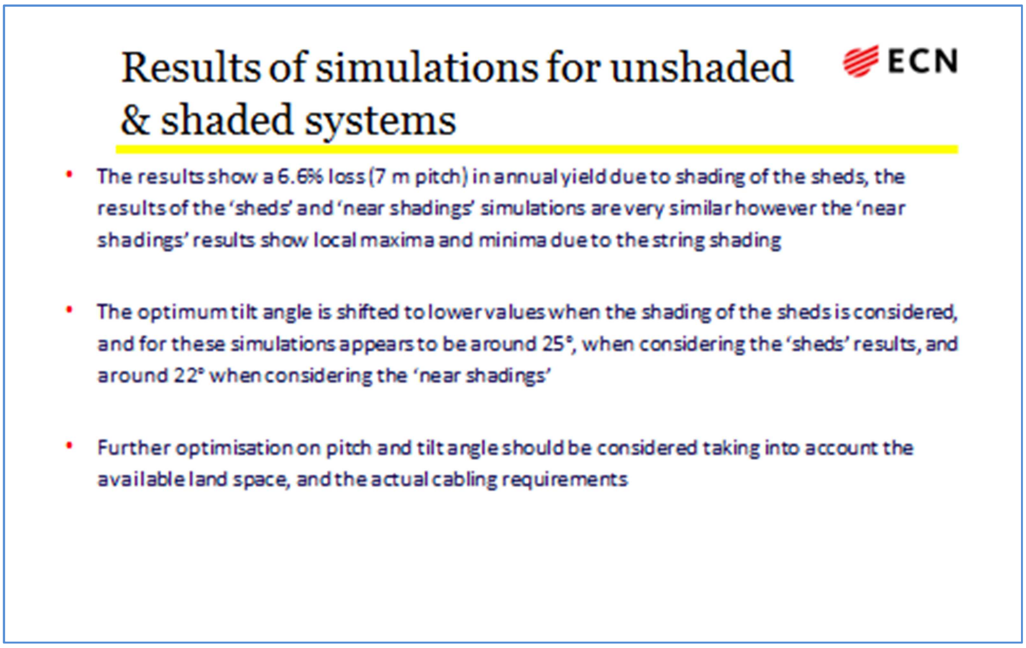
Effect of tilt with and without shade

- Both of these have been performed and the sensitivity to tilt angle compared with that of the 'unshaded' simulations
- For all of these the pitch of the system has been selected at 7m
- The modules have been placed in rows of 4 in landscape format



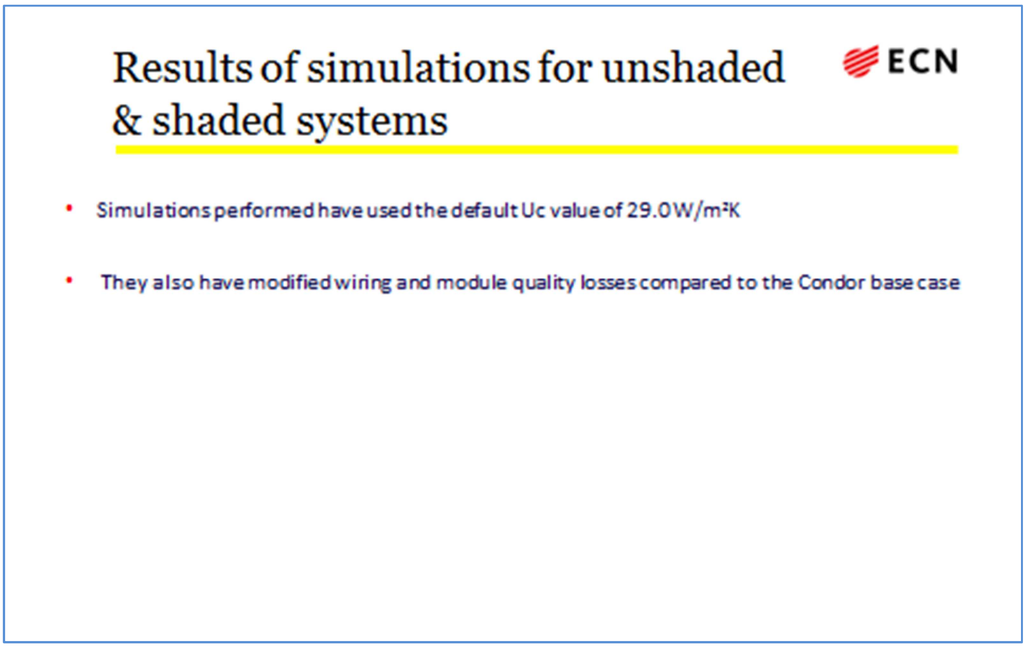
Results of simulations for unshaded & shaded systems

- Results of simulations for unshaded and shaded systems as a function of tilt angle
- The optimum tilt angle shifts to lower values when the shed shading is considered
- Slightly different results are obtained when using the 'sheds' or the 'near shading – module strings' methods



Results of simulations for unshaded & shaded systems

- The results show a 6.6% loss (7 m pitch) in annual yield due to shading of the sheds, the results of the 'sheds' and 'near shadings' simulations are very similar however the 'near shadings' results show local maxima and minima due to the string shading
- The optimum tilt angle is shifted to lower values when the shading of the sheds is considered, and for these simulations appears to be around 25°, when considering the 'sheds' results, and around 22° when considering the 'near shadings'
- Further optimisation on pitch and tilt angle should be considered taking into account the available land space, and the actual cabling requirements

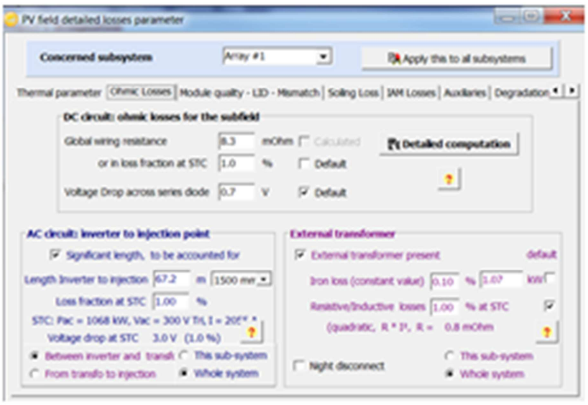


Results of simulations for unshaded & shaded systems

- Simulations performed have used the default Uc value of 29.0 W/m²K
- They also have modified wiring and module quality losses compared to the Condor base case

Ohmic losses settings

- Parameters derived from Pvsyst base setting for 1 MW case



Concerned subsystem: Array #1

DC circuit: ohmic losses for the subfield

Global wiring resistance 8.3 mOhm ☐ Calculated

or in loss fraction at STC 1.0 % ☐ Default

Voltage Drop across series diode 0.7 V ☑ Default

AC circuit: inverter to injection point

☑ Significant length, to be accounted for

Length Inverter to injection 67.2 m 1500 mm²

Loss fraction at STC 1.00 %

STC: Pac = 1068 kW, Vac = 300 V Tri, I = 20

Voltage drop at STC 3.0 V (1.0 %)

● Between inverter and transfo ○ This sub-system

○ From transfo to injection ● Whole system

External transformer

☑ External transformer present (default)

Iron loss (constant value) 0.10 % 1.07 kW ☐

Resistive/Inductive losses 1.00 % at STC ☑

(quadratic, R * I², R = 0.8 mOhm

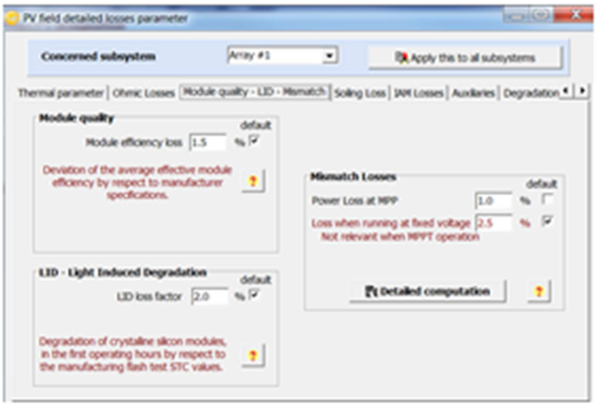
☐ Night disconnect

○ This sub-system

● Whole system

Module quality losses

- Parameters derived from Pvsyst base setting for 1 MW case



Concerned subsystem: Array #1

Module quality

Module efficiency loss 1.5 % ☑ default

Deviation of the average effective module efficiency by respect to manufacturer specifications.

LID - Light Induced Degradation

LID loss factor 2.0 % ☑ default

Degradation of crystaline silicon modules, in the first operating hours by respect to the manufacturing flash test STC values.

Mismatch Losses

Power Loss at MPP 1.0 % ☐ default

Loss when running at fixed voltage 2.5 % ☑

Not relevant when MPPT operation

A.3. Note PVsyst simulation

Overview and summary

Condor has used PVsyst to calculate the energy yield of a 1MW PV system installed in Boughezoul, Algeria. Their base case simulation, unshaded and with 35° tilt angle showed an annual yield of 2029MWh. However, they have used a thermal model setting for integrated modules, giving higher thermal losses, and they have not considered shading of the module sheds.

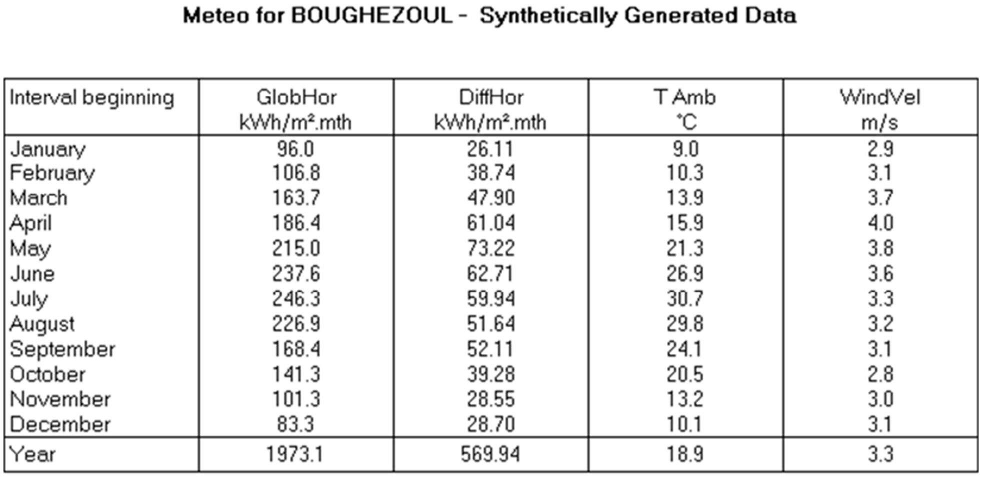
NOTE: The results of these simulations are indicative only, and ECN do not provide any guarantee as to the actual yield of a real PV system based on these layouts.

Procedure used by ECN

Checked meteorological data and compare with other source
Replicate run with given PVsyst simulation from Condor and determined sources of uncertainty. Run further simulations with modified parameters to check sensitivity

A.4. Meteorological data

Condor has used Meteonorm 7.1.3.19872 to generate hourly data required for PVsyst calculations, this was compared to ECN's Meteonorm 7.1.10.25939 output for the same given latitude. The data was the same. PVGIS[2] data was also downloaded for comparison. The PVGIS data showed a total irradiation 4% less than Meteonorm, highlighting the variability of irradiance data from different sources.



Meteo for BOUGHEZOUL - Synthetically Generated Data

Interval beginning	GlobHor kWh/m².mth	DiffHor kWh/m².mth	T Amb °C	WindVel m/s
January	96.0	26.11	9.0	2.9
February	106.8	38.74	10.3	3.1
March	163.7	47.90	13.9	3.7
April	186.4	61.04	15.9	4.0
May	215.0	73.22	21.3	3.8
June	237.6	62.71	26.9	3.6
July	246.3	59.94	30.7	3.3
August	226.9	51.64	29.8	3.2
September	168.4	52.11	24.1	3.1
October	141.3	39.28	20.5	2.8
November	101.3	28.55	13.2	3.0
December	83.3	28.70	10.1	3.1
Year	1973.1	569.94	18.9	3.3

Table 3: Summary of Meteonorm meteorological data

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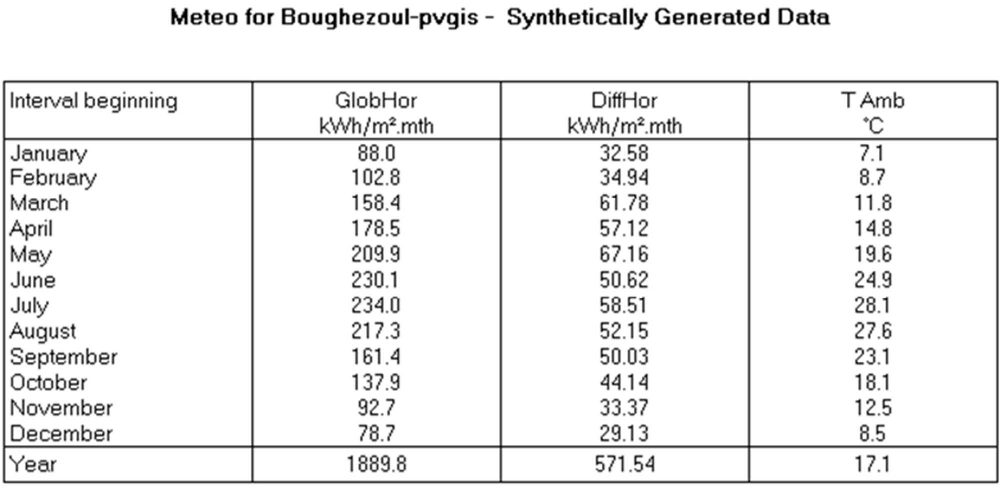
[2] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa



Meteo for Boughezoul-pvgis - Synthetically Generated Data

Interval beginning	GlobHor kWh/m².mth	DiffHor kWh/m².mth	T Amb °C
January	88.0	32.58	7.1
February	102.8	34.94	8.7
March	158.4	61.78	11.8
April	178.5	57.12	14.8
May	209.9	67.16	19.6
June	230.1	50.62	24.9
July	234.0	58.51	28.1
August	217.3	52.15	27.6
September	161.4	50.03	23.1
October	137.9	44.14	18.1
November	92.7	33.37	12.5
December	78.7	29.13	8.5
Year	1889.8	571.54	17.1

Table 4: Summary of PVGIS meteorological data

Repeat simulation

A model has been constructed in PVsyst at ECN to replicate the results of Condor, the meteorological data from Condor has been used for the simulations. The PV module has been constructed based on the data sheet supplied of the CEM250-60 module, and the inverter has been taken from the PVsyst data base. Using all the same settings and losses as used in the Condor simulation the results were successfully replicated.

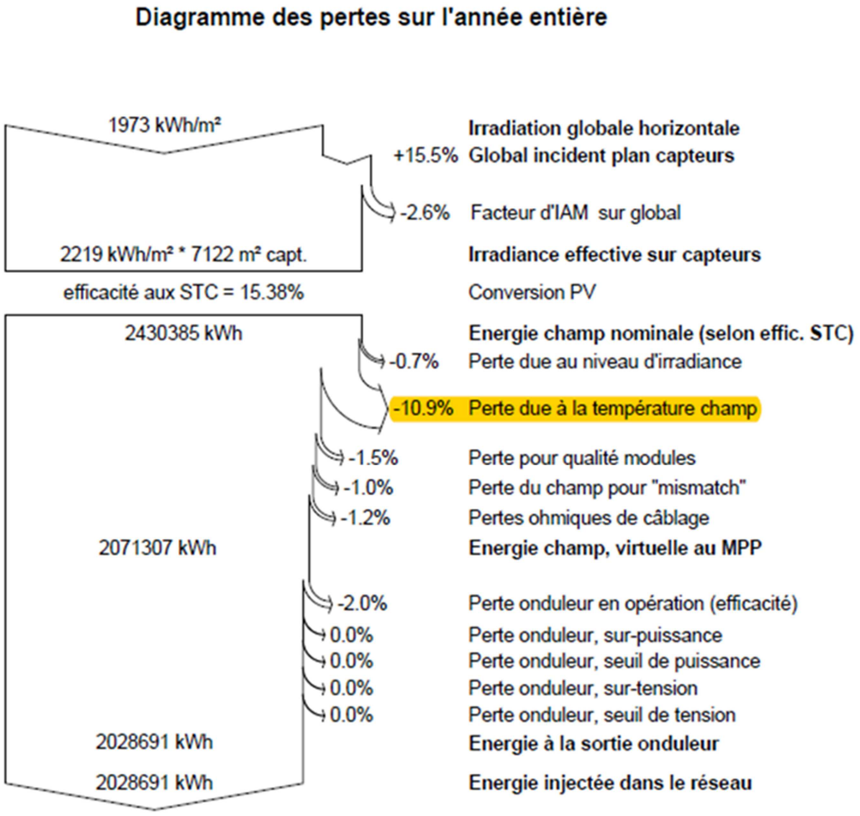


Figure 14: PVsyst Loss diagram from Condor base case, the temperature loss of 10.9% is larger than expected, due to settings in the thermal model, and no shading has been considered.

Comments on the base case

The simulation performed by Condor has not taken into account the shading of modules by the shed in front, and the U_c value of 20.0 W/m^{2}K for 'semi-integrated' modules has been used.

Effect of thermal model settings

The PVsyst default value for U_c for a free mounted module is 29.0 W/m^{2}K. Or if wind speed is available the suggested values are: U_c = 25.0 W/m^{2}K, and U_v = 1.2 W/m^{2}K/m/s.

Simulations have been performed by ECN to show the effect of the thermal parameter setting, **Error! Reference source not found.**, showing that the 'semi-integrated' parameter results in ~4% less energy yield than when using the 'free mounted' values.

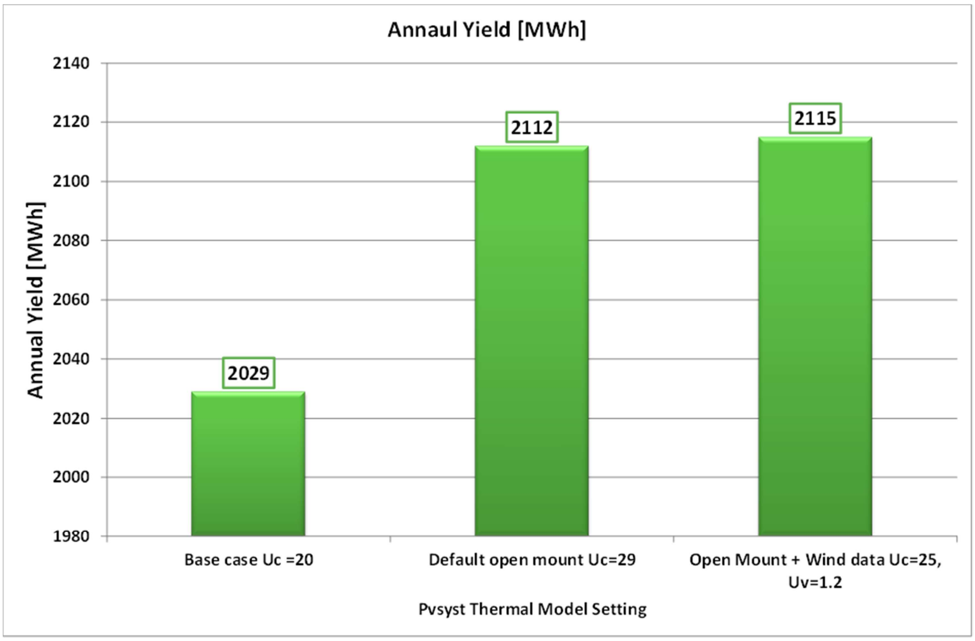
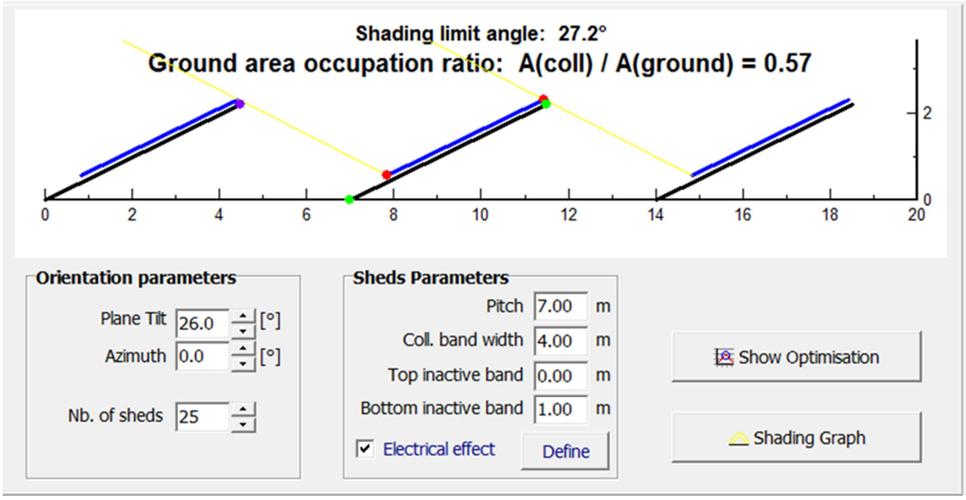


Figure 15: Effect of Thermal model setting - showing a 4.1% difference between the 'semi-integrated' U_c setting of Condor and the default ' Free mounted modules with air circulation' setting.

Effect of tilt without and without shade

PVsyst has several ways to calculate the effects of shade in sheds systems. The system can be defined in the 'Orientation' settings, where the selection of unlimited sheds is made, and the pitch and tilt angle can be optimised (Figure 16 and Figure 17).



Shading limit angle: 27.2°

Ground area occupation ratio: A(coll) / A(ground) = 0.57

Orientation parameters

Plane Tilt 26.0 [°]

Azimuth 0.0 [°]

Nb. of sheds 25

Sheds Parameters

Pitch 7.00 m

Coll. band width 4.00 m

Top inactive band 0.00 m

Bottom inactive band 1.00 m

☑ Electrical effect

Figure 16: Settings for unlimited sheds

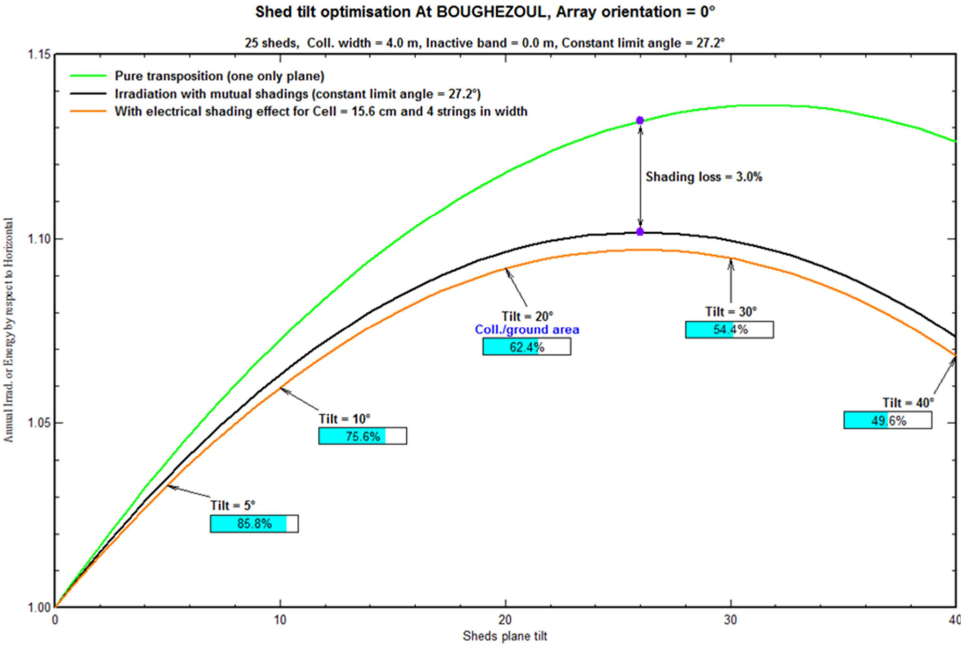


Figure 17: System layout optimisation in 'unlimited sheds' window

It is also possible to use the ‘near shadings’ settings to input a 3D shading scene, where the shading electrical effect of the module strings can be taken into account. (Figure 18)

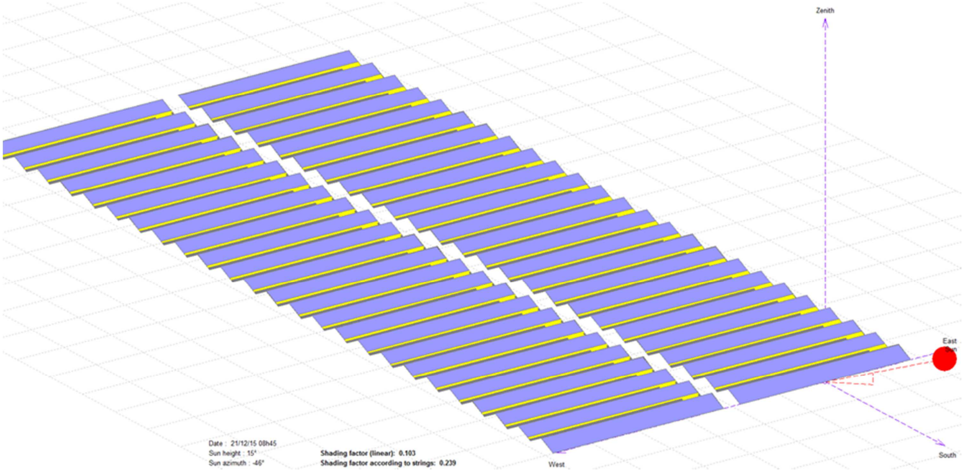


Figure 18: Figure 5 Near Shadings window, showing complete system layout and effect of shading.

Both of these have been performed and the sensitivity to tilt angle compared with that of the ‘unshaded’ simulations.

For all of these the pitch of the system has been selected at 7m. The modules have been placed in rows of 4 in landscape format.

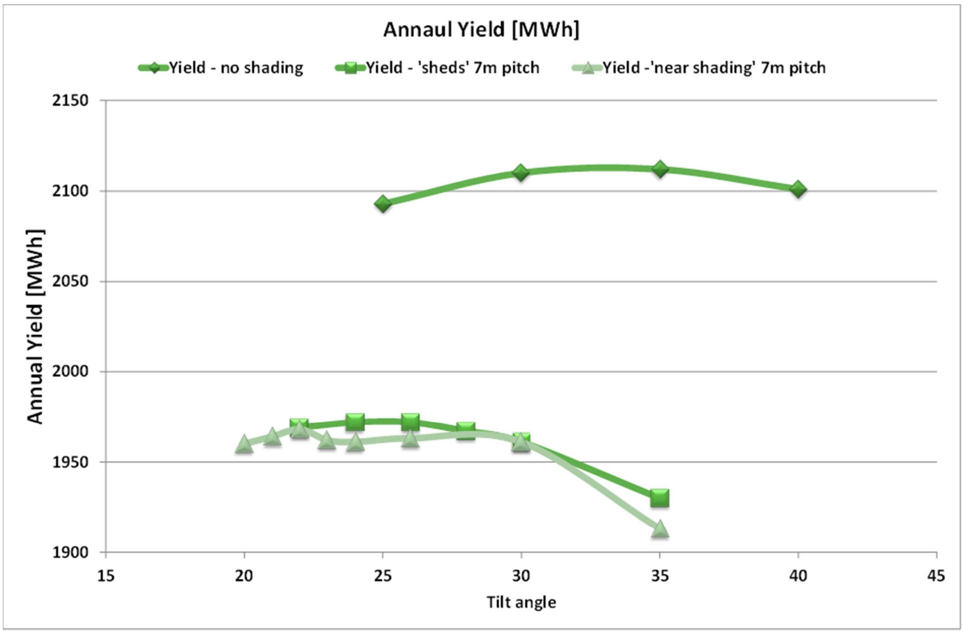


Figure 19: Results of simulations for unshaded and shaded systems as a function of tilt angle. The optimum tilt angle shifts to lower values when the shed shading is considered. Slightly different results are obtained when using the ‘sheds’ or the ‘near shading – module strings’ methods.

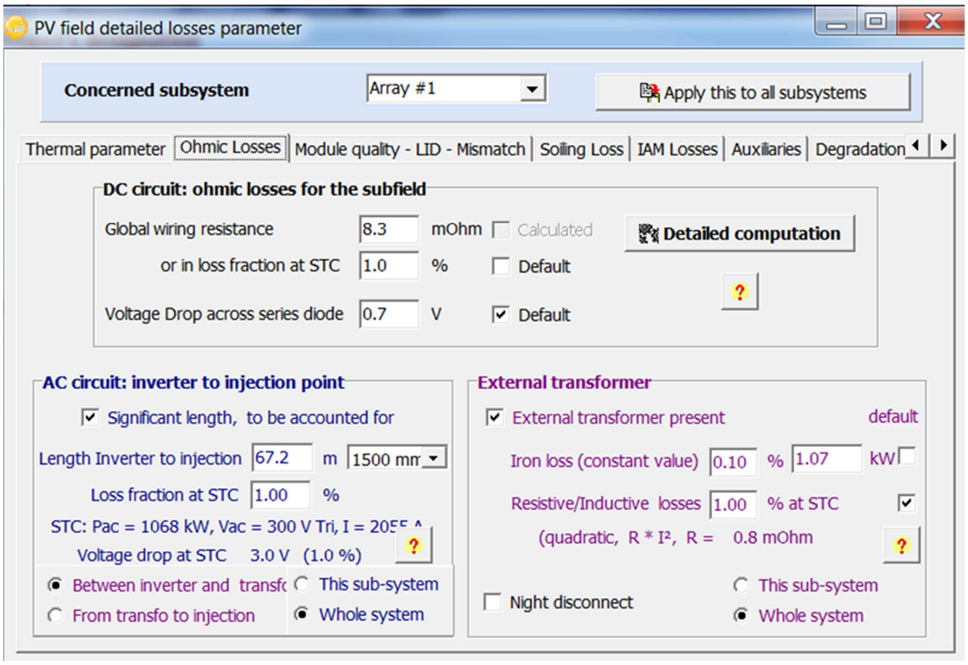
The results, seen in Figure 19, show a 6.6% loss in annual yield due to shading of the sheds, the results of the ‘sheds’ and ‘near shadings’ simulations are very similar however the ‘near shadings’ results show local maxima and minima due to the string shading.

The optimum tilt angle is shifted to lower values when the shading of the sheds is considered, and for these simulations appears to be around 25°, when considering the 'sheds' results, and around 22° when considering the 'near shadings'.

Further optimisation on pitch and tilt angle should be considered taking into account the available land space, and the actual cabling requirements.

Notes and details on ECN simulations:

The simulations performed and shown in Figure 6, have used the default U_c value of 29.0 W/m2K. These simulations also have modified wiring and module quality losses compared to the Condor base case. See Figure 20 and Figure 21.



Concerned subsystem Array #1

DC circuit: ohmic losses for the subfield

Global wiring resistance 8.3 mOhm ☐ Calculated

or in loss fraction at STC 1.0 % ☐ Default

Voltage Drop across series diode 0.7 V ☑ Default

AC circuit: inverter to injection point

☑ Significant length, to be accounted for

Length Inverter to injection 67.2 m 1500 mm

Loss fraction at STC 1.00 %

STC: Pac = 1068 kW, Vac = 300 V Tri, I = 205

Voltage drop at STC 3.0 V (1.0 %)

● Between inverter and transfo ○ This sub-system

○ From transfo to injection ● Whole system

External transformer

☑ External transformer present default

Iron loss (constant value) 0.10 % 1.07 kW ☐

Resistive/Inductive losses 1.00 % at STC ☑

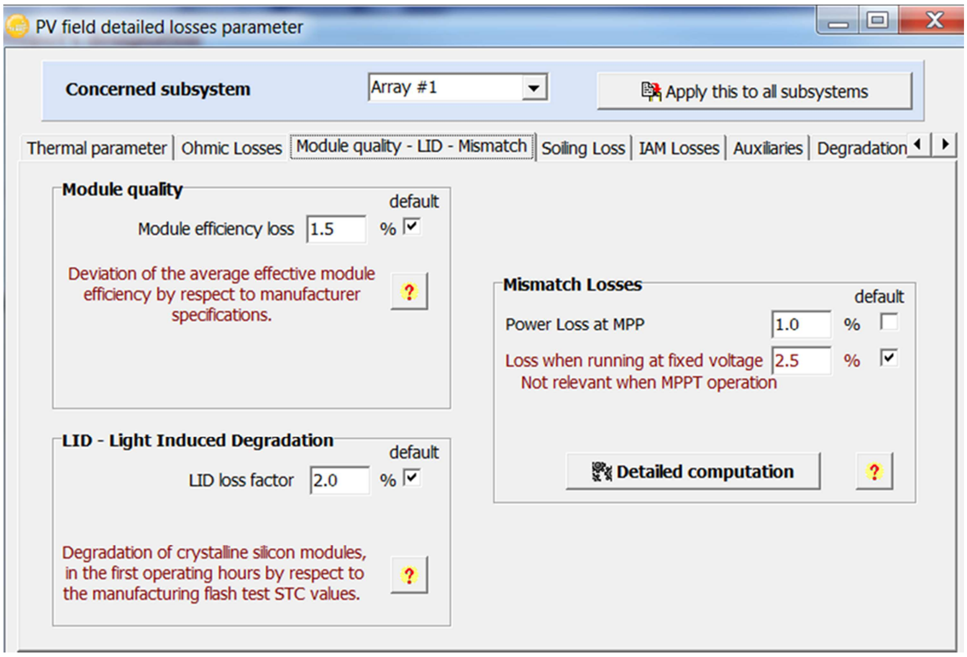
(quadratic, R * I², R = 0.8 mOhm

☐ Night disconnect

○ This sub-system

● Whole system

Figure 20: Ohmic losses settings



Concerned subsystem: Array #1

Module quality

default

Module efficiency loss 1.5 % ☑

Deviation of the average effective module efficiency by respect to manufacturer specifications.

LID - Light Induced Degradation

default

LID loss factor 2.0 % ☑

Degradation of crystalline silicon modules, in the first operating hours by respect to the manufacturing flash test STC values.

Mismatch Losses

default

Power Loss at MPP 1.0 % ☐

Loss when running at fixed voltage 2.5 % ☑

Not relevant when MPPT operation

Figure 21: Module quality losses

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