Performance and Cost Analysis of Solar Systems Considering Different PV and Inverter Models

A thesis submitted to the
Graduate School of Natural and Applied Sciences

by

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in partial fulfillment for the
degree of Master of Science

in

Industrial and Systems Engineering

İSTANBUL ŞEHİR UNIVERSITY

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Industrial and Systems Engineering.

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This is to confirm that this thesis complies with all the standards set by the Graduate School of Natural and Applied Sciences of İstanbul Şehir University:

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Mohamed Al Battal

Abstract

As solar technology progresses, there are different options in terms of system designs, solar panel types, for PV (photovoltaic) systems for specific building or plant type applications. It is necessary to evaluate the differences between these types in addition to study the impact of using different PV and inverter models on different systems in order to obtain the most suitable and feasible design that can be used to achieve economic feasibility with the best technology type for an application. In this study, we will design different solar systems together with a cost analysis to get the most efficient design that generate most possible energy for the most suitable price to provide a 350kWp capacity on $7500m^2$ land. The designs are made to supply an integrated building that consume 20,000 kWh/month (240MWh/year) located in Istanbul - Turkey. This study provides comparisons of energy outputs and cost expenses between three different systems using two types of PV panels & three types of inverters for each system.

Keywords: Photovoltaic System, System Design, Comparison of Alternative PV Technologies, Financial Assessment.

Farklı PV Sistemlerinin Enerji Performansı ve Maliyet Değerlendirmesi

Mohamed Al Battal

Öz

Güneş teknolojisi ilerledikçe, sistem tasarımları, güneş paneli tipleri, PV (fotovoltaik) sistemleri için özel bina veya tesis tipi uygulamaları için farklı seçenekler vardır. Farklı PV ve invertör modellerinin farklı sistemler üzerinde kullanılmasının etkilerini incelemek için bu tipler arasındaki farklılıkları değerlendirmek gerekir, bir uygulama için en iyi teknoloji türüyle ekonomik fizibilite sağlamak için kullanılabilecek en uygun ve uygulanabilir tasarımın elde edilmesi için. Bu çalışmada, 7500m2 arsa üzerinde 350kWp kapasite sağlamak için en uygun fiyata en uygun enerjiyi üreten en verimli tasarımı elde etmek için maliyet analiziyle birlikte farklı güneş sistemleri tasarlayacağız. Tasarımlar, İstanbul - Türkiye'de bulunan 20.000 kWh/ay (240MWh/yıl) tüketen entegre bir bina tedarik etmek iči̇n yapılmıştır. Bu çalışma, her bir sistem için iki tür PV panel ve üç tür invertör kullanan üç farklı sistem arasındaki enerji çıktıları ve maliyet harcamalarının karşılaştırılmasını sağlar.

Anahtar Sözcükler: Fotovoltaik Sistem, Sistem Tasarımı, Alternatif PV Teknolojilerinin Karşılaştırılması, Finansal Değerlendirme.

Acknowledgments

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Abbreviations

PV	**P**hoto **V**oltaic
DC	**D**irect **C**urrent
AC	**A**lternative **C**urrent
Wp	**W**att **p**eak
kWp	**k**ilo **W**att **p**eak
MWh	**M**ega **W**att **h**our
kWac	**k**ilo **W**att **A**lternative **c**urrent
PR	**P**erformance **R**atio
UNP	**U**nit **N**ominal **P**ower
IAM	**I**ncidence **A**ngle **M**odifier

Chapter 1

Solar Energy

1.1 Introduction

The world's growing increases the demand on basic elements and industries which require continual use of fossil fuel-based energy sources. Unfortunately, this became a real issue, the dependence on these sources creates several challenges such as depletion of fossil fuel reserves, the continual fuel price fluctuations and environmental impacts. These issues create unsustainable situations that ultimately lead to an irreversible threat to human societies [12]. The electricity generation process from fossil fuel-based energy sources generates elements that adversely affect the climate due to the process of combustion that lead to the emission of greenhouse gasses such as carbon dioxide, which act as a partial blanket for the longwave radiation. This is known as the natural greenhouse effect. The emission and spread of the greenhouse gases affect negatively and do real impact on the atmosphere causing the global warming, water and soil pollution is also observed [13]. Nevertheless, renewable energy sources are the most suitable alternative and the only solution to the growing challenges [14]. Many studies have been made to create new way to generate electricity, a way that generate an infinite clean energy that covers the need without affecting the environment. Thus, in 1839 the French scientist Alexandre-Edmond Becquerel find out the photovoltaic effect that explains the process of electricity generation from sunlight [15]. At 1941 the American scientist Russell Ohl created the first solar cell. The basic principle of sunlight to electricity is called photo-electric effect [16], in this phenomenon the electricity conversion depends on the photons of the sunlight. Once solar system constructed an infinite electricity can be produced without any dependence on earth resources, generating electricity with no waste or pollution. Renewable energy sources reduce greenhouse gas emissions significantly if replaced by fossil fuels. As renewable sources of energy are naturally obtained from the continuous energy flows in our environment [17]. Producing a usable electricity from a solar system require a set of solar panels and inverters. Solar panels generate a direct current (DC) from sunlight conversion. Inverters are devices converts DC to alternative current (AC) for electricity usage. Solar systems face some shortcomings such as: interruption of power generation due to seasonal variation as most renewable energy sources rely on climate, which is why their exploitation requires complex ways of design, planning and control [18]. In addition to the variety of solar panel models, inverters and systems scientists and industries have discovered and manufactured so far makes us question, on what system type should we rely? How would different panel and inverter models affect the energy output? This study will present a case with different designs of different solar systems using different panel and inverter models together with a cost analysis to test the difference in energy output and to get the most efficient design that covers the need besides the economic feasibility. With regard to the types of solar systems, a brief explanation of the advantages and disadvantages of each type will be provided in Figure 1.1.

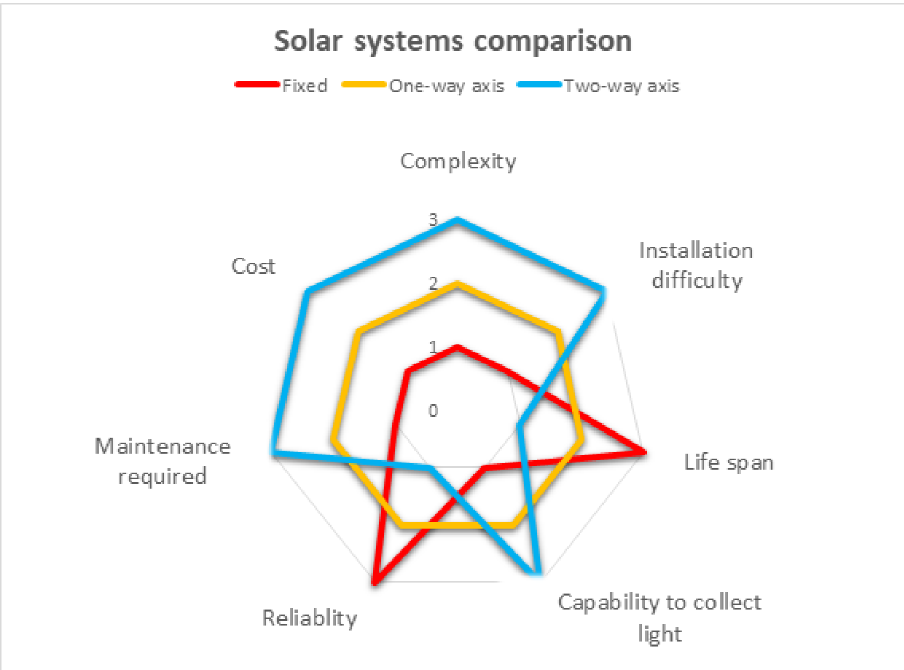


FIGURE 1.1: Solar system comparison [19]

1.2 Types of Solar Energy Collectors

Solar collectors are devices that capture the sunlight and convert it to electricity, these devices formed by connecting many solar cells forming a panel. Two types of solar panels are widely used based on geographical and environmental features, fixed solar panels and trackers panels.

1.2.1 Fixed Panel

Fixed panels are placed in a fixed angle that gives the maximum collection of sunlight, which is usually the optimum tilt as it is shown in Figure 1.2. Achieving maximum efficiency require setting the panels towards the sun to allow most of sun rays to be captured. Due to the lack of moving parts in the design, they are easy to design, easy to construct and maintain.

FIGURE 1.2: Fixed-axis panel [1]

1.2.2 Single-Axis Panel

Single-axis panel have one-way free movement either horizontal or vertical way which rotates around a tilted shaft according to sun position estimated by light intensity sensors as it is shown in Figure. 1.3.

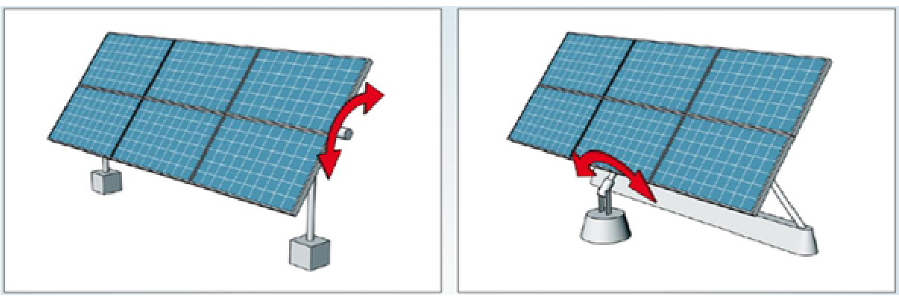


FIGURE 1.3: Single-axis panel [1]

1.2.3 Dual-Axis Panel

Dual-axis panels are the most light collectable systems due to having two degree of freedom, they can move in both directions horizontal and vertical, therefore these panels can angle themselves to direct the sun anywhere even if aim is off by 10° the output is still 98.5% of the full tracking maximum [20] Figure 1.4.

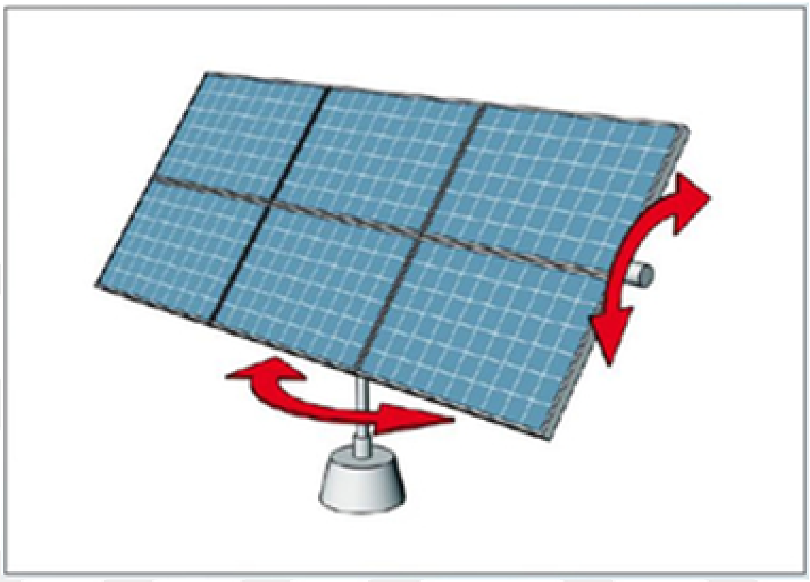


FIGURE 1.4: Dual-axis panel [1]

1.3 Component of Solar Panel

Solar panel is formed from connecting many solar cells together, to create an electrical flow [21], silicon material is used in the manufacturing of solar panel because it's a natural semiconductor, easy obtained and can be easily doped. Constructing the silicon material in a positive layer and negative layer will create an electrical field like batteries. Using crystallized silicon on its own will not conduct the electricity very well, in this regards some of impurities need to be added to create an electric current. Figure 1.5 shows that adding pentavalent impurities to the intrinsic semiconductor like phosphorus creates negative charge (n-type) while positive charge (p-type) layer is formed by adding trivalent impurities to the intrinsic semiconductor like boron.

When p-type and n-type semiconductors joined together, the surface between them called P-N junction, the movement of electrons at P-N junction creates an electrical field that makes electrons to flow only through one direction from p-type to n-type layer. When

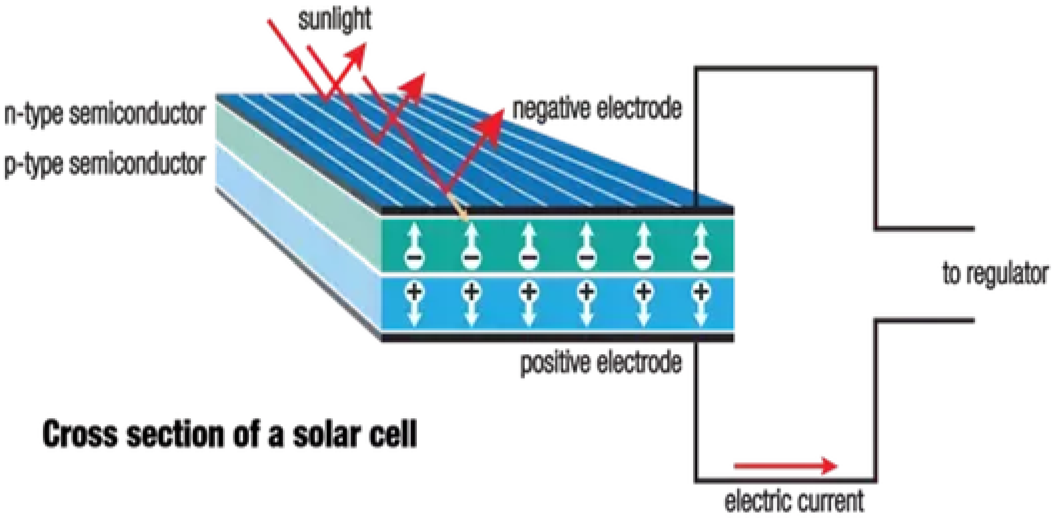


FIGURE 1.5: Solar panel component [22]

sunlight strikes the solar panel, the sunlight energy strikes electrons in p-type and n-type layers. Due to the different charges, the sunlight rays will flow from the top layer (n-type) to the bottom layer (p-type), but because of the electrical field formed in the P-N junction blocks the way and prevents this to happen. Therefore, an external circuit with thin wires need to be connected to the top layer of the panel (n-type layer) to provide a path for the electrons to flow from the n-type layer to p-type layer providing a supply of electricity.

1.4 Electricity Generation

Solar panels convert photons from the sun rays into direct current (DC) electricity flowing in one direction only from the negative to positive side around a circuit, hence the name direct current. For home usage the direct current (DC) converted to alternating current (AC) electricity because it can be easily transformed from one voltage to another with the capability to transform huge amounts of electricity because of its frequency with very low energy losses to almost any desired voltage. Figure 1.6 shows the electrical generation process through solar panel system, the excess energy (DC) coming from solar panels can be stored in separated batteries.

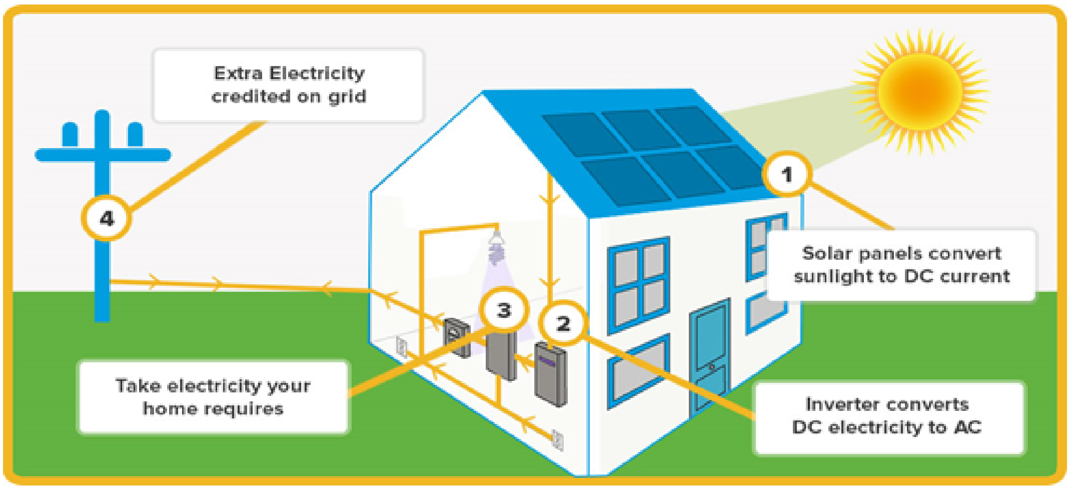


FIGURE 1.6: Electrical generation process [23]

1.5 Solar Tracking Systems

When Fixed Solar panels had been discovered it was used to supply small to big demand of energy. However, Fixed panels do not have the capability to supply the demanded energy due to the movement of the sun throughout the day or seasonal and weather conditions. In fact, weather condition plays an important role in the electricity production, cloudy days reduces the ability of collector to capture sunlight compared to sunny days. The energy supplying process depends fundamentally on the amount of sunlight collected by the collectors. In this regard, a lot of studies showed that the Fixed solar panels generate high rate of energy within a period of time in the day and not in the others. For this case many studies proposed optimizing the slope angle of solar panels in which the panels can collect sunlight at all possible geographic latitudes and periods. A study had been made to test the ability of tracking system in Düzce - Turkey, they found that tracking system achieved 35% power more than the Fixed system shown in Figure 1.7, 1.8 that presents the differences in radiation intensity and the active power generated between Fixed and tracking Dual-axis system throughout a day.

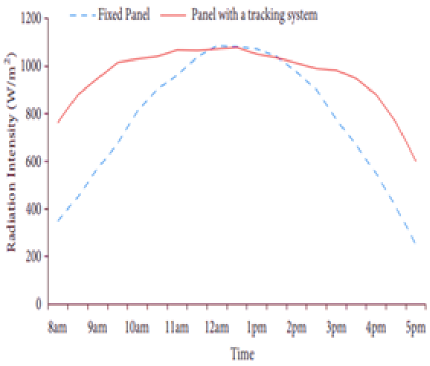


FIGURE 1.7: Active power production [2]

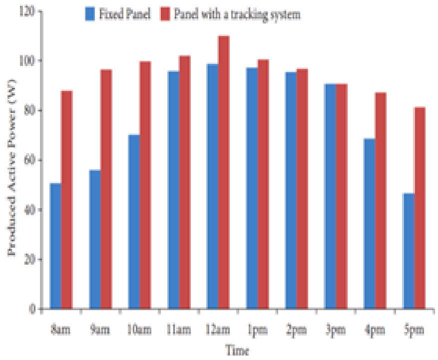


FIGURE 1.8: Radiation intensity [2]

The superior energy production can be noticed in the Dual-axis tracking system while the Fixed system barely reaches the maximum power in the same situation. Figures 1.9, 1.10 displays another solar comparison between Fixed and the Dual-axis, the comparison were made in the same location at Chagrin falls, Ohio in January of 2016 [3].

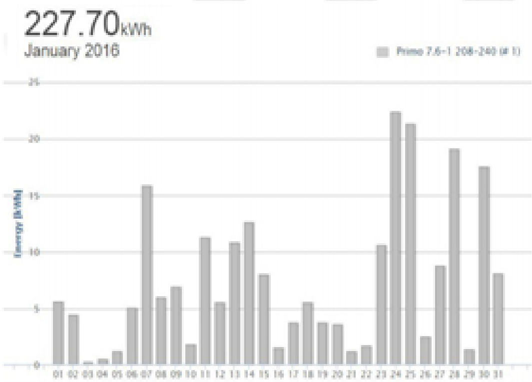


FIGURE 1.9: Fixed-axis energy production [3]

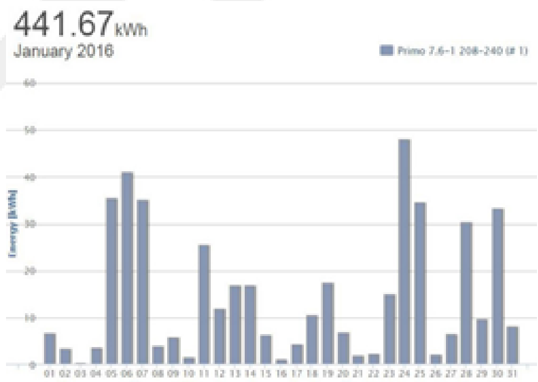


FIGURE 1.10: Dual-axis energy production [3]

It was reported that Dual-axis system performed nearly double value than that in Fixed state, 227kWh compared to 441kWh.

Furthermore, One-axis tracking systems showed remarkable advantages over Fixed ones in Bakersfield - California with 25% performance improvement, as it stated in Figure 1.11 [4].

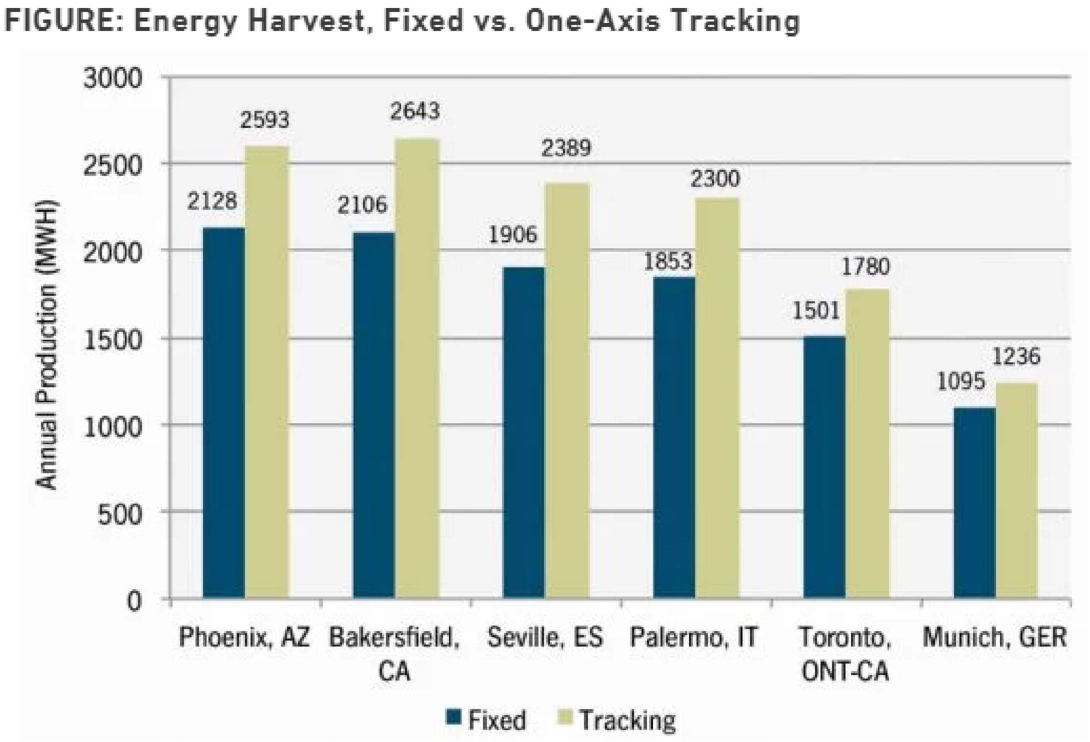


FIGURE 1.11: Fixed - One-axis comparison [4]

1.6 Motivation

There are many tradeoffs in industrial scale use of PV systems. Solar cells are manufactured into modules and these modules are brought together in a system design to meet requirements for a selected location with certain radiation history. System will have panels with inverters to allow grid-operation once connected. Although constructing solar plants will allow us generate energy, there are many challenges to solve, such as variety of solar panel models, inverters and systems can be designed for a specific location and country. Therefore, the purpose of this study is to determine and evaluate the differences between performing different panel and inverter models in different solar systems to test how would this affect the output results along with performing cost assessment in parallel to find the optimum solution. In this study, we will design different solar systems that will provide a 350 kilowatt peak (kWp) capacity. The kWp is the peak power of a PV system or panel under a standardized test for panels across all manufacturers to ensure that the values listed are capable of comparison.

Chapter 2

Design and Simulation Results

2.1 Design Overview

Designing an appropriate solar panels affected by many factors, these factors need to be emphasized and identified before starting the design such as the amount of energy to be produced and the location of the panels, which have a real impact to the design regarding shadow effect. Shadowing effect occurs when solar panels does not receive the same amount of sunlight throughout the system due to the existence of obstacles. Figure 2.1 shows the difference in energy output just shortly when the sun rises and gets to the panels at 9:00 am. The panels on the right side have been subjected to the effect of the shadow resulting from the presence of an object that obscures the rays from the plates, resulting in a decrease of 75% compared to the panels in full sun. The figure shows how shadow on panels affect the energy output compared to the ones on full light. Hence all obstacles, objects and buildings surrounding the location of the solar system must be in the calculation to achieve an accurate result for the designs.

2.1.1 Design Requirements

In order to design a solar power plant, we need to ensure that several things are achieved. The first step in designing a solar PV system is to locate the solar grid that allows the sunlight to reach the PV modules as much as possible. The second step is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as in our study to be 20,000 kWh for an existing building. The third

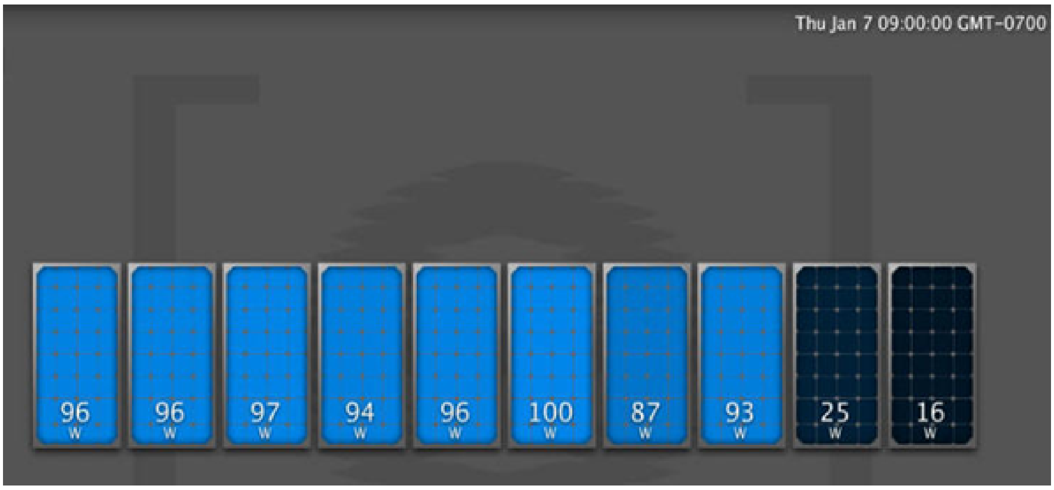


FIGURE 2.1: Panel energy output [5]

step is selecting the size of PV modules, knowing that different size of PV modules will produce different amount of power. The fourth step is selecting the size of inverters. The input rating of the inverter should be higher than the total watt of appliances, hence the inverters should be large enough to handle the total amount of watts you will be using at one time. After applying these steps, we can use a software to design the solar plant. In this study PVsyst software had been used because it's based on a quick and simple procedure by specifying the desired power or available area and choosing the PV and inverter modules from the internal database then PVsyst will propose an array/system configuration, that allows to conduct a preliminary simulation. In addition, the software embeds a color-coded warning/errors messaging system if there's a mismatch or issue.

2.2 Grid Location

Well-designed solar panel system has clear and unobstructed access to the sun for most of the day throughout the year. In fact, setting a PV system correctly is critical in order to achieve maximum power production and thus maximum energy offset and financial return. Therefore, the location that has been selected to be a place for the system is the marked area shown in Figure 2.2. The displayed area has remarkable features as it is 9m height to minimize the shadow effect as much as possible, and has an area around $7500m^2$ that can carry large numbers of PV panels. Furthermore, setting the solar grid on the columns can be exploited to give an aesthetic appearance to the area.

FIGURE 2.2: Proposed grid location [6]

2.2.1 Drawings Preparation

After selecting the solar plant location, the surroundings need to be drawn so PVsyst software can calculate the shadow effect on solar panels. Sketchup softwar had been used to draw the location of the solar grid and all of the surroundings since PVsyst accept Sketchup format. After drawing the location, the file can be exported to PVsyst software for analyzing. An engineering plan for the proposed location had been used. The engineering plan shows essential dimensions in order to understand the nature of the surroundings that may have a direct impact on solar plant performance such as buildings height and distances. Drawings must be drawn to scale, but not unnecessarily full scale. This engineering plan shown in Figure 2.3 has been used to draw the area that surrounds the PV solar plant in Sketchup software, including all buildings and plateaus if any surrounding, to get an accurate result regarding the calculation of shadow effect.

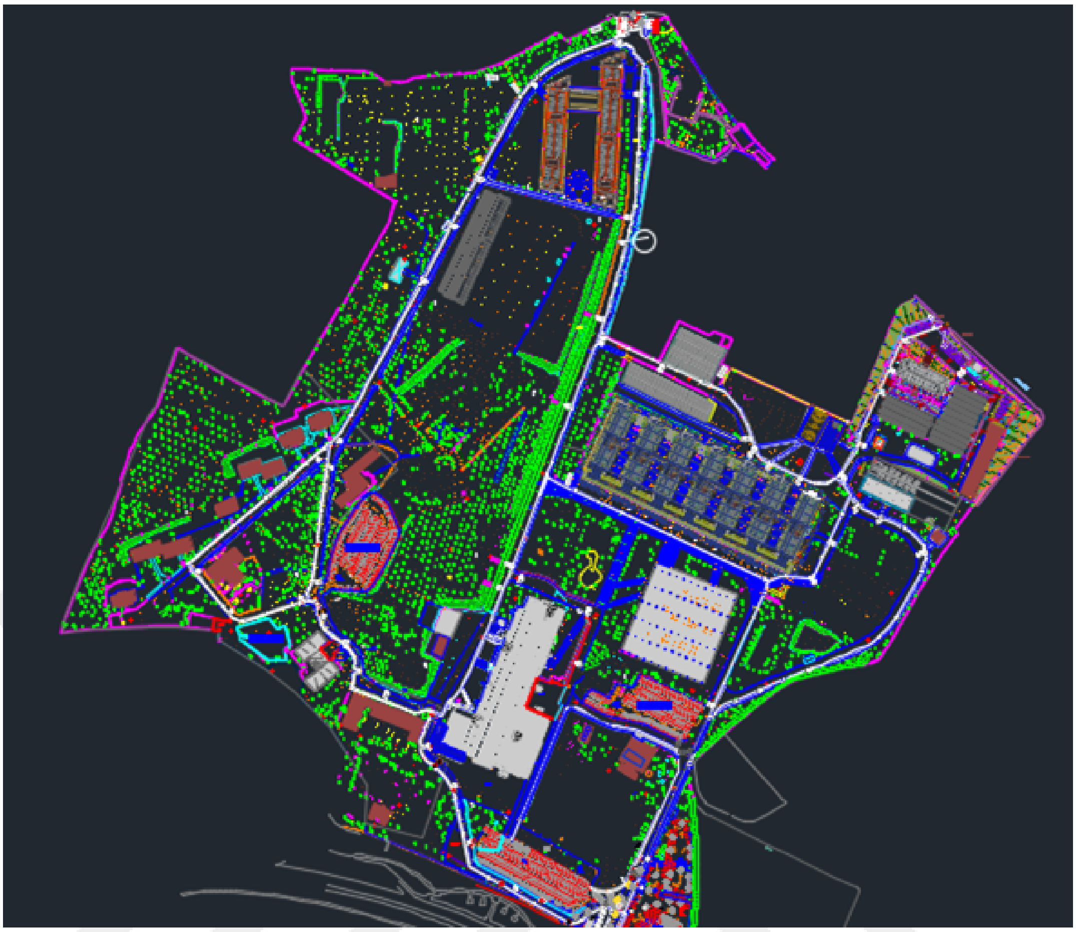


Figure 2.3: Engineering plan for grid location

Taking the work on a wider scale, a tool from google earth [24] was used to draw the plateaus and islands near the solar plant location if any exists to ensure covering all of the elevations that may affect the design calculation results. This tool helps determining the elevation of any selected points in the map. The spacing between points has been fixed which means that the distance between every two points is the same. Each point has a specific elevation shown in Figures 2.4, 2.5. One plateaus with 100m height and three islands with 190m height near solar plant location has been identified to be drawn for their potential impact on the design.

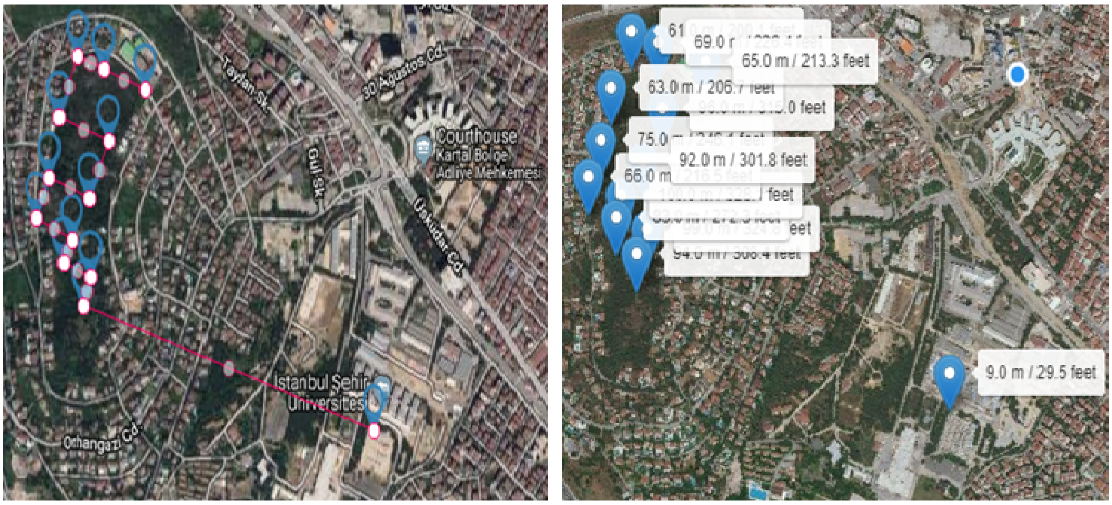


FIGURE 2.4: Surroundings elevations [7]

FIGURE 2.5: Islands elevations [8]

The dimensions and elevations data obtained from google earth tool and engineering plan are used in Sketchup software to have a copy of reality. The Sketchup software drawing results displayed in Figure 2.6 can be used in PVsyst software.

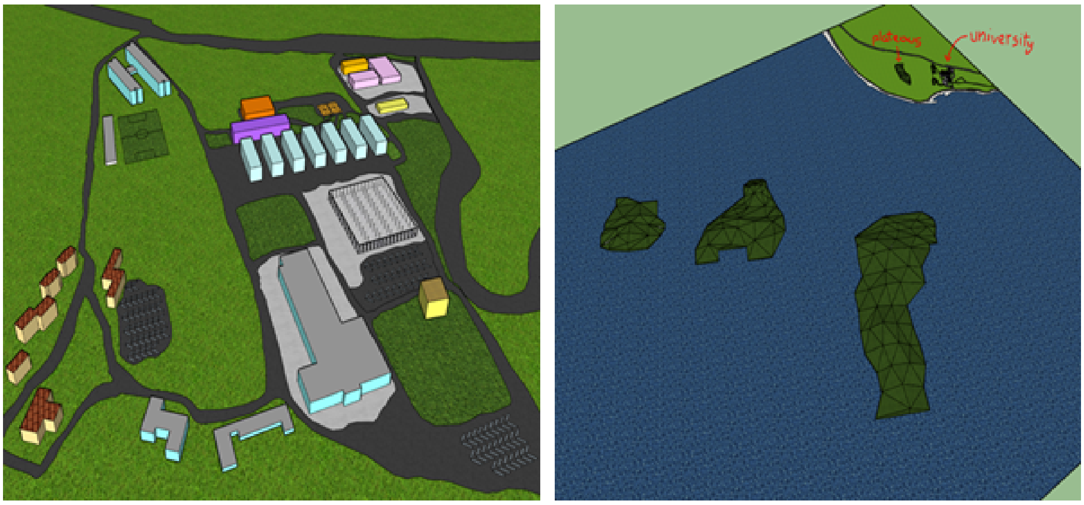


Figure 2.6: Sketchup plan drawing

2.3 Solar Panel Design

After drawing the location of the solar system, there are parameters need to be defined to start designing the solar system such as system type, solar panel / inverter models and capacity's, latitude / longitude of the solar grid location, altitude and azimuth angles. The defined coordinates allow PVsyst software to provide the solar radiation from the internal database. All solar panels receive a nameplate power rating indicating the amount of power they produce under industry-standard test conditions. Most solar panels on the market have power ratings in the range of **200 to 350 watts** watts. These ratings represent the output power under ideal conditions. These ratings are useful as a way to make consistent comparisons between panels. A higher power rating means that the panels are more effective at producing power. For electricity usage the output direct current (DC) energy coming from the system need to be changed to alternative current (AC) using inverters. Solar systems are very much dependent on which inverter type are used. String type inverter will be used in the design therefore all the solar panels are connected in series and controlled as one long chain. Hence, the monitoring can't be done on panel-level, but instead per string as it is shown in Figure 2.7. Regarding trackers, the design will consist Fixed, One-axis and Two-axis trackers.

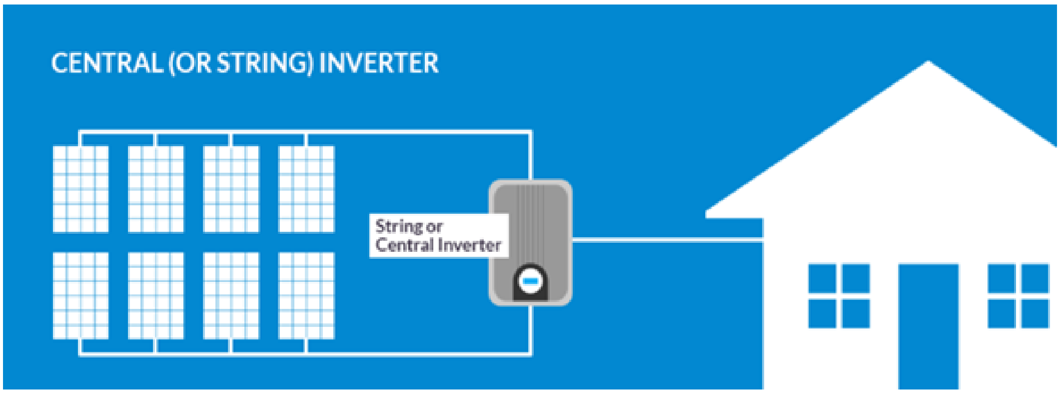


FIGURE 2.7: Central inverter [9]

Solar designs will be presented in a form of reports that displays all the parameters used in the design with showing the results obtained to achieve 350kWp capacity. All designs will face the same conditions, location, height, spacing, tilt angle, and no. of inverters to have fair comparison for all alternatives. After performing all design alternatives, we will subject all designs to comparison so that we can see the effectiveness of each design compared to others.

2.3.1 Fixed Panel Design

At this point after drawing the location of the solar system. We can start designing the solar systems. First, different factors for the solar system design need to be defined, starting by choosing the system type then setting the tilt and azimuth angles after that selecting the panel and inverter models. In this study two different panel models with different capacities have been used, Yingli PV 310Wp [25] and Panasonic PV 230Wp [26]. These panel models have different intrinsic structure as Yingli PV is polycrystalline panel which made of multifaceted silicon crystals while Panasonic PV is HIT panel which stands for Heterojunction with Intrinsic Thin layer which designed with thin amorphous silicon layers to reduce electron carrier loss to minimal levels. In this study, the performance of these two different intrinsic structures of panel models will be subjected into comparison when facing the same conditions. Three different inverters will be used in the designs, SMA 60.0 kWac [27], Hyundai 50.0 kWac [28], Solarmax 50.0 kWac [29]. The longitude and latitude for the proposed location were obtained from google maps. According to the location of the solar system PVsyst provide meteorological data as its stated in Figure 2.10. The result of performing these PV and inverter models will be subjected into comparison to see which alternative has the maximum power output.

2.3.1.1 Fixed Axis Simulation Report using Yingli PV

PVsyst software has a quick and simple procedure to perform a design simulation starting by specifying the system type whether its Fixed, One-axis or Two-axis system in the orientation part in PVsyst software as it shown in Figure 2.8. then defining the tilt and azimuth angles as it shown in Figure 2.9. Next step, is selecting the system part in PVsyst software as it shown in Figure 2.8 then defining the desired power or available area for the solar grid and choosing the PV and inverter models from the internal database as it shown in Figure 2.10. Then we can import the drawing we have drawn using sketchup software in the near shading part Figure 2.8 and set the panel's spacing. This allows to conduct a preliminary simulation. If there was any issue or mismatching when setting the parameters, the software will embed a color-coded warning/errors message. The Figures 2.12, 2.13, 2.17, 2.18 are simulation report from PVsyst after defining the parameters which contains four pages, each page shows the defined parameters and the results obtained from performing the design simulation. The report presents design simulation performed using 310Wp Yingli solar PV with 60.0 kWac SMA inverter.

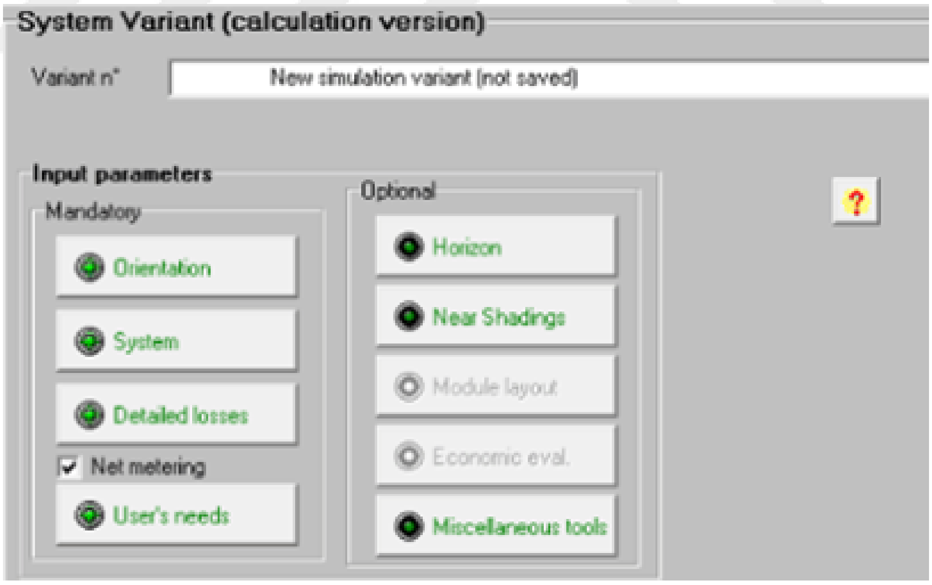


FIGURE 2.8: Input parameters

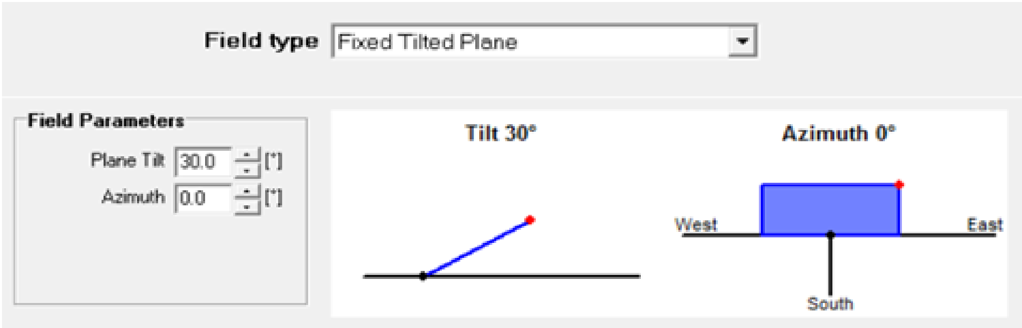


FIGURE 2.9: Fixed-axis definition

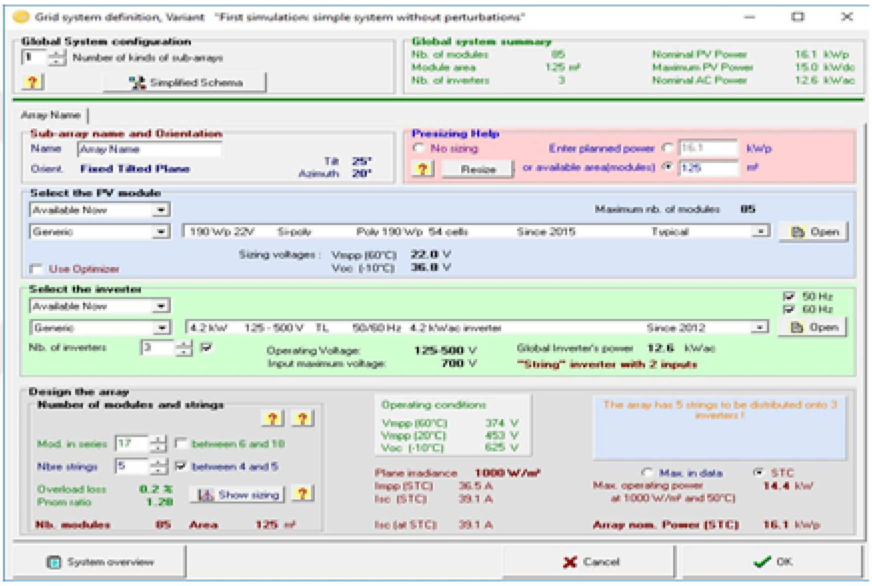
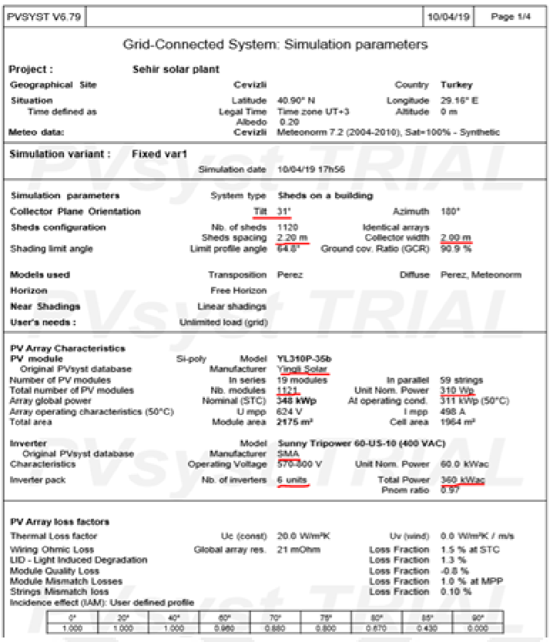


FIGURE 2.10: Grid system definition

FIGURE 2.11: Simulation



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Grid-Connected System: Simulation parameters

Project : **Sehir solar plant**

Geographical Site	Cevizli		Country	Turkey
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	Cevizli	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant : **Fixed var1**

Simulation date 10/04/19 17h56

Simulation parameters	System type	Sheds on a building		
Collector Plane Orientation	Tilt	31°	Azimuth	180°
Sheds configuration	Nb. of sheds	1120	Identical arrays	
	Sheds spacing	2.20 m	Collector width	2.00 m
Shading limit angle	Limit profile angle	64.8°	Ground cov. Ratio (GCR)	90.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

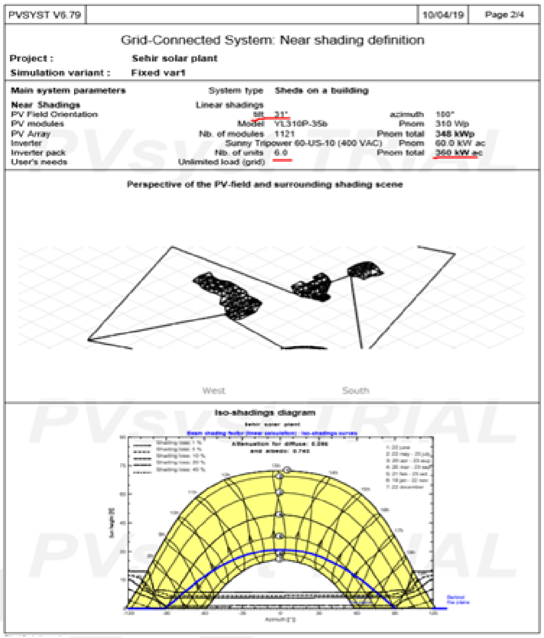
PV Array Characteristics				
PV module Si-poly	Model	YL310P-35b		
Original PVsyst database	Manufacturer	Yingli Solar		
Number of PV modules	In series	19 modules	In parallel	59 strings
Total number of PV modules	Nb. modules	1121	Unit Nom. Power	310 Wp
Array global power	Nominal (STC)	348 kWp	At operating cond.	311 kWp (50°C)
Array operating characteristics (50°C)	U mpp	624 V	I mpp	498 A
Total area	Module area	2175 m²	Cell area	1964 m²
Inverter	Model	Sunny Tripower 60-US-10 (400 VAC)		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	360 kWac
			Pnom ratio	0.97

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	21 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.980	0.880	0.800	0.670	0.430	0.000

FIGURE 2.12: Fixed, Yingli - SMA simulation report 1



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Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	Sheds on a building		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	348 kWp
Inverter	Sunny Tripower 60-US-10 (400 VAC)		Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	360 kW ac
User's needs	Unlimited load (grid)			

FIGURE 2.13: Fixed, Yingli - SMA simulation report 2

A study done by Suzi Dilara Mangan, Gül Koçlar Oral [30] shows that the optimum angle for Istanbul is 31°. The azimuth angle is 180° which is the compass direction from which the sunlight is coming according to location of panels [31]. When the drawing had been imported to PVsyst software the panels had been assigned to be 2.2m x 2m according to spacing calculation [32] as shown in Figures 2.14, 2.15. All solar panel alternative designs had the same defined parameters. Results shown in Figure 2.12 shows that to provide almost 350 kWp plant require 1121 PV modules with 6 SMA 60.0 kWac inverters that will convert DC to AC from 1121 panels. Note, that 60.0 kWac inverter has been used which provides 360 kWac power which is larger than the capacity of the plant (350 kWp), which can be considered as an oversized inverter. In this regards we will see how the slightly over sized inverter will perform against the two other inverters that had been used with 50 kWac Unit Nominal Power (UNP) in the comparison part.

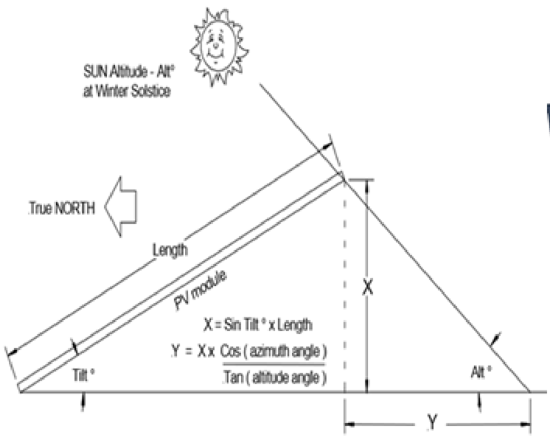


FIGURE 2.14: Spacing calculation [10]

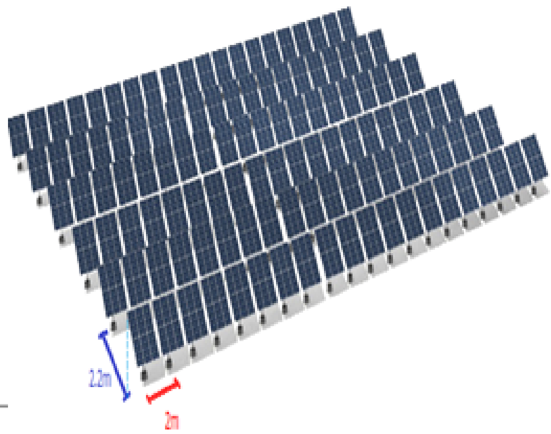


FIGURE 2.15: Panel spacing

Length of panel is 2m, tilt angle is 31°, then X = 1.03. Azimuth angle for when winter solstice (December 22) is 164.5°, Altitude angle in the same month is 24.12°[31], then Y = -2.21m

In the second page of the report Figure 2.13, simulation shows the shading diagram on the solar grid according to the defined location and the sun's movement [33] as it shown in Figure 2.16.

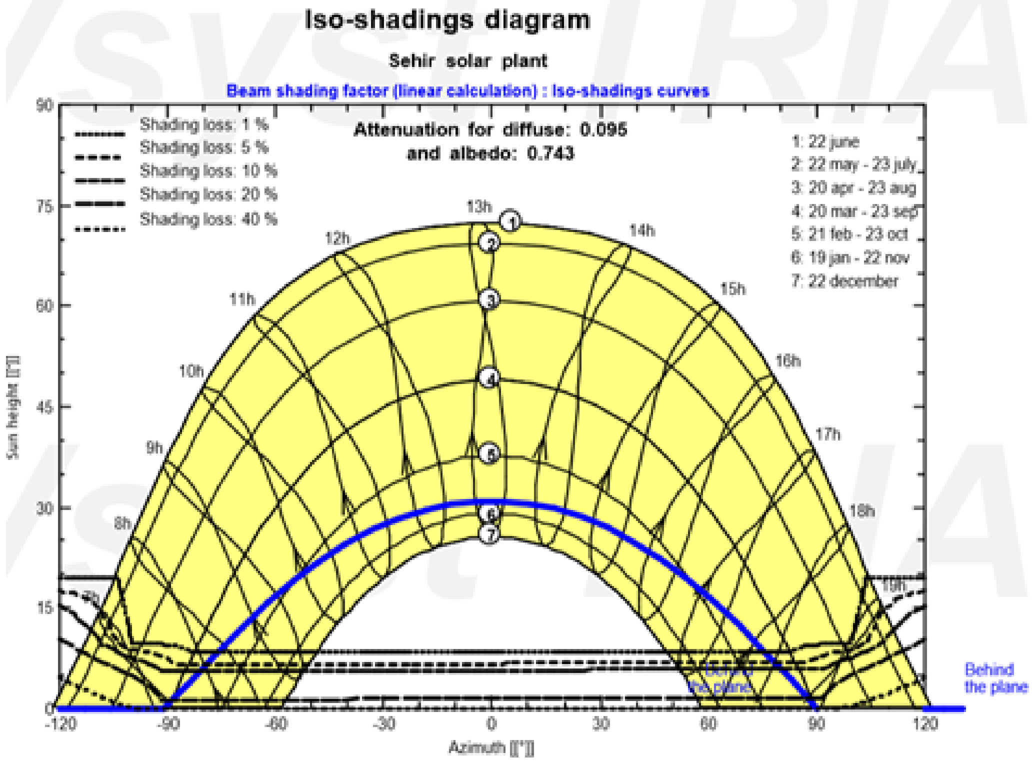


FIGURE 2.16: Fixed shading diagram

The chart shows the graphical expression of the shading factor. This graph gives an artificial assessment of the shading distribution according to the season and time of the day during the year. The black lines show the amount of shading loss for some given shading factors, superimposed on the sun paths. As long as the sun path do not cross the black lines then no loss caused by shading will appear. The blue line of beam shading factor indicate the tangential limits of the plane when the sun rays are parallel to the plane. Numbers from 1 to 7 refers to the path of the sun in a certain period; the worst case of sun path is during the winter season when the sun is at lowest point, Number 6 refers to 19 of January and 22 of November, if we are at 15 of January we will be somewhere between No. 6 and 7 which is below the blue line. The black lines obtained from the calculations are good that we almost have no shading loss caused by nearby obstacles between 9 am to 5 pm.

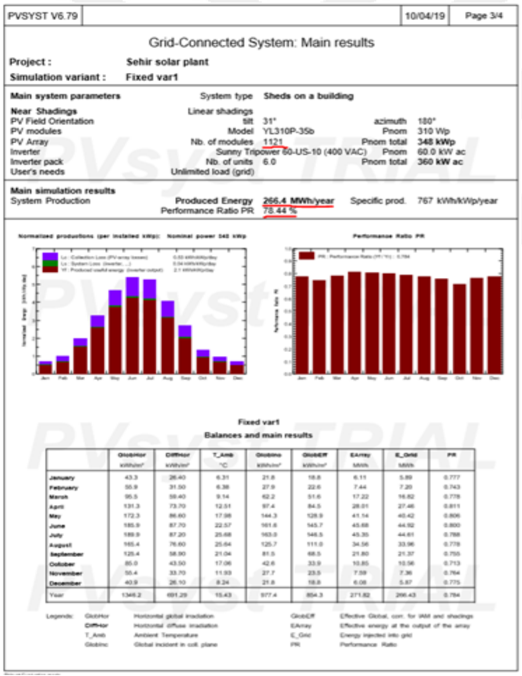


FIGURE 2.17: Fixed, Yingli - SMA simulation report 3

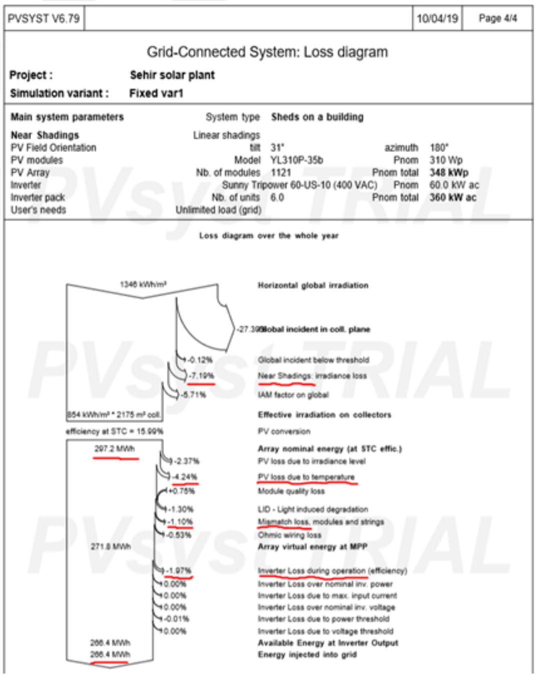


FIGURE 2.18: Fixed, Yingli - SMA simulation report 4

The simulation shows that performing Yingli solar PV 310Wp with SMA 60.0 kWac inverter generates 266.4 MWh/year coming out from 1121 panels with 78.44% performance ratio (PR). PR affected by losses such as shadings, ageing, module quality, mismatching and wiring [34]. Figure 2.17 also shows the electrical generation every month as it shown in Figure 2.19.

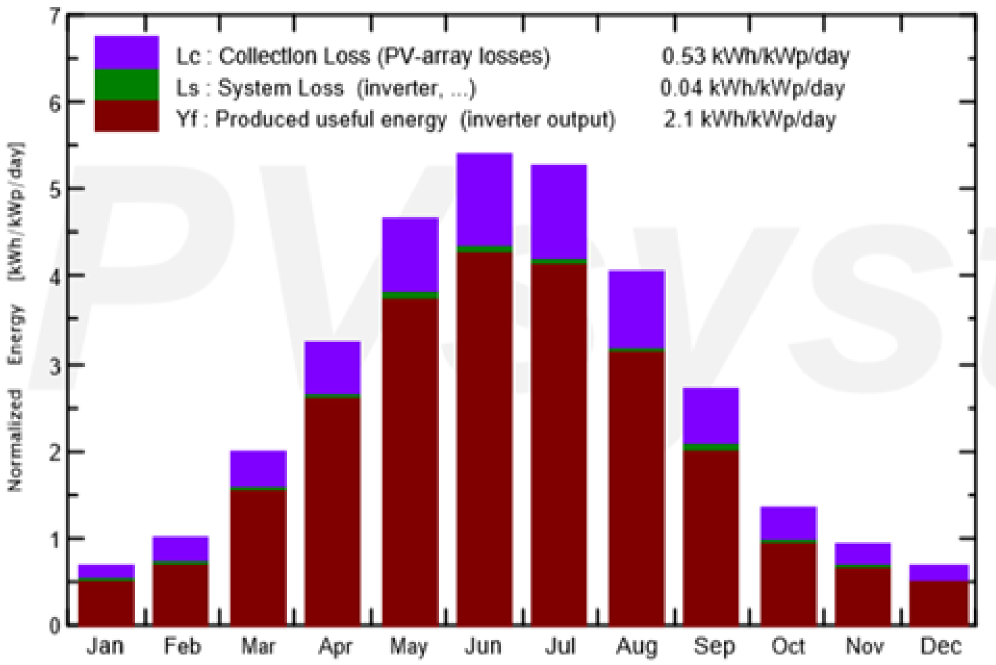


FIGURE 2.19: Fixed-axis monthly production

The results show that in the summer season, system generates more energy than in the winter season. Although the design system has the capability to generate 297.2 MWh/year as it is shown in Figure 2.18 it generates 266.4 MWh/year because of losses plant exposed to over the year. The graph shows 7.19% loss due to shading, this value shows the amount of energy production loss due to the shading on panels caused by the existence of obstacles preventing the sunlight from reaching the panels throughout the year. The Incidence Angle Modifier (IAM) had 5.71% loss which corresponds to the decrease of irradiance reaching PV cells caused by the reflection of sunlight on the glass layer of the PV panel. Irradiance level had 2.37% loss which shows the intrinsic behavior of the PV modules as Yingli PV is polycrystalline solar panel that are made from multifaceted silicon crystals. The plant had 4.24% loss due to temperature which shows the temperature behavior of the PV model. In fact, the electrical performances of a silicon solar cell shows that the cells are very sensitive to temperature [35]. A study had been made to show the effect of temperature on solar cells [36], the study tested the performance of polycrystalline silicon and showed that the performance of solar cells is dependent on environmental conditions and their output parameters such as output voltage, current, power, and efficiency vary by light intensity and temperature.

Real modules are never identical, with long term aging, modules do not degrade the same way especially when having big systems which have different string wire lengths. Temperature may also be different from part to another (colder at the edges), which all lead to have mismatch loss [37]. The plant had 1.97% inverter loss which refers to the inverter efficiency during operation. These factors led to this shortage of energy production to 266.4 MWh/year.

2.3.1.2 Fixed Axis Energy Output Comparison

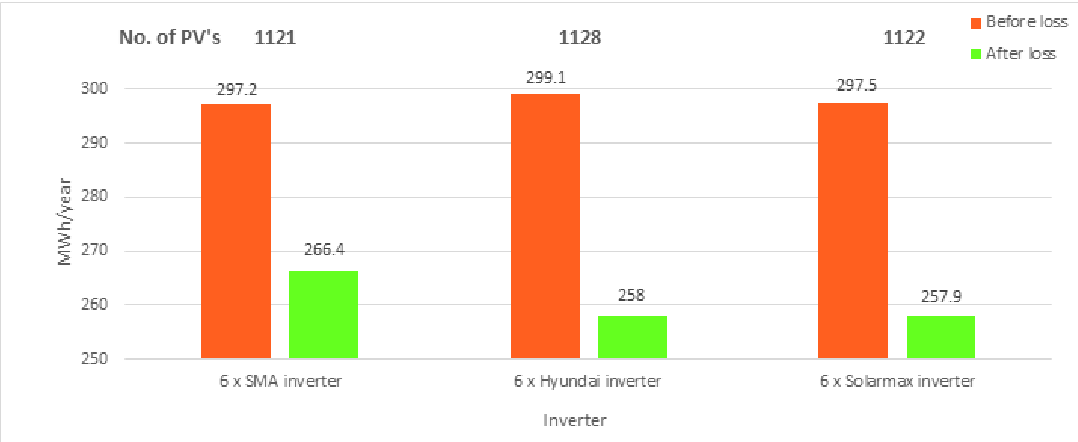


FIGURE 2.20: Fixed, Yingli PV Energy output [67]

Performing Fixed-axis system again in PVsyst software using same PV model (Yingli) but with Hyundai and Solar max inverters have different energy output as it shown in Figure 2.20. The Figure shows that using Hyundai and Solarmax inverters with Yingli PV have the capability to generate almost the same energy with 1.6 MWh/year difference 299.1, 297.5 MWh/year respectively, but the Figure shows that the actual output energy for both systems is 258, 257.9 MWh/year with just 0.1 MWh/year difference due to the different percentage of losses in each system. Note that 7 more panels were used with system using Hyundai 50 kWac inverter. However, it generates 8.4 MWh/year less than when SMA inverter is used because it has less overall losses with different inverter capacity.

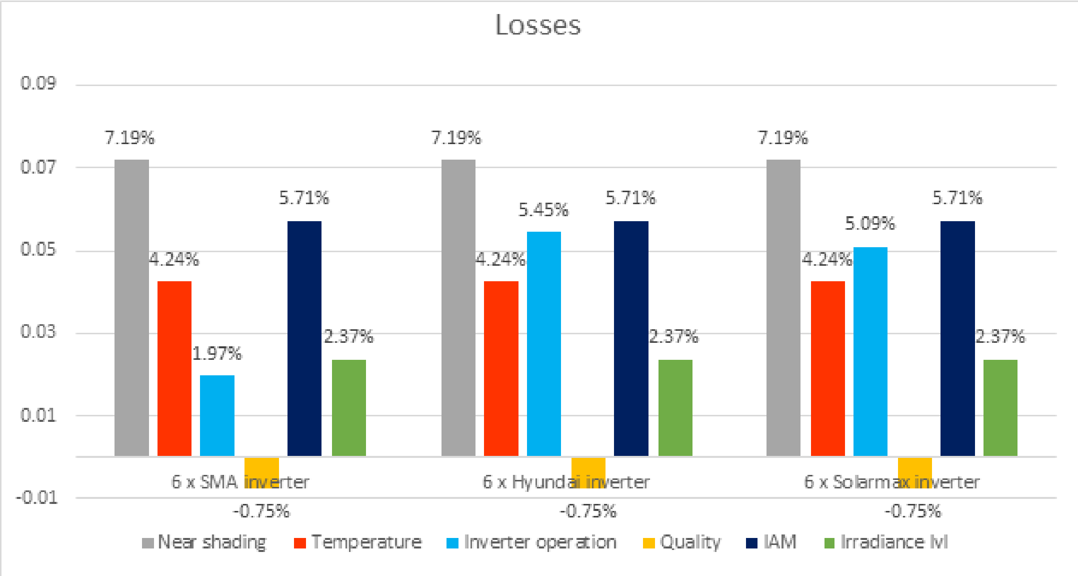
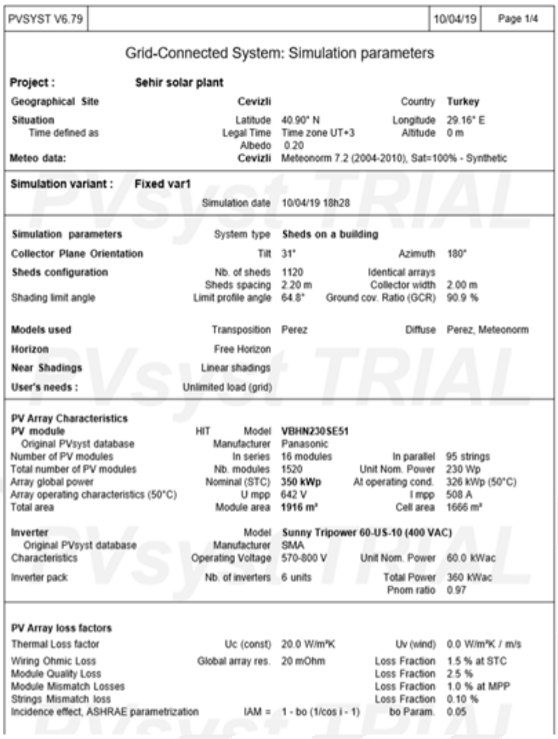


FIGURE 2.21: Fixed, Yingli Inverter Losses

Figure 2.21 shows that all alternatives have the same shading, temperature, quality, IAM factor and irradiance losses because of using same PV model with facing the same conditions (Fixed axis). The negative value of quality loss -0.75% is a gain, the quality factor refers to confidence value to the real model (models will never be better than announced). PVsyst usually consider a conservative value according to the PV module manufacturer tolerance specifications [38]. The differences were observed in inverter losses during operation. The least loss was recorded when SMA inverter is used with 3.48% less than when Hyundai inverter is used, which also increased the slight difference in energy output.

2.3.1.3 Fixed Axis Simulation Report using Panasonic PV



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Grid-Connected System: Simulation parameters

Project : **Sehir solar plant**

Geographical Site — Cevizli — Country Turkey
Situation — Latitude 40.90° N — Longitude 29.16° E
Time defined as — Legal Time Time zone UT+3 — Altitude 0 m
Albedo 0.20
Meteo data: — Cevizli — Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic

Simulation variant : **Fixed var1**
Simulation date 10/04/19 18h28

Simulation parameters — System type **Sheds on a building**
Collector Plane Orientation — Tilt 31° — Azimuth 180°
Sheds configuration — Nb. of sheds 1120 — Identical arrays
Sheds spacing 2.20 m — Collector width 2.00 m
Shading limit angle — Limit profile angle 64.8° — Ground cov. Ratio (GCR) 90.9 %

Models used — Transposition Perez — Diffuse Perez, Meteonorm
Horizon — Free Horizon
Near Shadings — Linear shadings
User's needs : — Unlimited load (grid)

PV Array Characteristics
PV module — HIT — Model **VBHN230SE51**
Original PVsyst database — Manufacturer Panasonic
Number of PV modules — In series 16 modules — In parallel 95 strings
Total number of PV modules — Nb. modules 1520 — Unit Nom. Power 230 Wp
Array global power — Nominal (STC) **350 kWp** — At operating cond. 326 kWp (50°C)
Array operating characteristics (50°C) — U mpp 642 V — I mpp 508 A
Total area — Module area **1916 m²** — Cell area 1666 m²

Inverter — Model **Sunny Tripower 60-US-10 (400 VAC)**
Original PVsyst database — Manufacturer SMA
Characteristics — Operating Voltage 570-800 V — Unit Nom. Power 60.0 kWac
Inverter pack — Nb. of inverters 6 units — Total Power 360 kWac
Pnom ratio 0.97

PV Array loss factors
Thermal Loss factor — Uc (const) 20.0 W/m²K — Uv (wind) 0.0 W/m²K / m/s
Wiring Ohmic Loss — Global array res. 20 mOhm — Loss Fraction 1.5 % at STC
Module Quality Loss — Loss Fraction 2.5 %
Module Mismatch Losses — Loss Fraction 1.0 % at MPP
Strings Mismatch loss — Loss Fraction 0.10 %
Incidence effect, ASHRAE parametrization — IAM = 1 - bo (1/cos i - 1) — bo Param. 0.05

FIGURE 2.22: Fixed, Panasonic - SMA simulation report 1

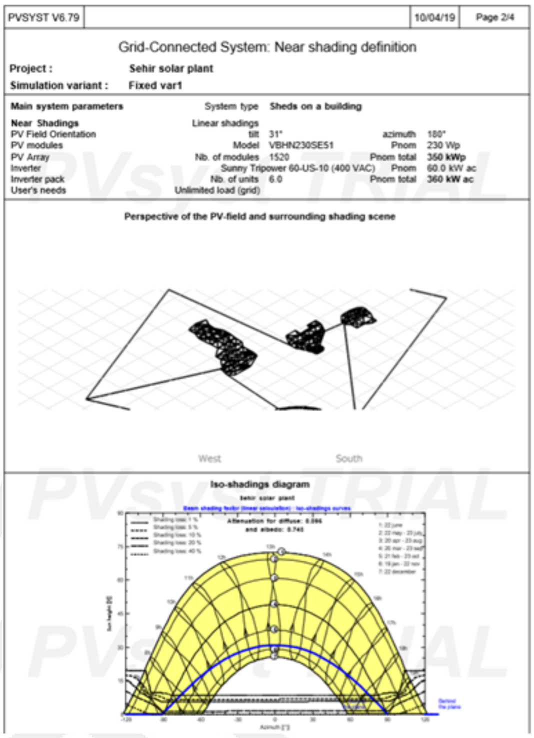
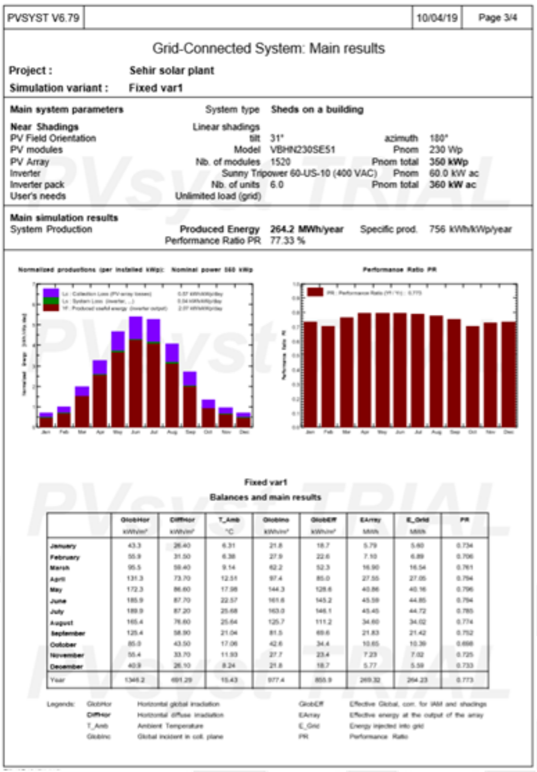


FIGURE 2.23: Fixed, Panasonic - SMA simulation report 2

Panasonic 230 Wp UNP with six 60 kWac SMA inverters were used in this alternative, facing the same conditions. Figure 2.22 shows that to achieve 350 kWp capacity, 1520 PV modules will be required which about 400 more modules than when Yingli (310 Wp) is used. This will put us under question, is $7500m^2$ space sufficient for installing grid that uses Panasonic PV panels? A calculation will be performed for space requirement when all alternative designs are done.



	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	43.3	26.40	6.31	21.8	18.7	5.79	5.60	0.734
February	55.9	31.50	6.38	27.9	22.6	7.10	6.89	0.706
March	95.5	59.40	9.14	62.2	52.3	16.90	16.54	0.761
April	131.3	73.70	12.51	97.4	85.0	27.55	27.05	0.794
May	172.3	86.60	17.98	144.3	128.6	40.86	40.16	0.796
June	185.9	87.70	22.57	161.6	145.2	45.59	44.85	0.794
July	189.9	87.20	25.68	163.0	146.1	45.45	44.72	0.785
August	165.4	76.60	25.64	125.7	111.2	34.60	34.02	0.774
September	125.4	58.90	21.04	81.5	69.6	21.83	21.42	0.752
October	85.0	43.50	17.06	42.6	34.4	10.65	10.39	0.698
November	55.4	33.70	11.93	27.7	23.4	7.23	7.02	0.725
December	40.9	26.10	8.24	21.8	18.7	5.77	5.59	0.733
Year	1346.2	691.29	15.43	977.4	855.9	269.32	264.23	0.773

FIGURE 2.24: Fixed, Panasonic - SMA simulation report 3

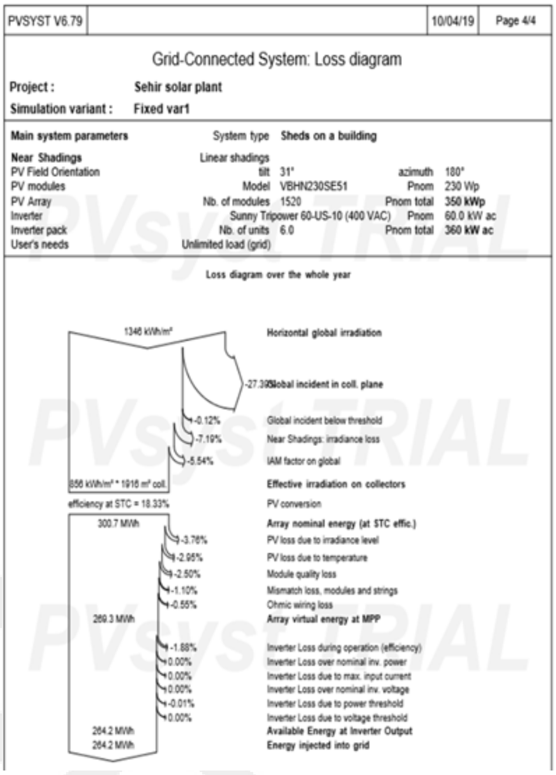


FIGURE 2.25: Fixed, Panasonic - SMA simulation report 4

It was established that using Panasonic solar PV with 230Wp capacity and SMA 60.0 kWac inverter generates 264.2.0 MWh/year with 77.33% PR. Note that these results are similar to the alternative design using Yingli with SMA. Regarding losses, we can see that Panasonic panels have less losses caused by temperature with 2.95% compared to 4.24% for Yingli PV. In other hand using Panasonic PV with SMA inverter has 2.5% model quality loss while it was +0.75% for Yingli.

2.3.1.4 Fixed Axis Energy Output Comparison

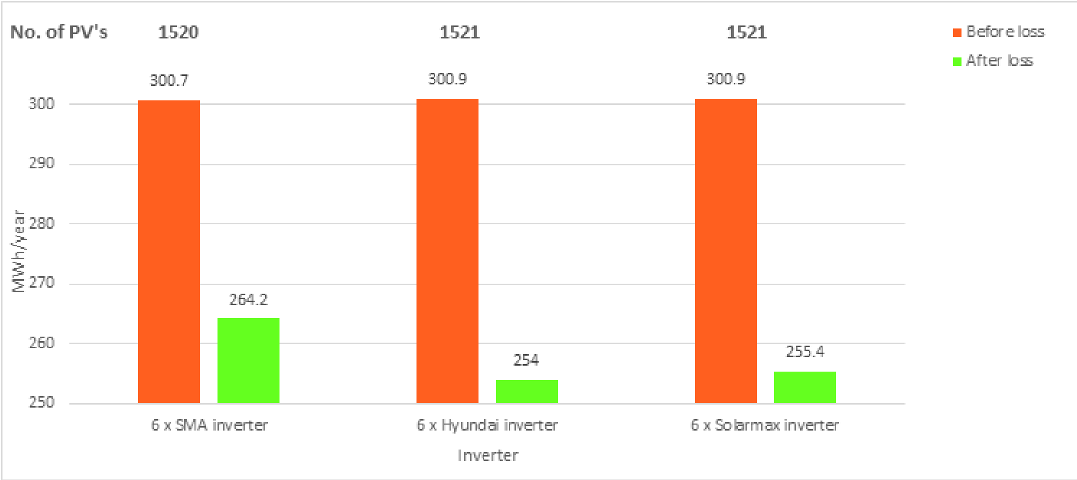


FIGURE 2.26: Fixed Panasonic PV Energy output [87]

Results displayed in Figure 2.26 shows that Fixed system with Panasonic PV model had the same energy output before loss elimination. This would give a better view into assessing the impact of each inverter to the design. As its reported that design with 60 kWac SMA inverter had higher energy output after eliminating losses. Using Hyundai and Solarmax inverters to Panasonic PV have the capability to generate the same energy with no difference 300.9, 300.9 MWh/year respectively, but the actual output energy for both systems is 254, 255.4 MWh/year with just 1.4 MWh/year difference due to the loss difference of inverter operation for each system shown in Figure 2.27.

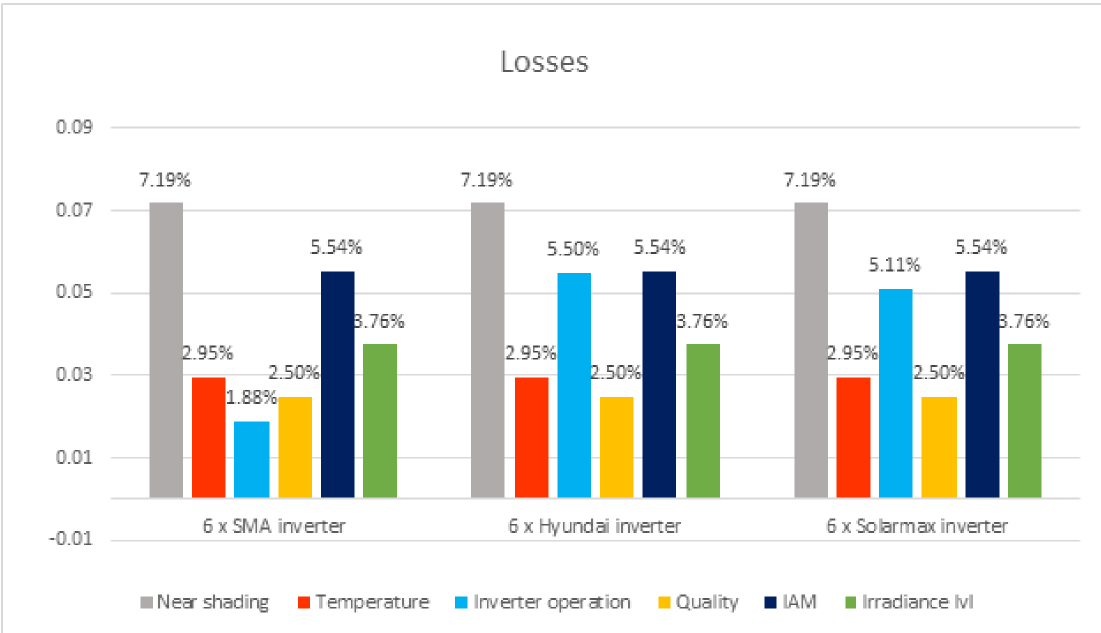


FIGURE 2.27: Fixed, Panasonic Inverter Losses

Using same panel model led to have same shading, temperature, quality, IAM factor and irradiance level losses. Anyhow, given the percentage of losses resulting from quality, this system had 2.5% negative value compared to 0.75% positive value for Yingli panels. Therefore, the results of these design alternative are logical compared with designs using Yingli panels. Figure 2.27 shows that differences were reported in inverters during operation. The least loss was recorded when SMA inverter is used with 1.88% compared to 5.5% and 5.11% for Hyundai and Solarmax.

2.3.1.5 Fixed Axis Systems Comparison

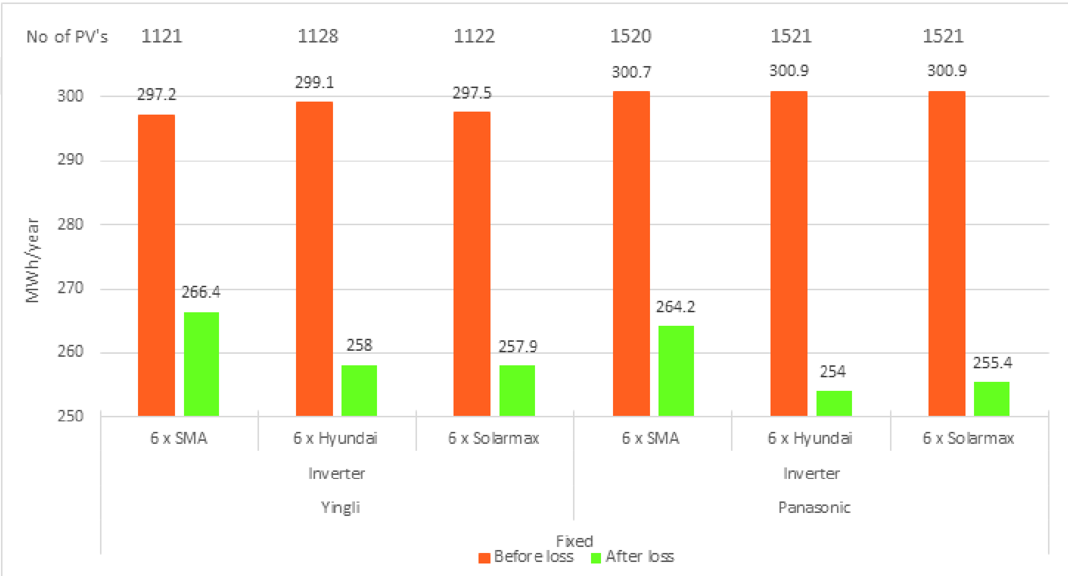


FIGURE 2.28: Fixed, Yingli - Panasonic systems comparison

As shown in Figure 2.28 there is difference in energy output before loss elimination between Yingli and Panasonic systems. Even though the global irradiation is the same for both systems Figures 2.18, 2.25 such as Yingli with SMA has the capability to generates 297.2 MWh/year while Panasonic with same inverter generates 300.7 MWh/year. In fact, that was because of IAM factor which affect the light absorption, that corresponds to irradiance reaching the PV cells surface. This decrease is mainly due to reflections on the glass cover, which increases with the incidence angle as it is shown in Figure 2.29 [39].

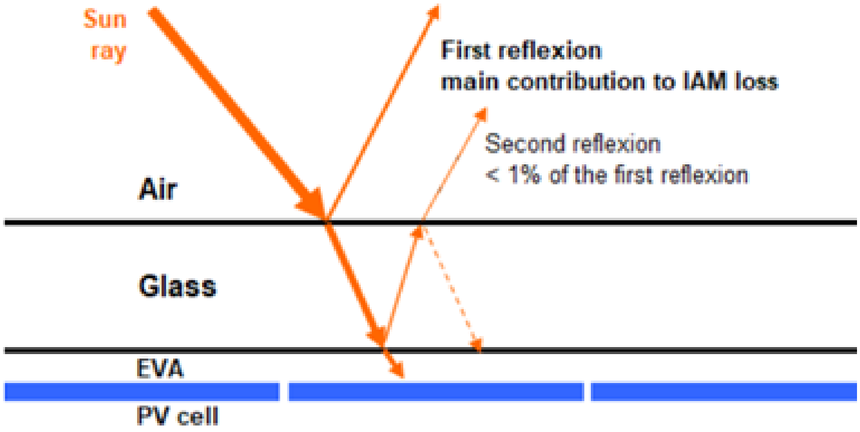


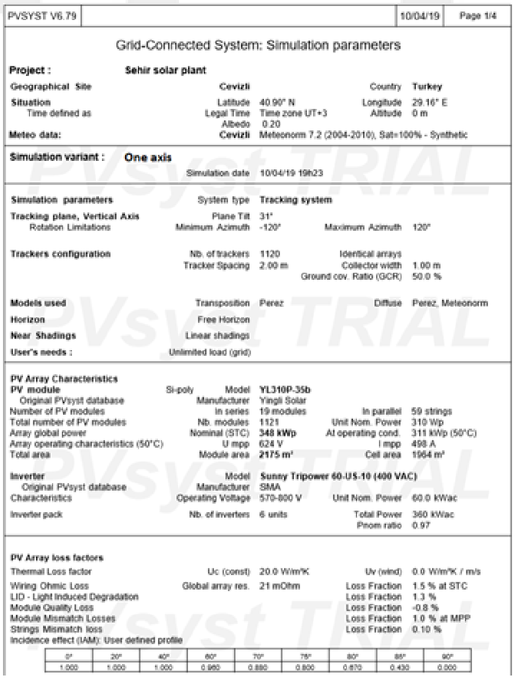
FIGURE 2.29: Incidence Angle Modifier - IAM [11]

Figures 2.18, 2.25 shows that Yingli panels had 5.71% loss due to IAM while Panasonic had 5.54%, which explains the slight difference between energy output. However, Panasonic models had more energy output because of less IAM factor. Results after entering loss calculation were in favor of designs with Yingli panels because the total proportion of losses is lower in Yingli design systems which made the difference. Figure 2.28 shows that systems with Yingli panel models has more promising results but still many factors will affect the final design decision such as checking the area required for both panel systems, system type (Fixed, One-axis, Two-axis) results, cost of systems. These factors play an important role in which choosing the best efficient design that covers the need besides achieving economic feasibility.

2.3.2 One Vertical Axis Panel Design

The grid's location along with the sun's movement shows that if the Vertical axis system is used would give better results because vertical system tracks the sun's azimuth which allow panels to be exposed more to the sun [40]. The capability to collect light is better in One-way axis trackers than Fixed-axis systems as it has been mentioned in Figure 1.1 due to the existence of moving parts that help the panel angle itself to direct the sun. In this part of the design we expect to have more energy produced because One-axis trackers are capable of generating more electricity in roughly the same amount of space needed for Fixed-tilt systems. The design will be performed using same panel models (Yingli 310Wp - Panasonic 230Wp) with same inverter models (SMA 60.0 kWac - Hyundai 50.0 kWac - Solarmax 50.0 kWac). Same parameters have been defined such as tilt angle and spacing to examine the obtained output with subjecting all designs into comparison to see which alternative would have better energy output. In addition, One-axis results will be compared to those of the Fixed system to inspect the amount of difference if any exist. Regarding maximum and minimum orientation for the One-axis system, it has been defined to be 120° degrees according to the sun's path for the defined location. The following report will present data and calculations for a design performed using 310Wp Yingli solar PV with 60.0 kWac SMA inverter. All calculations that will be presented are based on real data.

2.3.2.1 One Axis Simulation Report using Yingli PV



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Grid-Connected System: Simulation parameters

Project : Sehir solar plant

Geographical Site: Cevizli — Country: Turkey
Situation — Latitude: 40.90° N — Longitude: 29.16° E
Time defined as — Legal Time: Time zone UT+3 — Altitude: 0 m
Albedo: 0.20
Meteo data: Cevizli — Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic

Simulation variant : One axis
Simulation date: 10/04/19 19h23

Simulation parameters — System type: Tracking system
Tracking plane, Vertical Axis — Plane Tilt: 31°
Rotation Limitations — Minimum Azimuth: -120° — Maximum Azimuth: 120°

Trackers configuration — Nb. of trackers: 1120 — Identical arrays
Tracker Spacing: 2.00 m — Collector width: 1.00 m
Ground cov. Ratio (GCR): 50.0 %

Models used — Transposition: Perez — Diffuse: Perez, Meteonorm
Horizon — Free Horizon
Near Shadings — Linear shadings
User's needs : — Unlimited load (grid)

PV Array Characteristics
PV module — Si-poly — Model: YL310P-35b
Original PVsyst database — Manufacturer: Yingli Solar
Number of PV modules — In series: 19 modules — In parallel: 59 strings
Total number of PV modules — Nb. modules: 1121 — Unit Nom. Power: 310 Wp
Array global power — Nominal (STC): 348 kWp — At operating cond.: 311 kWp (50°C)
Array operating characteristics (50°C) — U mpp: 624 V — I mpp: 498 A
Total area — Module area: 2175 m² — Cell area: 1964 m²

Inverter — Model: Sunny Tripower 60-US-10 (400 VAC)
Original PVsyst database — Manufacturer: SMA
Characteristics — Operating Voltage: 570-800 V — Unit Nom. Power: 60.0 kWac
Inverter pack — Nb. of inverters: 6 units — Total Power: 360 kWac
Pnom ratio: 0.97

PV Array loss factors
Thermal Loss factor — Uc (const): 20.0 W/m²K — Uv (wind): 0.0 W/m²K / m/s
Wiring Ohmic Loss — Global array res.: 21 mOhm — Loss Fraction: 1.5 % at STC
LID - Light Induced Degradation — Loss Fraction: 1.3 %
Module Quality Loss — Loss Fraction: -0.8 %
Module Mismatch Losses — Loss Fraction: 1.0 % at MPP
Strings Mismatch loss — Loss Fraction: 0.10 %
Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

FIGURE 2.30: One-way, Yingli - SMA simulation report 1

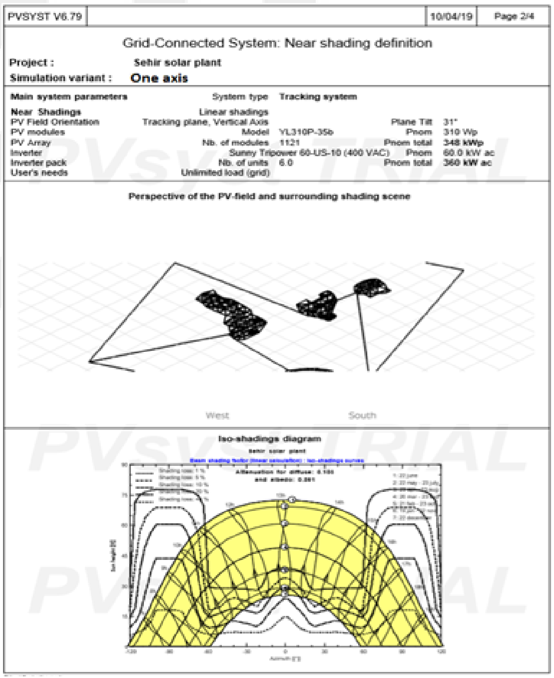


FIGURE 2.31: One-way, Yingli - SMA simulation report 2

Results in Figure 2.30 shows that One-axis system require 1121 PV modules to achieve the desired energy output as it was in Fixed system. Hence, number of PV modules depends on the panel UNP which is 310 Wp. Note that the shading chart in Figure 2.31 had different output compared to Fixed system. The irregular look of the lines is due to the interpolations across discrete calculation points [33]. Note that the blue line of beam shading factor does not exist in One-axis track system.

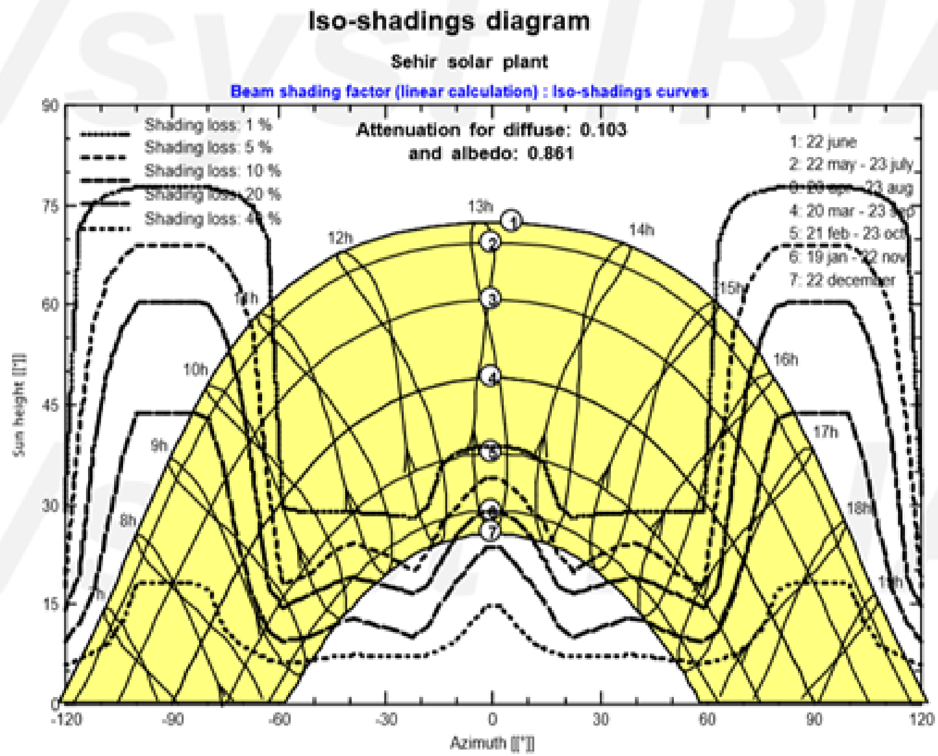


Figure 2.32: One-way shading diagram

Same parameters were defined in this alternative design but different shading diagram obtained. It was figured that the reason behind this is the movement of single-track system that caused the shades on nearby panels.

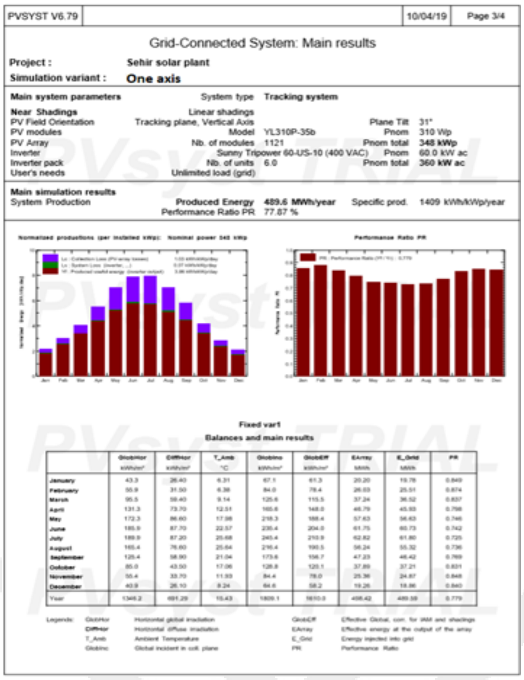


FIGURE 2.33: One-way, Yingli - SMA simulation report 3

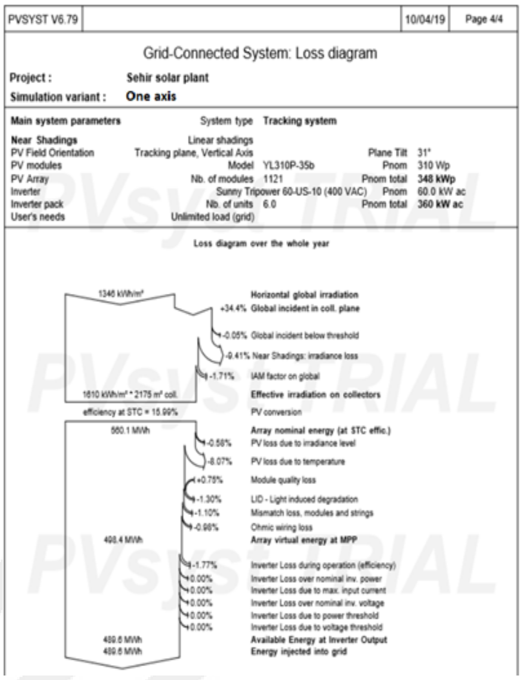


FIGURE 2.34: One-way, Yingli - SMA simulation report 4

Performing Yingli solar PV 310Wp with SMA 60.0 kWac inverter in One-axis track system generates 489.6 MWh/year produced from 1121 panels with 77.87% PR. Figure 2.34 shows that the design system capable to generate 560.1 MWh/year but after eliminating losses the energy output decreased to 489.6 MWh/year. Note that loss due to shading is 9.41% while it was 7.19% in Fixed system due to panels movement. Targeting the sun reduced the IAM factor loss to 1.71% compared to 5.71% in the Fixed system, this better performance was obtained due to the movement of the panel system which allow no refraction as possible of the solar radiation when it reaches the panels. Following the sun's azimuth increased the radiation exposure time, causing temperature loss to increase to 8.07% compared to 4.24% in the Fixed system.

2.3.2.2 One Axis Energy Output Comparison

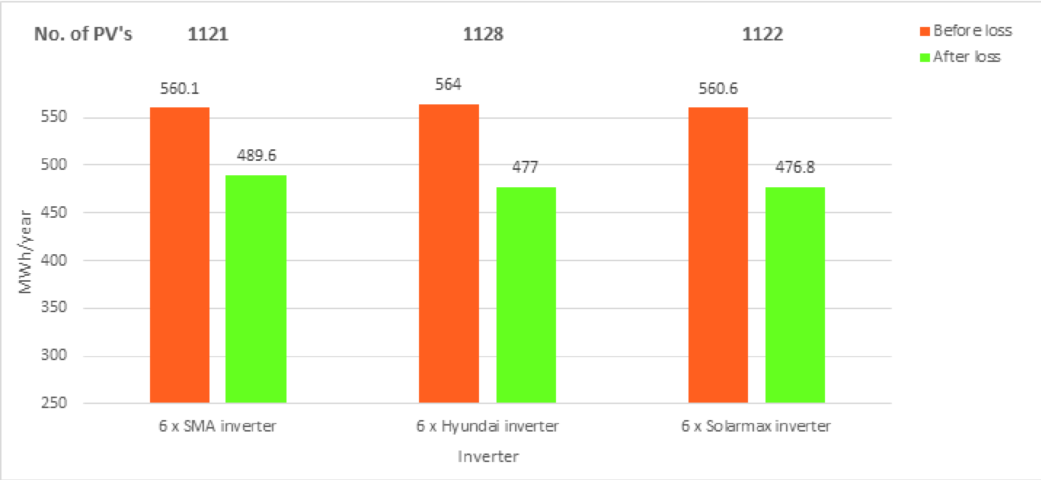


FIGURE 2.35: One-way Yingli PV Energy output [91]

The chart shows that results are close to each other regarding energy output before applying loss elimination calculations. System with SMA inverter had more energy output after consideration of loss calculations with more than 12.5 MWh/year difference compared to other alternatives due to different percentage of losses in each system shown in Figure 2.36. Note that although 7 more panels had been used with Hyundai 50 kWac inverter it generates 12.6 MWh/year less than when SMA inverter is used.

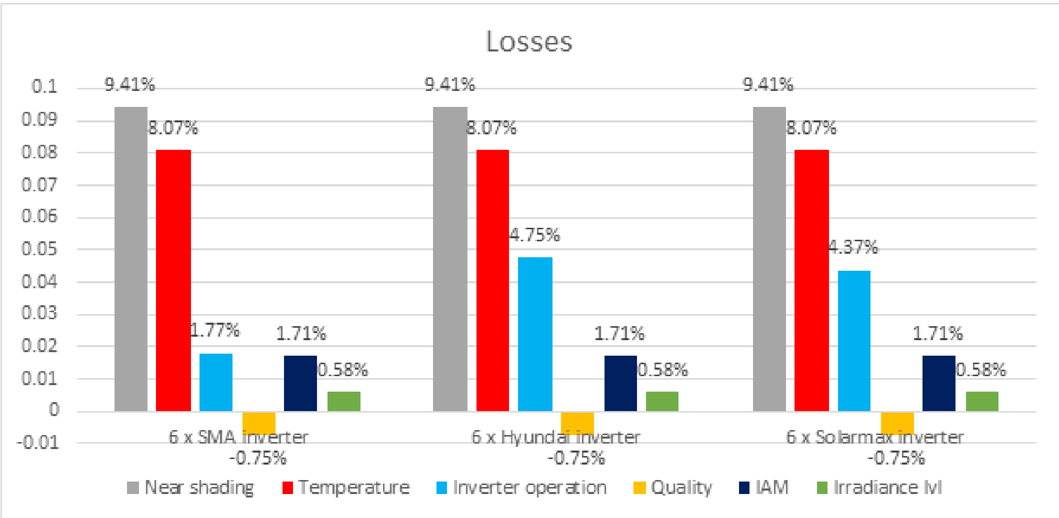


FIGURE 2.36: One-way, Yingli - Inverters losses

Note that all alternatives had the same, temperature, quality, IAM factor and irradiance level losses because of using same PV model. The differences were observed in inverter performance. The least loss was recorded when SMA inverter is used with 1.77% compared to 4.75% and 4.37% for Hyundai and Solarmax respectively which increased the difference in energy output. Note that Figure 2.37 shows that all losses due to inverter operation had lower value than in Fixed system.

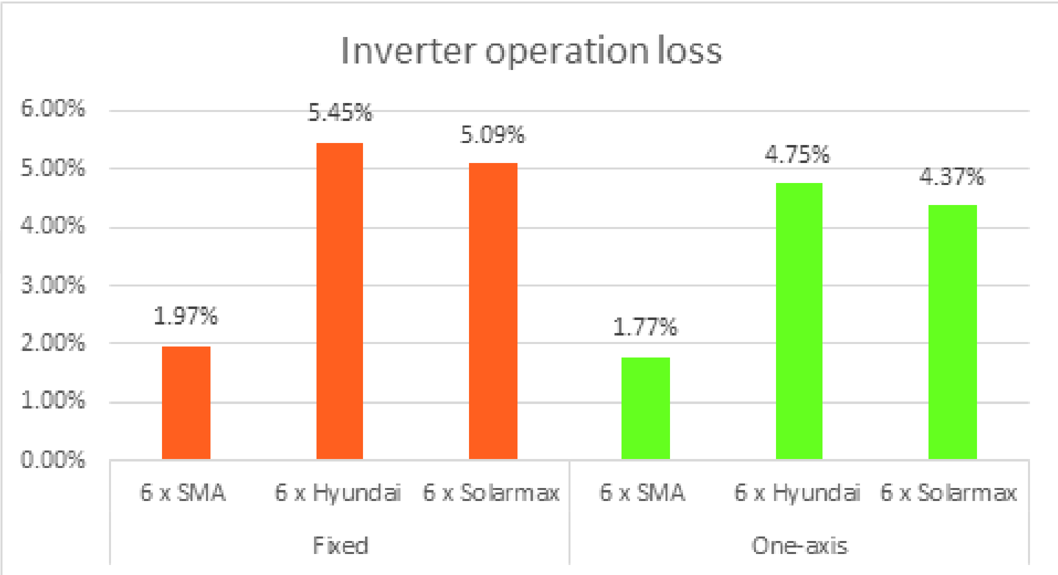
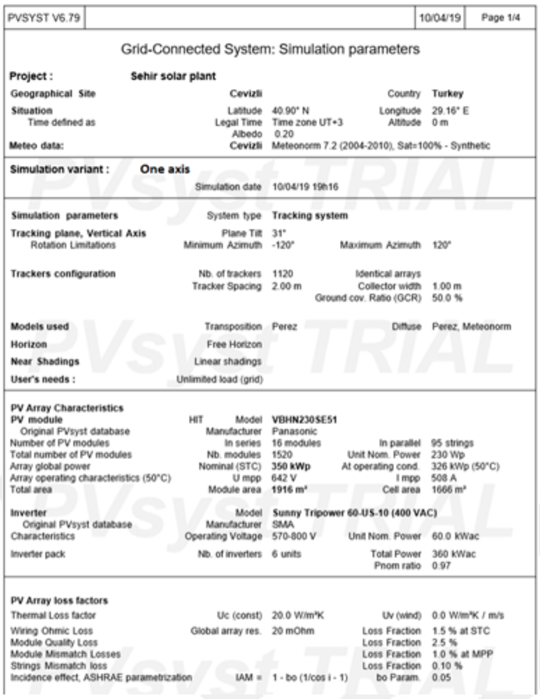


FIGURE 2.37: Fixed - One-axis inverter operation loss

2.3.2.3 One Axis Simulation Report using Panasonic PV



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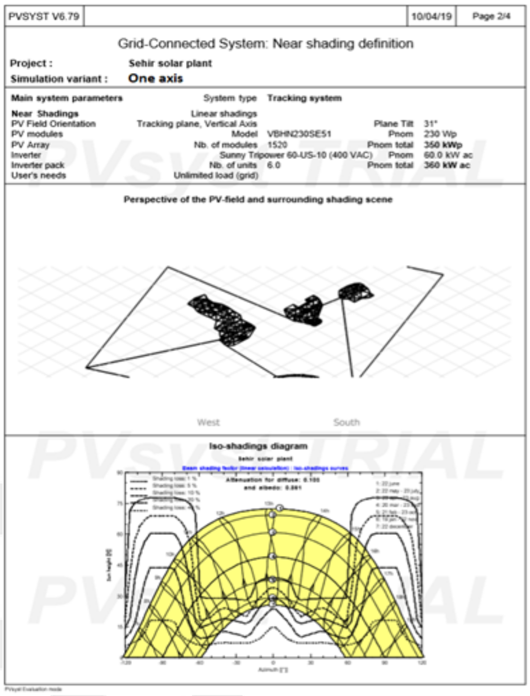
Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		
Simulation variant :	**One axis**			
	Simulation date	10/04/19 19h16		
Simulation parameters	System type	**Tracking system**		
Tracking plane, Vertical Axis	Plane Tilt	31°		
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.00 m	Collector width	1.00 m
			Ground cov. Ratio (GCR)	50.0 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			
PV Array Characteristics				
PV module	HIT Model	**VBHN230SE51**		
Original PVsyst database	Manufacturer	Panasonic		
Number of PV modules	In series	16 modules	In parallel	95 strings
Total number of PV modules	Nb. modules	1520	Unit Nom. Power	230 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)	U mpp	642 V	I mpp	508 A
Total area	Module area	**1916 m²**	Cell area	1666 m²
Inverter	Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	360 kWac
			Pnom ratio	0.97
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	20 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

FIGURE 2.38: One-way, Panasonic - SMA simulation 1



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Grid-Connected System: Near shading definition

Project :	**Sehir solar plant**			
Simulation variant :	**One axis**			
Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

FIGURE 2.39: One-way, Panasonic - SMA simulation 2

Facing the same conditions, 1520 Panasonic PV modules with 230 Wp UNP and six 60 kWac SMA inverters were used in this alternative. It was figured that the shading chart shown in Figure 2.43 is the same as when Yingli PV model was used. This shows that the UNP of the PV does not affect the movement of track system because the purpose of designing these different design systems is to obtain the maximum energy output for the same fixed factors.

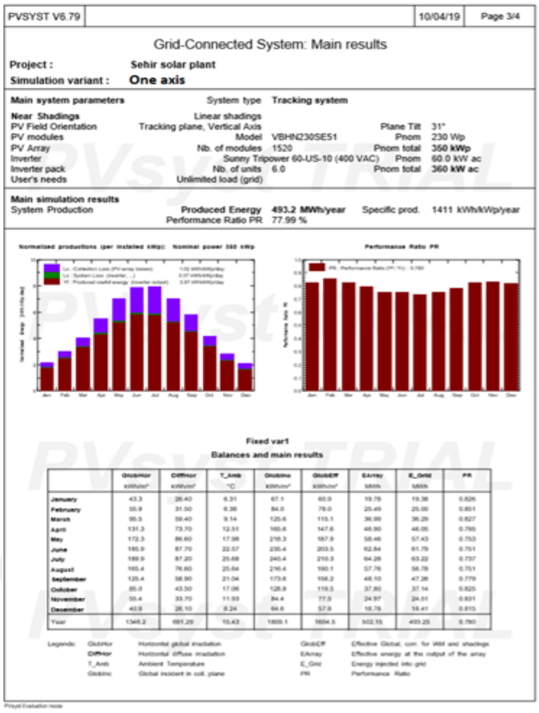


FIGURE 2.40: One-way, Panasonic - SMA simulation 3

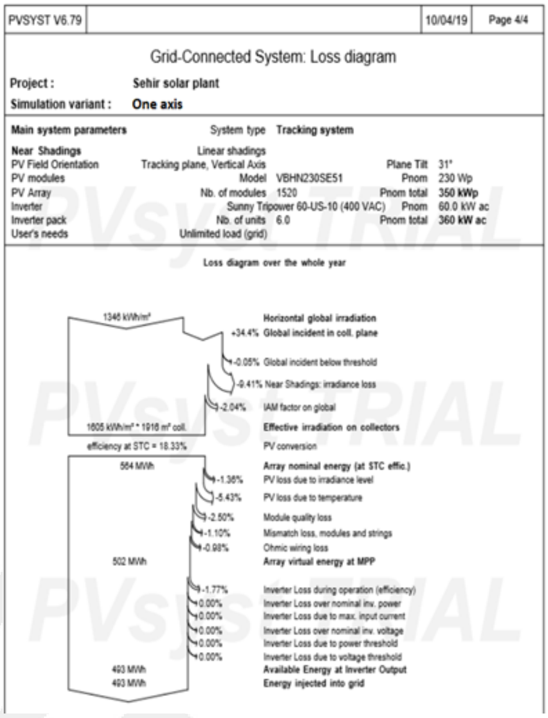


FIGURE 2.41: One-way, Panasonic - SMA simulation 4

This system is capable to generate 564 MWh/year compared to 560.1 MWh/ year for Yingli PV. After loss elimination this system generates 493.2 MWh/year compared to 489.6 MWh/year using Yingli PV. It was figured that in Figure 2.28 regarding energy output for the alternatives of Fixed system, that Panasonic PV model had more energy output than Yingli PV model before loss elimination but not after. However, in the current system, Panasonic had more energy output than when Yingli PV model was used even after loss elimination.

2.3.2.4 One Axis Energy Output Comparison

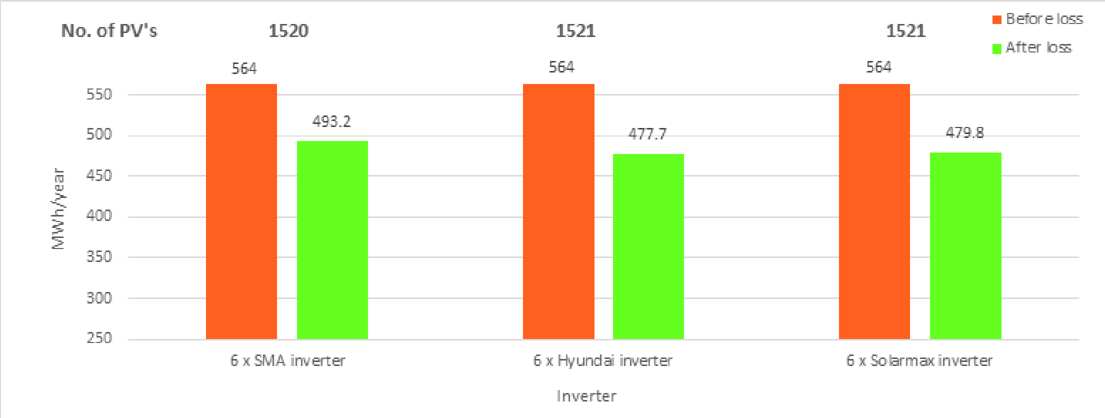


FIGURE 2.42: One-way Panasonic PV Energy output [103]

This chart shows that results were the same regarding energy output before applying loss elimination. This would give a better view into assessing the impact of each inverter to the design. According to Figure 2.42, system with SMA inverter had more energy output after consideration of loss calculations with more than 15.5, 13.4 MWh/year when Hyundai and Solarmax inverters is used. The results show increasing in the energy production gap between systems, as One-axis system that used Yingli PV with SMA inverter had 12.5 MWh/year difference with the other inverters that has been used.

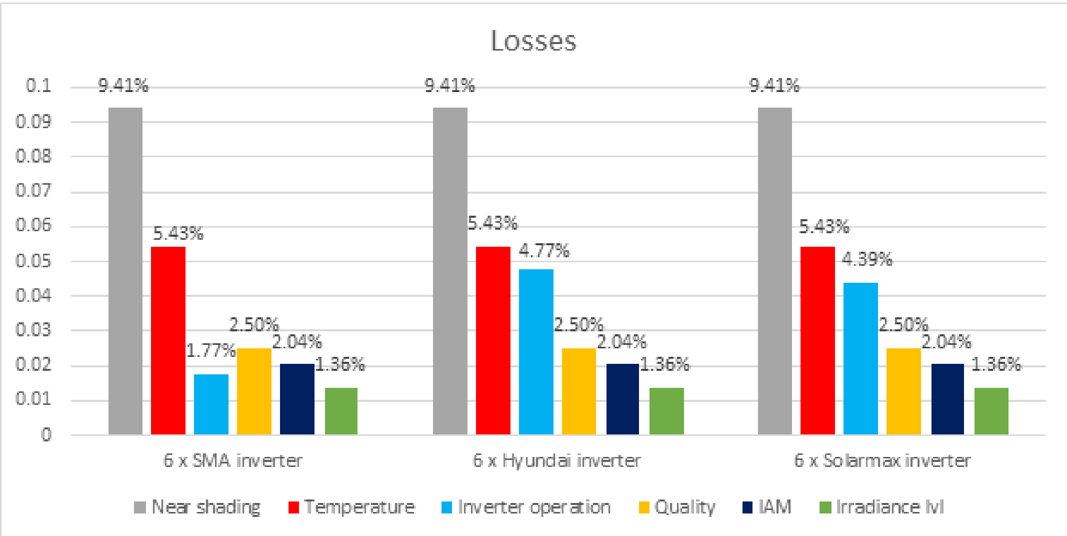


FIGURE 2.43: One-way, Panasonic - Inverters losses

The differences were observed in inverter performance. The least loss was recorded when SMA inverter is used with 1.77% compared to 4.77% and 4.39% for Hyundai and Solarmax respectively. It was figured that the reason behind having better energy output using Panasonic PV and SMA inverter than Yingli PV with SMA inverter after loss elimination is that the temperature loss difference between Panasonic and Yingli models in Fixed system was 1.29%, but in One-axis system the temperature difference increased to be 2.64%, which means that Panasonic PV's perform better when exposing to heat compared to Yingli models.

2.3.2.5 One Axis Systems Comparison

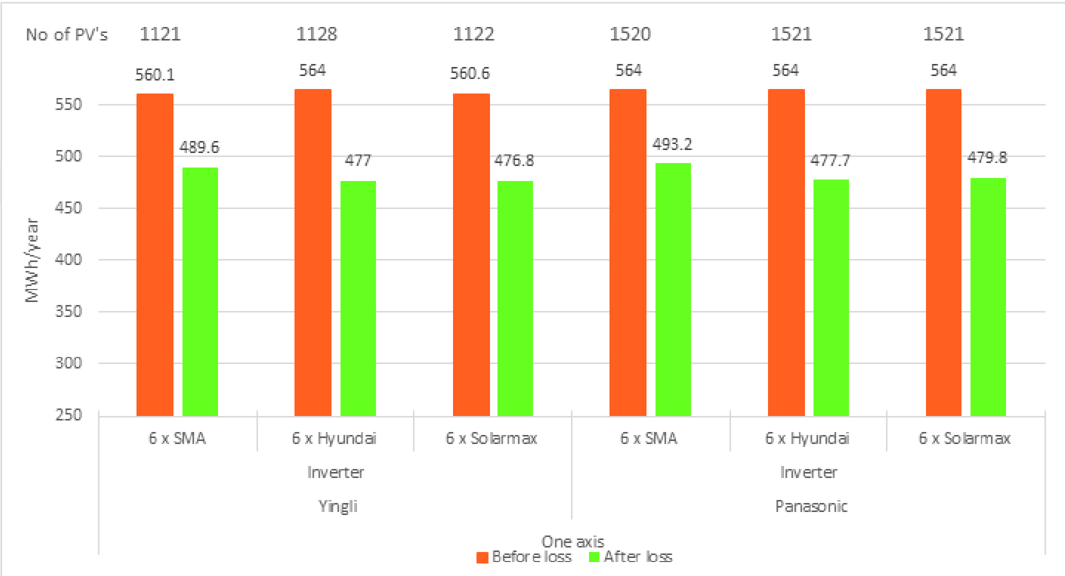


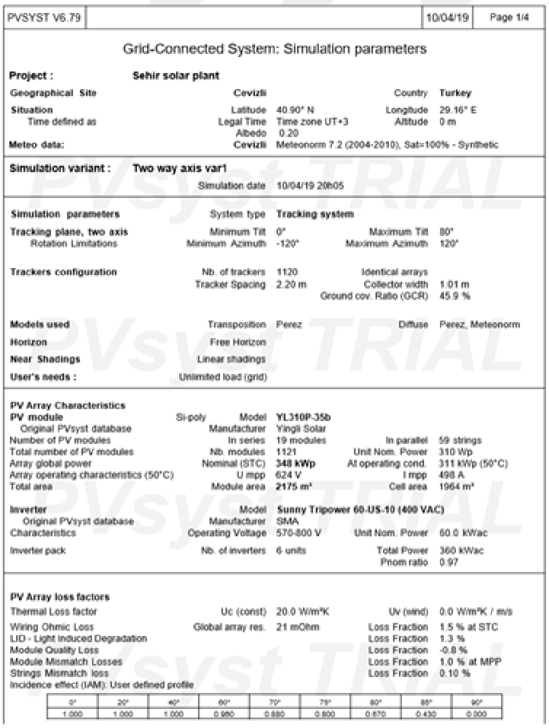
FIGURE 2.44: One-axis, Yingli - Panasonic systems comparison

As shown in Figure 2.44 there is difference in energy output before loss elimination between Yingli and Panasonic systems even though the global irradiation is the same for both systems Figures 2.34, 2.41. In fact, the reason behind that is the difference in irradiance reaching the PV cells surface (IAM). Note that Yingli PV with SMA had 70.5 MWh/year energy shortage after applying loss calculation, almost the same reduction happened when Panasonic was used with SMA inverter with 70.8 MWh/year. But in Fixed-axis, Figure 2.28 shows that Yingli and Panasonic with SMA inverter had different energy shortage because of different loss proportion systems were exposed to leading to have 5.7 MWh/year difference 30.8, 36.5 MWh/year for Yingli and Panasonic respectively.

2.3.3 Two-Axis Panel Design

This part of design, Two-axis panels will be used using same panel and inverter models. We expect more energy production because of the capability of light collection is the best in Two-axis track system due to existing of two moving parts that allow the panel angle itself to direct the sun anywhere which increase the capability of system to generate more electricity in roughly the same amount of space needed for any other system. The modules orientation had been assigned to be 120° with the capability to tilt them self within 0° to 80° degrees. A comparison will be held between all design systems (Fixed, One-axis, Two-axis) to inspect the amount of energy output differences. The next report will present data and calculations for a design performed using 310Wp Yingli solar PV with 60.0 kWac SMA inverter. All calculations that will be presented are based on real data.

2.3.3.1 Two Axis Simulation Report using Yingli PV



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Grid-Connected System: Simulation parameters

Project : Sehir solar plant

Geographical Site Cevizli Country Turkey

Situation Latitude 40.90° N Longitude 29.16° E

Time defined as Legal Time Time zone UT+3 Altitude 0 m

Albedo 0.20

Meteo data: Cevizli Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic

Simulation variant : Two way axis var1

Simulation date 10/04/19 20h05

Simulation parameters System type Tracking system

Tracking plane, two axis Minimum Tilt 0° Maximum Tilt 80°

Rotation Limitations Minimum Azimuth -120° Maximum Azimuth 120°

Trackers configuration Nb. of trackers 1120 Identical arrays

Tracker Spacing 2.20 m Collector width 1.01 m

Ground cov. Ratio (GCR) 45.9 %

Models used Transposition Perez Diffuse Perez, Meteonorm

Horizon Free Horizon

Near Shadings Linear shadings

User's needs : Unlimited load (grid)

PV Array Characteristics

PV module Si-poly Model YL310P-35b

Original PVsyst database Manufacturer Yingli Solar

Number of PV modules In series 19 modules In parallel 59 strings

Total number of PV modules Nb. modules 1121 Unit Nom. Power 310 Wp

Array global power Nominal (STC) 348 kWp At operating cond. 311 kWp (50°C)

Array operating characteristics (50°C) U mpp 624 V I mpp 498 A

Total area Module area 2175 m² Cell area 1964 m²

Inverter Model Sunny Tripower 60-US-10 (400 VAC)

Original PVsyst database Manufacturer SMA

Characteristics Operating Voltage 570-800 V Unit Nom. Power 60.0 kWac

Inverter pack Nb. of inverters 6 units Total Power 360 kWac

Pnom ratio 0.97

PV Array loss factors

Thermal Loss factor Uc (const) 20.0 W/m²K Uv (wind) 0.0 W/m²K / m/s

Wiring Ohmic Loss Global array res. 21 mOhm Loss Fraction 1.5 % at STC

LID - Light Induced Degradation Loss Fraction 1.3 %

Module Quality Loss Loss Fraction -0.8 %

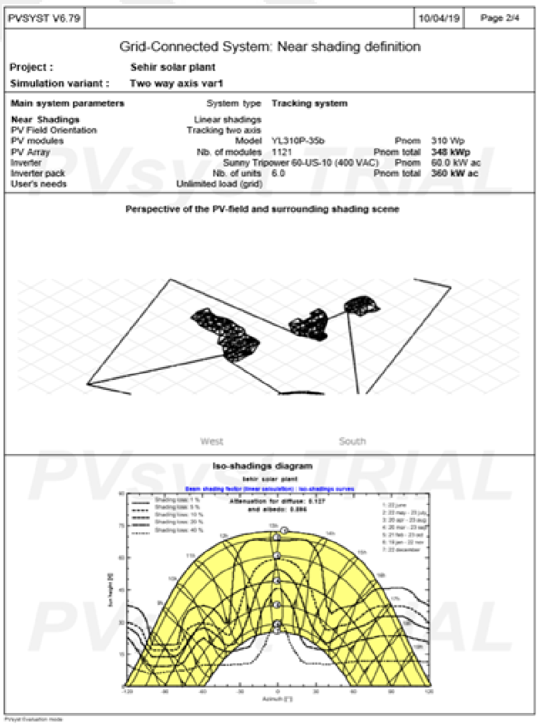
Module Mismatch Losses Loss Fraction 1.0 % at MPP

Strings Mismatch loss Loss Fraction 0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.980	0.880	0.800	0.670	0.430	0.000

FIGURE 2.45: Two-way, Yingli - SMA simulation 1



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Grid-Connected System: Near shading definition

Project : Sehir solar plant

Simulation variant : Two way axis var1

Main system parameters System type Tracking system

Near Shadings Linear shadings

PV Field Orientation Tracking two axis

PV modules Model YL310P-35b Pnom 310 Wp

PV Array Nb. of modules 1121 Pnom total 348 kWp

Inverter Sunny Tripower 60-US-10 (400 VAC) Pnom 60.0 kW ac

Inverter pack Nb. of units 6.0 Pnom total 360 kW ac

User's needs Unlimited load (grid)

Perspective of the PV-field and surrounding shading scene

FIGURE 2.46: Two-way, Yingli - SMA simulation 2

According to Figure 2.45 same defined factors with the same number of Yingli PV modules have used in the design. Note that the shading chart in Figure 2.46 has different distribution compared to One-axis system, this different output was because of increasing of the system's movement which enabled the panels to affect each other more often.

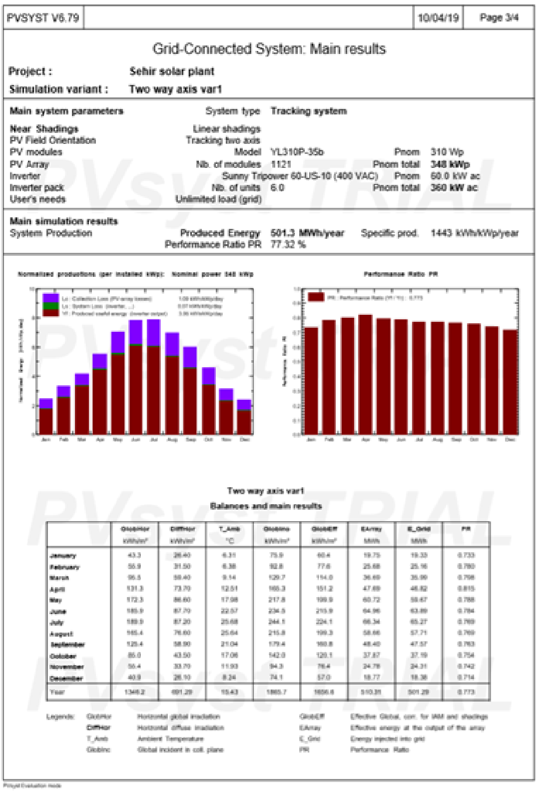


FIGURE 2.47: Two-way, Yingli - SMA simulation 3

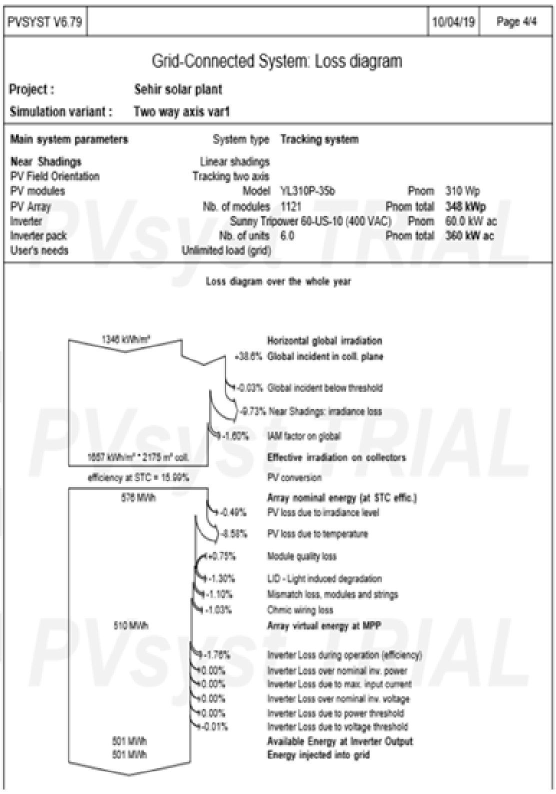


FIGURE 2.48: Two-way, Yingli - SMA simulation 4

This design alternative generates 501.3 MWh/year produced from 1121 PV modules with 77.32% PR. Shading loss shown in Figure 2.48 increased to 9.73% compared to 9.41%, 7.19% in One-axis and Fixed systems. The IAM factor had slightly better value than it was in the One-axis system. Irradiance loss value shows also slight improvement. Tracking the sun in all possible directions increased the radiation exposure time, causing temperature loss to increase to 8.58% compared to 8.07%, 4.24% in One-axis and Fixed systems respectively. In addition, Figure 2.47 show same inverter performance.

2.3.3.2 Two Axis Energy Output Comparison

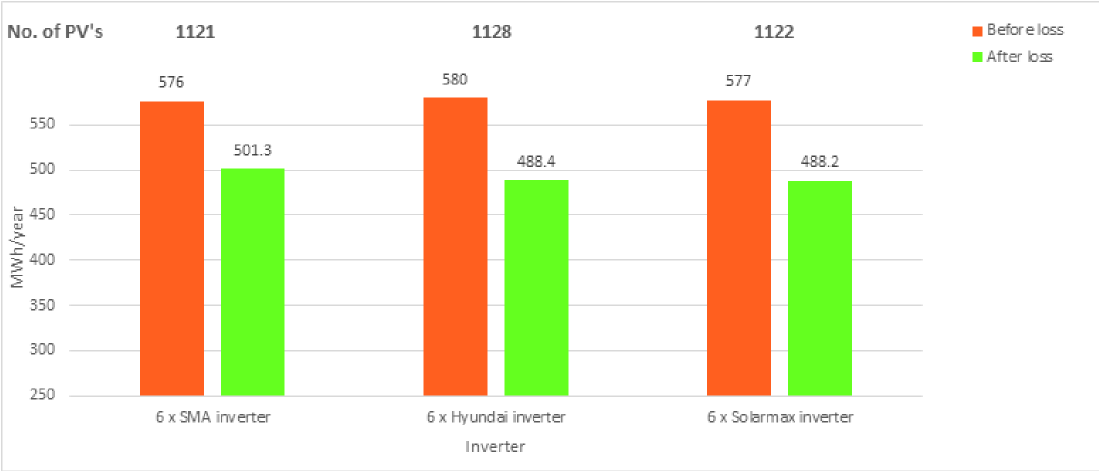


FIGURE 2.49: Two-way Yingli PV Energy output [115]

The chart shows system with SMA inverter had more energy output after consideration of loss calculations with more than 12.5 MWh/year difference compared to other alternatives even though it had less energy output before loss elimination.

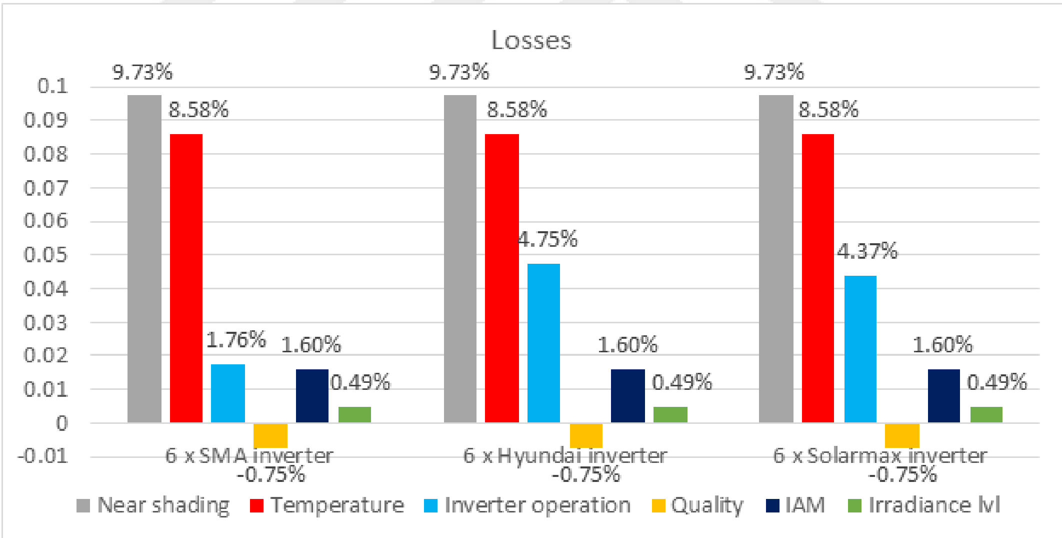
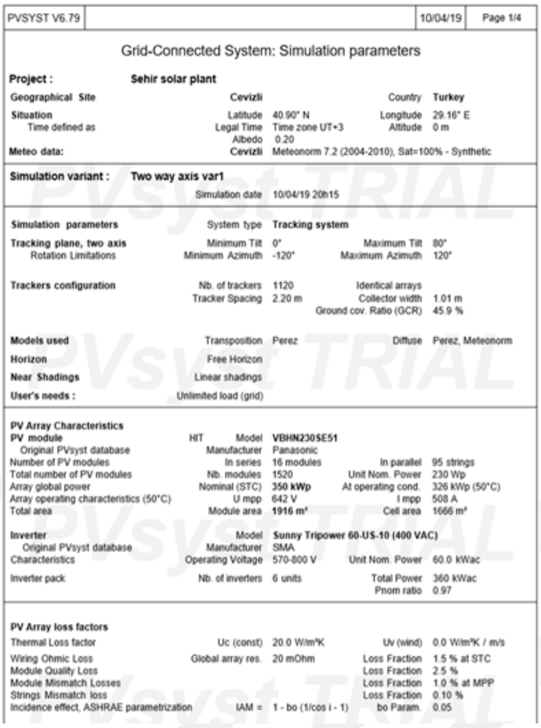


FIGURE 2.50: Two-way, Yingli - Inverters losses

All alternatives had the same shading, temperature, quality, IAM factor and irradiance level losses because of using same PV model. The differences were observed in inverter during operation. The least loss was recorded when SMA inverter is used with 1.76% compared to 4.75% and 4.37% for Hyundai and Solarmax respectively.

2.3.3.3 Two Axis Simulation Report using Panasonic PV



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant : **Two way axis var1**

Simulation date 10/04/19 20h15

Simulation parameters	System type	**Tracking system**		
Tracking plane, two axis	Minimum Tilt	0°	Maximum Tilt	80°
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.20 m	Collector width	1.01 m
			Ground cov. Ratio (GCR)	45.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

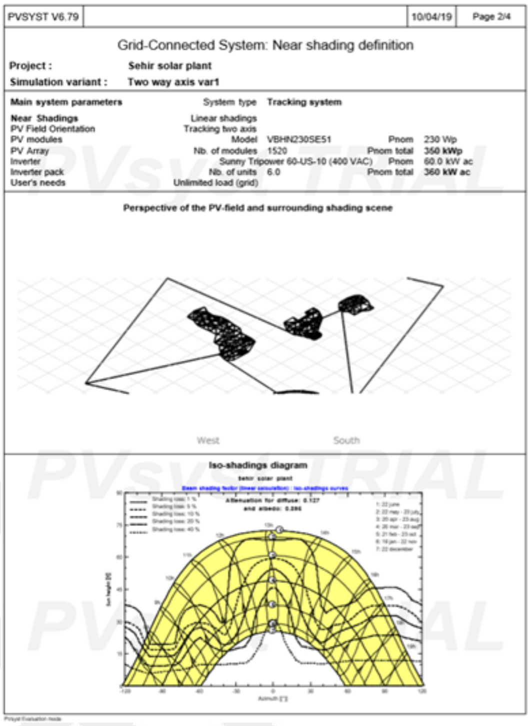
PV Array Characteristics

PV module	HIT Model	**VBHN230SE51**		
Original PVsyst database	Manufacturer	Panasonic		
Number of PV modules	In series	16 modules	In parallel	95 strings
Total number of PV modules	Nb. modules	1520	Unit Nom. Power	230 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)	U mpp	642 V	I mpp	508 A
Total area	Module area	**1916 m²**	Cell area	1666 m²
Inverter	Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	360 kWac
			Pnom ratio	0.97

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	20 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

FIGURE 2.51: Two-way, Panasonic - SMA simulation 1



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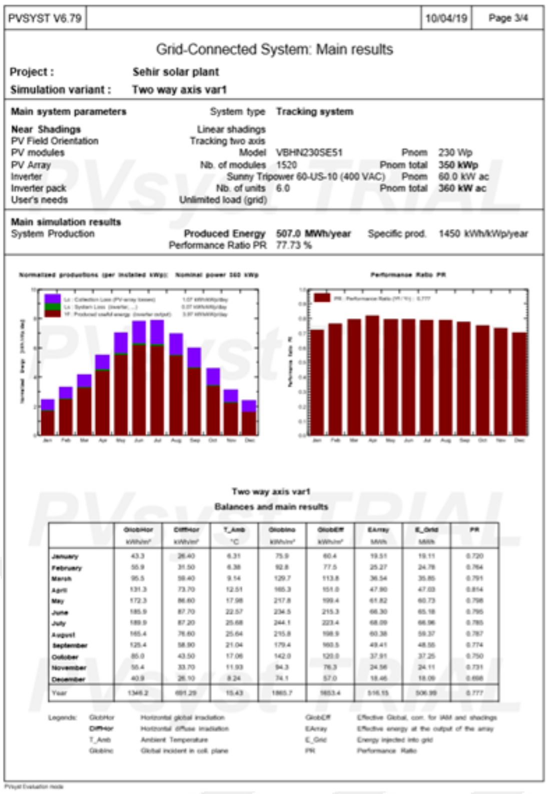
Grid-Connected System: Near shading definition

Project :	**Sehir solar plant**			
Simulation variant :	**Two way axis var1**			
Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter	Sunny Tripower 60-US-10 (400 VAC)		Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

FIGURE 2.52: Two-way, Panasonic - SMA simulation 2

Facing the same conditions, same number of modules require to achieve the 350kWp. Figure 2.52 shows the same shading chart as when Yingli PV model was used.



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Grid-Connected System: Main results

Project : Sehir solar plant
Simulation variant : Two way axis var1

Main system parameters — System type: Tracking system
Near Shadings: Linear shadings
PV Field Orientation: Tracking two axis
PV modules: Model VBHN230SE51, Pnom 230 Wp
PV Array: Nb. of modules 1520, Pnom total 350 kWp
Inverter: Sunny Tripower 60-US-10 (400 VAC), Pnom 60.0 kW ac
Inverter pack: Nb. of units 6.0, Pnom total 360 kW ac
User's needs: Unlimited load (grid)

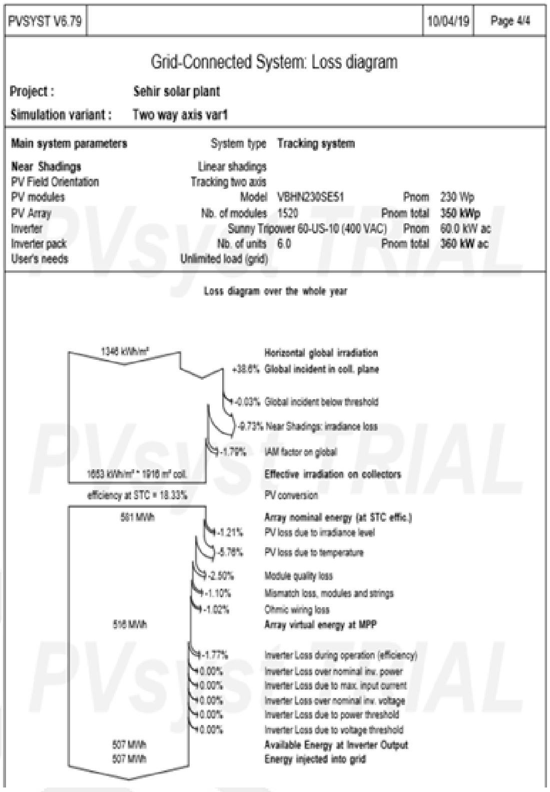
Main simulation results
System Production: Produced Energy 507.0 MWh/year, Specific prod. 1450 kWh/kWp/year
Performance Ratio PR 77.73 %

Two way axis var1
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	43.3	26.40	6.31	75.9	60.4	19.51	19.11	0.720
February	55.9	31.50	6.38	92.8	77.5	25.27	24.78	0.764
March	95.5	59.40	9.14	129.7	113.8	36.54	35.85	0.791
April	131.3	73.70	12.51	165.3	151.0	47.90	47.03	0.814
May	172.3	86.60	17.98	217.8	199.4	61.82	60.73	0.798
June	185.9	87.70	22.57	234.5	215.3	66.30	65.18	0.795
July	189.9	87.20	25.68	244.1	223.4	68.09	66.96	0.785
August	165.4	76.60	25.64	215.8	198.9	60.38	59.37	0.787
September	125.4	58.90	21.04	179.4	160.5	49.41	48.55	0.774
October	85.0	43.50	17.06	142.0	120.0	37.91	37.25	0.750
November	55.4	33.70	11.93	94.3	76.3	24.56	24.11	0.731
December	40.9	26.10	8.24	74.1	57.0	18.46	18.09	0.698
Year	1346.2	691.29	15.43	1865.7	1653.4	516.55	506.99	0.777

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

FIGURE 2.53: Two-way, Panasonic - SMA simulation 3



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Grid-Connected System: Loss diagram

Project : Sehir solar plant
Simulation variant : Two way axis var1

Main system parameters — System type: Tracking system
Near Shadings: Linear shadings
PV Field Orientation: Tracking two axis
PV modules: Model VBHN230SE51, Pnom 230 Wp
PV Array: Nb. of modules 1520, Pnom total 350 kWp
Inverter: Sunny Tripower 60-US-10 (400 VAC), Pnom 60.0 kW ac
Inverter pack: Nb. of units 6.0, Pnom total 360 kW ac
User's needs: Unlimited load (grid)

FIGURE 2.54: Two-way, Panasonic - SMA simulation 4

This system generates 507 MWh/year compared to 501.3 MWh/ year when Yingli PV was used. Figure 2.54 shows better IAM factor and irradiance level values compared with the same PV model in One-axis and Fixed systems but this system has higher shading and temperature loss values.

2.3.3.4 Two Axis Energy Output Comparison

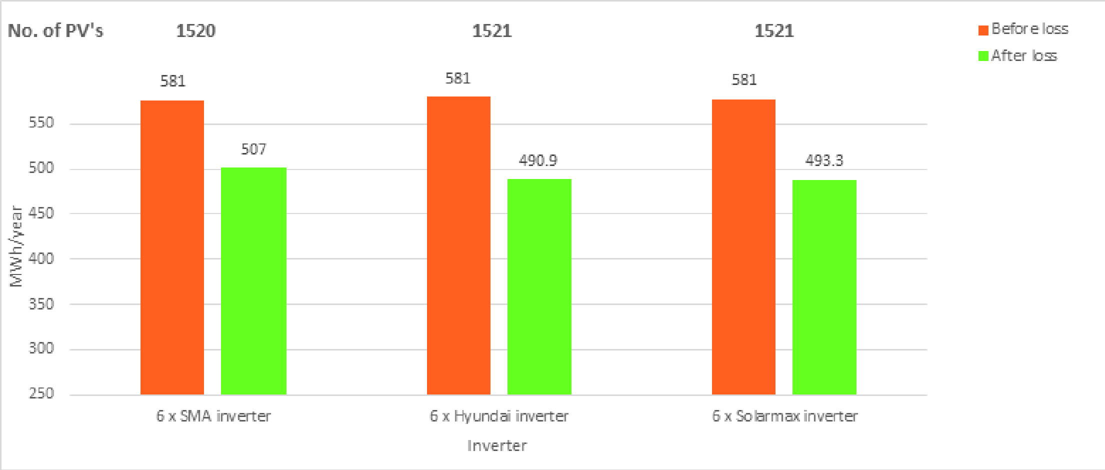


Figure 2.55: Two-way, Panasonic PV Energy output [127]

This chart shows that the energy output results were the same before loss elimination, this will give better view on inverter performance in Two-axis system. The figure shows that system with SMA inverter had more energy output after consideration of loss calculations with more than 16.1, 13.7 MWh/year when Hyundai and Solarmax inverters is used. The results show increasing in the energy production gap between systems, as One-axis Yingli model with SMA inverter system had 15.5, 13.4 MWh/year difference with the other inverters that had been used.

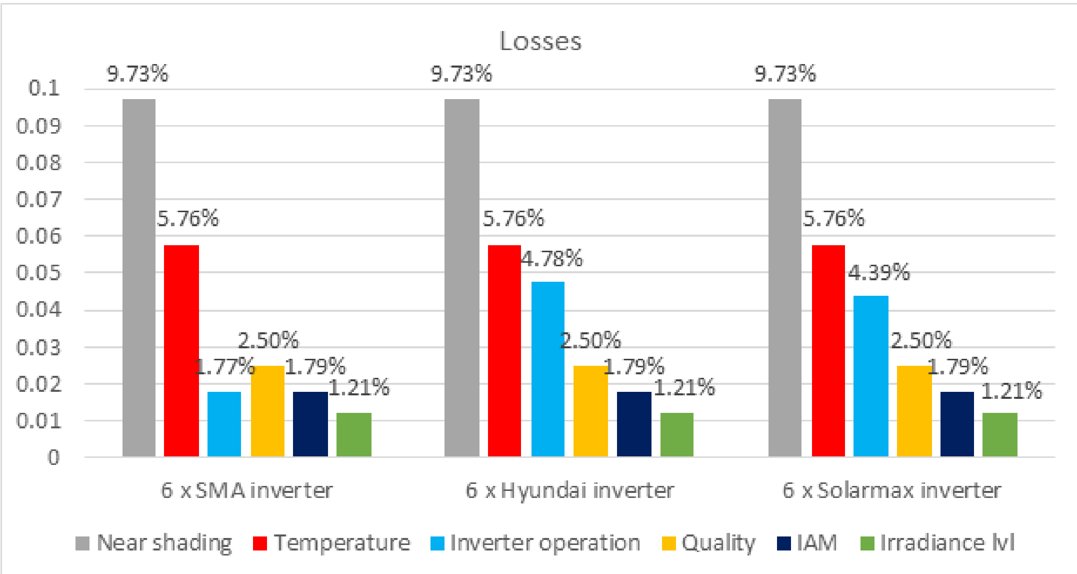


Figure 2.56: Two-way, Panasonic - Inverters losses

Note that all alternatives had the same shading, temperature, quality, IAM factor and irradiance level losses. The differences were observed in inverter performance. The least loss was recorded when SMA inverter is used with 1.77% compared to 4.78% and 4.39% for Hyundai and Solarmax respectively which increased the difference in energy output. Note that Panasonic PV models have more resistance to sun heat compared to systems with Yingli PV model leading to have 2.82% less temperature loss.

2.3.3.5 Two Axis Systems Comparison

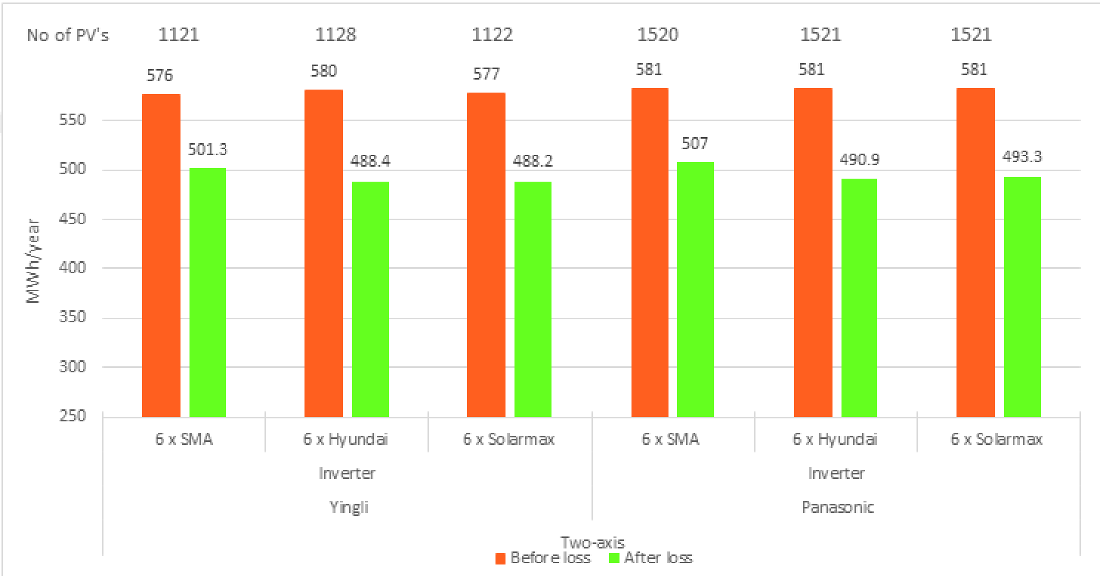


FIGURE 2.57: Two-axis, Yingli - Panasonic systems comparison

The figure shows difference in energy output before loss elimination between Yingli and Panasonic systems, even though the global irradiation is the same for both systems Figures 2.48, 2.54. The reason behind that is the amount of radiation reaching the PV cells surface (IAM). Note that Yingli PV with SMA had 74.7 MWh/year energy shortage after applying loss calculation, almost the same reduction happened when Panasonic was used with SMA inverter with 74 MWh/year unlike the Fixed system which have 5.7 MWh/year difference between the output of using these different panel models.

2.3.4 Design Comparison for All Systems

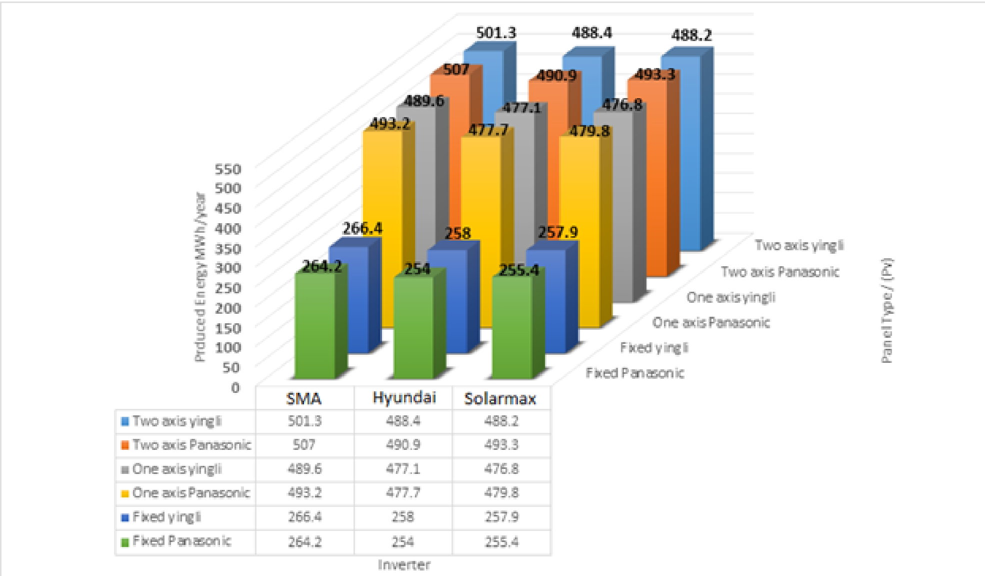


FIGURE 2.58: Design comparison for all systems

Many design had been performed using different PV and inverter models each had different energy output according to PV, inverter and system type although having the same defined factors such as: location, height, spacing, tilt angle and number of inverters. The designs had been performed to test the differences in energy output between Fixed, One-axis and Two-axis systems using same PV and inverter models. In addition to examine and evaluate the effect of using different PV and inverter model for each system type. The results obtained were close to each other if we take each system separately. The factors that influenced the existence of these different results are the type of the panels and inverters that have been selected of each have different characteristics and capability to help achieving the desired energy. From the results obtained we can see that each PV model have different behavior than the other model. According to the results, Panasonic model have higher heat resistance than Yingli model when it used in any system. IAM factor also had been reported to be better in Panasonic model which refers to the specifications of the glass which in turn can affect the amount of sunlight that reaches the solar cells through the amount of solar refraction when the sunlight strikes the glass. In the other side Yingli models had better results in the quality and irradiance level parts which reflect the intrinsic behavior of the PV model. But when comparing temperature, IAM factor and irradiance level between systems we find that they have different values, in the sense that changing the type of system leads to change the results in these parameters either be larger or smaller values. When track system had been designed, we have noticed increasing in temperature loss because modules will expose more to the sun. In the other side the IAM factor had better results because the motion of the panels reduces the refraction of the solar radiation when it reach the glass plate.

The different UNP in inverters showed how much it can affect the energy output when comparing the results in each system separately. The results show that the slightly oversized inverter performed better than the other inverters that had lower UNP. Oversizing an inverter will drive it to its full capacity more often which allow the PV plant nominal power to be achieved faster in the morning, in addition the PV plant remains connected to the grid longer in the evening which maximizes the power output in low light conditions [41]. Figures 2.21, 2.36 and 2.50 show the inverters performance when connected with Yingli model, the difference is clear between the oversized inverter and the other inverters. However, the other two inverters with the same UNP have nearly the same result, the difference was because of the efficiency of each inverter. Also it had been observed that the inverter performed better when used in track systems.

Performing all of these different designs to achieve 350 kWp capacity showed that there is a clear difference in energy output between Fixed and Track systems, but not between One-axis and Two-axis according to Figure 2.58. According to the location of the grid, One vertical axis system can genarete energy as much as Two-axis system, which indicates that One-axis design system has the most promising results regarding energy output compared to the others. However, we still need to perform cost analysis to get the most suitable design that also achieve the economic feasibility.

Chapter 3

Cost Analysis

3.1 Assessing System Cost

Performing many alternatives gives many different energy outputs, each output refers to a system capability to generate power. If a certain system can generate certain amount of energy that achieve the desired output, then no need to invest in another system that would give the same amount but costs more.

Figure 2.58 shows that there is no much difference between One-axis and Two-axis systems giving a preliminary clarification on which systems could be more appropriate. In order to have full knowledge about the cost of each system, this part of the thesis will show the cost of each alternative based on price of each element in the design. Some of element prices varies from type to type, which can affect the decision, adding into account the expenses of operation. The price of each element in the design is based on power capacity and presented in Figure 3.1 [42].

PV	Cost/Wp
Yingli Solar pv - YL310P-35b	0.34 USD/Wp
Panasonic pv - VBHN230SE51	0.36 USD/Wp
Inverter	**Cost**
SMA - Sunny Tripower 60-US-10 (400 VAC)	53 USD/kWac
Hyundai - HPC-050HT-E	59 USD/kWac
Solarmax 50 TS	5000 USD/Unit
Trackers	**Cost/MWp**
Fixed	$ 80,000
One-axis	$ 200,000
Two-axis	$ 300,000
Operation expenses	**Cost/MWp**
Electrical installation	$ 25,000.00
Mechanical installaion	$ 25,000.00
Medium voltage components/MW	$ 50,000.00
Transmission line	$ 25,000.00
Cabling	$ 30,000.00
SCADA/MW	$ 10,000.00
Commissioning	$ 10,000.00
Annual Operation & Maintenance	$ 20,000.00
Delivery	**Cost/load**
Transportation/truck	$ 1,000.00

FIGURE 3.1: Prices

3.1.1 System Cost Calculation

System cost calculation displayed in a form of tables that shows all design components along with prices. Tabel 3.1 present the cost calculations of Fixed system.

Table 3.1: Fixed system cost calculation

	Fixed system					
Assumptions	Yingli PV			Panasonic PV		
Panel calculation						
Units	1121	1128	1122	1520	1521	5121
Price	0.34 USD/Wp			0.36 USD/Wp		
Track system	28,000 USD			28,000 USD		
Total	146,153	146,891	146,258	153,856	153,938	153,938
Inverter calculation	SMA	Hyundai	Solarmax	SMA	Hyundai	Solarmax
Units	6	6	6	6	6	6
Price	19,080	17,700	30,000	19,080	17,700	30,000
Total model cost	**165,233**	**164,591**	**176,258**	**172,936**	**171,638**	**183,938**
Operation expenses						
Transportation/truck	4,000	4,000	4,000	4,000	4,000	4,000
Electrical installation	8,750	8,750	8,750	8,750	8,750	8,750
Mechanical installation	8,750	8,750	8,750	8,750	8,750	8,750
Medium voltage components	17,500	17,500	17,500	17,500	17,500	17,500
Transmission line	8,750	8,750	8,750	8,750	8,750	8,750
Cabling	10,500	10,500	10,500	10,500	10,500	10,500
SCADA	3,500	3,500	3,500	3,500	3,500	3,500
Commissioning	3,500	3,500	3,500	3,500	3,500	3,500
Annual operation & maintenance	7,000	7,000	7,000	7,000	7,000	7,000
Total	**237,483**	**236,841**	**248,508**	**245,186**	**243,888**	**256,188**

The table shows that 1121 Yingli PV modules with the track system cost $ 146,153. The model costs $ 165,233 after adding the price of 6 SMA inverters and so on for the rest of alternatives. Because the operating expenses are based on power capacity of the plant. All prices will be fixed since all alternatives are designed to achieve 350 kWp capacity, which means that panel, inverter and track system prices will play the critical role of achieving the least price. Having 400 more PV modules in systems using Panasonic PV model increased the total cost than systems using Yingli PV model.

TABLE 3.2: One-axis system cost calculation

	One-axis system					
Assumptions	Yingli PV			Panasonic PV		
Panel calculation						
Units	1121	1128	1122	1520	1521	5121
Price	0.34 USD/Wp			0.36 USD/Wp		
Track system	70,000 USD			70,000 USD		
Total	188,153	188,891	188,258	195,856	195,938	195,938
Inverter calculation	SMA	Hyundai	Solarmax	SMA	Hyundai	Solarmax
Units	6	6	6	6	6	6
Price	19,080	17,700	30,000	19,080	17,700	30,000
Total model cost	**207,233**	**206,591**	**218,258**	**214,936**	**213,638**	**225,938**
Operation expenses						
Transportation/truck	4,000	4,000	4,000	4,000	4,000	4,000
Electrical installation	8,750	8,750	8,750	8,750	8,750	8,750
Mechanical installation	8,750	8,750	8,750	8,750	8,750	8,750
Medium voltage components	17,500	17,500	17,500	17,500	17,500	17,500
Transmission line	8,750	8,750	8,750	8,750	8,750	8,750
Cabling	10,500	10,500	10,500	10,500	10,500	10,500
SCADA	3,500	3,500	3,500	3,500	3,500	3,500
Commissioning	3,500	3,500	3,500	3,500	3,500	3,500
Annual operation & maintenance	7,000	7,000	7,000	7,000	7,000	7,000
Total	**279,483**	**278,841**	**290,508**	**287,186**	**285,888**	**298,188**

TABLE 3.3: Two-axis system cost calculation

	One-axis system					
Assumptions	Yingli PV			Panasonic PV		
Panel calculation						
Units	1121	1128	1122	1520	1521	5121
Price	0.34 USD/Wp			0.36 USD/Wp		
Track system	105,000 USD			105,000 USD		
Total	223,153	223,891	223,258	230,856	230,938	230,938
Inverter calculation	SMA	Hyundai	Solarmax	SMA	Hyundai	Solarmax
Units	6	6	6	6	6	6
Price	19,080	17,700	30,000	19,080	17,700	30,000
Total model cost	**242,233**	**241,591**	**253,258**	**249,936**	**248,638**	**260,938**
Operation expenses						
Transportation/truck	4,000	4,000	4,000	4,000	4,000	4,000
Electrical installation	8,750	8,750	8,750	8,750	8,750	8,750
Mechanical installation	8,750	8,750	8,750	8,750	8,750	8,750
Medium voltage components	17,500	17,500	17,500	17,500	17,500	17,500
Transmission line	8,750	8,750	8,750	8,750	8,750	8,750
Cabling	10,500	10,500	10,500	10,500	10,500	10,500
SCADA	3,500	3,500	3,500	3,500	3,500	3,500
Commissioning	3,500	3,500	3,500	3,500	3,500	3,500
Annual operation & maintenance	7,000	7,000	7,000	7,000	7,000	7,000
Total	**314,483**	**315,841**	**325,508**	**322,186**	**320,888**	**333,188**

According to the cost analysis tables, Two-axis system had the highest price with $300,000/MWp for the track system ending up with $314,483 for Yingli PV with SMA inverter compared to $279,483 - $237,483 for One-axis and Fixed systems. Figure 3.2 summarizes the cost of all systems along with their energy production.

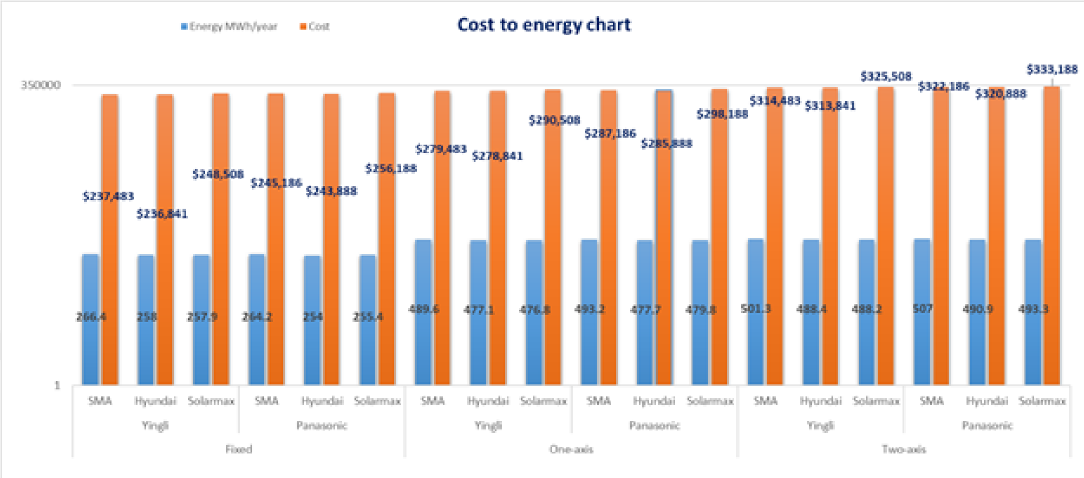


FIGURE 3.2: Cost to energy

It was established that the best alternative design system that have the best result (The most reasonable price for energy produced) for 350 kWp plant to be selected was One-axis Yingli PV with SMA inverter. This system generates 489.6MWh/year and cost $279,483. Although, there are other alternatives that have more energy production but did not have reasonable price. Taking Yingli PV with SMA inverter in Two-axis system as an example, it produces 501.3 MWh/year and cost $314.483. The reason behind not nominating systems with Panasonic PV models within qualified nominators is their need for more space for the defined spacing to achieve 350 kWp capacity as it is shown in Figure 3.3.

3.2 Grid Installation

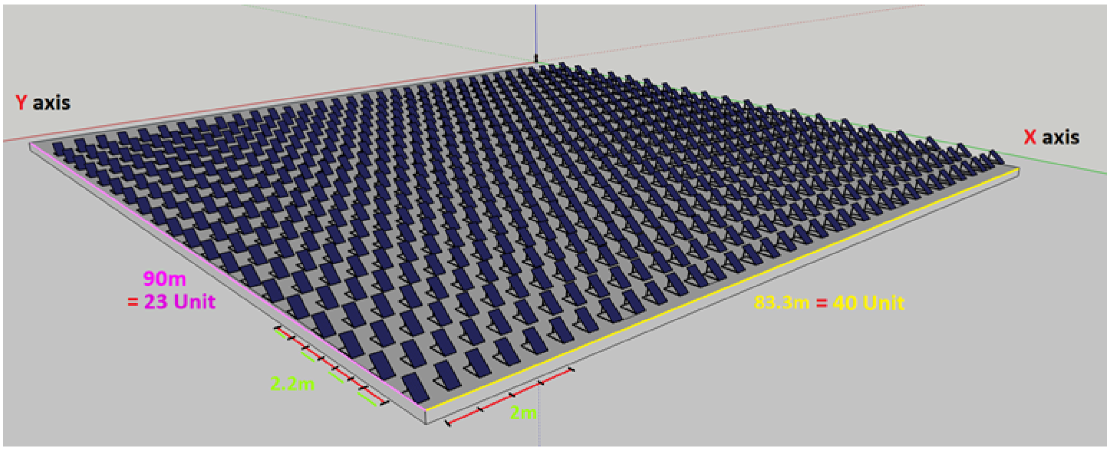


Figure 3.3: Grid

The area proposed in the design ($7500m^2$) can handle with the defined spacing 920 modules to achieve 350 kWp capacity. Setting 1520 Panasonic PV modules for the defined spacing require $12700m^2$ = 50 units on X axis and 31 units on Y axis. Regarding the best alternative we got from performing all designs (One-axis Yingli PV with SMA inverter), it requires 1121 PV modules to achieve the desired capacity. The required area to set the panels is $9200m^2$, a steel structure design that will cover the area of the columns need to be designed as having 5m cantilever on the four sides. In this case the area will be $9333m^2$ which we can set the grid as having 47 units in X-axis and 24 units in Y-axis. For Panasonic model case, the area need to get expand even more, even if there is an available area to expand the steel structure, the design will not be feasible because Panasonic design models already have more cost than Yingli models, in addition to more cost will be considered regarding designing and installing larger steel structure which require constructing new steel columns to have non deflected steel roof.

3.2.1 Steel Structure Design

Designing the proposed suggestion to handle 1121 PV modules require to determine the weight of each element in the system as it is shown in Figure 3.4.

	Yingli YL310P-35b	One axis frame SM3SPMOG	SMA Sunny Tripower 60-US-10 (400 VAC)
Weight kg/unit	27	9	75
Units	1121	1121	6
	30267	10089	450
Total weight kg	**40806**		

FIGURE 3.4: Weight of system

The weight of the system elements is approximately 41 tons devided by the area ($9333m^2$) equals to having 4.37 kg/m^2. Figure 3.5 shows the steel structure design [43].

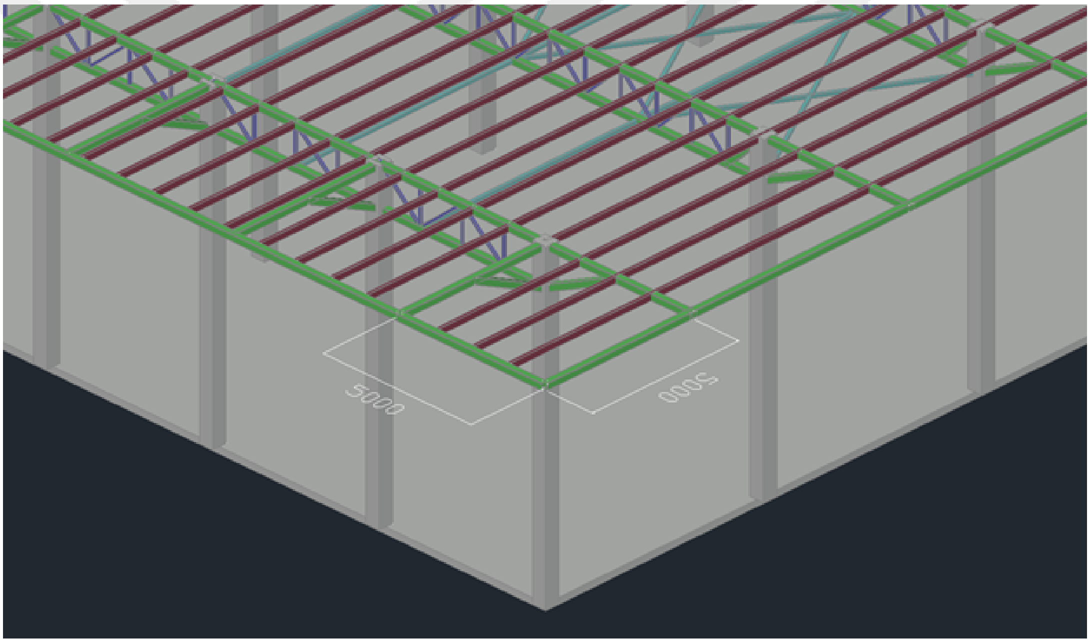
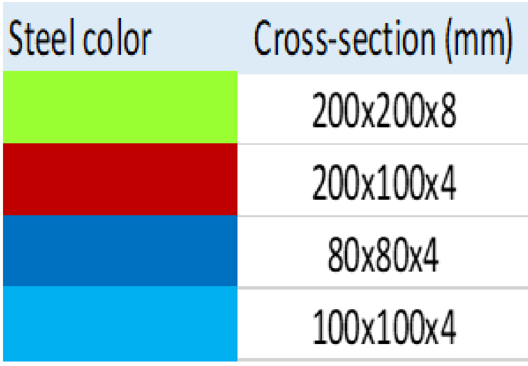


FIGURE 3.5: Steel structure

Figure 3.5 shows that the steel structure design contains rods, trusses and bracing system that would provide huge increases in bending resistance. The figure shows that different steel sizes (cross-sections) had been used, each color refers to specific cross section shown in Figure 3.6. Figures 3.7 - 3.9 displays the steel for each cross-section used.



Steel color	Cross-section (mm)
	200x200x8
	200x100x4
	80x80x4
	100x100x4

FIGURE 3.6: Steel cross-section

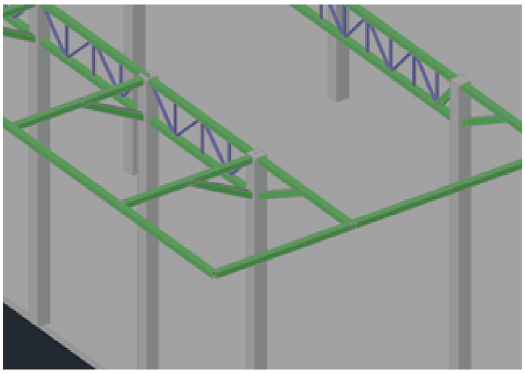


FIGURE 3.7: Steel design 1

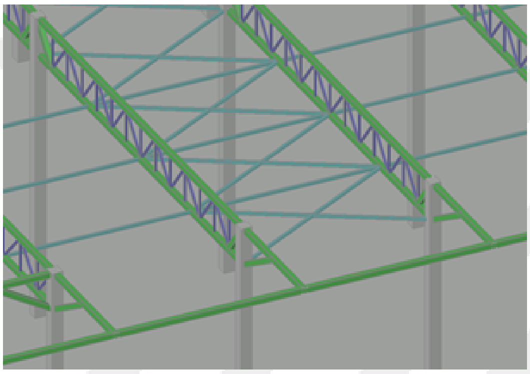


FIGURE 3.8: Steel design 2

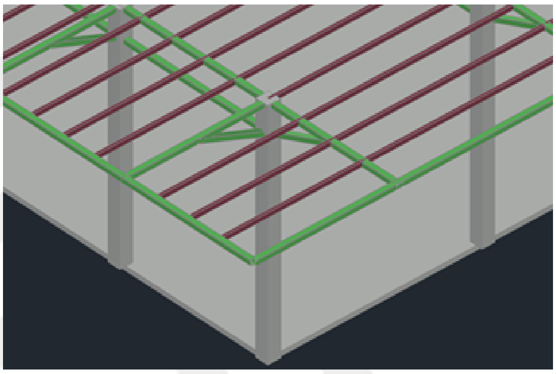


FIGURE 3.9: Steel design 3

Note that the price of steel structure will not affect the solar system design selection since the price of constructing a steel design covering $9333m^2$ will be the same. Based on steel structure design, the weight of the steel system according to the quantity of rods used to cover $9333m^2$ area equals to 42kg/m^2. The price of constructing one kilogram of steel is \$1.58 [44] including sandblasting, shop primer, assembling, transportation, last painting and taxes. The weight of steel that had been used equal to $9333m^2$ x 42 kg/m^2 = 391,986 kg, as a result the final cost of steel needed to implement the design is \$619,338 need to be added to the price of the best alternative we have obtained (Yingli PV with SMA inverter - \$279,483) which equals to \$898,821.

3.3 Return of Investment

The price of 1 kWh in Turkey in 2019 is 0.09 U.S. Dollars [45]. The integrated building consumes 20,000 kWh/month, which means that this building spends $1,800 per month on electrical bills. Different scenarios will be applied to Fixed and One-axis systems to discuss their financial status.

3.3.1 First Scenario

The first scenario is Fixed-axis (Yingli PV with SMA inverter) that generates more than 20,000 kWh/month as an average value and costs $856,821 including the steel structure price which is $619,338. But taking into account the exact electrical generation of the best designed alternative in Fixed-axis per month is shown in Figure 3.10.

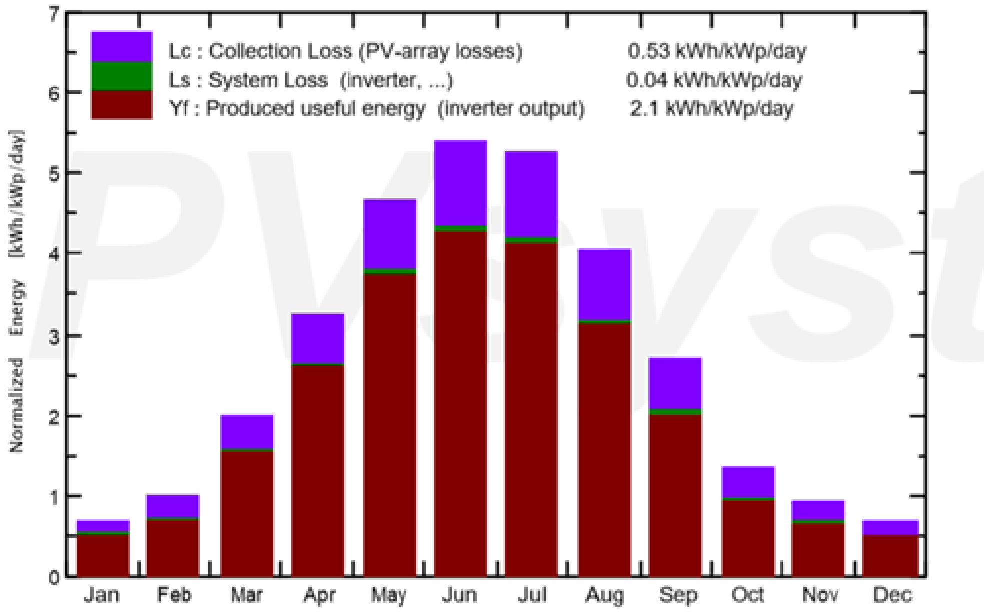


FIGURE 3.10: Fixed-axis, Yingli-SMA energy production/month

This figure presents a normalized energy production (per installed kWp) which means as it is stated in the figure, that the average useful energy produced is 2.1 kWh/kWp/day multiplied by 30 days to get the monthly value then multiplying the result with 350 kWp which is the desired capacity of the plant. Doing this simple calculation gives the exact energy production for a specific month. According to the monthly production we can see that the solar system generates more electricity in summer season compared to the other seasons, which means that this system can't fully supply the integrated building with the demanded energy throughout the year according to the following calculations shown in Table 3.4.

TABLE 3.4: Fixed-axis, Yingli-SMA useful energy production/month

Month	Useful Energy (kWh/kWp/day)	Useful Energy (kWh/kWp/month)	Design Capacity	Solar Energy Production
January	0.5	15	350	5250
February	0.7	21	350	7350
March	1.6	48	350	16800
April	2.6	78	350	**27300**
May	3.8	114	350	**39900**
June	4.3	129	350	**45150**
July	4.2	126	350	**44100**
August	3.2	96	350	**33600**
September	2.1	63	350	**22050**
October	1	30	350	10500
November	0.7	21	350	7350
December	0.5	15	350	5250
Average	2.1			

According to the results, the first and the last three months of the year, the solar grid can't supply the integrated building with the demanded energy which means it needs to get the rest of energy from the utility grid. The saving and disbursement amounts are summarized in Table 3.5.

TABLE 3.5: Fixed-axis, Yingli-SMA Savings and Disbursements

Month	Building electrical consumption (kWh)	Solar energy electrical generation (kWh)	Utility grid electricity price ($)	Saving ($)	Disbursement ($)
January	20,000	5250	0.9	472.5	1327.5
February	20,000	7350	0.9	661.5	1138.5
March	20,000	16800	0.9	1512	288
April	20,000	27300	0.9	1800	0
May	20,000	39900	0.9	1800	0
June	20,000	45150	0.9	1800	0
July	20,000	44100	0.9	1800	0
August	20,000	33600	0.9	1800	0
September	20,000	22050	0.9	1800	0
October	20,000	10500	0.9	945	855
November	20,000	7350	0.9	661.5	1138.5
December	20,000	5250	0.9	472.5	1327.5
			TOTAL SAVING	**15,525**	**6075**

Table 3.5 shows that implementing Fixed-axis solar system allows to save $15,525 for the first year instead of paying $21,600 for the electricity. With an installed solar system, only $6,075 need to be paid to supply the building in the months that have shortage in production. The cost of 1 kWh for this system is $\frac{\text{Investment cost}}{\text{Total solar energy electrical generation}} = \frac{\$856{,}821}{264600} = \$3.238$

3.3.2 Second Scenario

The second scenario is for using the best alternative we have determined in the One-axis system which is Using Yingli PV and SMA inverter. The exact energy production for this system is shown in Table 3.6.

TABLE 3.6: One-axis, Yingli-SMA useful energy production/month

Month	Useful Energy (kWh/kWp/day)	Useful Energy (kWh/kWp/month)	Design Capacity	Solar Energy Production
January	1.9	57	350	19950
February	2.7	81	350	**28350**
March	3.5	105	350	**36750**
April	4.4	132	350	**46200**
May	5.3	159	350	**55650**
June	5.9	177	350	**61950**
July	5.8	174	350	**60900**
August	5	150	350	**52500**
September	4.3	129	350	**45150**
October	3.4	102	350	**35700**
November	2.4	72	350	**25200**
December	1.8	54	350	18900
Average	3.86			

According to the exact energy production, One-axis system is capable to supply the integrated building almost throughout the year with slight shortage in winter season at January and December. The saving and disbursement amounts for the first year are summarized in Table 3.7.

TABLE 3.7: First year, Fixed-axis, Yingli-SMA Savings and Disbursements

Month	Building electrical consum-ption (kWh)	Solar energy electrical generation (kWh)	Utility grid electricity price ($)	Amount of electricity shortage (kWh)	Saving ($)	Disbur -sement ($)
January	20,000	57	350	19950	1795.5	4.5
February	20,000	81	350	**28350**	1800	0
March	20,000	105	350	**36750**	1800	0
April	20,000	132	350	**46200**	1800	0
May	20,000	159	350	**55650**	1800	0
June	20,000	177	350	**61950**	1800	0
July	20,000	174	350	**60900**	1800	0
August	20,000	150	350	**52500**	1800	0
September	20,000	129	350	**45150**	1800	0
October	20,000	102	350	**35700**	1800	0
November	20,000	72	350	**25200**	1800	0
December	20,000	54	350	18900	1701	99
				TOTAL SAVING	21,496.50	103.5

Table 3.7 shows that implementing One-axis solar system allows to save $21,496.5 for the first year instead of paying $21,600 for the electricity. With an installed solar system, only $103.5 need to be paid to supply the building with the demanded energy in the months that have shortage in production. The cost of 1 kWh for this system is $\frac{\text{Investment cost}}{\text{Total solar energy electrical generation}} = \frac{\$898{,}821}{487200} = \$1.84$

3.3.2.1 Investment Calculations Findings

The One-axis solar system costs $279,483. Since the steel structure costs $619,338, the total investment = $898,821 So as to test the eligibility of the investment compared to the electricity from the utility grid, we need to calculate how much it would cost paying the utility grid for 25 years. In order to calculate that, we need to put the increasing of the electrical price in Turkey in the calculations. The increasing in electricity price assumed to be 3% for every year. The price of 1 kW in the starting year is $0.09. The integrated building consumes 20,000 kWh/month, which means that it spends $21,600 per year on electrical bills for the first year. The cost for the following 25 years is shown in Table 3.8.

Table 3.8: 25-year grid electricity payment

		Starting Price in 2019 (USD/kWh)	$0.09	Percentage of Yearly Changing in Electricity Prices	3.00%
Period	Year	Integrated Building Consumption (kWh/Year)		Electricity Price (USD/kWh)	Grid Electricty Price
0	2019	240,000		$ 0.0900	$ 21,600
1	2020	240,000		$ 0.0927	$ 22,248
2	2021	240,000		$ 0.0955	$ 22,915
3	2022	240,000		$ 0.0983	$ 23,603
4	2023	240,000		$ 0.1013	$ 24,311
5	2024	240,000		$ 0.1043	$ 25,040
6	2025	240,000		$ 0.1075	$ 25,792
7	2026	240,000		$ 0.1107	$ 26,565
8	2027	240,000		$ 0.1140	$ 27,362
9	2028	240,000		$ 0.1174	$ 28,183
10	2029	240,000		$ 0.1210	$ 29,029
11	2030	240,000		$ 0.1246	$ 29,899
12	2031	240,000		$ 0.1283	$ 30,796
13	3032	240,000		$ 0.1322	$ 31,720
14	3033	240,000		$ 0.1361	$ 32,672
15	3034	240,000		$ 0.1402	$ 33,652
16	3035	240,000		$ 0.1444	$ 34,662
17	3036	240,000		$ 0.1488	$ 35,702
18	3037	240,000		$ 0.1532	$ 36,773
19	3038	240,000		$ 0.1578	$ 37,876
20	3039	240,000		$ 0.1626	$ 39,012
21	3040	240,000		$ 0.1674	$ 40,182
22	3041	240,000		$ 0.1724	$ 41,388
23	3042	240,000		$ 0.1776	$ 42,629
24	3043	240,000		$ 0.1830	$ 43,908
				Total	**$ 787,520**

The figure shows that if the system had not been installed, the total amount that the integrated building must pay after 25 years is equal to \$787,520 which is less than the total investment, hence its inefficient.

3.3.3 Third Scenario

This scenario will be applied neglecting the price of steel structure to see the results of implementing the solar system alone. The Fixed-axis system cost \$237,483 which mean that the cost of 1 kWh for this system is $\frac{\text{Solar system cost}}{\text{Total solar energy electrical generation}} = \frac{\$237,483}{264600} =$ \$0.89

3.3.4 Fourth Scenario

Neglecting the price of the steel structure for the One-axis system makes the cost of 1 kWh for the system equals to $\frac{\text{Solar system cost}}{\text{Total solar energy electrical generation}} = \frac{\$279{,}483}{487200} = \$0.57$

It had been observed that the price of the steel structure is inefficient which cost 221% more than the price of the One-axis solar system.

Investing in One-axis system costs $279,483 and can supply the integrated building throughout the year with the demanded energy when paying the total disbursement amounts for the winter season for January and December months which is $103.5 per year according to the energy output for the One-axis system per month in Table 3.7.

The return of investment calculations will be held for 25 years since the average lifespan for a solar system is 25 years [46]. To have an accurate calculation we need to involve solar panels efficiency over time because solar panels loses its efficiency over time. According to Yingli manufacturer, for the first year, the company guarantees that you will receive 98% of the minimal rated power [47]. Over the course of the next ten years, we will receive 92% of the minimal rated power output with a loss rate of 0.6% each year. From the 11th year until the 25th year, the warranty will cover 82% of the minimal rated power output with a loss rate of 0.66% each year, which mean that the system loses 18% of the potential at the end of the investment duration. In addition, the electricity prices increase yearly in Turkey. It is assumed to be 3% for every year and the starting price will be $0.09 as it's the price for every kW consumed in 2019 [45]. The increase in efficiency losses increase the disbursement amount that will cover the electricity demand of the integrated building. For the first year the electricity saving amount is $21,496.50 as it has been calculated in Table 3.7. The return of investment, electricity saving and disbursement amounts for the coming years are shown in Table 3.9.

The amount of money that has been invested for this system is $279,483. The table shows that after 12.78 years the invested money will be returned, according to following formula.

$$\frac{13-12}{283,547.33-264,196.19} = \frac{X-12}{279,483-264,196.28}$$

The income, operation and investment costs are presented in Table 3.10. But first, the inflation rate need to be added to the calculation which is the continuous increase in

TABLE 3.9: Return of investment 1

Investment Duration		25 years	Percentage of Yearly Changing in Electricity	3.00%	Starting Price in 2019 (USD/kWh)			$0.09	Income of Investment Table		
Period	Year	Installed Capacity	Specific Production per kWp installed (kWh/kWp/Year)	Efficiency (%)	Production (kWh)	Integrated Building Consumption (kWh/Year)	Amount of Electricity Shortage (kWh/Year)	Electricity Price (USD/kWh)	Electricity Saving ($)	Disbursement Amounts in Months Faced Shortage in Production	Income (USD/Year)
0	2019	350	1,409	98	486,360	240,000	1,150.00	$ 0.0900	21,496.50	103.5	21,496.50
1	2020	350	1,409	97.4	483,382	240,000	1,157.08	$ 0.0927	20,937.59	107.26	42,434.09
2	2021	350	1,409	96.8	480,405	240,000	1,164.26	$ 0.0955	20,808.61	111.16	63,242.70
3	2022	350	1,409	96.2	477,427	240,000	1,171.52	$ 0.0983	20,679.63	115.21	83,922.34
4	2023	350	1,409	95.6	474,449	240,000	1,178.87	$ 0.1013	20,550.65	119.41	104,472.99
5	2024	350	1,409	95	471,471	240,000	1,186.32	$ 0.1043	20,421.68	123.77	124,894.67
6	2025	350	1,409	94.4	468,494	240,000	1,193.86	$ 0.1075	20,292.70	128.30	145,187.36
7	2026	350	1,409	93.8	465,516	240,000	1,201.49	$ 0.1107	20,163.72	132.99	165,351.08
8	2027	350	1,409	93.2	462,538	240,000	1,209.23	$ 0.1140	20,034.74	137.86	185,385.82
9	2028	350	1,409	92.6	459,561	240,000	1,217.06	$ 0.1174	19,905.76	142.92	205,291.58
10	2029	350	1,409	92	456,583	240,000	1,225.00	$ 0.1210	19,776.78	148.17	225,068.36
11	2030	350	1,409	91.34	453,307	240,000	1,233.85	$ 0.1246	19,634.90	153.71	244,703.26
12	2031	350	1,409	90.68	450,032	240,000	1,242.83	$ 0.1283	19,493.03	159.48	**264,196.28**
13	3032	350	1,409	90.02	446,756	240,000	1,251.94	$ 0.1322	19,351.15	165.47	**283,547.43**
14	3033	350	1,409	89.36	443,481	240,000	1,261.19	$ 0.1361	19,209.27	171.69	302,756.71
15	3034	350	1,409	88.7	440,205	240,000	1,270.57	$ 0.1402	19,067.40	178.16	321,824.10
16	3035	350	1,409	88.04	436,930	240,000	1,280.10	$ 0.1444	18,925.52	184.88	340,749.62
17	3036	350	1,409	87.38	433,654	240,000	1,289.77	$ 0.1488	18,783.64	191.86	359,533.26
18	3037	350	1,409	86.72	430,379	240,000	1,299.58	$ 0.1532	18,641.76	199.12	378,175.03
19	3038	350	1,409	86.06	427,103	240,000	1,309.55	$ 0.1578	18,499.89	206.67	396,674.91
20	3039	350	1,409	85.4	423,828	240,000	1,319.67	$ 0.1626	18,358.01	214.51	415,032.93
21	3040	350	1,409	84.74	420,553	240,000	1,329.95	$ 0.1674	18,216.13	222.67	433,249.06
22	3041	350	1,409	84.08	417,277	240,000	1,340.39	$ 0.1724	18,074.26	231.15	451,323.32
23	3042	350	1,409	83.42	414,002	240,000	1,350.99	$ 0.1776	17,932.38	239.97	469,255.70
24	3043	350	1,409	82.76	410,726	240,000	1,361.77	$ 0.1830	17,790.50	249.14	487,046.20
Total					11,234,420	6,000,000	31,196.86				

the overall level of prices of goods and services in a specific period. The inflation rate is so important as the central banks publish their forecasts of inflation rate for the next years and update their forecasting frequently according to situation. The history of most economies shows that there is always a period with a lower inflation rate after every period of the high inflation rate. The yearly inflation rate is in between 1% and 3% except for some extreme cases. The 25 years is long time to be forecasted, hence the best way for forecasting the inflation rate for the next 25 years is by taking the average of past years' inflation rates with ignoring the trend because if the trend of the past years is downward the forecast of the inflation rate will drop over the years. Since the price of the system is in the U.S dollars, the forecasting of the inflation rate will be calculated according to the history of the inflation rates of the united states. As a result, the next 25 years of US inflation rate forecasts are computed as yearly 2.41%. In addition, to fund the project, a loan from a bank will used with 8% of interest

TABLE 3.10: Return of investment 2

Investment Duration		25 years	Yearly Changing in Electricity Prices	3.00%	Starting Price in 2019 (USD/kWh)					$ 0.09	System capacity	350 kWp						
		Income									Operation cost	Investment cost						
Period	Year	Installed Capacity	Specific Production per kWp installed (kWh/kWp/Year)	Efficiency (%)	Production (kWh)	Integrated Building Consumption (kWh/Year)	Electricity Price (USD/kWh)	Amount of Electricity Shortage (kWh/Year)	NPV of Income	Inflation rate (%)	Maintenance & Operational costs	Loan principal Payment	NPV of Loan	Interest (%)	Interest ($)	NPV of Interest	Total Payment	NPV of Total Payment
0	2019	350	1,409	98	486,360	240,000	$ 0.0900	1,150.00	21,496.50	2.41%	$ 7,000.00	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
1	2020	350	1,409	97.4	483,382	240,000	$ 0.0927	1,157.08	20,937.59	2.41%	$ 7,168.700	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
2	2021	350	1,409	96.8	480,405	240,000	$ 0.0955	1,164.26	20,808.61	2.41%	$ 7,341.466	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
3	2022	350	1,409	96.2	477,427	240,000	$ 0.0983	1,171.52	20,679.63	2.41%	$ 7,518.395	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
4	2023	350	1,409	95.6	474,449	240,000	$ 0.1013	1,178.87	20,550.65	2.41%	$ 7,699.588	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
5	2024	350	1,409	95	471,471	240,000	$ 0.1043	1,186.32	20,421.68	2.41%	$ 7,885.148	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
6	2025	350	1,409	94.4	468,494	240,000	$ 0.1075	1,193.86	20,292.70	2.41%	$ 8,075.180	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
7	2026	350	1,409	93.8	465,516	240,000	$ 0.1107	1,201.49	20,163.72	2.41%	$ 8,269.792	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
8	2027	350	1,409	93.2	462,538	240,000	$ 0.1140	1,209.23	20,034.74	2.41%	$ 8,469.094	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
9	2028	350	1,409	92.6	459,561	240,000	$ 0.1174	1,217.06	19,905.76	2.41%	$ 8,673.199	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
10	2029	350	1,409	92	456,583	240,000	$ 0.1210	1,225.00	19,776.78	2.41%	$ 8,882.224	$ 23,290.00	$ 22,728.71	8%	$ 1,863.20	$ 1,818.30	$ 25,153.20	$ 24,547.01
11	2030	350	1,409	91.34	453,307	240,000	$ 0.1246	1,233.85	19,634.90	2.41%	$ 9,096.285	$ 23,293.00	$ 22,731.64	8%	$ 1,863.44	$ 1,818.53	$ 25,156.44	$ 24,550.17
12	2031	350	1,409	90.68	450,032	240,000	$ 0.1283	1,242.83	19,493.03	2.41%	$ 9,315.506	$ -	$ -	8%	$ -	$ -	$ -	$ -
13	3032	350	1,409	90.02	446,756	240,000	$ 0.1322	1,251.94	19,351.15	2.41%	$ 9,540.009	$ -	$ -	8%	$ -	$ -	-	$ -
14	3033	350	1,409	89.36	443,481	240,000	$ 0.1361	1,261.19	19,209.27	2.41%	$ 9,769.924	$ -	$ -	8%	$ -	$ -	-	$ -
15	3034	350	1,409	88.7	440,205	240,000	$ 0.1402	1,270.57	19,067.40	2.41%	$ 10,005.379	$ -	$ -	8%	$ -	$ -	-	$ -
16	3035	350	1,409	88.04	436,930	240,000	$ 0.1444	1,280.10	18,925.52	2.41%	$ 10,246.508	$ -	$ -	8%	$ -	$ -	-	$ -
17	3036	350	1,409	87.38	433,654	240,000	$ 0.1488	1,289.77	18,783.64	2.41%	$ 10,493.449	$ -	$ -	8%	$ -	$ -	-	$ -
18	3037	350	1,409	86.72	430,379	240,000	$ 0.1532	1,299.58	18,641.76	2.41%	$ 10,746.341	$ -	$ -	8%	$ -	$ -	-	$ -
19	3038	350	1,409	86.06	427,103	240,000	$ 0.1578	1,309.55	18,499.89	2.41%	$ 11,005.328	$ -	$ -	8%	$ -	$ -	-	$ -
20	3039	350	1,409	85.4	423,828	240,000	$ 0.1626	1,319.67	18,358.01	2.41%	$ 11,270.557	$ -	$ -	8%	$ -	$ -	-	$ -
21	3040	350	1,409	84.74	420,553	240,000	$ 0.1674	1,329.95	18,216.13	2.41%	$ 11,542.177	$ -	$ -	8%	$ -	$ -	-	$ -
22	3041	350	1,409	84.08	417,277	240,000	$ 0.1724	1,340.39	18,074.26	2.41%	$ 11,820.343	$ -	$ -	8%	$ -	$ -	-	$ -
23	3042	350	1,409	83.42	414,002	240,000	$ 0.1776	1,350.99	17,932.38	2.41%	$ 12,105.214	$ -	$ -	8%	$ -	$ -	-	$ -
24	3043	350	1,409	82.76	410,726	240,000	$ 0.1830	1,361.77	17,790.50	2.41%	$ 12,396.949	$ -	$ -	8%	$ -	$ -	-	$ -
Total					11,234,420	6,000,000		$ 31,196.86	$ 487,046.20		$ 236,336.76	$ 279,483.00	$ 272,747.46		$ 22,358.64	$21,819.80	$ 301,841.64	$ 294,567.26

Chapter 4

Survey and Discussion

4.1 Findings

The solar potential analysis of the proposed area reveals that the One-axis system with Panasonic PV model has 86.76% more energy production than in Fixed-axis. As for the One-axis system that use Yingli PV model have 83.78% more energy production that in Fixed-axis.

The analysis of the proposed area shows that PV and inverter models can affect the energy output, plus different behavior of the PV's had been observed when different models used in different solar systems as when Panasonic PV model used in Fixed-axis the temperature loss was equal to 2.95%, but when used in One-axis system the loss increased to 5.43%, which means exposing the panels to the sun for a longer period increased the loss by 2.48%. In the other side, when Yingli PV had been used in Fixed-axis system the temperature loss was equals to 4.24% while it was 8.07% in One-axis system, which means that we have 3.83% difference. The amount of increase in temperature losses in both systems is not the same, this shows that even if we have the same defined parameters facing the same conditions, different values may be obtained. Figures 2.21, 2.27, 2.36, 2.43 show that there is no shading loss difference between Fixed and One-axis systems either with using any model type but having different values when temperature is involved, which shows that a specific PV can perform differently than other PV's. The different values in temperature loss describe the unique structure of Panasonic HIT panel which have an amorphous layer that allows to maintain high conversion efficiency and performance at hot temperatures, generating more energy throughout the day [48].

Another coefficient is in favor of Panasonic model, is the irradiance level that reflect the intrinsic behavior of the PV model as when Panasonic models used in Fixed-axis system the irradiance level loss was equal to 3.76% while it was 1.36% in One-axis system which means that there is an improvement of 2.4%. In the other side, when Yingli model is used in Fixed-axis system the irradiance level was equal to 2.37% while it was 0.58% in One-axis system, this indicates that Panasonic model has improved its performance by higher rate.

The best result we have obtained after performing all of the design alternatives is the One-axis system that use Yingli PV with SMA inverter because it has the best energy output for the most reasonable price in addition that this system fits the proposed area. This system can supply 489.6 MWh/year. But to supply a property with 240 MWh/year demand, Fixed system is enough. According to results, the following table show the average energy output and system price for each Fixed and One-axis systems in kWh/month and MWh/year.

Table 4.1: Fixed, One-axis energy production

No	PV Model	Inverter Model	kWh/month	MWh/year	Price $
Fixed	Yingli	SMA	22,050	266.4	237,483
		Hyundai	21,210	258	236,841
		Solarmax	21,315	257.9	248,508
	Panasonic	SMA	21,735	264.2	245,186
		Hyundai	20,895	254	243,888
		Solarmax	21,000	255.4	256,188
One-axis	Yingli	SMA	40,530	489.6	279,483
		Hyundai	39,270	477.1	278,841
		Solarmax	39,480	476.8	290,508
	Panasonic	SMA	40,635	493.2	287,186
		Hyundai	39,270	477.7	285,888
		Solarmax	39,480	479.8	298,188

The table shows that Fixed-axis system can supply the property with the demanded energy and according to price list the best alternative to select is Yingli PV with SMA inverter that have the best energy output with the most reasonable price in addition that it fits the designed steel structure after consideration of number of modules. Although Fixed-axis system can provide the demanded energy, its price compared to the best alternative we got in One-axis system (Yingli PV with SMA inverter) is not great if we take into account the benefits and advantages that we can get from producing more energy knowing that the average lifespan of a solar system is 25 years [46].

The One-axis vertical system has a great output compared to Fixed-axis system with more than 80% difference in power generation for the proposed location. This high difference was because of the advantages we have obtained from using the vertical system that allows the solar panels to track the sun's azimuth, generating more energy. A study had been made in Florida-America [49], to test the difference between the Fixed and One-axis horizontal track system. The location of the study was in Boca Raton, Florida with following information's.

TABLE 4.2: Florida case study, location status

City	Boca Raton
State	FL
Latitude	26.21°N
Longitude	80.04°W
Elevation	11m

The Fixed system was designed with 23°inclination angle. The assigned angle was set to achieve the best energy production throughout the year. As for One-axis panels, the board turn range from (0-90°) System used Trina PV with 305W capacity and Sunny boy 7000US-12 inverter. Based on the location and the selected components the daily results are shown in Table 4.3.

TABLE 4.3: Florida case study, results

	Tracker (kWh)	Fixed (kWh)	Tracker rate (%)
October 15, 2014	37.539	35.432	5.95
January 15, 2015	16.756	17.001	-1.44
April 15, 2015	51.395	42.292	21.52
July 14, 2015	32.097	24.943	28.68

Based on the study results the One-axis system generally performed better than the Fixed system but did not reach an increase of 30% in terms of energy production. Since the track system is horizontal, its production based on summer months when the sun is overhead at noon, that give an advantage for the Fixed system in winter months when the sun moves at lower altitudes, this explains why the January results were in favor of the Fixed system when they could receive more sun radiation at midday.

The energy output changes between systems according to the location of the grid. In the previous study, One-axis system had 28.68% more in terms of energy production but in other location One-axis system had just 7% more energy output as this study that been made in Khyber Pakhtunkhwa, Pakistan [50] with 2 kWp capacity grid. Hanwha Q cells PV model had been used using 8 PV modules with 250 W capacity and 2.0 kWac Sunny boy inverter from SMA. A 32°tilt angle had been assigned to the E-W Fixed-axis while the horizontal One-axis system had been installed in E-W orientation with 130°(-65°/65°) of free movement, and the tilt limits for the Dual-axis is (10°/90°). The site coordinates are 33°51'1N 72°51'8E. Based on the study, the monthly measured results are shown in Table 4.4.

Table 4.4: Pakistan case study, results

Month	Fixed-axis (kWh)	One-axis (kWh)	Two-axis (kWh)
January	228.6	251.96	308.0
February	259.36	269.87	288.9
March	276.68	289.69	321.2
April	253.32	266.40	339.1
May	255.95	287.25	350.8
June	248.93	279.24	340.2
July	225.53	253.89	288.9
August	247.99	259.20	315.9
September	256.87	269.95	347.2
October	241.96	256.92	315.4
November	217.47	232.40	310.4
December	204.08	220.30	306.0
Year	2917	3137	3832

Based on the measured results, single horizontal axis system performed better than Fixed-axis system with just 7% more energy production, when Two-axis system produced 24% more energy.

The previous studies are presented to show how much location would affect the results obtained when comparing systems together. In our study, One-axis system results show how much sun radiation was lost by Fixed system that allowed the One-axis system to generate much more energy. In addition, there was no considerable difference between the two tracking systems that the One-axis vertical system had the capability to capture and to generate almost as the Two-axis system.

4.2 Recommendations

If we can achieve the desired energy, selecting PV's with higher resistance to heat is preferable, because temperature considered as a critical issue when forecasting energy production. Long term high temperature working conditions can cause irreversible degradation of its energy production [51]. PV panels can only convert to 20% of the sun's radiation that fall onto the PV panels [52], the remaining major part is converted to heat [51]. According to a study made by Sendhil kumar, Tapas Mallik, M Katz and S Weingaertner, 0.4 - 0.5% decrease in PV panel efficiency conversion can be reached for each degree rise in temperature [53]. Based on this study results, an oversized inverter has the capability to help the system to achieve more energy than other systems. In addition, not to always depend on the latest technology system (Two-axis) to supply your project, based on the results on this study One-axis system is the best choice to be selected. Selecting panels with higher capacity can save area for future expanding and investment.

Conclusion

It has been observed that many types of solar panel plants can be designed to reach the desired energy, but the best design is a result of optimization of production of energy and cost feasibility for a given application and requirements. Panels with SMA inverter has more energy outcome resulting from inverter oversizing, which overcame the other inverters that have less unit nominal power; In addition, inverters performed better in track systems. It has been observed that the losses that had the greatest impact on energy production were shading, temperature, model quality, IAM factor and irradiance level. It has been noticed that the greatest impact on increasing the price difference between Fixed, One-axis and Two-axis systems because of an element that was capable to increase the price difference between Fixed-axis and the One-way axis by almost 18%, which was a result of the cost of the track system (panel's frame). The optimum design cannot be reached by reaching the desired energy only, but also by reaching the reasonable cost. It has been established that the most modern methodologies may not be always sufficient to achieve the desired goals.

Appendix A

Fixed axis Appendix

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Grid-Connected System: Simulation parameters

Project : **Sehir solar plant**

Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant : **Fixed var1**

Simulation date 10/04/19 17h56

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	31°	Azimuth	180°
Sheds configuration	Nb. of sheds	1120	Identical arrays	
	Sheds spacing	2.20 m	Collector width	2.00 m
Shading limit angle	Limit profile angle	64.8°	Ground cov. Ratio (GCR)	90.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module	Si-poly	Model	**YL310P-35b**		
Original PVsyst database		Manufacturer	Yingli Solar		
Number of PV modules		In series	19 modules	In parallel	59 strings
Total number of PV modules		Nb. modules	1121	Unit Nom. Power	310 Wp
Array global power		Nominal (STC)	**348 kWp**	At operating cond.	311 kWp (50°C)
Array operating characteristics (50°C)		U mpp	624 V	I mpp	498 A
Total area		Module area	**2175 m²**	Cell area	1964 m²
Inverter		Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack		Nb. of inverters	6 units	Total Power	360 kWac
				Pnom ratio	0.97

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	21 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

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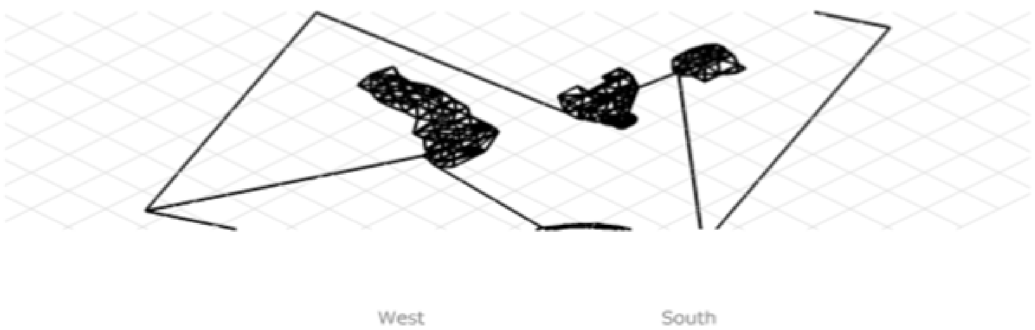
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

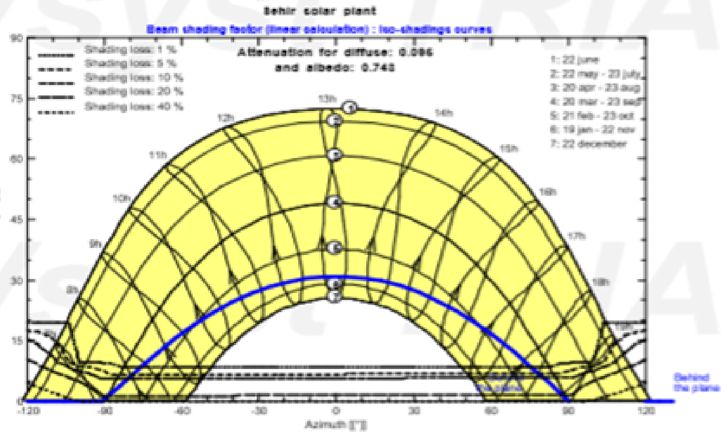
Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

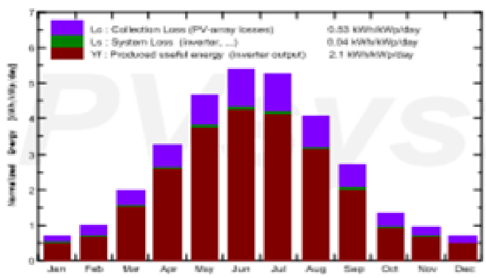
Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

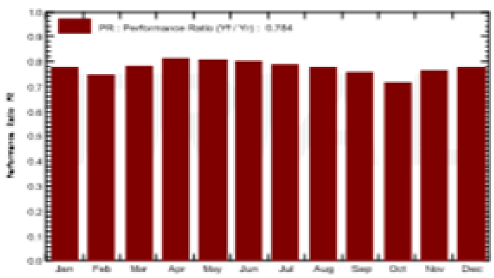
Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**266.4 MWh/year**	Specific prod.	767 kWh/kWp/year
	Performance Ratio PR	78.44 %		

Normalized productions (per installed kWp): Nominal power 348 kWp



Performance Ratio PR



Fixed var1

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	43.3	26.40	6.31	21.8	18.8	6.11	5.89	0.777
February	55.9	31.50	6.38	27.9	22.6	7.44	7.20	0.743
March	95.5	59.40	9.14	62.2	51.6	17.22	16.82	0.778
April	131.3	73.70	12.51	97.4	84.5	28.01	27.46	0.811
May	172.3	86.60	17.98	144.3	128.9	41.14	40.42	0.806
June	185.9	87.70	22.57	161.6	145.7	45.68	44.92	0.800
July	189.9	87.20	25.68	163.0	146.5	45.35	44.61	0.788
August	165.4	76.60	25.64	125.7	111.0	34.56	33.96	0.778
September	125.4	58.90	21.04	81.5	68.5	21.80	21.37	0.755
October	85.0	43.50	17.06	42.6	33.9	10.85	10.56	0.713
November	55.4	33.70	11.93	27.7	23.5	7.59	7.36	0.764
December	40.9	26.10	8.24	21.8	18.8	6.08	5.87	0.775
Year	1346.2	691.29	15.43	977.4	854.3	271.82	266.43	0.784

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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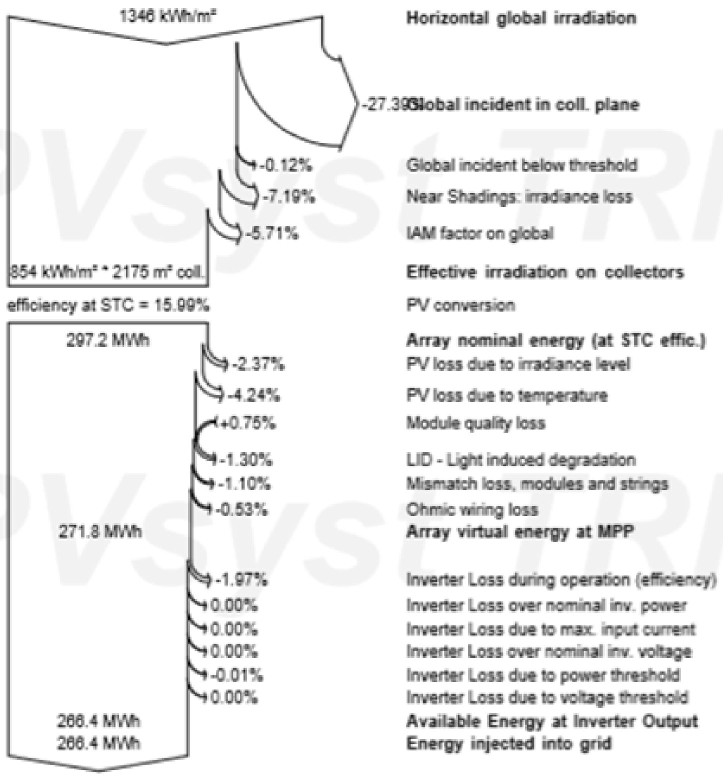
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Fixed var1**			
	Simulation date	10/04/19 18h09		

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	31°	Azimuth	180°
Sheds configuration	Nb. of sheds	1120	Identical arrays	
	Sheds spacing	2.20 m	Collector width	2.00 m
Shading limit angle	Limit profile angle	64.8°	Ground cov. Ratio (GCR)	90.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics				
PV module Si-poly	Model	**YL310P-35b**		
Original PVsyst database	Manufacturer	Yingli Solar		
Number of PV modules	In series	12 modules	In parallel	94 strings
Total number of PV modules	Nb. modules	1128	Unit Nom. Power	310 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	313 kWp (50°C)
Array operating characteristics (50°C)	U mpp	394 V	I mpp	794 A
Total area	Module area	**2189 m²**	Cell area	1976 m²
Inverter	Model	**HPC-050HT-E**		
Original PVsyst database	Manufacturer	Hyundai		
Characteristics	Operating Voltage	300-600 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	300 kWac
			Pnom ratio	1.17

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	8.3 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

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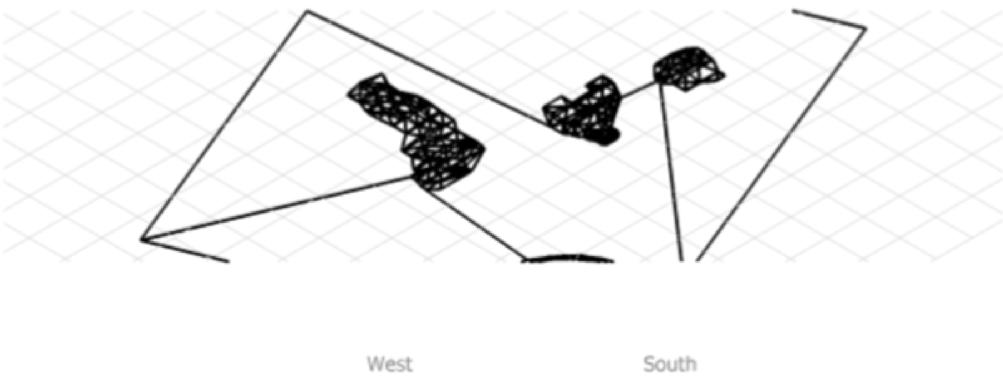
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

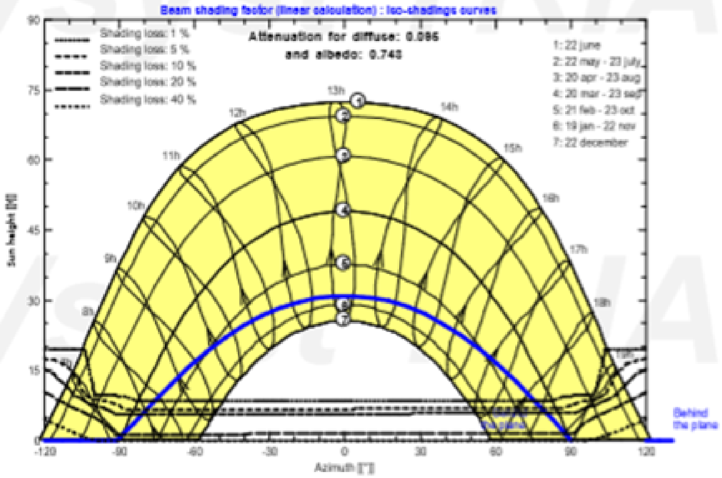
Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1128	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



PVsyst Evaluation mode

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Grid-Connected System: Main results

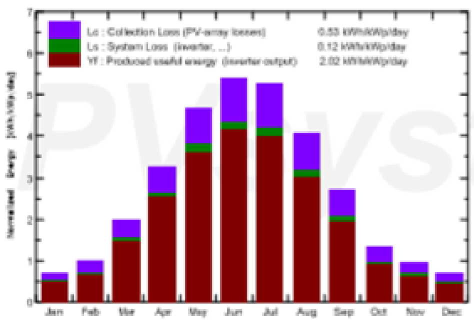
Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

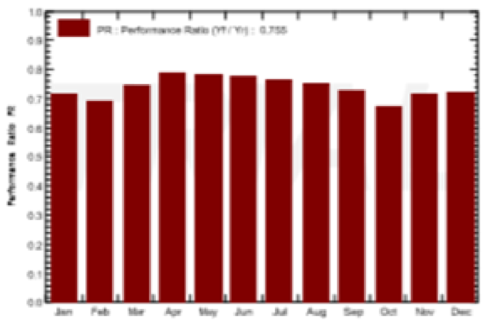
Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1128	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	Produced Energy	**258.0 MWh/year**	Specific prod.	738 kWh/kWp/year
	Performance Ratio PR	75.48 %		

Normalized productions (per installed kWp): Nominal power 350 kWp



Performance Ratio PR



Fixed var1

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	43.3	26.40	6.31	21.8	18.8	6.15	5.44	0.713
February	55.9	31.50	6.38	27.9	22.6	7.49	6.75	0.692
March	95.5	59.40	9.14	62.2	51.6	17.32	16.19	0.744
April	131.3	73.70	12.51	97.4	84.5	28.18	26.74	0.785
May	172.3	86.60	17.98	144.3	128.9	41.40	39.36	0.780
June	185.9	87.70	22.57	161.6	145.7	45.96	43.84	0.776
July	189.9	87.20	25.68	163.0	146.5	45.63	43.51	0.763
August	165.4	76.60	25.64	125.7	111.0	34.77	33.04	0.752
September	125.4	58.90	21.04	81.5	68.5	21.93	20.68	0.726
October	85.0	43.50	17.06	42.6	33.9	10.92	10.03	0.673
November	55.4	33.70	11.93	27.7	23.5	7.64	6.92	0.714
December	40.9	26.10	8.24	21.8	18.8	6.12	5.47	0.718
Year	1346.2	691.29	15.43	977.4	854.3	273.51	257.97	0.755

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	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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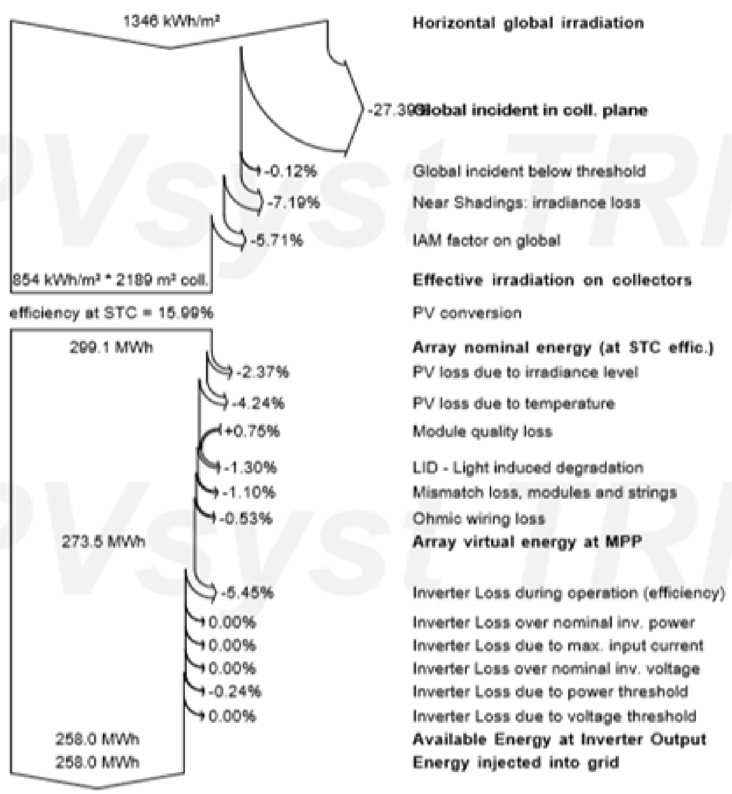
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1128	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Fixed var1**	
	Simulation date	10/04/19 18h20

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	31°	Azimuth	180°
Sheds configuration	Nb. of sheds	1120	Identical arrays	
	Sheds spacing	2.20 m	Collector width	2.00 m
Shading limit angle	Limit profile angle	64.8°	Ground cov. Ratio (GCR)	90.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics				
PV module Si-poly	Model	**YL310P-35b**		
Original PVsyst database	Manufacturer	Yingli Solar		
Number of PV modules	In series	17 modules	In parallel	66 strings
Total number of PV modules	Nb. modules	1122	Unit Nom. Power	310 Wp
Array global power	Nominal (STC)	**348 kWp**	At operating cond.	311 kWp (50°C)
Array operating characteristics (50°C)	U mpp	558 V	I mpp	557 A
Total area	Module area	**2177 m²**	Cell area	1965 m²
Inverter	Model	**Solarmax 50TS**		
Original PVsyst database	Manufacturer	SolarMax		
Characteristics	Operating Voltage	430-800 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	300 kWac
			Pnom ratio	1.16

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	17 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

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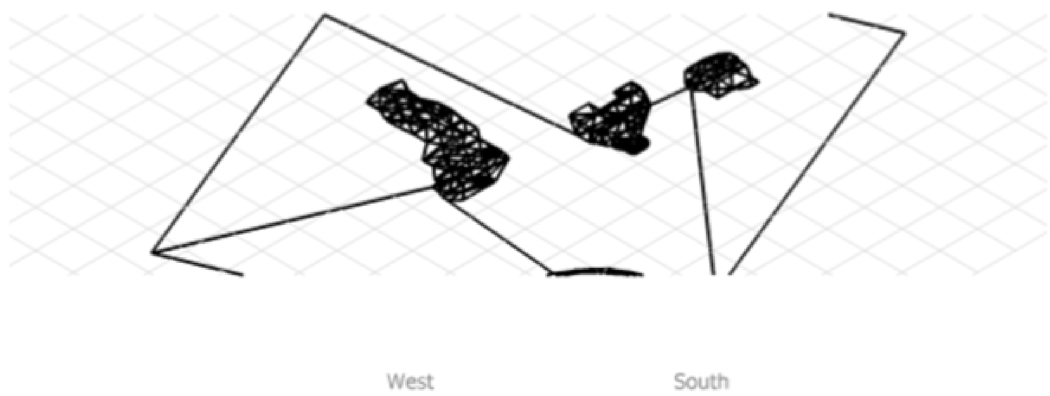
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

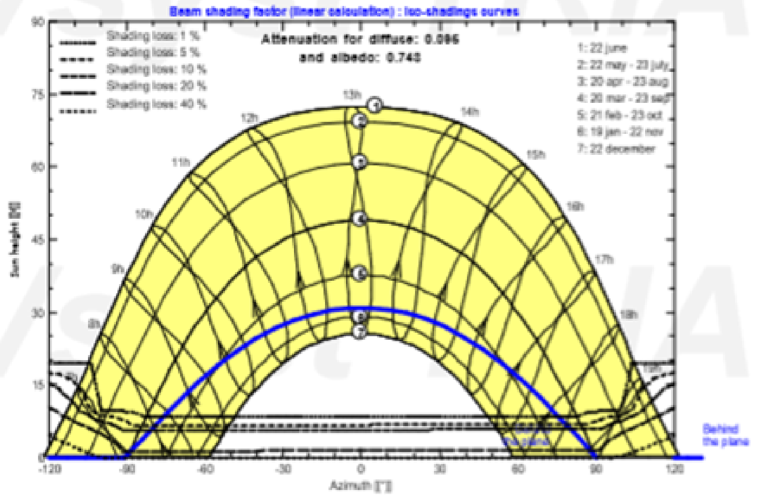
Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

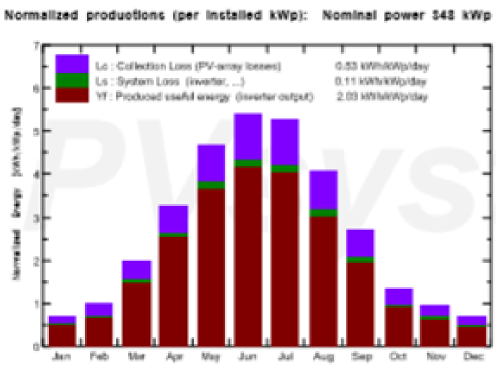
Main system parameters System type **Sheds on a building**

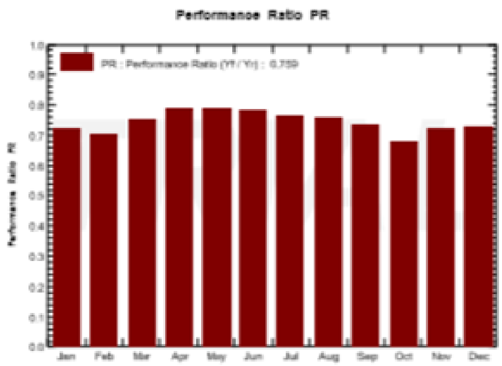
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results

System Production — **Produced Energy** **257.9 MWh/year** — Specific prod. 742 kWh/kWp/year

Performance Ratio PR 75.86 %





Fixed var1

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	43.3	26.40	6.31	21.8	18.8	6.12	5.47	0.722
February	55.9	31.50	6.38	27.9	22.6	7.45	6.78	0.699
March	95.5	59.40	9.14	62.2	51.6	17.23	16.21	0.749
April	131.3	73.70	12.51	97.4	84.5	28.03	26.71	0.788
May	172.3	86.60	17.98	144.3	128.9	41.18	39.36	0.784
June	185.9	87.70	22.57	161.6	145.7	45.72	43.79	0.779
July	189.9	87.20	25.68	163.0	146.5	45.39	43.47	0.767
August	165.4	76.60	25.64	125.7	111.0	34.59	33.03	0.756
September	125.4	58.90	21.04	81.5	68.5	21.82	20.67	0.729
October	85.0	43.50	17.06	42.6	33.9	10.86	10.04	0.678
November	55.4	33.70	11.93	27.7	23.5	7.60	6.93	0.718
December	40.9	26.10	8.24	21.8	18.8	6.08	5.47	0.722
Year	1346.2	691.29	15.43	977.4	854.3	272.06	257.92	0.759

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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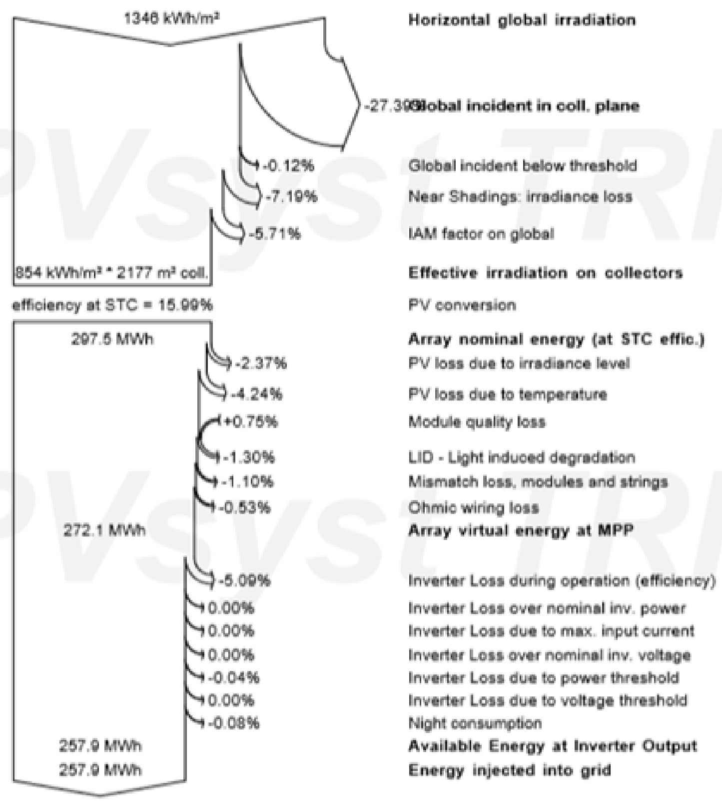
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Fixed var1**	
	Simulation date	10/04/19 18h28

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	31°	Azimuth	180°
Sheds configuration	Nb. of sheds	1120	Identical arrays	
	Sheds spacing	2.20 m	Collector width	2.00 m
Shading limit angle	Limit profile angle	64.8°	Ground cov. Ratio (GCR)	90.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module	HIT	Model	**VBHN230SE51**		
Original PVsyst database		Manufacturer	Panasonic		
Number of PV modules		In series	16 modules	In parallel	95 strings
Total number of PV modules		Nb. modules	1520	Unit Nom. Power	230 Wp
Array global power		Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)		U mpp	642 V	I mpp	508 A
Total area		Module area	**1916 m²**	Cell area	1666 m²
Inverter		Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack		Nb. of inverters	6 units	Total Power	360 kWac
				Pnom ratio	0.97

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	20 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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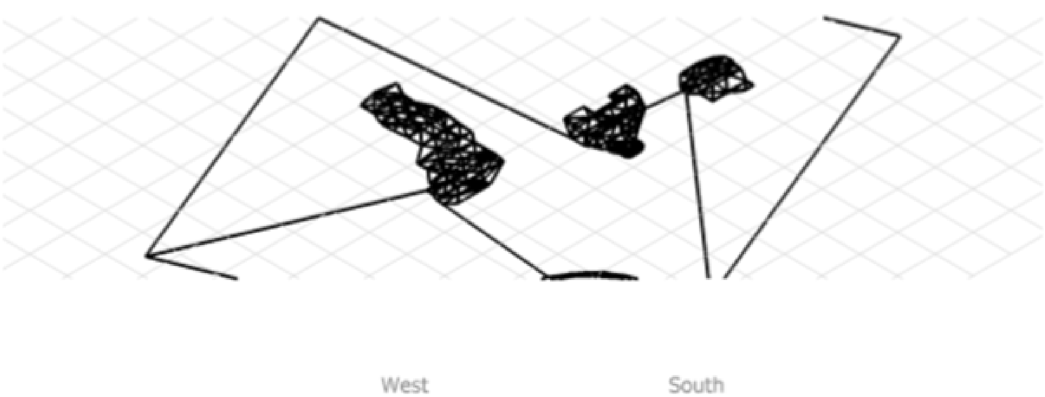
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

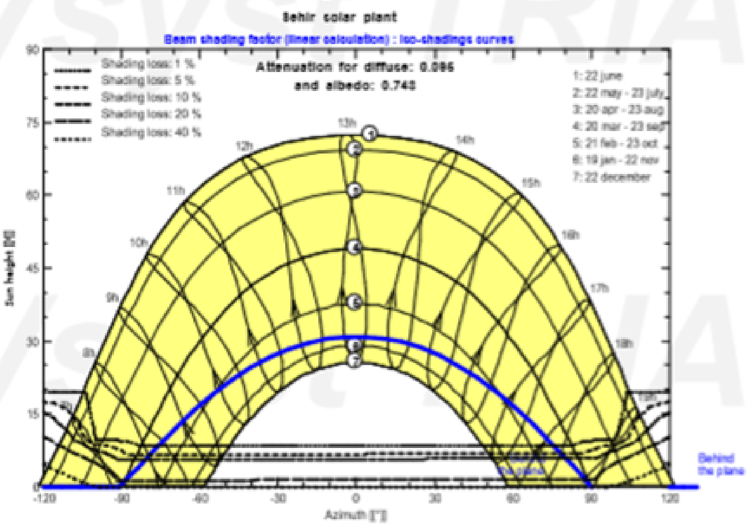
Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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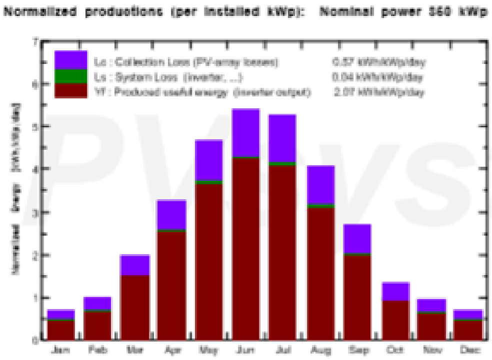
Grid-Connected System: Main results

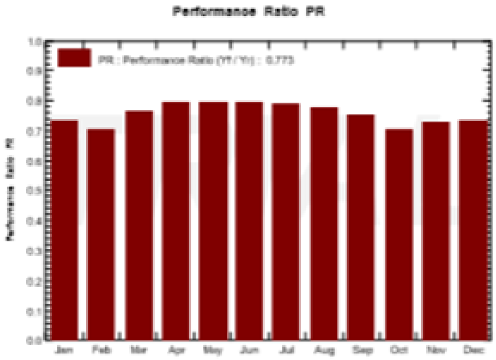
Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter	Sunny Tripower 60-US-10 (400 VAC)		Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**264.2 MWh/year**	Specific prod.	756 kWh/kWp/year
	Performance Ratio PR	77.33 %		





Fixed var1

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	43.3	26.40	6.31	21.8	18.7	5.79	5.60	0.734
February	55.9	31.50	6.38	27.9	22.6	7.10	6.89	0.706
March	95.5	59.40	9.14	62.2	52.3	16.90	16.54	0.761
April	131.3	73.70	12.51	97.4	85.0	27.55	27.05	0.794
May	172.3	86.60	17.98	144.3	128.6	40.86	40.16	0.796
June	185.9	87.70	22.57	161.6	145.2	45.59	44.85	0.794
July	189.9	87.20	25.68	163.0	146.1	45.45	44.72	0.785
August	165.4	76.60	25.64	125.7	111.2	34.60	34.02	0.774
September	125.4	58.90	21.04	81.5	69.6	21.83	21.42	0.752
October	85.0	43.50	17.06	42.6	34.4	10.65	10.39	0.698
November	55.4	33.70	11.93	27.7	23.4	7.23	7.02	0.725
December	40.9	26.10	8.24	21.8	18.7	5.77	5.59	0.733
Year	1346.2	691.29	15.43	977.4	855.9	269.32	264.23	0.773

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	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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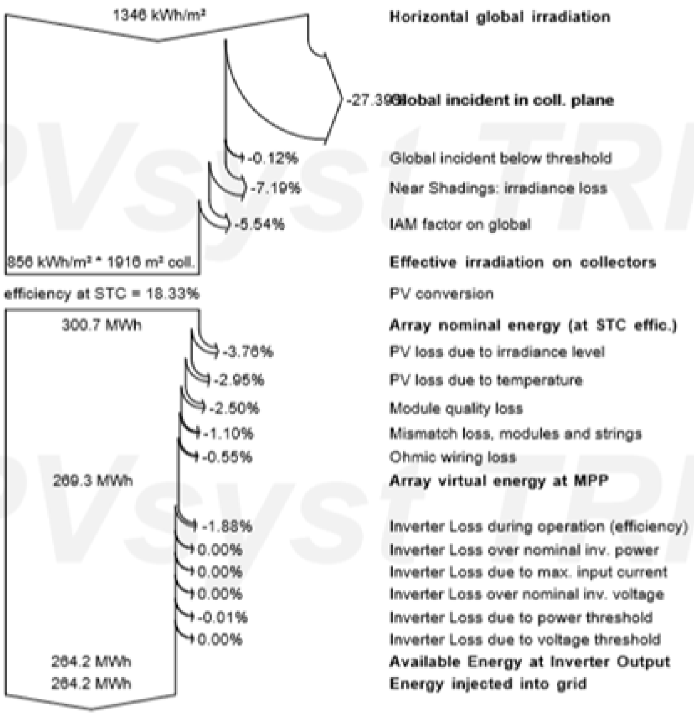
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Fixed var1**	
	Simulation date	10/04/19 18h23

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	31°	Azimuth	180°
Sheds configuration	Nb. of sheds	1120	Identical arrays	
	Sheds spacing	2.20 m	Collector width	2.00 m
Shading limit angle	Limit profile angle	64.8°	Ground cov. Ratio (GCR)	90.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics				
PV module	HIT Model	**VBHN230SE51**		
Original PVsyst database	Manufacturer	Panasonic		
Number of PV modules	In series	9 modules	In parallel	169 strings
Total number of PV modules	Nb. modules	1521	Unit Nom. Power	230 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)	U mpp	361 V	I mpp	903 A
Total area	Module area	**1918 m²**	Cell area	1667 m²
Inverter	Model	**HPC-050HT-E**		
Original PVsyst database	Manufacturer	Hyundai		
Characteristics	Operating Voltage	300-600 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	300 kWac
			Pnom ratio	1.17

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	6.5 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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Grid-Connected System: Near shading definition

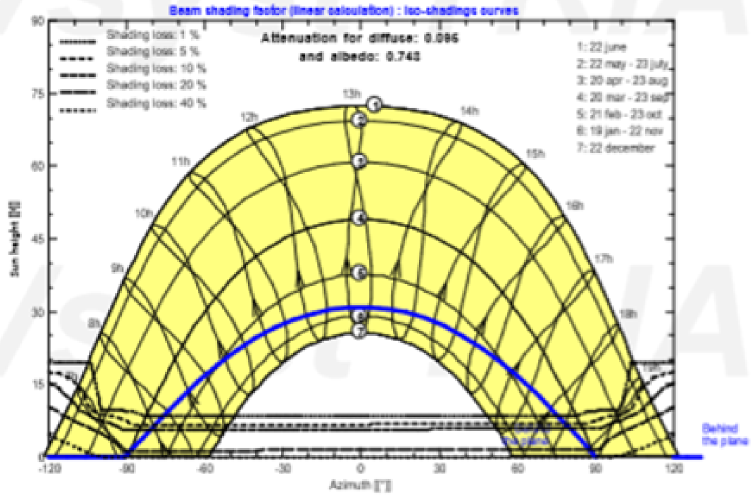
Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene

Iso-shadings diagram



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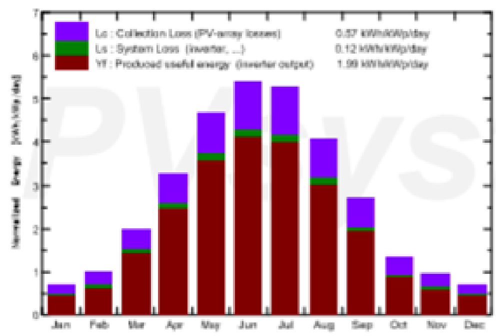
Grid-Connected System: Main results

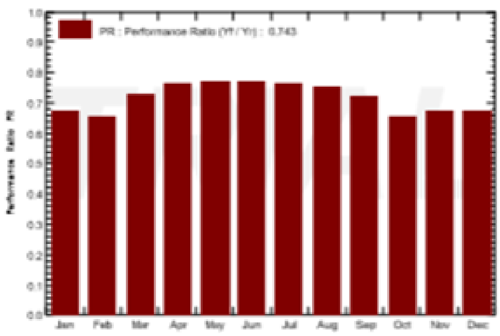
Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**254.0 MWh/year**	Specific prod.	726 kWh/kWp/year
	Performance Ratio PR	74.29 %		





Fixed var1

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	43.3	26.40	6.31	21.8	18.7	5.80	5.09	0.667
February	55.9	31.50	6.38	27.9	22.6	7.11	6.37	0.652
March	95.5	59.40	9.14	62.2	52.3	16.91	15.79	0.726
April	131.3	73.70	12.51	97.4	85.0	27.57	26.15	0.767
May	172.3	86.60	17.98	144.3	128.6	40.89	38.86	0.770
June	185.9	87.70	22.57	161.6	145.2	45.62	43.51	0.770
July	189.9	87.20	25.68	163.0	146.1	45.48	43.36	0.761
August	165.4	76.60	25.64	125.7	111.2	34.62	32.90	0.748
September	125.4	58.90	21.04	81.5	69.6	21.84	20.58	0.722
October	85.0	43.50	17.06	42.6	34.4	10.66	9.77	0.655
November	55.4	33.70	11.93	27.7	23.4	7.24	6.52	0.672
December	40.9	26.10	8.24	21.8	18.7	5.78	5.13	0.673
Year	1346.2	691.29	15.43	977.4	855.9	269.50	254.02	0.743

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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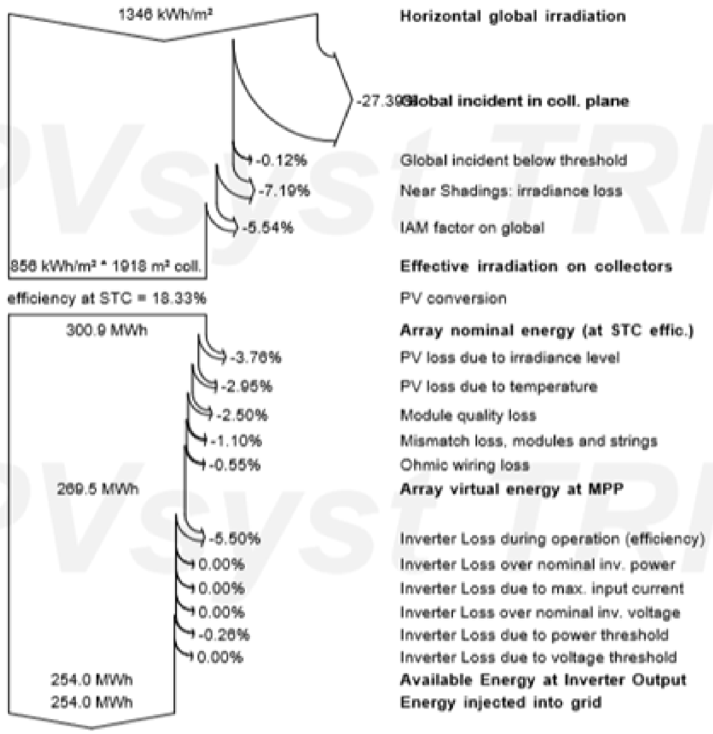
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Fixed var1**			
	Simulation date	10/04/19 18h21		

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	31°	Azimuth	180°
Sheds configuration	Nb. of sheds	1120	Identical arrays	
	Sheds spacing	2.20 m	Collector width	2.00 m
Shading limit angle	Limit profile angle	64.8°	Ground cov. Ratio (GCR)	90.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module	HIT Model	**VBHN230SE51**		
Original PVsyst database	Manufacturer	Panasonic		
Number of PV modules	In series	13 modules	In parallel	117 strings
Total number of PV modules	Nb. modules	1521	Unit Nom. Power	230 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)	U mpp	521 V	I mpp	625 A
Total area	Module area	**1918 m²**	Cell area	1667 m²
Inverter	Model	**Solarmax 50TS**		
Original PVsyst database	Manufacturer	SolarMax		
Characteristics	Operating Voltage	430-800 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	300 kWac
			Pnom ratio	1.17

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	14 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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Grid-Connected System: Near shading definition

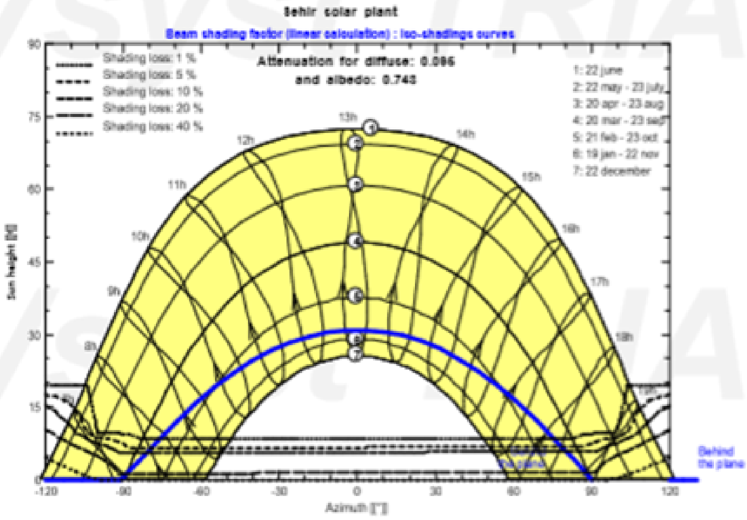
Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene

Iso-shadings diagram



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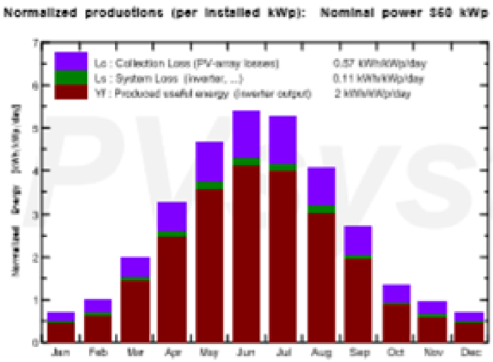
Grid-Connected System: Main results

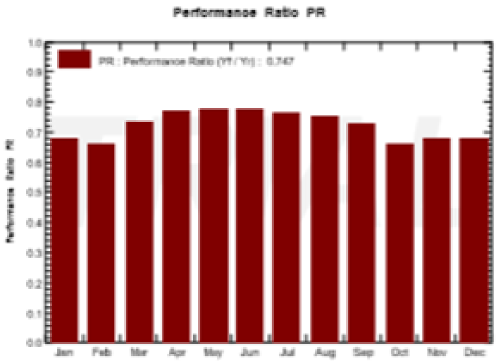
Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**255.4 MWh/year**	Specific prod.	730 kWh/kWp/year
	Performance Ratio PR	74.70 %		





Fixed var1

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	43.3	26.40	6.31	21.8	18.7	5.80	5.16	0.677
February	55.9	31.50	6.38	27.9	22.6	7.11	6.45	0.660
March	95.5	59.40	9.14	62.2	52.3	16.91	15.89	0.730
April	131.3	73.70	12.51	97.4	85.0	27.57	26.26	0.770
May	172.3	86.60	17.98	144.3	128.6	40.89	39.07	0.774
June	185.9	87.70	22.57	161.6	145.2	45.62	43.69	0.773
July	189.9	87.20	25.68	163.0	146.1	45.48	43.55	0.764
August	165.4	76.60	25.64	125.7	111.2	34.62	33.06	0.752
September	125.4	58.90	21.04	81.5	69.6	21.84	20.69	0.726
October	85.0	43.50	17.06	42.6	34.4	10.66	9.85	0.661
November	55.4	33.70	11.93	27.7	23.4	7.24	6.57	0.677
December	40.9	26.10	8.24	21.8	18.7	5.78	5.17	0.679
Year	1346.2	691.29	15.43	977.4	855.9	269.50	255.41	0.747

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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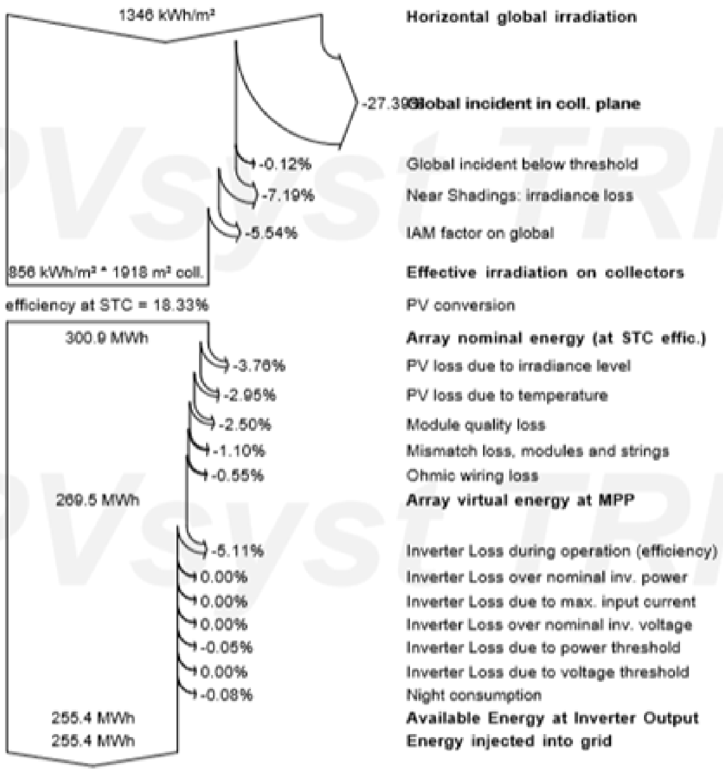
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Fixed var1**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Linear shadings			
PV Field Orientation	tilt	31°	azimuth	180°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Appendix B

One axis Appendix

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Grid-Connected System: Simulation parameters

Project : **Sehir solar plant**

Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant : **One axis**

Simulation date 10/04/19 19h23

Simulation parameters	System type	**Tracking system**		
Tracking plane, Vertical Axis	Plane Tilt	31°		
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.00 m	Collector width	1.00 m
			Ground cov. Ratio (GCR)	50.0 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics					
PV module	Si-poly	Model	**YL310P-35b**		
Original PVsyst database		Manufacturer	Yingli Solar		
Number of PV modules		In series	19 modules	In parallel	59 strings
Total number of PV modules		Nb. modules	1121	Unit Nom. Power	310 Wp
Array global power		Nominal (STC)	**348 kWp**	At operating cond.	311 kWp (50°C)
Array operating characteristics (50°C)		U mpp	624 V	I mpp	498 A
Total area		Module area	**2175 m²**	Cell area	1964 m²
Inverter		Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database		Manufacturer	SMA		
Characteristics		Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack		Nb. of inverters	6 units	Total Power	360 kWac
				Pnom ratio	0.97

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	21 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect (IAM): User defined profile				

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

PVsyst Evaluation mode

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Grid-Connected System: Near shading definition

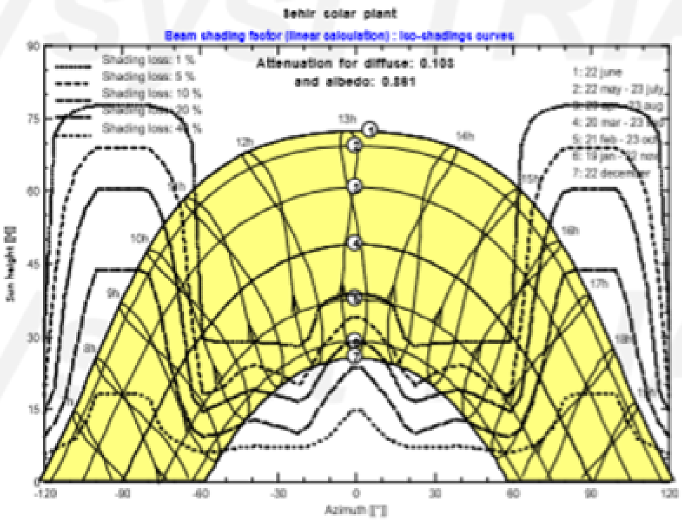
Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	360 kW ac
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene

Iso-shadings diagram



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Grid-Connected System: Main results

Project : **Sehir solar plant**

Simulation variant : **One axis**

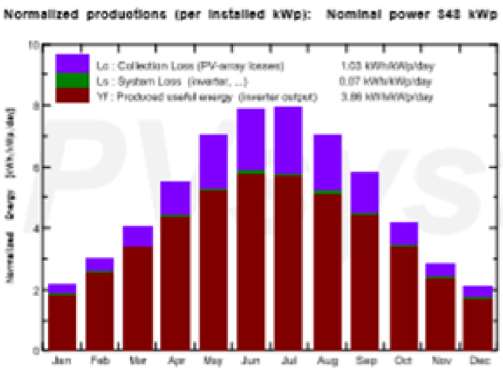
Main system parameters System type **Tracking system**

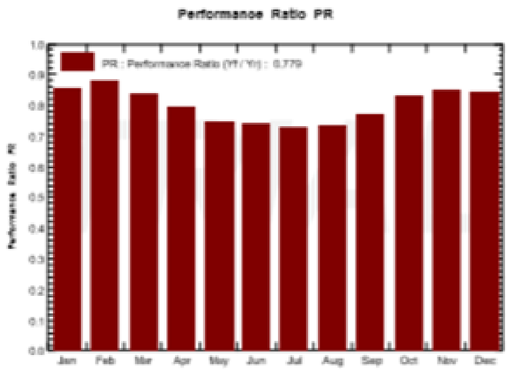
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter	Sunny Tripower 60-US-10 (400 VAC)		Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results

System Production **Produced Energy** **489.6 MWh/year** Specific prod. 1409 kWh/kWp/year

Performance Ratio PR 77.87 %





Fixed var1

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	43.3	26.40	6.31	67.1	61.3	20.20	19.78	0.849
February	55.9	31.50	6.38	84.0	78.4	26.03	25.51	0.874
March	95.5	59.40	9.14	125.6	115.5	37.24	36.52	0.837
April	131.3	73.70	12.51	165.6	148.0	46.79	45.93	0.798
May	172.3	86.60	17.98	218.3	188.4	57.63	56.63	0.746
June	185.9	87.70	22.57	235.4	204.0	61.75	60.73	0.742
July	189.9	87.20	25.68	245.4	210.9	62.82	61.80	0.725
August	165.4	76.60	25.64	216.4	190.5	56.24	55.32	0.736
September	125.4	58.90	21.04	173.6	156.7	47.23	46.42	0.769
October	85.0	43.50	17.06	128.8	120.1	37.89	37.21	0.831
November	55.4	33.70	11.93	84.4	78.0	25.36	24.87	0.848
December	40.9	26.10	8.24	64.6	58.2	19.26	18.86	0.840
Year	1346.2	691.29	15.43	1809.1	1610.0	498.42	489.59	0.779

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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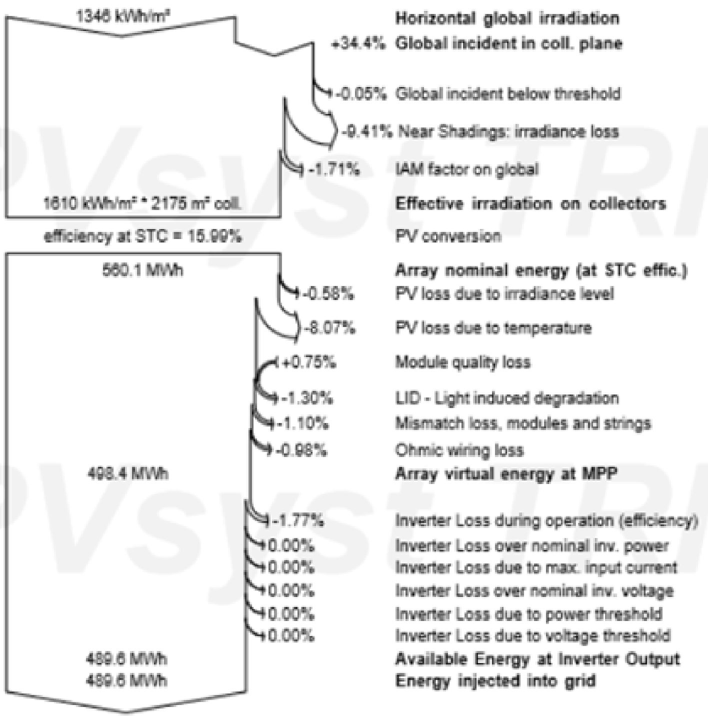
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**One axis**			
	Simulation date	10/04/19 19h22		

Simulation parameters	System type	**Tracking system**		
Tracking plane, Vertical Axis	Plane Tilt	31°		
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.00 m	Collector width	1.00 m
			Ground cov. Ratio (GCR)	50.0 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module	Si-poly	Model	**YL310P-35b**		
Original PVsyst database		Manufacturer	Yingli Solar		
Number of PV modules		In series	12 modules	In parallel	94 strings
Total number of PV modules		Nb. modules	1128	Unit Nom. Power	310 Wp
Array global power		Nominal (STC)	**350 kWp**	At operating cond.	313 kWp (50°C)
Array operating characteristics (50°C)		U mpp	394 V	I mpp	794 A
Total area		Module area	**2189 m²**	Cell area	1976 m²
Inverter		Model	**HPC-050HT-E**		
Original PVsyst database		Manufacturer	Hyundai		
Characteristics		Operating Voltage	300-600 V	Unit Nom. Power	50.0 kWac
Inverter pack		Nb. of inverters	6 units	Total Power	300 kWac
				Pnom ratio	1.17

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	8.3 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

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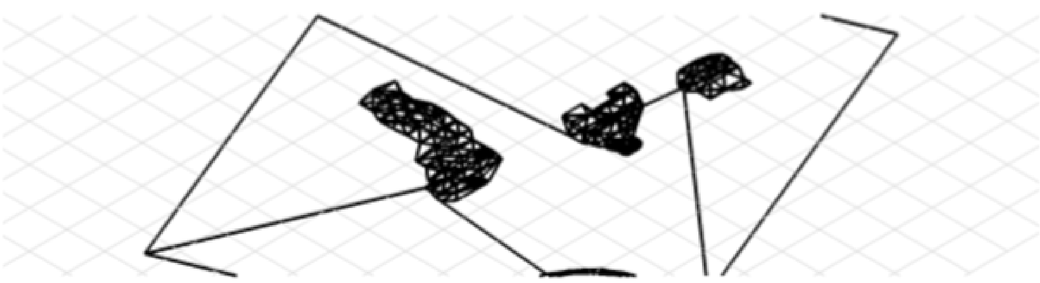
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

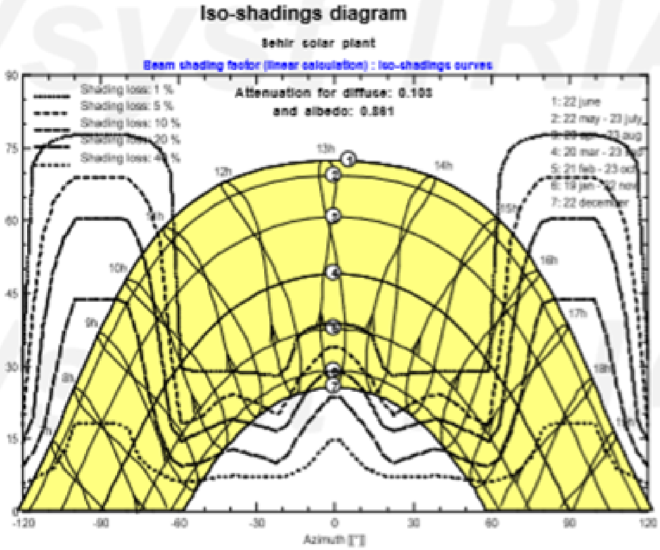
Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1128	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

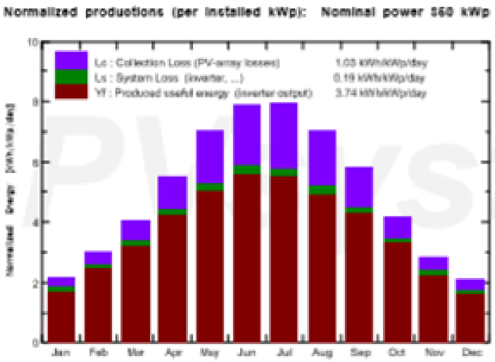
Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**			
Near Shadings	Linear shadings				
PV Field Orientation	Tracking plane, Vertical Axis			Plane Tilt	31°
PV modules	Model	YL310P-35b		Pnom	310 Wp
PV Array	Nb. of modules	1128		Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E		Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0		Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)				

Main simulation results

System Production	**Produced Energy**	**477.1 MWh/year**	Specific prod.	1364 kWh/kWp/year
	Performance Ratio PR	75.41 %		



Fixed var1

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	43.3	26.40	6.31	67.1	61.3	20.33	19.14	0.816
February	55.9	31.50	6.38	84.0	78.4	26.19	24.81	0.845
March	95.5	59.40	9.14	125.6	115.5	37.46	35.54	0.809
April	131.3	73.70	12.51	165.6	148.0	47.04	44.79	0.773
May	172.3	86.60	17.98	218.3	188.4	57.99	55.20	0.723
June	185.9	87.70	22.57	235.4	204.0	62.14	59.29	0.720
July	189.9	87.20	25.68	245.4	210.9	63.22	60.33	0.703
August	165.4	76.60	25.64	216.4	190.5	56.59	53.93	0.713
September	125.4	58.90	21.04	173.6	156.7	47.53	45.25	0.745
October	85.0	43.50	17.06	128.8	120.1	38.12	36.26	0.805
November	55.4	33.70	11.93	84.4	78.0	25.51	24.22	0.821
December	40.9	26.10	8.24	64.6	58.2	19.38	18.31	0.810
Year	1346.2	691.29	15.43	1809.1	1610.0	501.51	477.06	0.754

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

PVsyst Evaluation mode

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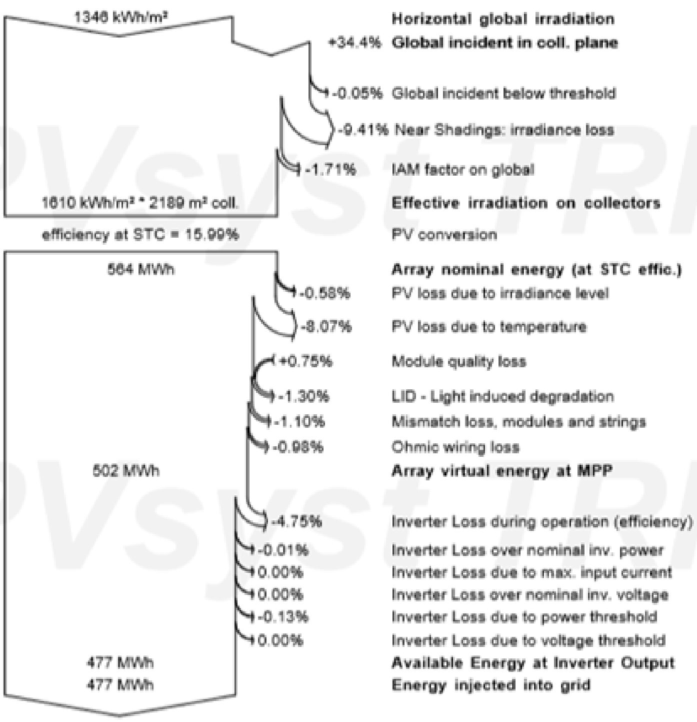
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1128	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**One axis**			
	Simulation date	10/04/19 19h21		

Simulation parameters	System type	**Tracking system**		
Tracking plane, Vertical Axis	Plane Tilt	31°		
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.00 m	Collector width	1.00 m
			Ground cov. Ratio (GCR)	50.0 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics					
PV module	Si-poly	Model	**YL310P-35b**		
Original PVsyst database		Manufacturer	Yingli Solar		
Number of PV modules		In series	17 modules	In parallel	66 strings
Total number of PV modules		Nb. modules	1122	Unit Nom. Power	310 Wp
Array global power		Nominal (STC)	**348 kWp**	At operating cond.	311 kWp (50°C)
Array operating characteristics (50°C)		U mpp	558 V	I mpp	557 A
Total area		Module area	**2177 m²**	Cell area	1965 m²
Inverter		Model	**Solarmax 50TS**		
Original PVsyst database		Manufacturer	SolarMax		
Characteristics		Operating Voltage	430-800 V	Unit Nom. Power	50.0 kWac
Inverter pack		Nb. of inverters	6 units	Total Power	300 kWac
				Pnom ratio	1.16

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	17 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect (IAM): User defined profile				

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

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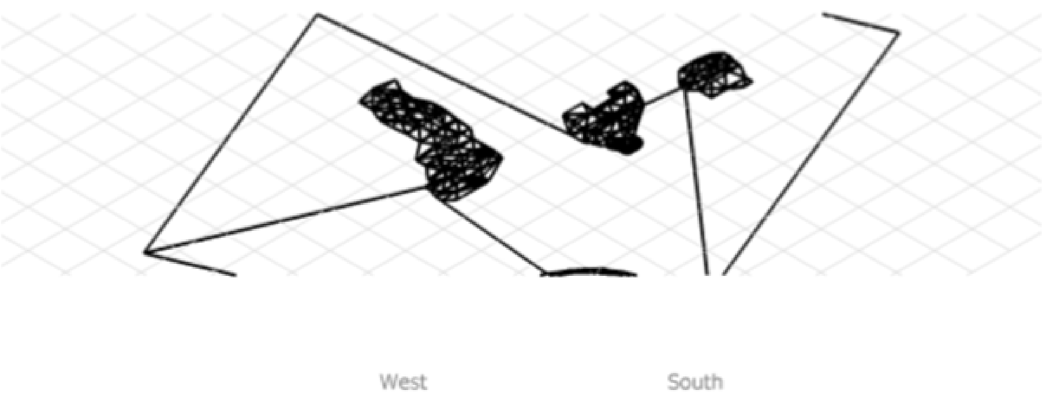
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

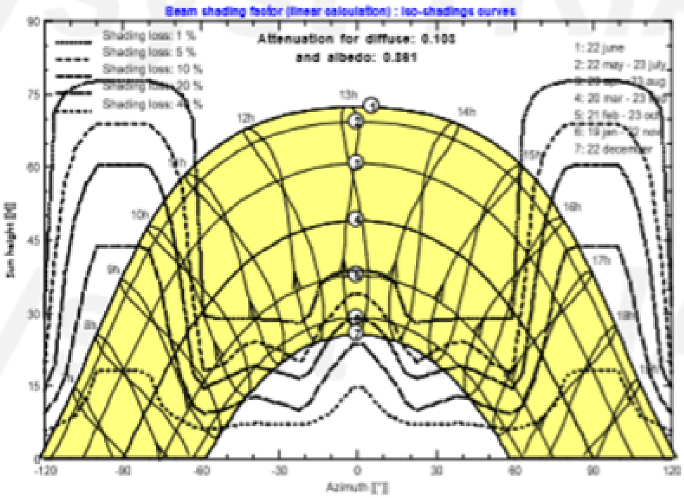
Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

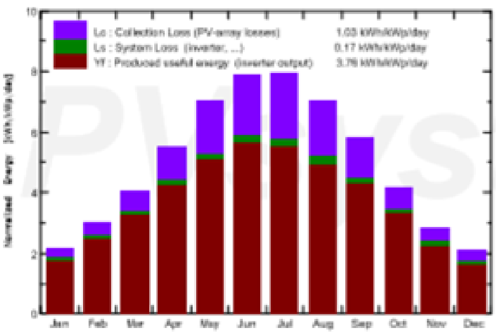
Project : **Sehir solar plant**

Simulation variant : **One axis**

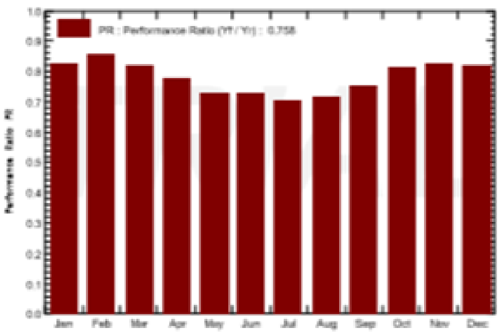
Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**476.8 MWh/year**	Specific prod.	1371 kWh/kWp/year
	Performance Ratio PR	75.77 %		

Normalized productions (per installed kWp): Nominal power 348 kWp



Performance Ratio PR



Fixed var1

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	43.3	26.40	6.31	67.1	61.3	20.22	19.16	0.821
February	55.9	31.50	6.38	84.0	78.4	26.05	24.82	0.850
March	95.5	59.40	9.14	125.6	115.5	37.27	35.54	0.814
April	131.3	73.70	12.51	165.6	148.0	46.82	44.76	0.777
May	172.3	86.60	17.98	218.3	188.4	57.69	55.17	0.727
June	185.9	87.70	22.57	235.4	204.0	61.81	59.22	0.723
July	189.9	87.20	25.68	245.4	210.9	62.89	60.26	0.706
August	165.4	76.60	25.64	216.4	190.5	56.29	53.89	0.716
September	125.4	58.90	21.04	173.6	156.7	47.27	45.21	0.749
October	85.0	43.50	17.06	128.8	120.1	37.92	36.25	0.809
November	55.4	33.70	11.93	84.4	78.0	25.38	24.19	0.824
December	40.9	26.10	8.24	64.6	58.2	19.27	18.30	0.814
Year	1346.2	691.29	15.43	1809.1	1610.0	498.88	476.78	0.758

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	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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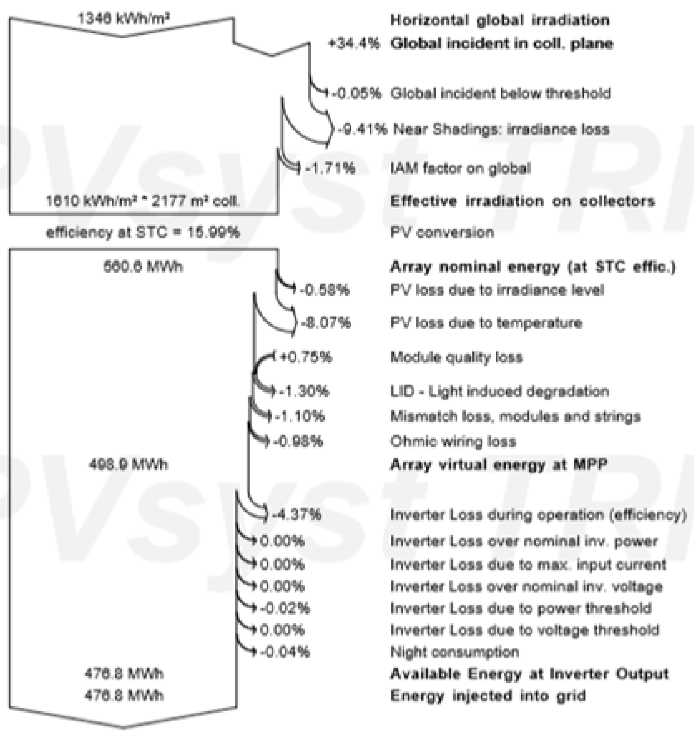
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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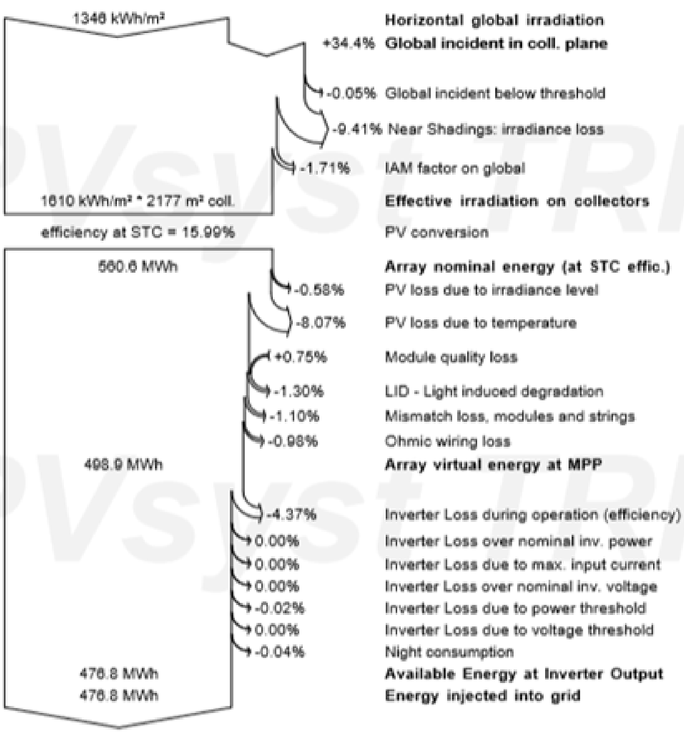
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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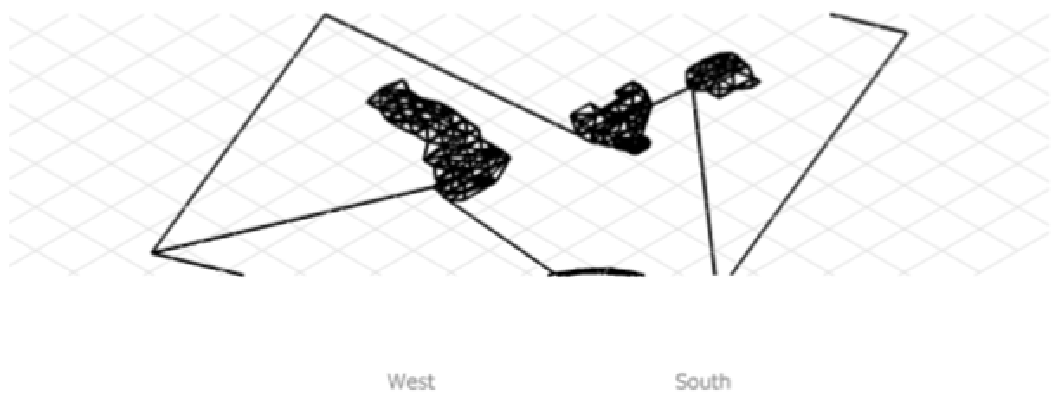
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

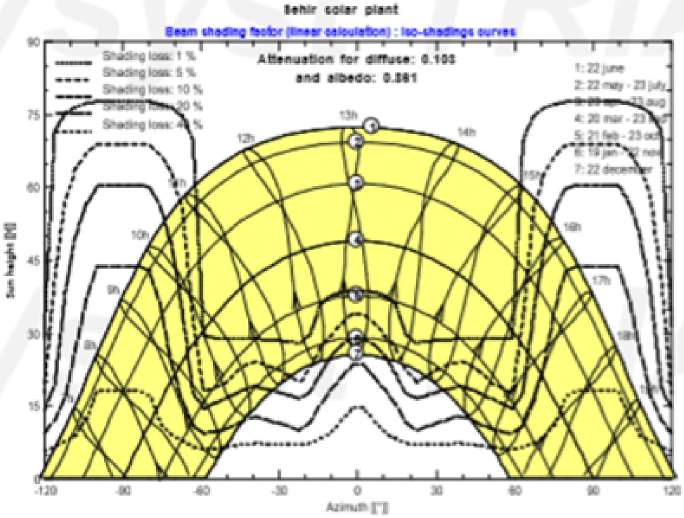
Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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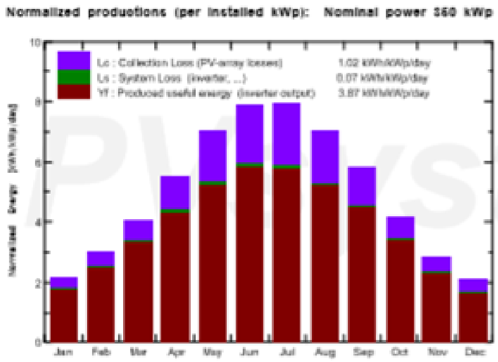
Grid-Connected System: Main results

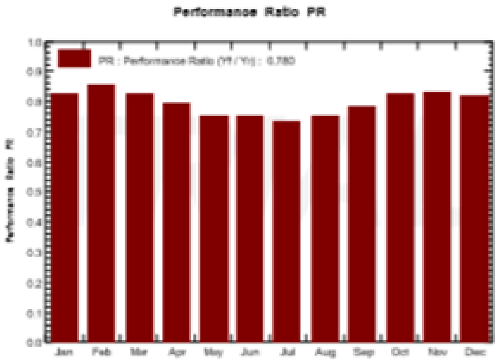
Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**			
Near Shadings	Linear shadings				
PV Field Orientation	Tracking plane, Vertical Axis			Plane Tilt	31°
PV modules	Model	VBHN230SE51		Pnom	230 Wp
PV Array	Nb. of modules	1520		Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)		Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0		Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)				

Main simulation results					
System Production	**Produced Energy**	**493.2 MWh/year**	Specific prod.	**1411** kWh/kWp/year	
	Performance Ratio PR	77.99 %			





Fixed var1

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	43.3	26.40	6.31	67.1	60.9	19.78	19.38	0.826
February	55.9	31.50	6.38	84.0	78.0	25.49	25.00	0.851
March	95.5	59.40	9.14	125.6	115.1	36.99	36.29	0.827
April	131.3	73.70	12.51	165.6	147.6	46.90	46.05	0.795
May	172.3	86.60	17.98	218.3	187.9	58.46	57.43	0.753
June	185.9	87.70	22.57	235.4	203.5	62.84	61.79	0.751
July	189.9	87.20	25.68	245.4	210.3	64.28	63.22	0.737
August	165.4	76.60	25.64	216.4	190.1	57.76	56.78	0.751
September	125.4	58.90	21.04	173.6	156.2	48.10	47.26	0.779
October	85.0	43.50	17.06	128.8	119.5	37.80	37.14	0.825
November	55.4	33.70	11.93	84.4	77.5	24.97	24.51	0.831
December	40.9	26.10	8.24	64.6	57.8	18.78	18.41	0.815
Year	1346.2	691.29	15.43	1809.1	1604.5	502.15	493.25	0.780

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	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

PVsyst Evaluation mode

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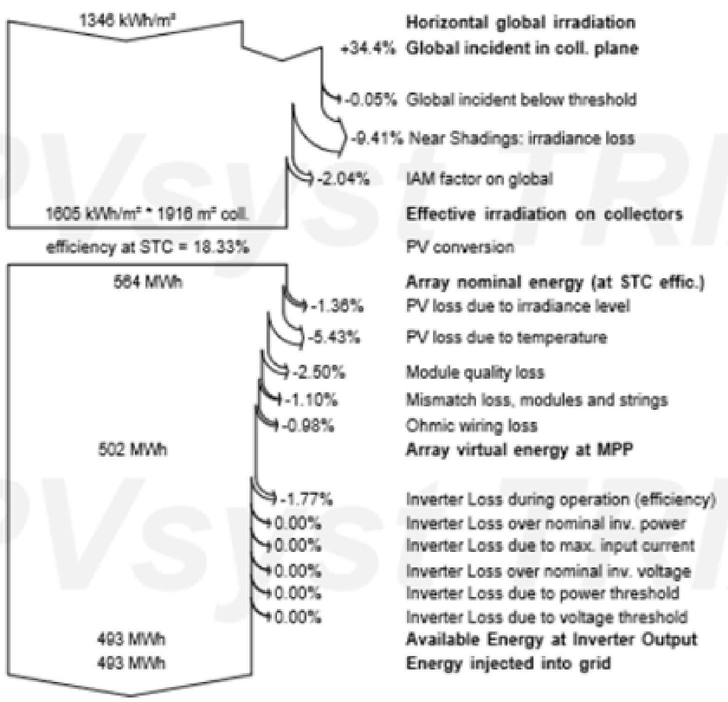
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project : **Sehir solar plant**

Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant : **One axis**

Simulation date 10/04/19 19h18

Simulation parameters	System type	**Tracking system**		
Tracking plane, Vertical Axis	Plane Tilt	31°		
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.00 m	Collector width	1.00 m
			Ground cov. Ratio (GCR)	50.0 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module	HIT	Model	**VBHN230SE51**		
Original PVsyst database		Manufacturer	Panasonic		
Number of PV modules		In series	9 modules	In parallel	169 strings
Total number of PV modules		Nb. modules	1521	Unit Nom. Power	230 Wp
Array global power		Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)		U mpp	361 V	I mpp	903 A
Total area		Module area	**1918 m²**	Cell area	1667 m²
Inverter		Model	**HPC-050HT-E**		
Original PVsyst database		Manufacturer	Hyundai		
Characteristics		Operating Voltage	300-600 V	Unit Nom. Power	50.0 kWac
Inverter pack		Nb. of inverters	6 units	Total Power	300 kWac
				Pnom ratio	1.17

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	6.5 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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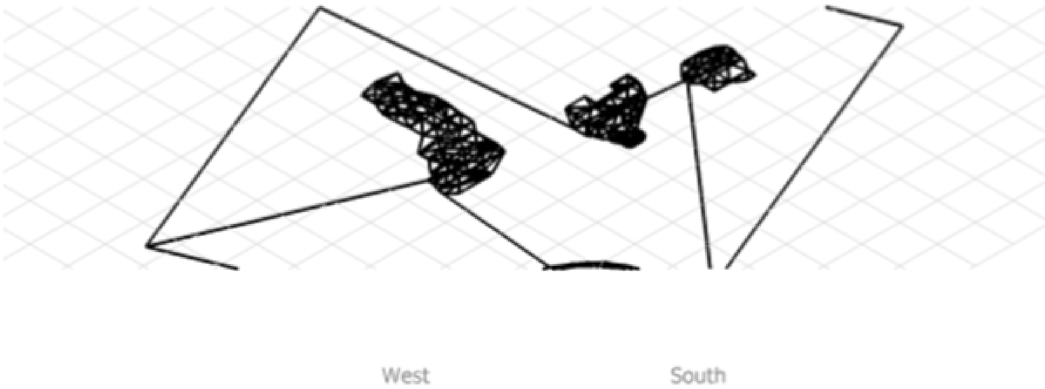
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

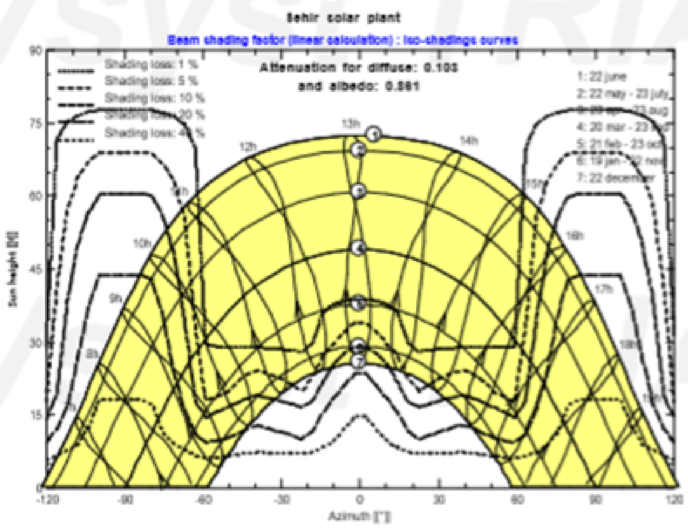
Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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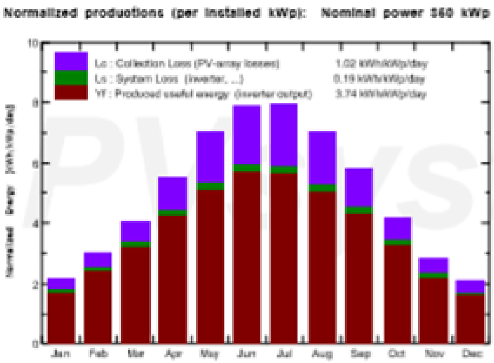
Grid-Connected System: Main results

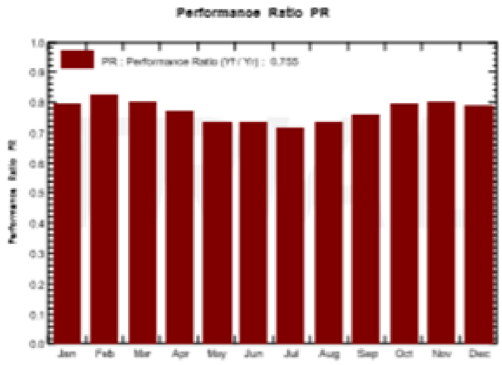
Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**477.7 MWh/year**	Specific prod.	1365 kWh/kWp/year
	Performance Ratio PR	75.47 %		





Fixed var1

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	43.3	26.40	6.31	67.1	60.9	19.79	18.62	0.794
February	55.9	31.50	6.38	84.0	78.0	25.50	24.14	0.822
March	95.5	59.40	9.14	125.6	115.1	37.00	35.09	0.799
April	131.3	73.70	12.51	165.6	147.6	46.83	44.57	0.769
May	172.3	86.60	17.98	218.3	187.9	58.46	55.63	0.728
June	185.9	87.70	22.57	235.4	203.5	62.87	59.98	0.728
July	189.9	87.20	25.68	245.4	210.3	64.31	61.36	0.715
August	165.4	76.60	25.64	216.4	190.1	57.80	55.06	0.728
September	125.4	58.90	21.04	173.6	156.2	48.12	45.80	0.754
October	85.0	43.50	17.06	128.8	119.5	37.81	35.96	0.798
November	55.4	33.70	11.93	84.4	77.5	24.99	23.71	0.803
December	40.9	26.10	8.24	64.6	57.8	18.79	17.74	0.785
Year	1346.2	691.29	15.43	1809.1	1604.5	502.27	477.68	0.755

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	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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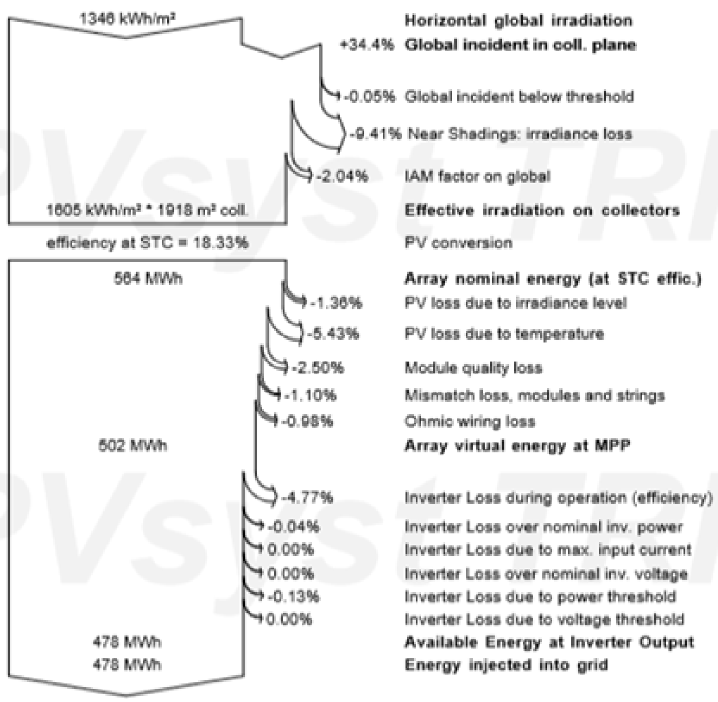
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**One axis**			
	Simulation date	10/04/19 19h20		

Simulation parameters	System type	**Tracking system**		
Tracking plane, Vertical Axis	Plane Tilt	31°		
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.00 m	Collector width	1.00 m
			Ground cov. Ratio (GCR)	50.0 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics				
PV module	HIT Model	**VBHN230SE51**		
Original PVsyst database	Manufacturer	Panasonic		
Number of PV modules	In series	13 modules	In parallel	117 strings
Total number of PV modules	Nb. modules	1521	Unit Nom. Power	230 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)	U mpp	521 V	I mpp	625 A
Total area	Module area	**1918 m²**	Cell area	1667 m²
Inverter	Model	**Solarmax 50TS**		
Original PVsyst database	Manufacturer	SolarMax		
Characteristics	Operating Voltage	430-800 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	300 kWac
			Pnom ratio	1.17

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	14 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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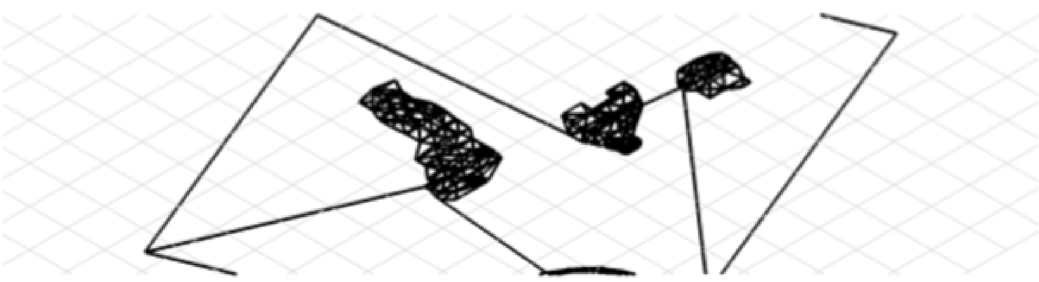
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

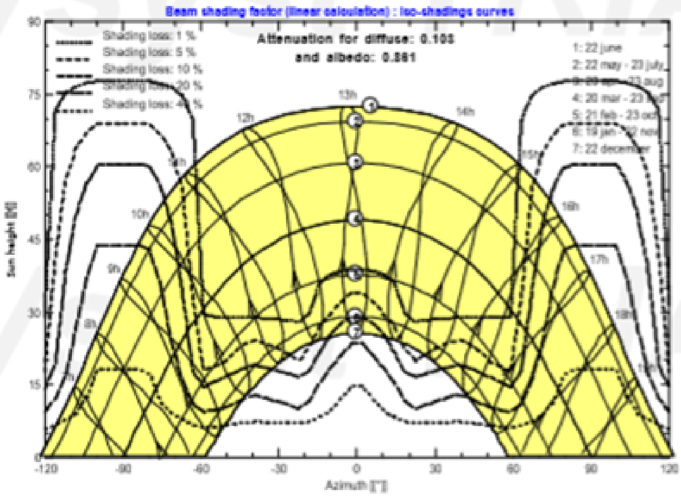
Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**			
Near Shadings	Linear shadings				
PV Field Orientation	Tracking plane, Vertical Axis			Plane Tilt	31°
PV modules	Model	VBHN230SE51		Pnom	230 Wp
PV Array	Nb. of modules	1521		Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS		Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0		Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)				

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

Project : **Sehir solar plant**

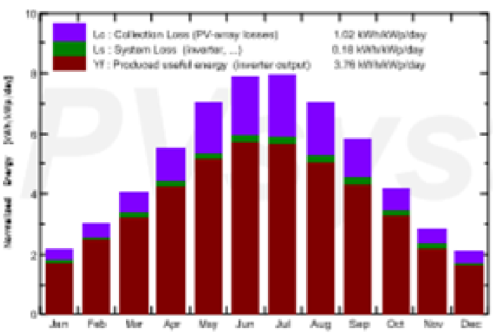
Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

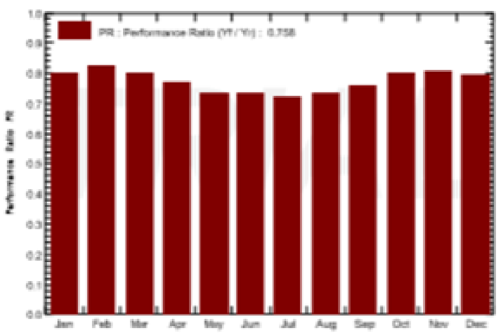
Main simulation results

System Production	**Produced Energy**	**479.8 MWh/year**	Specific prod.	1372 kWh/kWp/year
	Performance Ratio PR	75.82 %		

Normalized productions (per installed kWp): Nominal power 350 kWp



Performance Ratio PR



Fixed var1

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	43.3	26.40	6.31	67.1	60.9	19.79	18.74	0.799
February	55.9	31.50	6.38	84.0	78.0	25.50	24.28	0.827
March	95.5	59.40	9.14	125.6	115.1	36.99	35.27	0.803
April	131.3	73.70	12.51	165.6	147.6	46.81	44.74	0.772
May	172.3	86.60	17.98	218.3	187.9	58.44	55.89	0.732
June	185.9	87.70	22.57	235.4	203.5	62.86	60.22	0.731
July	189.9	87.20	25.68	245.4	210.3	64.30	61.61	0.718
August	165.4	76.60	25.64	216.4	190.1	57.80	55.32	0.731
September	125.4	58.90	21.04	173.6	156.2	48.09	45.99	0.757
October	85.0	43.50	17.06	128.8	119.5	37.81	36.14	0.802
November	55.4	33.70	11.93	84.4	77.5	24.99	23.81	0.807
December	40.9	26.10	8.24	64.6	57.8	18.79	17.83	0.789
Year	1346.2	691.29	15.43	1809.1	1604.5	502.19	479.84	0.758

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

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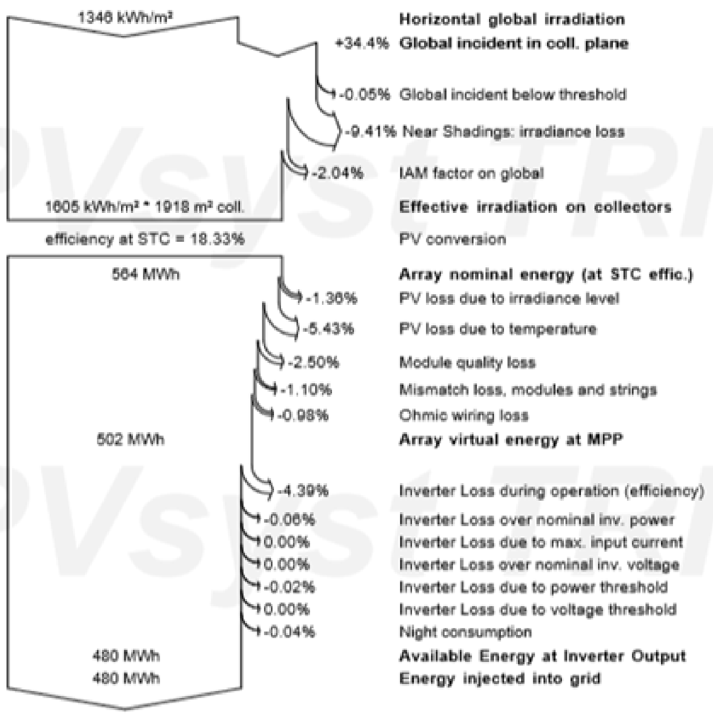
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **One axis**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking plane, Vertical Axis		Plane Tilt	31°
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Appendix C

Two axis Appendix

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Grid-Connected System: Simulation parameters

Project : **Sehir solar plant**

Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant : **Two way axis var1**

Simulation date 10/04/19 20h05

Simulation parameters	System type	**Tracking system**		
Tracking plane, two axis	Minimum Tilt	0°	Maximum Tilt	80°
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.20 m	Collector width	1.01 m
			Ground cov. Ratio (GCR)	45.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module Si-poly	Model	**YL310P-35b**		
Original PVsyst database	Manufacturer	Yingli Solar		
Number of PV modules	In series	19 modules	In parallel	59 strings
Total number of PV modules	Nb. modules	1121	Unit Nom. Power	310 Wp
Array global power	Nominal (STC)	**348 kWp**	At operating cond.	311 kWp (50°C)
Array operating characteristics (50°C)	U mpp	624 V	I mpp	498 A
Total area	Module area	**2175 m²**	Cell area	1964 m²
Inverter	Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	360 kWac
			Pnom ratio	0.97

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	21 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

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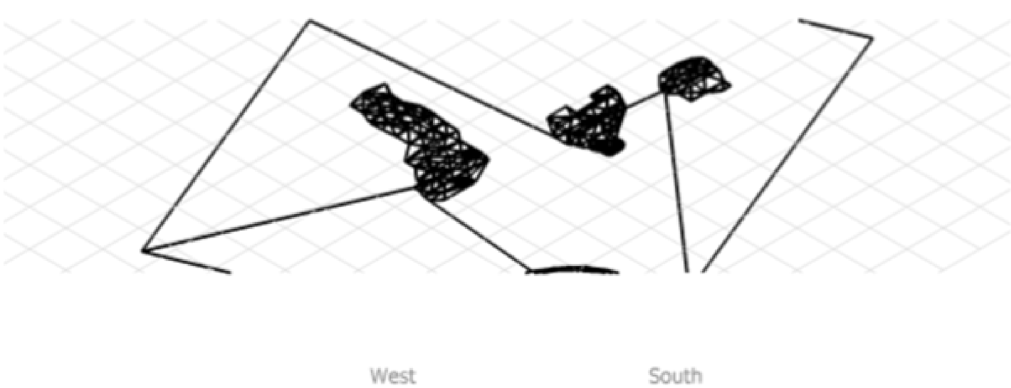
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

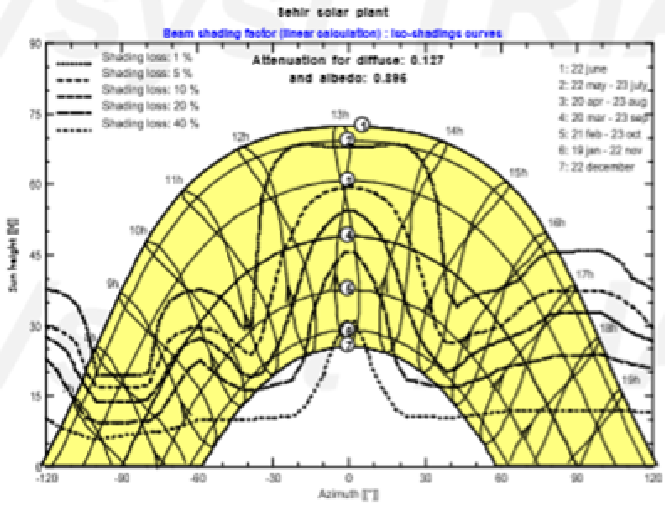
Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



PVsyst Evaluation mode

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Grid-Connected System: Main results

Project : **Sehir solar plant**

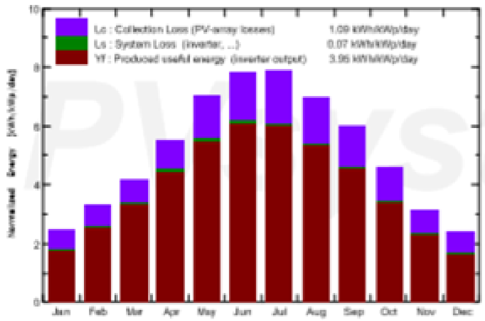
Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

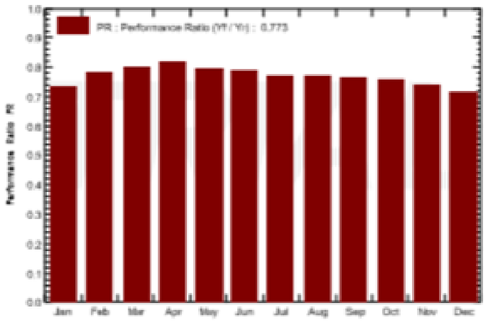
Main simulation results

System Production	**Produced Energy**	**501.3 MWh/year**	Specific prod.	1443 kWh/kWp/year
	Performance Ratio PR	77.32 %		

Normalized productions (per installed kWp): Nominal power 348 kWp



Performance Ratio PR



Two way axis var1

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	43.3	26.40	6.31	75.9	60.4	19.75	19.33	0.733
February	55.9	31.50	6.38	92.8	77.6	25.68	25.16	0.780
March	95.5	59.40	9.14	129.7	114.0	36.69	35.99	0.798
April	131.3	73.70	12.51	165.3	151.2	47.69	46.82	0.815
May	172.3	86.60	17.98	217.8	199.9	60.72	59.67	0.788
June	185.9	87.70	22.57	234.5	215.9	64.96	63.89	0.784
July	189.9	87.20	25.68	244.1	224.1	66.34	65.27	0.769
August	165.4	76.60	25.64	215.8	199.3	58.66	57.71	0.769
September	125.4	58.90	21.04	179.4	160.8	48.40	47.57	0.763
October	85.0	43.50	17.06	142.0	120.1	37.87	37.19	0.754
November	55.4	33.70	11.93	94.3	76.4	24.78	24.31	0.742
December	40.9	26.10	8.24	74.1	57.0	18.77	18.38	0.714
Year	1346.2	691.29	15.43	1865.7	1656.6	510.31	501.29	0.773

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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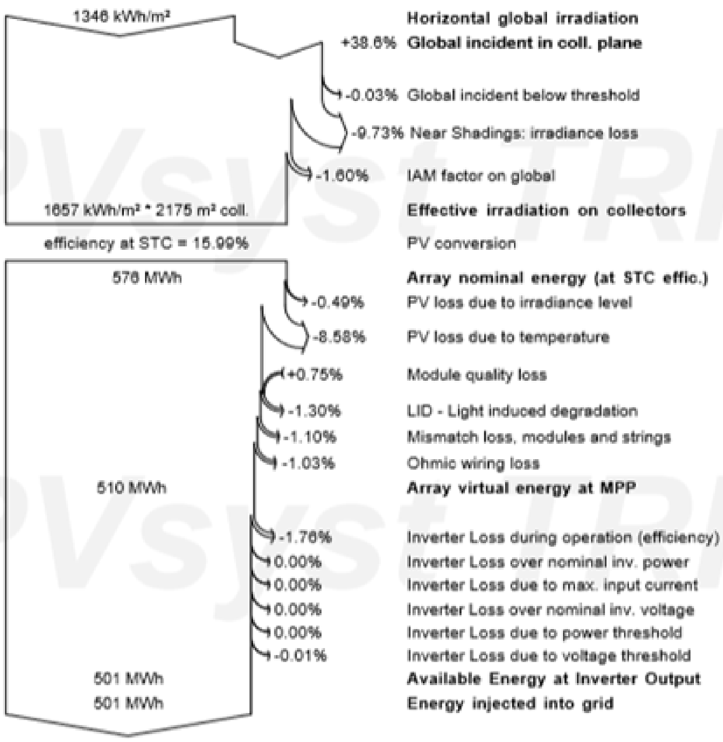
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1121	Pnom total	**348 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Two way axis var1**			
	Simulation date	10/04/19 20h08		

Simulation parameters	System type	**Tracking system**		
Tracking plane, two axis	Minimum Tilt	0°	Maximum Tilt	80°
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.20 m	Collector width	1.01 m
			Ground cov. Ratio (GCR)	45.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics					
PV module	Si-poly	Model	**YL310P-35b**		
Original PVsyst database		Manufacturer	Yingli Solar		
Number of PV modules		In series	12 modules	In parallel	94 strings
Total number of PV modules		Nb. modules	1128	Unit Nom. Power	310 Wp
Array global power		Nominal (STC)	**350 kWp**	At operating cond.	313 kWp (50°C)
Array operating characteristics (50°C)		U mpp	394 V	I mpp	794 A
Total area		Module area	**2189 m²**	Cell area	1976 m²
Inverter		Model	**HPC-050HT-E**		
Original PVsyst database		Manufacturer	Hyundai		
Characteristics		Operating Voltage	300-600 V	Unit Nom. Power	50.0 kWac
Inverter pack		Nb. of inverters	6 units	Total Power	300 kWac
				Pnom ratio	1.17

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	8.3 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

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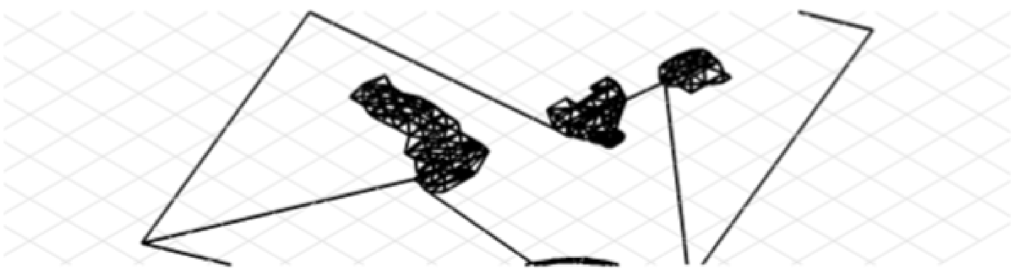
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

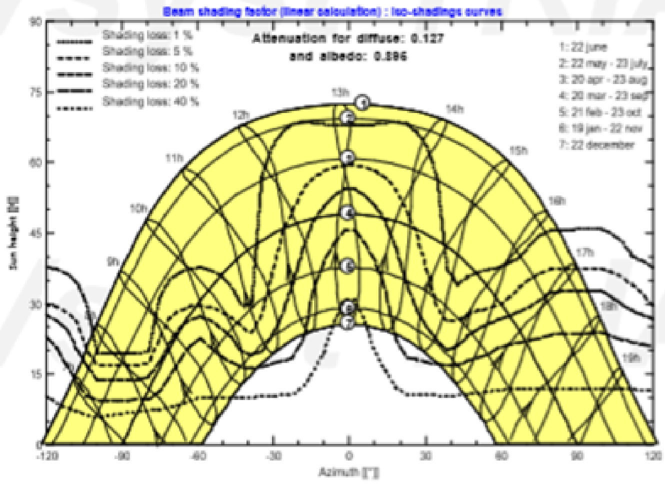
Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1128	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



PVsyst Evaluation mode

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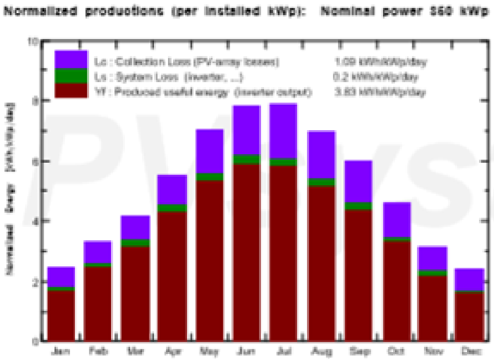
Grid-Connected System: Main results

Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1128	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**488.4 MWh/year**	Specific prod.	1397 kWh/kWp/year
	Performance Ratio PR	74.86 %		



Two way axis var1

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	43.3	26.40	6.31	75.9	60.4	19.87	18.68	0.704
February	55.9	31.50	6.38	92.8	77.6	25.84	24.46	0.754
March	95.5	59.40	9.14	129.7	114.0	36.92	35.01	0.772
April	131.3	73.70	12.51	165.3	151.2	47.97	45.65	0.790
May	172.3	86.60	17.98	217.8	199.9	61.10	58.17	0.764
June	185.9	87.70	22.57	234.5	215.9	65.37	62.37	0.761
July	189.9	87.20	25.68	244.1	224.1	66.77	63.72	0.746
August	165.4	76.60	25.64	215.8	199.3	59.03	56.28	0.746
September	125.4	58.90	21.04	179.4	160.8	48.70	46.37	0.739
October	85.0	43.50	17.06	142.0	120.1	38.10	36.22	0.730
November	55.4	33.70	11.93	94.3	76.4	24.94	23.63	0.717
December	40.9	26.10	8.24	74.1	57.0	18.89	17.81	0.687
Year	1346.2	691.29	15.43	1865.7	1656.6	513.50	488.38	0.749

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	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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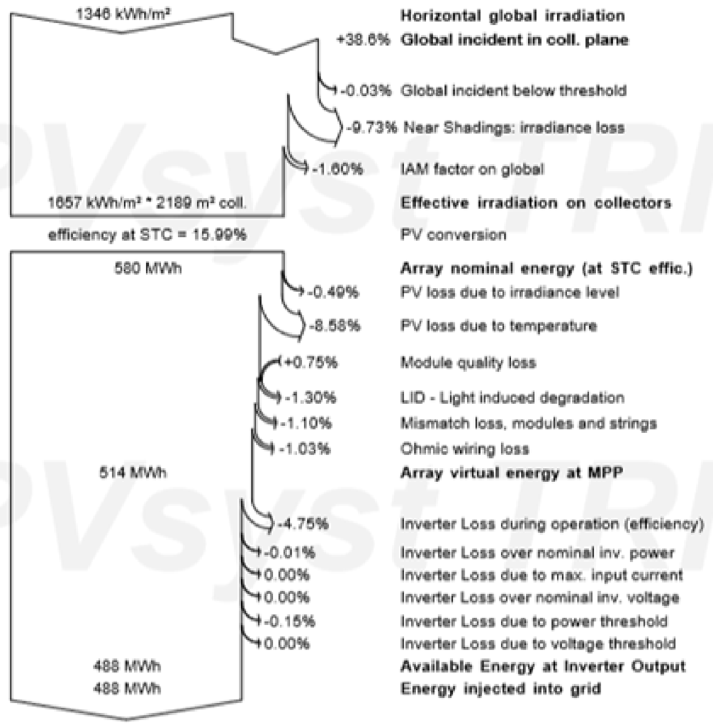
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1128	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Two way axis var1**	
	Simulation date	10/04/19 20h10

Simulation parameters	System type	**Tracking system**		
Tracking plane, two axis	Minimum Tilt	0°	Maximum Tilt	80°
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.20 m	Collector width	1.01 m
			Ground cov. Ratio (GCR)	45.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module	Si-poly	Model	**YL310P-35b**		
Original PVsyst database		Manufacturer	Yingli Solar		
Number of PV modules		In series	17 modules	In parallel	66 strings
Total number of PV modules		Nb. modules	1122	Unit Nom. Power	310 Wp
Array global power		Nominal (STC)	**348 kWp**	At operating cond.	311 kWp (50°C)
Array operating characteristics (50°C)		U mpp	558 V	I mpp	557 A
Total area		Module area	**2177 m²**	Cell area	1965 m²
Inverter		Model	**Solarmax 50TS**		
Original PVsyst database		Manufacturer	SolarMax		
Characteristics		Operating Voltage	430-800 V	Unit Nom. Power	50.0 kWac
Inverter pack		Nb. of inverters	6 units	Total Power	300 kWac
				Pnom ratio	1.16

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	17 mOhm	Loss Fraction	1.5 % at STC
LID - Light Induced Degradation			Loss Fraction	1.3 %
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): User defined profile

0°	20°	40°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.960	0.880	0.800	0.670	0.430	0.000

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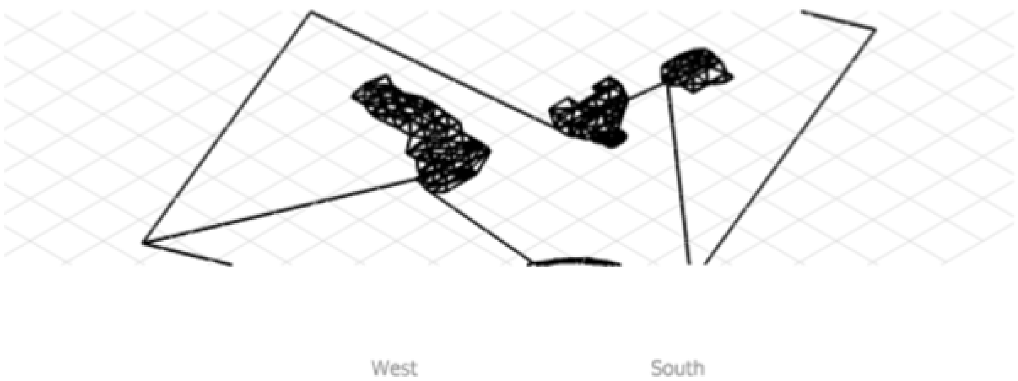
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

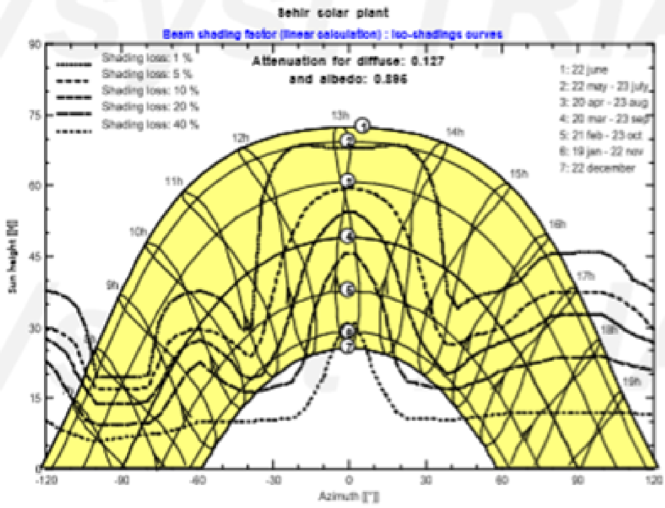
Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



PVsyst Evaluation mode

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Grid-Connected System: Main results

Project : **Sehir solar plant**

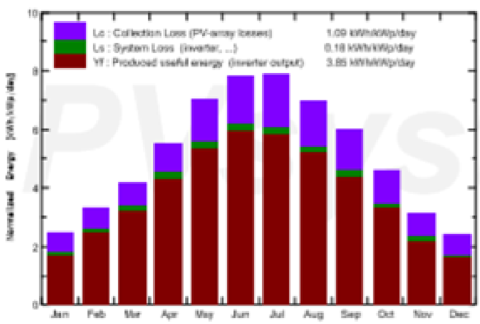
Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

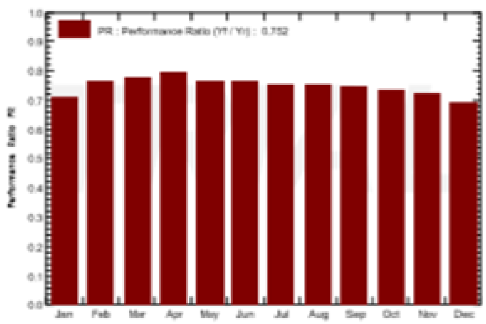
Main simulation results

System Production	**Produced Energy**	**488.2 MWh/year**	Specific prod.	1404 kWh/kWp/year
	Performance Ratio PR	75.23 %		

Normalized productions (per installed kWp): Nominal power 348 kWp



Performance Ratio PR



Two way axis var1

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	43.3	26.40	6.31	75.9	60.4	19.77	18.71	0.709
February	55.9	31.50	6.38	92.8	77.6	25.70	24.47	0.758
March	95.5	59.40	9.14	129.7	114.0	36.73	35.02	0.776
April	131.3	73.70	12.51	165.3	151.2	47.73	45.63	0.794
May	172.3	86.60	17.98	217.8	199.9	60.78	58.14	0.768
June	185.9	87.70	22.57	234.5	215.9	65.02	62.31	0.764
July	189.9	87.20	25.68	244.1	224.1	66.42	63.66	0.750
August	165.4	76.60	25.64	215.8	199.3	58.71	56.23	0.749
September	125.4	58.90	21.04	179.4	160.8	48.44	46.34	0.743
October	85.0	43.50	17.06	142.0	120.1	37.90	36.22	0.733
November	55.4	33.70	11.93	94.3	76.4	24.80	23.64	0.721
December	40.9	26.10	8.24	74.1	57.0	18.79	17.81	0.691
Year	1346.2	691.29	15.43	1865.7	1656.6	510.79	488.20	0.752

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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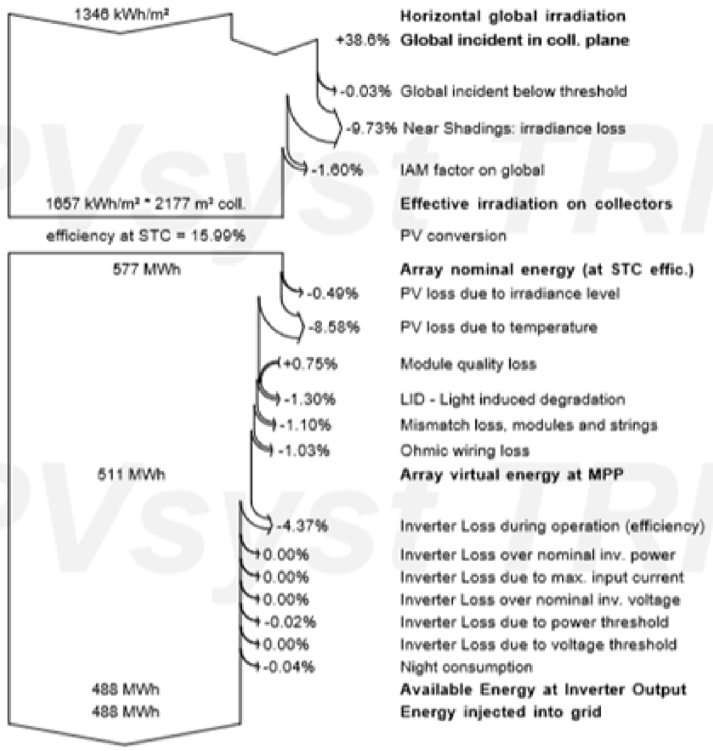
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	YL310P-35b	Pnom	310 Wp
PV Array	Nb. of modules	1122	Pnom total	**348 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Two way axis var1**			
	Simulation date	10/04/19 20h15		

Simulation parameters	System type	**Tracking system**		
Tracking plane, two axis	Minimum Tilt	0°	Maximum Tilt	80°
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.20 m	Collector width	1.01 m
			Ground cov. Ratio (GCR)	45.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics				
PV module HIT	Model	**VBHN230SE51**		
Original PVsyst database	Manufacturer	Panasonic		
Number of PV modules	In series	16 modules	In parallel	95 strings
Total number of PV modules	Nb. modules	1520	Unit Nom. Power	230 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)	U mpp	642 V	I mpp	508 A
Total area	Module area	**1916 m²**	Cell area	1666 m²
Inverter	Model	**Sunny Tripower 60-US-10 (400 VAC)**		
Original PVsyst database	Manufacturer	SMA		
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power	60.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	360 kWac
			Pnom ratio	0.97

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	20 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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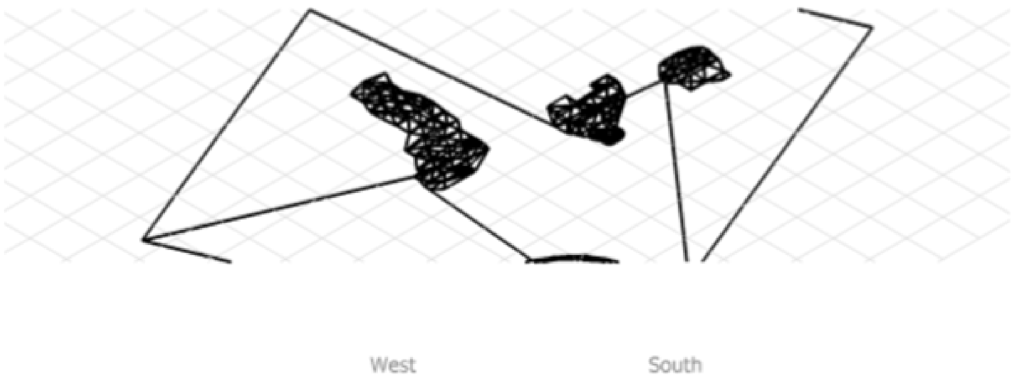
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

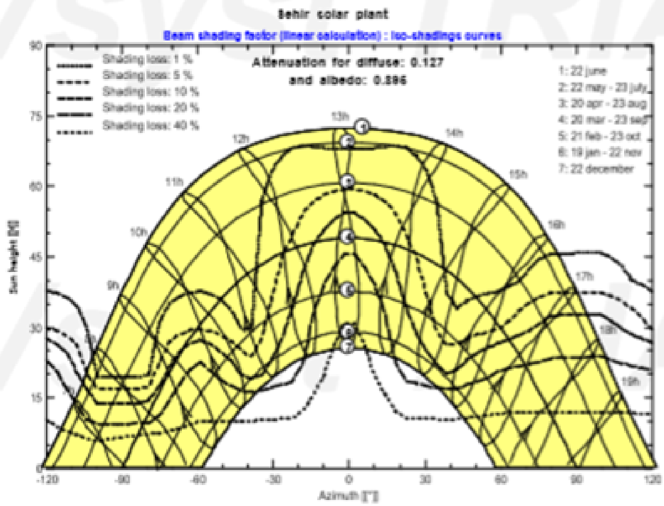
Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



PVsyst Evaluation mode

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Grid-Connected System: Main results

Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

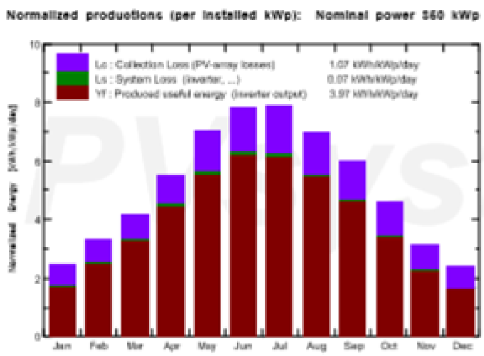
Main system parameters System type **Tracking system**

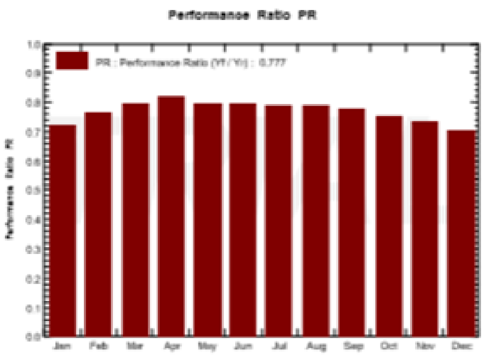
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results

System Production — **Produced Energy** **507.0 MWh/year** — Specific prod. 1450 kWh/kWp/year

Performance Ratio PR 77.73 %





Two way axis var1

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	43.3	26.40	6.31	75.9	60.4	19.51	19.11	0.720
February	55.9	31.50	6.38	92.8	77.5	25.27	24.78	0.764
Maroh	95.5	59.40	9.14	129.7	113.8	36.54	35.85	0.791
April	131.3	73.70	12.51	165.3	151.0	47.90	47.03	0.814
May	172.3	86.60	17.98	217.8	199.4	61.82	60.73	0.798
June	185.9	87.70	22.57	234.5	215.3	66.30	65.18	0.795
July	189.9	87.20	25.68	244.1	223.4	68.09	66.96	0.785
August	165.4	76.60	25.64	215.8	198.9	60.38	59.37	0.787
September	125.4	58.90	21.04	179.4	160.5	49.41	48.55	0.774
October	85.0	43.50	17.06	142.0	120.0	37.91	37.25	0.750
November	55.4	33.70	11.93	94.3	76.3	24.56	24.11	0.731
December	40.9	26.10	8.24	74.1	57.0	18.46	18.09	0.698
Year	1346.2	691.29	15.43	1865.7	1653.4	516.15	506.99	0.777

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	Ambient Temperature	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

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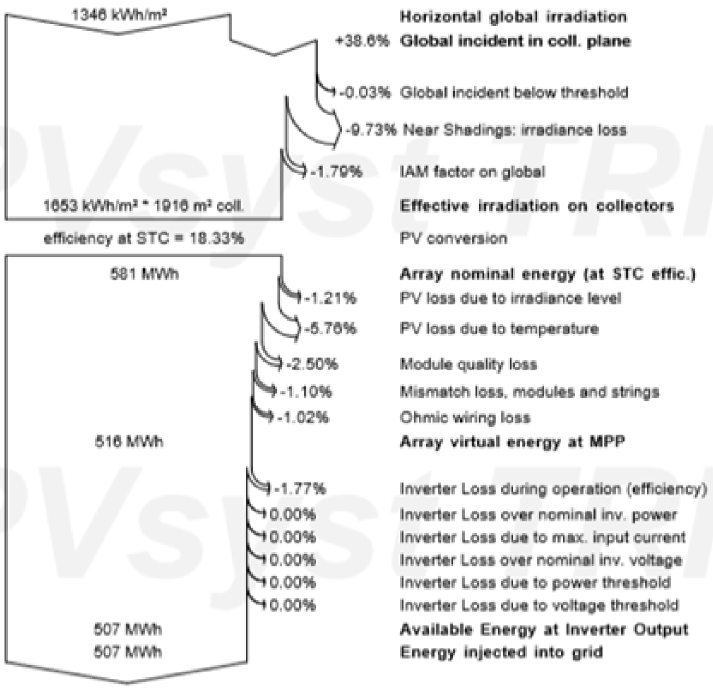
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1520	Pnom total	**350 kWp**
Inverter		Sunny Tripower 60-US-10 (400 VAC)	Pnom	60.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**360 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Two way axis var1**			
	Simulation date	10/04/19 20h13		

Simulation parameters	System type	**Tracking system**		
Tracking plane, two axis	Minimum Tilt	0°	Maximum Tilt	80°
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.20 m	Collector width	1.01 m
			Ground cov. Ratio (GCR)	45.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics				
PV module	HIT Model	**VBHN230SE51**		
Original PVsyst database	Manufacturer	Panasonic		
Number of PV modules	In series	9 modules	In parallel	169 strings
Total number of PV modules	Nb. modules	1521	Unit Nom. Power	230 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)	U mpp	361 V	I mpp	903 A
Total area	Module area	**1918 m²**	Cell area	1667 m²
Inverter	Model	**HPC-050HT-E**		
Original PVsyst database	Manufacturer	Hyundai		
Characteristics	Operating Voltage	300-600 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	300 kWac
			Pnom ratio	1.17

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	6.5 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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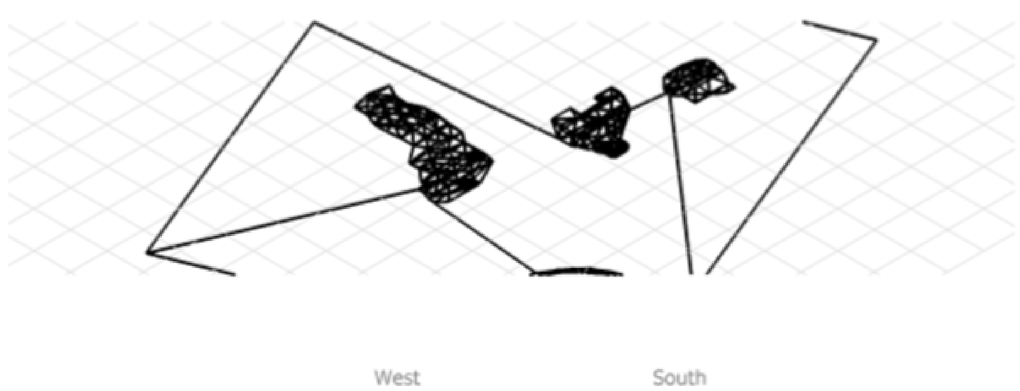
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

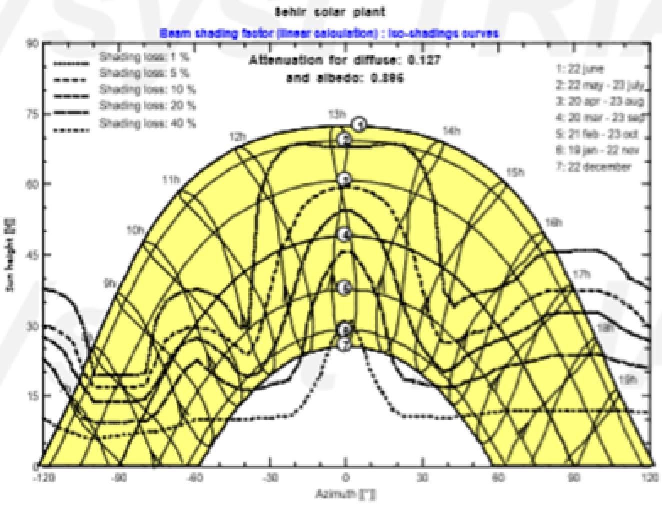
Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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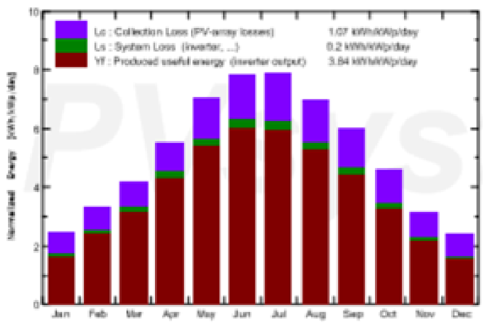
Grid-Connected System: Main results

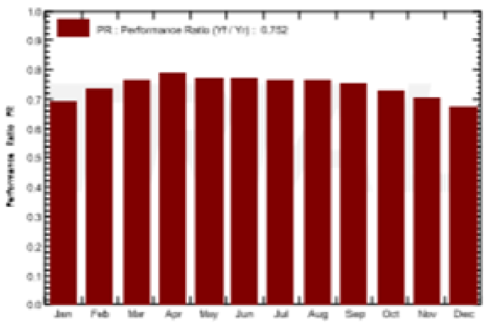
Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	Produced Energy	**490.9 MWh/year**	Specific prod.	1403 kWh/kWp/year
	Performance Ratio PR	75.22 %		





Two way axis var1

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	43.3	26.40	6.31	75.9	60.4	19.52	18.33	0.691
February	55.9	31.50	6.38	92.8	77.5	25.29	23.92	0.737
March	95.5	59.40	9.14	129.7	113.8	36.56	34.66	0.764
April	131.3	73.70	12.51	165.3	151.0	47.87	45.54	0.788
May	172.3	86.60	17.98	217.8	199.4	61.81	58.84	0.772
June	185.9	87.70	22.57	234.5	215.3	66.33	63.27	0.771
July	189.9	87.20	25.68	244.1	223.4	68.13	65.00	0.761
August	165.4	76.60	25.64	215.8	198.9	60.42	57.59	0.763
September	125.4	58.90	21.04	179.4	160.5	49.43	47.05	0.750
October	85.0	43.50	17.06	142.0	120.0	37.94	36.06	0.726
November	55.4	33.70	11.93	94.3	76.3	24.58	23.28	0.706
December	40.9	26.10	8.24	74.1	57.0	18.47	17.41	0.671
Year	1346.2	691.29	15.43	1865.7	1653.4	516.34	490.95	0.752

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	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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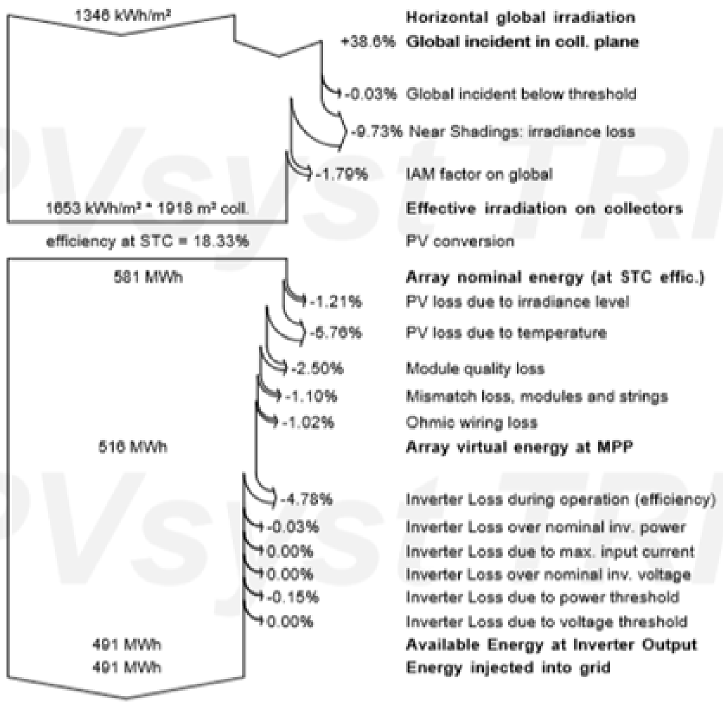
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	HPC-050HT-E	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Sehir solar plant**			
Geographical Site	**Cevizli**		Country	**Turkey**
Situation	Latitude	40.90° N	Longitude	29.16° E
Time defined as	Legal Time	Time zone UT+3	Altitude	0 m
	Albedo	0.20		
Meteo data:	**Cevizli**	Meteonorm 7.2 (2004-2010), Sat=100% - Synthetic		

Simulation variant :	**Two way axis var1**			
	Simulation date	10/04/19 20h11		

Simulation parameters	System type	**Tracking system**		
Tracking plane, two axis	Minimum Tilt	0°	Maximum Tilt	80°
Rotation Limitations	Minimum Azimuth	-120°	Maximum Azimuth	120°
Trackers configuration	Nb. of trackers	1120	Identical arrays	
	Tracker Spacing	2.20 m	Collector width	1.01 m
			Ground cov. Ratio (GCR)	45.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics				
PV module	HIT Model	**VBHN230SE51**		
Original PVsyst database	Manufacturer	Panasonic		
Number of PV modules	In series	13 modules	In parallel	117 strings
Total number of PV modules	Nb. modules	1521	Unit Nom. Power	230 Wp
Array global power	Nominal (STC)	**350 kWp**	At operating cond.	326 kWp (50°C)
Array operating characteristics (50°C)	U mpp	521 V	I mpp	625 A
Total area	Module area	**1918 m²**	Cell area	1667 m²
Inverter	Model	**Solarmax 50TS**		
Original PVsyst database	Manufacturer	SolarMax		
Characteristics	Operating Voltage	430-800 V	Unit Nom. Power	50.0 kWac
Inverter pack	Nb. of inverters	6 units	Total Power	300 kWac
			Pnom ratio	1.17

PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	14 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	2.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

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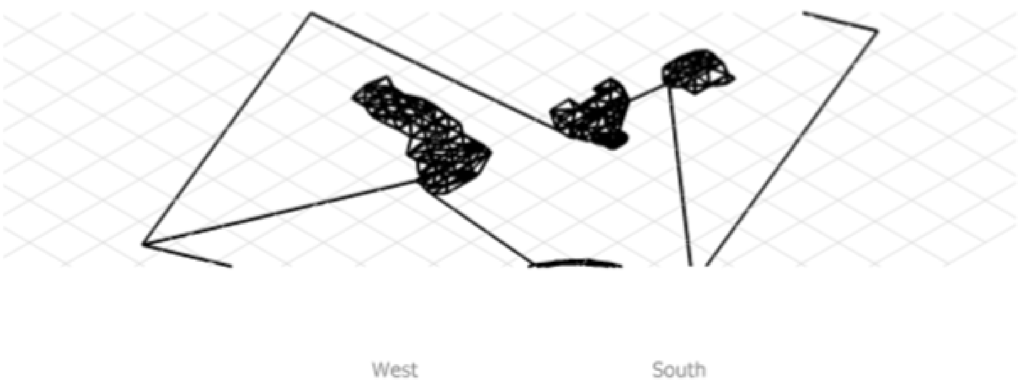
Grid-Connected System: Near shading definition

Project : **Sehir solar plant**

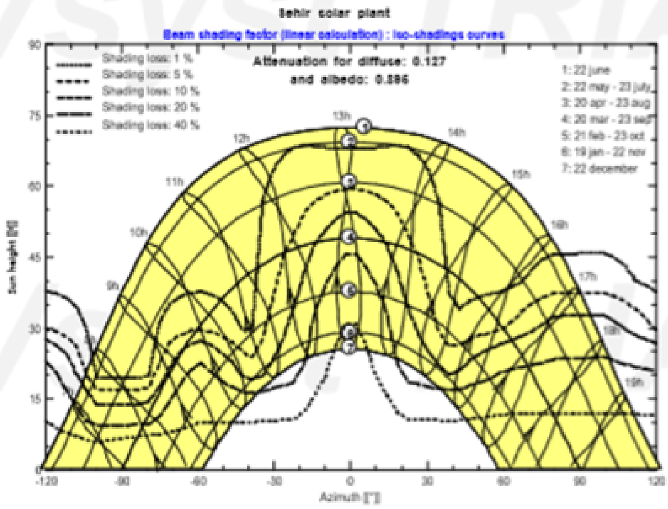
Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



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Grid-Connected System: Main results

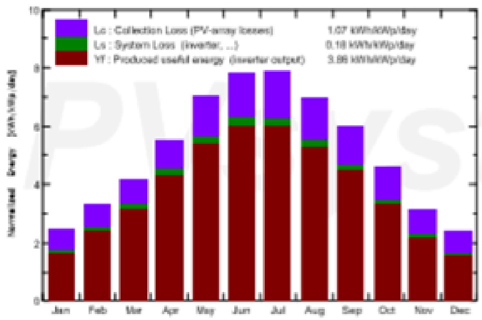
Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

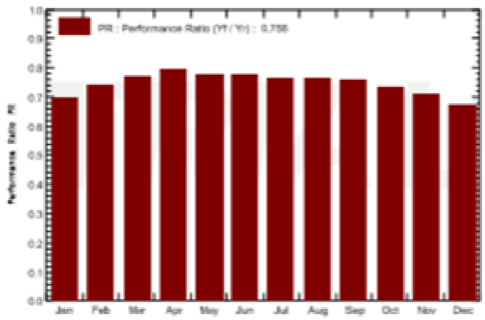
Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	Produced Energy	**493.3 MWh/year**	Specific prod.	1410 kWh/kWp/year
	Performance Ratio PR	75.59 %		

Normalized productions (per installed kWp): Nominal power 350 kWp



Performance Ratio PR



Two way axis var1

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	43.3	26.40	6.31	75.9	60.4	19.52	18.48	0.696
February	55.9	31.50	6.38	92.8	77.5	25.29	24.06	0.741
March	95.5	59.40	9.14	129.7	113.8	36.56	34.85	0.768
April	131.3	73.70	12.51	165.3	151.0	47.85	45.73	0.791
May	172.3	86.60	17.98	217.8	199.4	61.79	59.10	0.776
June	185.9	87.70	22.57	234.5	215.3	66.32	63.53	0.775
July	189.9	87.20	25.68	244.1	223.4	68.12	65.27	0.764
August	165.4	76.60	25.64	215.8	198.9	60.42	57.85	0.766
September	125.4	58.90	21.04	179.4	160.5	49.42	47.27	0.753
October	85.0	43.50	17.06	142.0	120.0	37.94	36.25	0.730
November	55.4	33.70	11.93	94.3	76.3	24.58	23.42	0.710
December	40.9	26.10	8.24	74.1	57.0	18.47	17.51	0.675
Year	1346.2	691.29	15.43	1865.7	1653.4	516.26	493.32	0.756

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	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	PR	Performance Ratio

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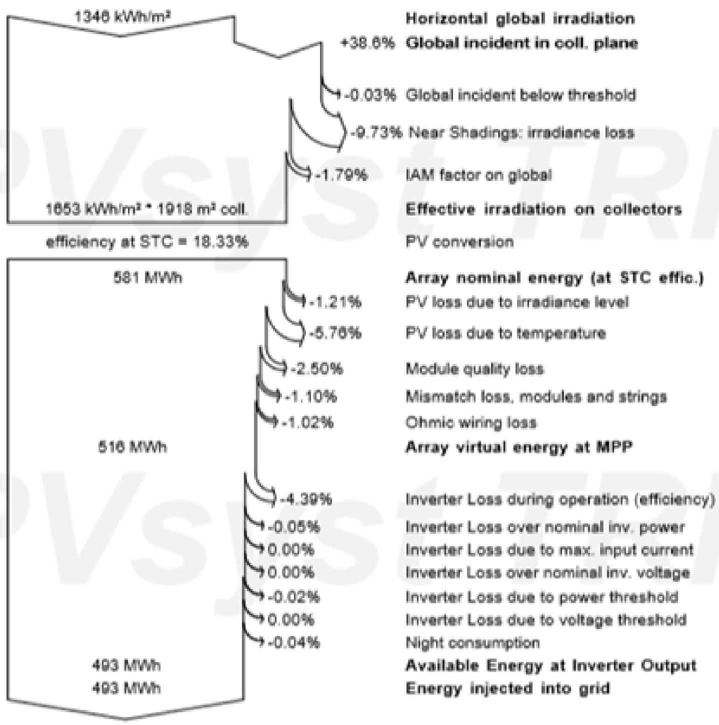
Grid-Connected System: Loss diagram

Project : **Sehir solar plant**

Simulation variant : **Two way axis var1**

Main system parameters	System type	**Tracking system**		
Near Shadings	Linear shadings			
PV Field Orientation	Tracking two axis			
PV modules	Model	VBHN230SE51	Pnom	230 Wp
PV Array	Nb. of modules	1521	Pnom total	**350 kWp**
Inverter	Model	Solarmax 50TS	Pnom	50.0 kW ac
Inverter pack	Nb. of units	6.0	Pnom total	**300 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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