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Yield Assessment Report Holmen

Holmen Solar Farm, (Mid-Jutland) Denmark

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European Energy
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1 Summary of Results

For the photovoltaic system under examination with an STC output of **21,261 kW_p**, an average annual energy yield of **26,629 MWh** has been calculated, taking into consideration the components used and the chosen location.

This results in an average annual specific yield of **1,252 kWh/kW_p** (P50 value) and a Performance Ratio of **91.4 %**.

The total uncertainty has a standard deviation of **5.5 %.**

These figures are to be regarded as mean figures for an „average irradiation year“ (here: **1,038 kWh/m^2** on the horizontal) in accordance with the consideration of a plant availability of 100 % and a power factor of 1.

No ageing degradation of the modules is considered for this evaluation.

2 Purpose and object of the Assessment

Forecast of annual average energy yield of the photovoltaic plant till POC including power transformer and MV line.

2.1 System Description

Location: Holmen (Mid-Jutland), Denmark (55.851° N, 8.321° E)

Total PV power: 21,261 kW_p

2.1.1 Type of Mounting

Single axis tracking system East/ West

Arrangement: 1 module, portrait

Rotation limitations: 55°

Row spacing (Pitch): 5.0 m

Sun Angle (21. December, 12 Noon): 10.65°

Shading Angle: 16.0°

2.1.2 Orientation of the Modules

Orientation of the module-axis: Azimuth 0° South

Inclination of the modules to the horizontal: 0°

2.1.3 Modules

Solar cell type: Mono crystalline silicon BiFi cells

Bifaciality factor: 70 % (according to pan file)

Make and Type: Longi, LR4-72HBD-440/ 445 M

DC rated output per module: 440/ 445 W_p

Number of Modules: 24,024/ 24,024

Total DC rated output power: 21,261.24 kW_p

2.1.4 Inverters

Make and Type: Huawei Technologies, SUN2000-105KTL-H1

AC rated output per inverter: 105 kVA (@40deg)

Number of inverters: 154

Total AC rated output power: 16,170 kVA

2.1.5 Transformers

Make and type: Schneider Electric, Minera 22/0.8

Output per transformer: 3,150 kVA

Number of transformers: 6

Total output power: 18,300 kVA

2.1.6 Power Transformer on POC

Make and type: SGB, DOTR 20MVA 60/20 kV ONAN

Output per transformer: 20,000 kVA

2.1.7 Module Interconnection

48,048 Modules interconnected in 1,848 strings with each 26 modules (up to 12 strings per inverter).

2.2 *Methodology of the Assessment*

2.2.1 Component Simulation

For the simulations, the data for solar module and inverter were fed into the PVsyst v6.86 simulation program. The datasheets and pan-files of the modules and inverters were provided by the client.

2.2.2 Temperature Behaviour

The simulated temperature behaviour of the modules has been based on very good rear ventilation corresponding to their free-standing mounting. The wind speed at the site is also decisive in the heat dissipation of the modules. The long-term average wind speed at the Holmen site at 10 meter elevation is 6.0 m/s.

2.2.3 Manufacturer's tolerance

No manufacturing tolerances were taken into account. The following assumption applies for this assessment: All solar modules from the manufacturer Longi, LR4-72HBD-440/ 445 M will achieve at minimum their rated output of 440 and 445 W_p respectively. We recommend that, to eliminate any discrepancies, the investor and/or project developer undertake measurements of individual modules through an independent institution.

2.2.4 Light induced degradation (LID)

The LID loss is related to the quality of the wafer manufacturing with p-type crystalline silicon cells and set up to **1.0 %**.

2.2.5 Mismatch

The power losses through mismatch - owing to the serial interconnection of a number of modules, each having slightly different characteristics - were set at **1.0 %**. Here horizontal string connection and data sheet power tolerance of 0 to +5 W_p were taken into account.

2.2.6 Cable losses

Due to the chosen decentralized inverter concept and according to the client information, the DC-side cable losses were set at **1.5 %** at STC and on the AC-side with cable losses at **0.7 %** rated power (MV line to POC included).

2.2.7 Transformer losses

The transformer losses were set at **0.1 %** constant iron losses and **0.8 %** rated inductive losses. The iron loss remains active and constant during the whole connecting time. Therefor night disconnect is recommended.

Additionally, the power transformer losses were set at **0.05 %** constant iron losses and **0.36 %** rated inductive losses according to client information.

2.2.8 Dirt and Soiling

For solar modules erected in open-spaces, soiling cannot be ruled out and an associated reduction in the modules' output occurs. The known self-cleaning effect of glass panes by rain requires a module tilt of at least 15°, which is the case here.

Since the client intends to undertake cleaning of the modules if necessary, the losses owing to dirt and soiling have been estimated at **1.0 %**.

2.2.9 Horizon shading

With respect to shading analysis, generally a distinction is made between horizon shading (caused by the surrounding topography and vegetation) and internal shading (produced by the rows of panels themselves).

Horizon shading is caused by mountain ranges in the nearby vicinity, for which it is site dependent, whereas internal shading caused by the arrays depends on the tilt angle, row spacing (pitch), module table height and the minimum sun angle at the given site, is design dependent.

The site horizon shows no elevation hence corresponding to no losses due to horizon shading.

2.2.10 Site and Shading

A site visit was not part of the assessment.

Figure 1: Location (source: Client)

The site is located in Mid-Jutland in Ringkøbing-Skjern Commune around 10 km away from the sea shore. The terrain is flat and even.

There are hedges around the site (4m height) and trees in western direction (approx. 20m height). Three wind turbines (75m total height) can be found in the North/ North-East. Thus shading obstacles are taken into account in this simulation if relevant for shading.

The layout provided by the client can be found in the appendix.

To evaluate the influence of the row shading with regards to the overall energy production, the shading scene is built using the 3D- Editor from PVsyst simulation program.

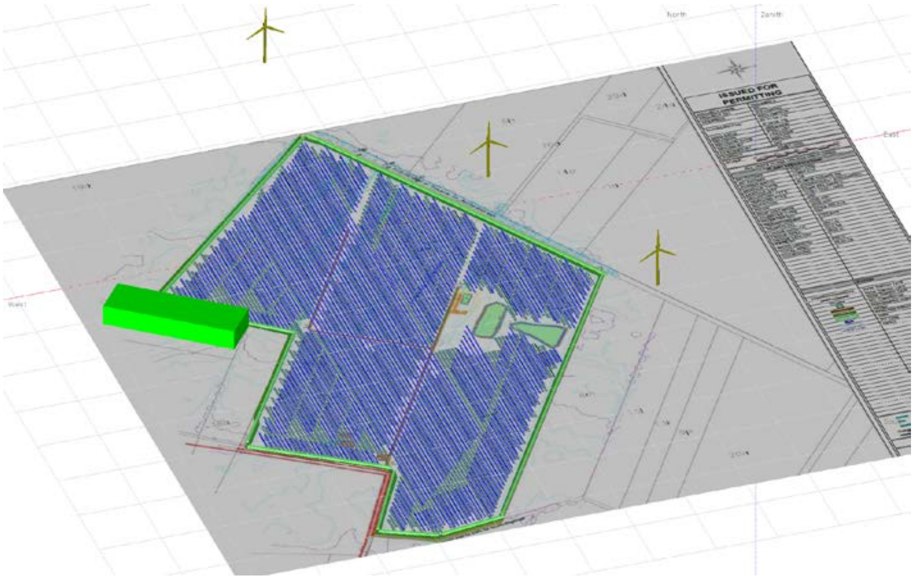

Figure 2: 3-D Shading Scene in PVsyst single axis

The normal solar inclination at the site is 10.65° (December 21, Noon). According to the client the row space (pitch) for single axis has been chosen with 5m and the shading angle is only theoretically but corresponds to 16°. Backtracking will lead to lower shading losses.

Here taking into account the string interconnection, the shading accounts for **3.9 %** of losses.

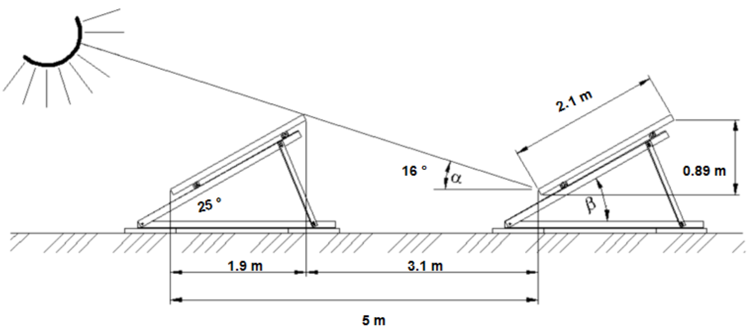

Figure 3: Module rows and shading angle single axis

The assumptions for the losses are based on experiences in connection with the evaluation of other photovoltaic installations.

2.2.11 Meteorological Data

The irradiation data set for the site Holmen is assessed based on the weather data provided by Danish Meteorological Institute (DMI). These data are provided by the client and seem plausible. According to report Teknisk Rapport 13-09 by DMI the data from 2001-2010 have been used for validating time series (see appendix).

DMI observes global horizontal irradiation at 28 ground measured stations in Denmark.

In the case of evaluating the expected global solar irradiation level at Holmen, data from climate grid Denmark 20x20 km have been used (grid cell 20007). The data represents the period from 2001 till 2019.

DMI observes air temperature and wind speed by climate grid Denmark 10x10 km. Thus ambient temperature and wind speed have been assessed using DMI.

The annual global horizontal irradiation at the site given by the examined source sum up to **1.038 kWh/m²a**.

When the photovoltaic modules are installed on a mounting, this will enhance the energy yield.

The conversion to the module plane i.e. at single axis system towards 0° South gives an annual global inclined surface irradiation of **1.371 kWh/m²a** (irradiation optimized tracking algorithm).

The annual diffuse irradiation has been assessed using Meteonorm 6.3 source.

The data set has been created with the weather simulation program Meteonorm and converted to hourly values with the help of a stochastic model.

2.2.12 Simulation program

The Simulation program used PVsyst v6.86- is a time step-increment simulation program developed by the University of Geneva. Here the individual components like the modules and inverters, their interaction with the fed in weather data and the fully shading scene are simulated on the basis of an hourly time scale over the whole year. The conversion from horizontal to tilted surfaces is in accordance with the model from Perez.

3 Assessment of the System's Technical Design

The PV system under assessment is to be operated with 154 decentral three- phase inverters from the manufacturer Huawei Technologies, which allow high plant availability for use in large solar farms.

3.1 Monitoring

The planned monitoring is evaluated positively because it provides rapid troubleshooting. Additionally the client has stated the intention to take out a maintenance contract with the inverter manufacturer for the entire period of the feed-in. This will provide for rapid servicing of any problems and ensure high system availability.

3.2 Module Certification

The mono crystalline solar modules are manufactured by Longi. The bifacial modules are certified and approved to IEC 61215 and IEC 61730 by TUV Sued. Additional certificates for ammonia corrosion and salt mist corrosion are also available.

3.3 Design and Sizing

The ratio of PV generator rated power (DC power) to the inverter rated power (AC rated power) has been chosen at 1.31. Considering the irradiation and temperatures at the site Holmen, regulation losses occur in the inverter at this design ratio with single axis system. These regulation losses cannot be reproduced accurately in the simulation based on hourly average values.

The working voltages of the sub-generators lie within the working voltage range of the inverters. The maximum generator open circuit voltage (at cold temperatures of below -10° C and high irradiation of 1,000 W/m²) at 1,407 V (445 W_p module class), is below the maximum system voltage of the inverter (1,500 V) and the maximum system voltage of the modules (1,500 V).

4 Forecast Energy Yield

The yield values shown in the table below are to be regarded as long-term averages and are for a PV plant with an availability of 100 % and a power factor of 1.

Table 1: Annual Energy Yield

Annual Energy Yield	
Simulation program	PVsyst v6.86
Specific yield	**1,252 kWh/kW$_p$**
Annual yield	**26,629 MWh**

4.1 Performance Ratio

The ratio of the actual amount of electricity generated to the theoretically possible yield at the site is referred to as the Performance Ratio (PR). It serves as a kind of plant efficiency figure in the evaluation of different systems at different locations. Average values are 80 %; very good systems can achieve more than 85 %.

For the system under assessment a PR of **91.4 %** is calculated. Here the bifacial effect with gain on front and back side is included.

4.2 *Monthly Distribution of yield (P50 values)*

Table 2: Monthly distribution (P50)

Month	GlobInc	T Array	E_Grid	Specific Yield	PR
	[kWh/m²]	[°C]	[MWh]	[kWh/kW$_p$/day]	[%]
January	20	5.1	362	0.55	87.4%
February	43	6.9	847	1.42	93.3%
March	102	11.6	2,045	3.10	94.3%
April	167	18.5	3,320	5.21	93.4%
May	216	23.2	4,201	6.37	91.5%
June	224	25.6	4,345	6.81	91.3%
July	219	28.5	4,193	6.36	90.0%
August	171	27.5	3,285	4.98	90.6%
September	112	22.9	2,170	3.40	91.0%
October	60	16.1	1,166	1.77	91.3%
November	24	10.1	444	0.70	87.7%
December	14	5.9	251	0.38	84.1%
Year	**1,371**	**19.4**	**26,629**	**3.43**	**91.4%**

4.3 Uncertainty Analysis

Table 3: Loss factors and uncertainty analysis

	Loss/ Gain	Specific Yield	Unit	PR	Uncertainty
Global horizontal irradiation, for 104435.8 m2 of collectors					
Horizontal global irradiation		**1039.0**	kWh/m^2		3.0%
Global incident in coll. plane	32.0%	1371	kWh/m^2	100%	2.5%
Global incident below threshold	-0.1%	1369.8	kWh/m^2	99.9%	0.1%
Near Shadings: irradiance loss	-3.6%	1320.5	kWh/m^2	96.3%	0.5%
IAM factor on global	-0.6%	1312	kWh/m^2	95.7%	0.5%
Soiling loss factor	-1.0%	1298.9	kWh/m^2	94.7%	0.5%
Ground reflection on front side	0.3%	**1302.3**	kWh/m^2	95.0%	0.1%
Bifacial: Global horizontal irrad. on reference reflexive ground = 242422.9 m2					
Global incident on ground		491.4	kWh/m^2		
Ground reflection loss (albedo)	-80.0%	98.3	kWh/m^2		
View Factor for rear side	-66.7%	75.9	kWh/m^2		
Sky diffuse on the rear side	24.3%	94.4	kWh/m^2		
Beam effective on the rear side	0.0%	94.4	kWh/m^2		
Shadings loss on rear side	-5.0%	89.6	kWh/m^2		
Global Irradiance on rear side		89.6	kWh/m^2		
Useable irradiance on the rear side	70.0%	62.8	kWh/m^2		
Effective irradiation on collectors		**1303.4**	kWh/m^2		
Global effective energy (Front + Back side)		**1366.1**	kWh/m^2	99.6%	3.0%
of collectors		104435.8	m2		
Total available irradiation		142674	MWh		
STC efficiency (one-diode model)		20.36%			
Array losses					
Array nominal energy at STC efficiency		1366.2	kWh/kW_p	99.6%	
PV loss due to irradiance level	-0.9%	1354.1	kWh/kW_p	98.8%	0.5%
PV loss due to temperature	-0.6%	1346.0	kWh/kW_p	98.2%	0.5%
Shadings: Electrical Loss acc. to strings	-0.3%	1341.7	kWh/kW_p	97.9%	0.5%
LID - Light induced degradation	-1.0%	1328.2	kWh/kW_p	96.9%	0.5%
Module array mismatch loss	-1.0%	1315.0	kWh/kW_p	95.9%	0.5%
Mismatch for back irradiance	-0.7%	1306.3	kWh/kW_p	95.3%	1.0%
Ohmic wiring loss	-0.8%	1295.2	kWh/kW_p	94.5%	1.0%
Array virtual energy at MPP		1295	kWh/kW_p		
System losses					
Inverter Loss during operation (efficiency)	-1.2%	1280.1	kWh/kW_p	93.4%	1.0%
Inverter Loss over nominal inv. power	-0.2%	1278.2	kWh/kW_p	93.2%	
Inverter Loss due to max. input current	0.0%	1278.2	kWh/kW_p	93.2%	
Inverter Loss over nominal inv. voltage	0.0%	1278.2	kWh/kW_p	93.2%	
Inverter Loss due to power threshold	0.0%	1278.2	kWh/kW_p	93.2%	
Inverter Loss due to voltage threshold	0.0%	1278.2	kWh/kW_p	93.2%	
Night consumption	0.0%	1278.1	kWh/kW_p	93.2%	
Available Energy at Inverter Output		1278	kWh/kW_p		
Losses after the inverter					
AC ohmic loss	-0.4%	1273.4	kWh/kW_p	92.9%	0.5%
External transfo loss	-1.6%	1252.5	kWh/kW_p	91.4%	0.5%
Energy injected into grid		**1252**	**kWh/kW_p**	**91.4%**	**5.5%**

4.3.1 Margin of variation

Assuming a normal distribution of the expected yields, an annual specific yield between **1,184 kWh/kW$_p$** and **1,321 kWh/kW$_p$** will be achieved with a probability of 68.3 % (one standard deviation) - i.e. **1,252 kWh/kW$_p$ ± 5.5%** (weighted average).

4.3.2 Probability of excess production

There is a probability of 90.0 % that the annual yield will exceed **1,165 kWh/kW$_p$** (P90 weighted average value).

There is a probability of 75.0 % that the annual yield will exceed **1,206 kWh/kW$_p$** (P75 weighted average value).

4.3.3 Variations in annual yield

The annual yield of the planned photovoltaic system could, however, deviate from the forecast given here. The following factors are mainly responsible for this:

Variations in the solar irradiation

Typical meteorological deviations for individual years against the long-term mean can be up to 8 %. In 2003, for example, the solar irradiation in parts of Europe was approximately 20 % above the long-term mean.

Reductions in performance

The actual generator output does not always accord with the sum of the module outputs according to their rating plates. In our yield forecast, we have not taken any output reduction into account.

Power Factor

In order to maintain grid stability some utilities require the supply of reactive power. This is giving by the power factor cos phi which describes the ratio of active power over apparent power. With power factor unequal 1 the active power is reduced thus the plant yield decreases.

Impact of Shading

The behaviour of photovoltaic systems is sensitive to shading. Even the (partial) shading of just a single cell is equivalent to shading all the in-series connected cells of the module concerned. As a result the output performance, even for small shadows such as those caused by overhead lines, lightning conductors, guy wires, antennas or tree branches, can result in output reductions.

Impact of Soiling

For free-standing solar panels, soiling and its associated output reduction cannot be ruled out. The known self-cleaning effect of glass panes by rain requires a minimum module slope of 15 °, which is the case here.

Inverter malfunction

At this site, the largest part of the annual solar energy yield is generated in the time from spring to autumn and only a small portion in the winter months. Inverter malfunctions - especially in the months of highest irradiation - may therefore result in significant yield losses. A monitoring system allows for quick trouble shooting and repair.

Bifacial factor

The bifacial factor is given my module manufacturer and mainly dependent on ground albedo.

5 Glossary

Albedo

Describes the ground reflection of the surroundings of a photovoltaic system. This reflected radiation is added to the irradiation present. If the surroundings are covered with snow, the albedo can reach 95 %. On average the reflection amounts to 20 %.

Azimuth

The azimuth angle gives the orientation of the PV generator. This has the value 0° for an orientation to the South (-90° East, +90° West).

Degradation

Degradation is used to describe the ageing processes in the module, which reduce its performance. The extent of degradation is dependent on the cell materials used; for crystalline modules it has a value of, for example, around 0.25 % annually.

Generator

Several interconnected modules, including the necessary cabling and the mounting assemblies, are described as a generator.

Global irradiation

This describes the total solar radiation that strikes a horizontal surface on earth and is measured in kilowatt-hours per square meter (kWh/m^2a) for a specific period (generally yearly).

Inverter

Solar modules generate direct current (DC). If this is to be fed into the mains electricity grid, the direct current must be converted by an inverter into alternating current (AC). Depending on the manufacturer and type, modern inverters have many more functions than just generating alternating current from direct current. These include:

- Operating the modules/string/generator at their maximum power point (MPP tracking)
- Converting the generator voltage up to grid level (transformation)
- Safety devices for monitoring the grid connection
- Feed-in management
- Grid support functions
- Production of reactive power

Irradiation assessment

These are not to be confused with yield reports. Weather services, such as, in Germany, the DWD create an irradiation assessment for a particular location, which depict the periodic progression of solar radiation. Irradiation assessments serve as a basis for yield reports.

Light induced degradation (LID)

LID describes a loss of performances arising in the very first hours of exposure to the sun, with crystalline modules (p-type) based on crystalline silicon cells fabricated on Czochralski (CZ) wafers until it stabilizes.

The LID loss is related to the quality of the wafer manufacturing and may be up to 3%.

Low light behaviour

The low light behaviour defines performances of the module under different irradiations. Usually the relative efficiencies at 200 W/m² and 25°C, with respect to the STC efficiency are taking into account.

As per the module datasheet, the low light behaviour of the module at 200 W/m² ranges between 1 and 5 % efficiency reduction.

Maintenance

In general, PV systems are very low maintenance because the generator responsible for the electricity generation contains no moving parts. However, it is recommended that a maintenance contract is taken out for the undertaking of module cleaning and checking all components so as to avoid outages.

Mismatch

Mismatch is a reduction in the output of a string or entire generator as a result of factory production tolerances. Here, the worst module within a series connection reduces the output of the entire string to its output. Properly pre-selected modules and verification on site can almost completely eliminate mismatch.

Nowadays typical values with plus sorted modules are below 1 % of the system output.

Module

A photovoltaic module generates electricity from sunlight and consists of a pre-assembled unit of solar cells connected together under factory conditions. A module is defined according to its nominal power output, current and voltage with accordingly approved tolerances. In the factory, the solar cells are 'encapsulated' in a solar module to protect them from the effects of weather, air and moisture. Several modules together form a solar generator.

Nominal or rated output

This is a module's peak output in kilowatt peak (kW_p) determined under standard test conditions (STC) in the laboratory. Tolerances are permissible to an extent defined by the manufacturer (e.g. 0/+ 5 W_p). Nowadays one finds mostly plus sorted modules.

To simplify comparison it is usual to relate parameters such as system costs and system yields to the nominal output. The total nominal output of a generator/power plant is the sum of the installed module outputs.

Performance Ratio

The “Performance Ratio” (PR) is an international measure for the efficiency of a complete system in operation. The PR can be described as the proportion of usable energy (at the inverter output) to the nominal value of energy which may be produced, arising from module area, module efficiency (according to data sheet) and the irradiation on the inclined module plane. It therefore allows for a comparison of differently designed installations, which is largely independent of the specific irradiation conditions for location and year. Values over 85 % will be achieved in very good facilities, which comprise the best selected components combined with "perfect" system engineering at a minimally shaded location.

Power Factor

In order to maintain grid stability some utilities require the supply of reactive power (kVAr). This is giving by the power factor cos phi which describes the ratio of active power (kW) over apparent power (kVA). With power factor equally 1 the active power is completely feed into the grid.

Usual power factors for utility scale PV plants might vary between -0.9 (inductive) and +0.9 (capacitive). Thus the active power and the energy feed into the grid are reduced.

Reactive power control

To facilitate higher levels of distributed PV penetration, utility scale PV plants need to participate in voltage regulation. Thus reactive power can be generated as a means of raising voltage levels or absorbed as a means of lowering voltage levels.

Solar Cells

Manufactured from silicon wafers (slices of silicon blocks) or thin film, this smallest electricity-producing unit consists of conducting paths applied to the substrate. Several interconnected solar cells build a solar module. Solar cells produce electricity by utilizing the photovoltaic effect to convert light falling on them.

Solar inclination

The lowest altitude of the sun (equivalent to the lowest solar elevation angle) at noon on the day of the winter solstice (Dec 21st in the northern hemisphere) is generally used as a basis for the shading calculation. This calculation basis is an economic compromise, and does not represent complete freedom of shading, as the sun occupies low positions morning and evening.

Theft protection

Especially in the case of open space facilities some means of theft protection for the modules is usually advisable or will be required by the insurers. Whether a fence is sufficient or the provision of additional safety measures must be determined on a case by case basis. The solar panels should be laid out sufficiently far from a fence to avoid shading.

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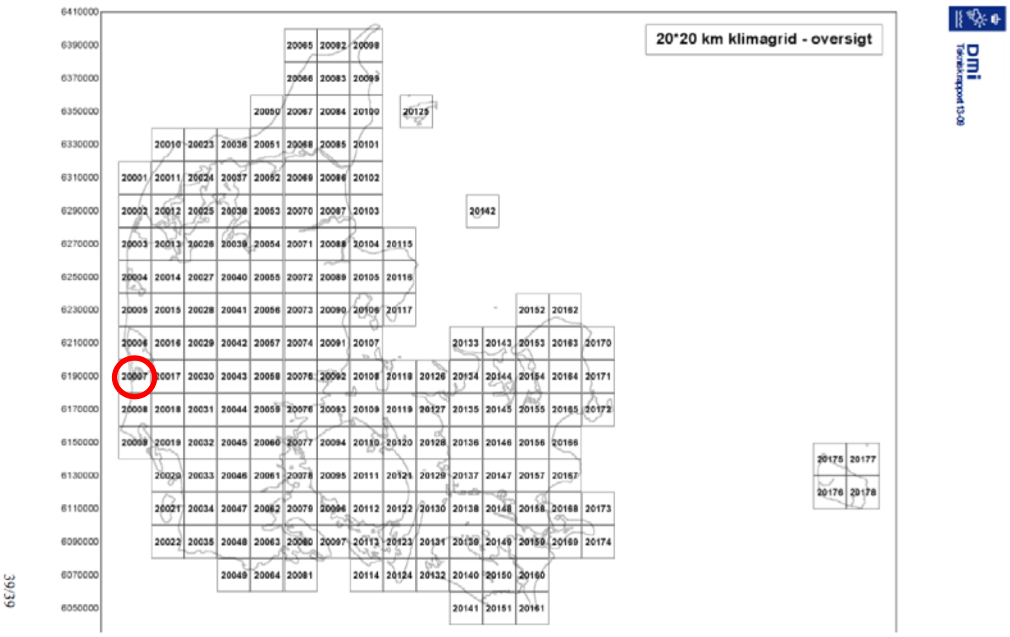
A Appendix

Meteorological Data Summary based on DMI source 2001-2019

meteo for Holmen - Synthetically Generated Data

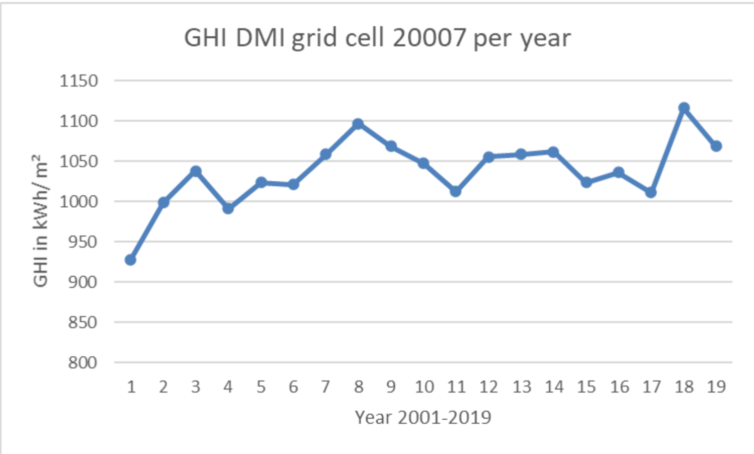
Interval beginning	GlobHor kWh/m².mth	DiffHor kWh/m².mth	T_Amb °C	WindVel m/s
January	15.0	9.80	2.0	6.9
February	32.0	17.70	1.8	6.1
March	76.0	38.30	3.5	6.1
April	123.0	51.50	7.7	5.5
May	165.0	80.40	11.3	5.7
June	169.0	77.30	14.4	5.8
July	164.0	68.10	17.3	5.3
August	133.0	74.80	17.4	5.5
September	86.0	46.30	14.5	6.1
October	47.0	28.80	10.2	6.2
November	18.0	11.10	6.7	6.7
December	11.0	7.60	3.1	6.0
Year	1039.0	511.70	9.2	6.0

DMI Grid cell 20x20km



DMI Data on global irradiation

	DMI grid cell 20007 Holmen GHI in kWh/m2																				
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	Average 2001-2010	Average 2001-2019
Jan	12.42	12.11	15.03	12.81	17.28	16.17	16.36	10.53	11.69	18.39	18.92	17.47	17.14	10.58	15.33	15.78	16.28	14.67	16.94	14.28	15.05
Feb	33.08	31.06	35.19	38.53	35.44	23.86	24.42	29.17	27.47	30.28	25.97	42.03	26.33	31.67	30.14	39.58	27.06	35.44	35.53	30.85	31.70
Mar	69.47	75.50	84.11	70.47	83.97	72.11	91.58	71.94	66.31	77.00	78.19	78.97	91.33	81.31	70.61	70.50	67.22	64.28	74.11	76.25	75.74
Apr	91.94	102.69	128.08	108.97	122.14	102.25	138.08	128.83	136.44	123.28	142.67	119.25	130.86	125.61	136.86	110.36	120.83	119.03	146.17	118.27	122.86
May	167.83	158.00	132.03	153.06	157.56	158.36	150.56	201.92	178.69	168.58	161.08	169.89	156.75	157.22	152.22	167.67	166.28	205.03	166.75	162.66	164.71
Jun	145.53	170.61	158.92	149.92	169.92	168.22	170.94	193.36	194.72	171.92	179.00	157.94	152.64	195.17	163.61	168.17	154.36	180.25	172.14	169.41	169.33
Jul	162.17	144.08	160.33	148.94	140.00	193.08	157.44	175.86	161.92	163.64	132.36	177.78	190.75	171.33	160.06	149.36	170.22	201.69	156.03	160.75	164.06
Aug	118.06	138.00	152.19	139.00	113.56	127.83	141.08	125.28	129.86	124.08	112.42	152.61	140.44	128.39	137.94	141.36	132.03	131.97	140.28	130.89	132.97
Sep	61.69	96.67	89.56	92.39	94.69	88.03	86.39	88.33	86.56	85.14	77.28	72.61	78.86	90.58	85.94	98.19	84.31	83.36	86.00	86.94	85.61
Oct	37.47	44.06	56.64	46.31	59.06	43.64	50.83	44.14	50.06	46.58	57.17	36.50	43.28	42.11	43.06	42.97	40.69	51.42	47.64	47.88	46.51
Nov	18.78	16.64	15.89	19.89	17.75	19.33	21.64	17.14	12.75	21.19	16.14	17.33	20.17	16.67	18.19	21.06	20.28	19.14	14.83	18.10	18.15
Dec	9.78	9.14	10.22	11.08	12.50	8.14	9.31	10.14	12.00	17.06	11.39	13.19	10.33	10.81	9.44	11.06	11.44	9.81	11.89	10.94	10.99
Average	**928**	**999**	**1038**	**991**	**1024**	**1021**	**1059**	**1097**	**1068**	**1047**	**1013**	**1056**	**1059**	**1061**	**1023**	**1036**	**1011**	**1116**	**1068**	**1027**	**1038**



Layout (Source: Client):

Datasheets:

PV Modul

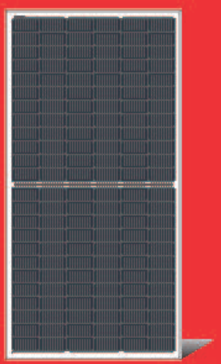
LR4-72HBD

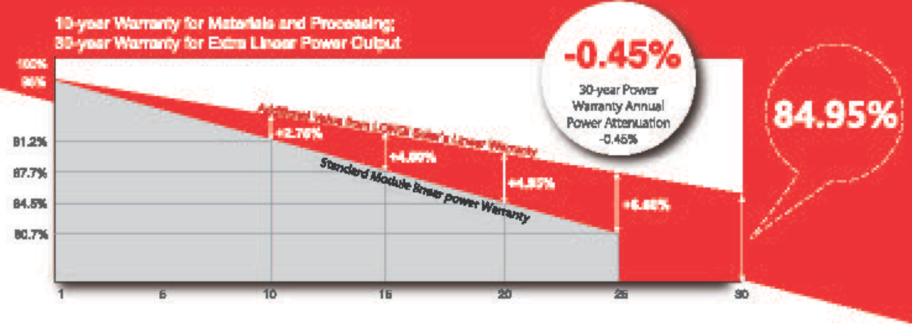
425~455M

Hi-MO 4

NEW

High Efficiency
Low LID Bifacial PERC with
Half-cut Technology





Complete System and Product Certifications

IEC 61215, IEC61730, UL61730

ISO 9001:2008: ISO Quality Management System

ISO 14001: 2004: ISO Environment Management System

TS62941: Guideline for module design qualification and type approval

OHSAS 18001: 2007 Occupational Health and Safety

* Specifications subject to technical changes and tests. LONGi Solar reserves the right of interpretation.

Front side performance equivalent to conventional low LID mono PERC:
- High module conversion efficiency (up to 20.9%)
- Better energy yield with excellent low irradiance performance and temperature coefficient
- First year power degradation <2%

Bifacial technology enables additional energy harvesting from rear side (up to 25%)

Glass/glass lamination ensures 30 year product lifetime, with annual power degradation < 0.45%, 1500V compatible to reduce BOS cost

Solid PID resistance ensured by solar cell process optimization and careful module BOM selection

Reduced resistive loss with lower operating current

Higher energy yield with lower operating temperature

Reduced hot spot risk with optimized electrical design and lower operating current

LONGi

Room 801, Tower 3, Lujiazui Financial Plaza, No.826 Century Avenue, Pudong Shanghai, 200120, China
Tel: +86-21-80162606 E-mail: module@longi-silicon.com Facebook: www.facebook.com/LONGi Solar

Note: Due to continuous technical innovation, R&D and improvement, technical data above mentioned may be of modification accordingly. LONGi have the sole right to make such modification at anytime without further notice; Demanding party shall request for the latest datasheet for such as contract need, and make it a consisting and binding part of lawful documentation duly signed by both parties.

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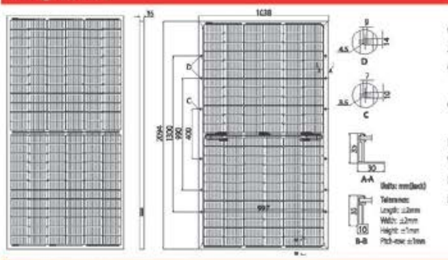
LR4-72HBD 425~455M

Design (mm)



Mechanical Parameters

Cell Orientation: 144 (6×24)
Junction Box: IP68, three diodes
Output Cable: 4mm², 300mm in length, length can be customized
Glass: Dual glass 2.0mm coated tempered glass
Frame: Anodized aluminum alloy frame
Weight: 27.5kg
Dimension: 2094×1038×35mm
Packaging: 30pcs per pallet 150pcs per 20'GP 660pcs per 40'HC

Operating Parameters

Operational Temperature: -40℃ ~ +85℃
Power Output Tolerance: 0 ~ +5 W
Voc and Isc Tolerance: ±3%
Maximum System Voltage: DC1500V (IEC/UL)
Maximum Series Fuse Rating: 25A
Nominal Operating Cell Temperature: 45±2℃
Safety Class: Class II
Fire Rating: UL type 3
Bifaciality: Glazing≥70%

Electrical Characteristics

Test uncertainty for Pmax: ±3%

Model Number	LR4-72HBD-425M		LR4-72HBD-430M		LR4-72HBD-435M		LR4-72HBD-440M		LR4-72HBD-445M		LR4-72HBD-450M		LR4-72HBD-455M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	425	316.0	430	319.7	435	323.5	440	327.2	445	330.9	450	334.6	455	338.3
Open Circuit Voltage (Voc/V)	48.7	45.4	48.9	45.6	49.1	45.7	49.2	45.8	49.4	46.0	49.6	46.2	49.8	46.4
Short Circuit Current (Isc/A)	11.22	9.08	11.30	9.14	11.36	9.20	11.45	9.27	11.52	9.32	11.58	9.38	11.65	9.43
Voltage at Maximum Power (Vmp/V)	40.4	37.5	40.6	37.7	40.8	37.9	41.0	38.1	41.2	38.3	41.4	38.4	41.6	38.6
Current at Maximum Power (Imp/A)	10.52	8.42	10.60	8.49	10.66	8.54	10.73	8.60	10.80	8.65	10.87	8.70	10.93	8.76
Module Efficiency(%)	19.6		19.8		20.0		20.2		20.5		20.7		20.9	

STC (Standard Testing Conditions): Irradiance 1000W/m², Cell Temperature 25℃, Spectra at AM1.5

NOCT (Nominal Operating Cell Temperature): Irradiance 800W/m², Ambient Temperature 20℃, Spectra at AM1.5, Wind at 1m/S

Electrical characteristics with different rear side power gain (reference to 445W front)

Pmax /W	Voc/V	Isc /A	Vmp/V	Imp /A	Pmax gain
467	49.4	12.09	41.2	11.34	5%
490	49.4	12.67	41.2	11.88	10%
512	49.5	13.24	41.3	12.42	15%
534	49.5	13.82	41.3	12.96	20%
556	49.5	14.40	41.3	13.50	25%

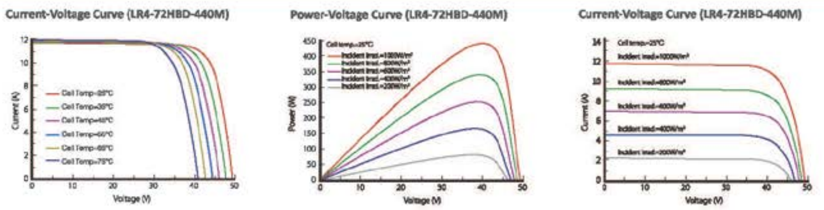
Temperature Ratings (STC)

Temperature Coefficient of Isc	+0.050%/℃
Temperature Coefficient of Voc	-0.284%/℃
Temperature Coefficient of Pmax	-0.350%/℃

Mechanical Loading

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

I-V Curve



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20200220-Draft

Inverter

HUAWEI

Smart String Inverter

SUN2000-105KTL-H1

Smart

- 12 strings intelligent monitoring and fast trouble-shooting
- Power Line Communication (PLC) supported
- Smart I-V Curve Diagnosis supported

Efficient

- Max. efficiency 99.0%
- European Efficiency 98.8%
- 6 MPPT per unit, effectively reducing string mismatch

Safe

- DC switch integrated, safe and convenient for maintenance
- Residual Current Monitoring Unit (RCMU) integrated
- Fuse free design

Reliable

- Natural cooling technology
- Protection degree of IP65
- Type II surge arresters for both DC and AC

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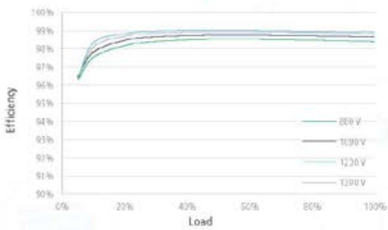
Smart String Inverter (SUN2000-105KTL-H1)

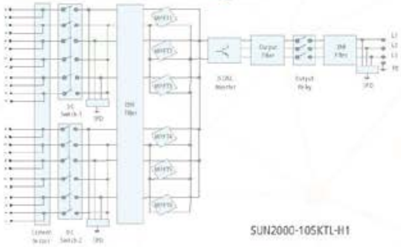
HUAWEI

Technical Specifications	SUN2000-105KTL-H1
	Efficiency
Max. Efficiency	99.0%
European Efficiency	98.8%
	Input
Max. Input Voltage	1,500 V
Max. Current per MPPT	25 A
Max. Short Circuit Current per MPPT	33 A
Start Voltage	650 V
MPPT Operating Voltage Range	600 V ~ 1,500 V
Rated Input Voltage	1,080 V
Number of Inputs	12
Number of MPP Trackers	6
	Output
Rated AC Active Power	105,000 W @40°C
Max. AC Apparent Power	116,000 VA @25°C
Max. AC Active Power (cosϕ=1)	116,000 W @25°C
Rated Output Voltage	800 V, 3W + PE
Rated AC Grid Frequency	50 Hz / 60 Hz
Rated Output Current	75.8 A
Max. Output Current	84.6 A
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Max. Total Harmonic Distortion	< 3%
	Protection
Input-side Disconnection Device	Yes
Anti-islanding Protection	Yes
AC Overcurrent Protection	Yes
DC Reverse-polarity Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Type II
AC Surge Arrester	Type II
DC Insulation Resistance Detection	Yes
Residual Current Monitoring Unit	Yes
	Communication
Display	LED Indicators, Bluetooth + APP
RS485	Yes
USB	Yes
Power Line Communication (PLC)	Yes
	General
Dimensions (W x H x D)	1,075 x 605 x 310 mm (42.3 x 23.8 x 12.2 inch)
Weight (with mounting plate)	79 kg (174.2 lb.)
Operating Temperature Range	-25°C ~ 60°C (-13°F ~ 140°F)
Cooling Method	Natural Convection
Max. Operating Altitude	4,000 m (13,123 ft.)
Relative Humidity	0 ~ 100%
DC Connector	Amphenol UTX
AC Connector	Waterproof PG Terminal + OT terminal
Protection Degree	IP65
Topology	Transformerless
	Standard Compliance *(more available upon request)*
Certificate	EN 62109-1/-2, IEC 62109-1/-2, IEC 62116, EN 50530, IEC 60068, IEC 61683
Grid Code	IEC 61727, ABNT NBR 16149, ABNT NBR 16150, ABNT NBR IEC 62116, VDE4120, RD 1699, RD 661, RD 413, RD 1565, UNE 206007-1 IN, UNE 206006 IN, P.O. 12.3, UTE C15-712-1, G59/3, CEI0-16

Efficiency Curve



Circuit Diagram



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PVsyst Simulation Results

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Grid-Connected System: Simulation parameters

Project :	**Holmen**			
Geographical Site	**Holmen**		Country	**Denmark**
Situation	Latitude	55.85° N	Longitude	8.32° E
Time defined as	Legal Time	Time zone UT+1	Altitude	1 m
	Albedo	0.20		
Meteo data:	**Holmen**	DMI 2001-2019 - Synthetic		

Simulation variant :	**Holmen 3-D tracker w trees 20m Turbines and PT 21MVA DMI19 Irropt v2**			
	Simulation date	07/04/20 21h48		

Simulation parameters	System type	**Tracking system with backtracking**		
Tracking plane, tilted Axis	Axis Tilt	0°	Axis Azimuth	0°
Rotation Limitations	Minimum Phi	-55°	Maximum Phi	55°
	Tracking algorithm	Irradiance optimization		
Backtracking strategy	Nb. of trackers	469	Identical arrays	
	Tracker Spacing	5.00 m	Collector width	2.11 m
Backtracking limit angle	Phi limits	+/- 64.8°	Ground cov. Ratio (GCR)	42.3 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	According to strings		Electrical effect	100 %
Bifacial system	Model	Unlimited trackers, 2D calculation		
	Tracker Spacing	5.00 m	Tracker width	2.15 m
	Backtracking limit angle	64.3°	GCR	43.1 %
	Ground albedo	20.0 %	Axis height above ground	1.65 m
	Module bifaciality factor	70 %	Rear shading factor	5.0 %
	Module transparency	0.0 %	Rear mismatch loss	10.0 %
User's needs :	Unlimited load (grid)			

PV Arrays Characteristics (2 kinds of array defined)

Sub-array "Holmen 445"	Si-mono	Model	**LR4-72 HBD 445 M -fk**		
Custom parameters definition		Manufacturer	Longi Solar		
Number of PV modules		In series	26 modules	In parallel	924 strings
Total number of PV modules		Nb. modules	24024	Unit Nom. Power	445 Wp
Array global power		Nominal (STC)	**10691 kWp**	At operating cond.	9801 kWp (50°C)
Array operating characteristics (50°C)		U mpp	972 V	I mpp	10081 A
Sub-array "Holmen 440"	Si-mono	Model	**LR4-72 HBD-440M_fk**		
Custom parameters definition		Manufacturer	Longi Solar		
Number of PV modules		In series	26 modules	In parallel	924 strings
Total number of PV modules		Nb. modules	24024	Unit Nom. Power	440 Wp
Array global power		Nominal (STC)	**10571 kWp**	At operating cond.	9690 kWp (50°C)
Array operating characteristics (50°C)		U mpp	968 V	I mpp	10014 A
Total	Arrays global power	Nominal (STC)	**21261 kWp**	Total	48048 modules
		Module area	**104436 m²**	Cell area	94858 m²
Inverter		Model	**SUN2000-105KTL-H1-fk**		
Custom parameters definition		Manufacturer	Huawei Technologies		
Characteristics		Operating Voltage	600-1500 V	Unit Nom. Power	105 kWac
				Max. power (=>25°C)	116 kWac

Grid-Connected System: Simulation parameters

Sub-array "Holmen 445"	Nb. of inverters	77 units	Total Power	8085 kWac
			Pnom ratio	1.32
Sub-array "Holmen 440"	Nb. of inverters	77 units	Total Power	8085 kWac
			Pnom ratio	1.31
Total	Nb. of inverters	154	Total Power	16170 kWac

PV Array loss factors

Array Soiling Losses			Loss Fraction	1.0 %
Thermal Loss factor	Uc (const)	29.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Array#1	1.6 mOhm	Loss Fraction	1.5 % at STC
	Array#2	1.6 mOhm	Loss Fraction	1.5 % at STC
	Global		Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.0 %
Module Quality Loss			Loss Fraction	0.0 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP

Incidence effect (IAM): User defined profile

0°	40°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	0.993	0.987	0.974	0.959	0.929	0.847	0.000

System loss factors

AC wire loss inverter to transfo	Inverter voltage	800 Vac tri		
	Wires: 3x10000.0 mm²	113 m	Loss Fraction	0.7 % at STC
External transformer	Iron loss (24H connexion)	31516 W	Loss Fraction	0.1 % at STC
	Resistive/Inductive losses	0.366 mOhm	Loss Fraction	1.2 % at STC

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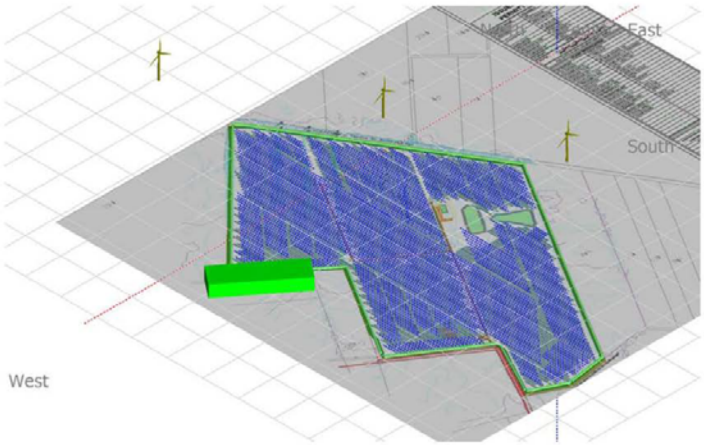
Grid-Connected System: Near shading definition

Project : **Holmen**

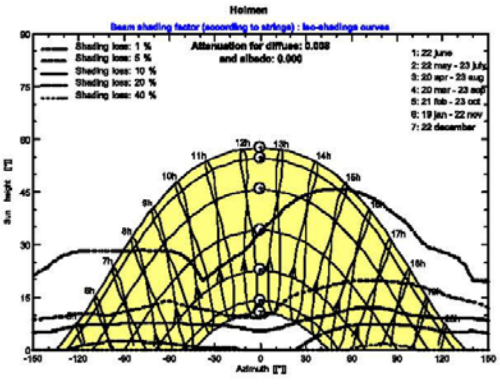
Simulation variant : **Holmen 3-D tracker w trees 20m Turbines and PT 21MVA DMI19 Irropt v2**

Main system parameters	System type	**Tracking system with backtracking**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	LR4-72 HBD 445 M -fk	Pnom	445 Wp
PV modules	Model	LR4-72 HBD-440M_fk	Pnom	440 Wp
PV Array	Nb. of modules	48048	Pnom total	**21261 kWp**
Inverter	Model	SUN2000-105KTL-H1-fk	Pnom	105 kW ac
Inverter pack	Nb. of units	154.0	Pnom total	**16170 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



Grid-Connected System: Main results

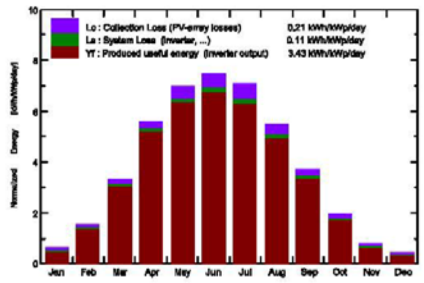
Project : **Holmen**

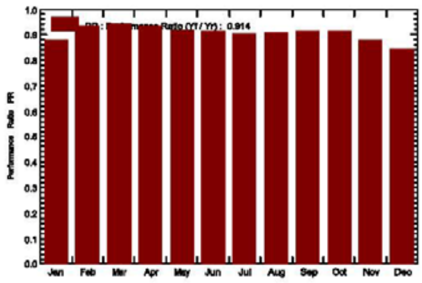
Simulation variant : **Holmen 3-D tracker w trees 20m Turbines and PT 21MVA DMI19 Irropt v2**

Main system parameters	System type	**Tracking system with backtracking**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	LR4-72 HBD 445 M -fk	Pnom	445 Wp
PV modules	Model	LR4-72 HBD-440M_fk	Pnom	440 Wp
PV Array	Nb. of modules	48048	Pnom total	**21261 kWp**
Inverter	Model	SUN2000-105KTL-H1-fk	Pnom	105 kW ac
Inverter pack	Nb. of units	154.0	Pnom total	**16170 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results

System Production	**Produced Energy**	**26629 MWh/year**	Specific prod.	1252 kWh/kWp/year
	Performance Ratio PR	91.36 %		





Holmen 3-D tracker w trees 20m Turbines and PT 21MVA DMI19 Irropt v2

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	15.0	9.80	2.00	19.5	17.9	393	362	0.874
February	32.0	17.70	1.80	42.7	39.9	883	847	0.933
March	76.0	38.30	3.50	102.0	96.4	2109	2045	0.943
April	123.0	51.50	7.70	167.2	159.6	3417	3320	0.934
May	165.0	80.40	11.30	215.9	206.3	4325	4201	0.915
June	169.0	77.30	14.40	223.9	214.0	4470	4345	0.913
July	164.0	68.10	17.30	219.2	209.9	4315	4193	0.900
August	133.0	74.80	17.40	170.5	162.0	3381	3285	0.906
September	86.0	46.30	14.50	112.1	106.1	2238	2170	0.910
October	47.0	28.80	10.20	60.1	56.5	1212	1166	0.913
November	18.0	11.10	6.70	23.8	21.9	475	444	0.877
December	11.0	7.60	3.10	14.0	12.9	280	251	0.841
Year	1039.0	511.69	9.20	1371.0	1303.4	27497	26629	0.914

Legends:

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

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Grid-Connected System: Loss diagram

Project : **Holmen**

Simulation variant : **Holmen 3-D tracker w trees 20m Turbines and PT 21MVA DMI19 Irropt v2**

Main system parameters	System type	**Tracking system with backtracking**		
Near Shadings	According to strings		Electrical effect	100 %
PV Field Orientation	tracking, tilted axis, Axis Tilt	0°	Axis Azimuth	0°
PV modules	Model	LR4-72 HBD 445 M -fk	Pnom	445 Wp
PV modules	Model	LR4-72 HBD-440M_fk	Pnom	440 Wp
PV Array	Nb. of modules	48048	Pnom total	**21261 kWp**
Inverter	Model	SUN2000-105KTL-H1-fk	Pnom	105 kW ac
Inverter pack	Nb. of units	154.0	Pnom total	**16170 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year