School of Information Technology and Engineering at the ADA University

School of Engineering and Applied Science at the George Washington University

DESIGN AND SIMULATION OF ROOFTOP SOLAR POWER SYSTEM FOR THE ADA UNIVERSITY CAMPUS

A Thesis

Presented to the Graduate Program of Electrical and Power Engineering

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By

Yusif Shiriyev

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THESIS ACCEPTANCE

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has been approved as meeting the requirement for the Degree of Master of Science in Electrical and Power Engineering of the School of Information Technology and Engineering, ADA University.

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ABSTRACT

This master's thesis has the primary purpose of constructing and carrying out an evaluation of two distinct solar cell technologies, namely crystalline solar cells with monocrystalline structure and polycrystalline solar cells, in a photovoltaic plant that is connected to the grid and has a capacity of 1390 kW. The objective is to determine which of these two technologies is superior to the other. The ADA University rooftop is where you will find this plant. In the process of making this comparison, both the payback period and LCOE for each technology are considered. There are three primary elements that comprise the thesis. These sections include an analysis of the system size, the geographical situation, the meteorological data, the key element choice, and the designing of the two photovoltaic (PV) systems. In both the first and second sections, an overview of the different solar cell technologies and the benefit of solar power is presented. This includes the integration of these technologies and the possibilities for future applications in photovoltaics.

A comprehensive analysis of Baku's weather is presented in the third part. If the weather isn't conducive to solar energy generation, then the budget can take a hit, thus it's important to check the forecast thoroughly before constructing a solar power plant.

Calculations pertaining to the selection of pertinent objects are the emphasis of sections four, five, six, and seven. The collected data allowed for both system requirements and economic evaluations. The simulation conducted using PVSYST shows that compared to the monocrystalline PV system, the polycrystalline PV system is cheaper. The reduced levelized cost of electricity (LCOE) and faster investment payback time of the polycrystalline PV system might be the reasons for this.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
OPEX	Operation Expense
CAPEX	Capital Expense
GlobHor	Horizontal diffuse irradiation
T_Amb	Ambient Temperature
GlobInc	Global incident in coll. plane
GlobEff	Effective Global, corr. For IAM shadings
EArray	Effective energy at the output of the array
PR	Performance Ratio
NPR	Nominal Power Ratio
PV	PhotoVoltaic
GaAs	Gallium Arsenide
CdTe	Cadmium Telluride
Cd	Cadmium

CHAPTER ONE

INTRODUCTION

1.1 Introduction

To begin with, solar energy is a clean and sustainable form of energy. It is based on capturing the plentiful sunshine that our planet receives every day. Solar energy generation, unlike traditional energy sources such as coal, natural gas, and oil, does not create damaging greenhouse gases or air pollution. As a result, it is an environmentally beneficial option that considerably minimizes our carbon footprint and contributes to the fight against climate change.

Furthermore, solar energy is a nearly infinite supply. The sun, which provides this energy, will continue to emit energy for billions of years. This starkly contrasts to limited fossil fuels, which are diminishing and prone to price fluctuation and international strife.

Solar energy provides more energy independence. Individuals, towns, and nations may produce their electricity by installing solar panels, lessening their dependency on centralized power systems and imported energy sources. This improves energy security and makes the country less vulnerable to supply outages and price volatility.

Solar energy can result in significant cost reductions over time. While there are costs associated with installation, solar panels usually have cheap operating and maintenance costs. Solar power is an appealing investment for households and companies because of the long-term financial benefits, such as lower energy costs and potential incentives.

Moreover, the solar business has become a big employment creator. It has given rise to countless job possibilities in manufacturing, installation, and maintenance. This expansion in the solar business promotes local economies and helps to expand employment markets.

Solar energy is extremely scalable and adaptable to a wide range of uses. Solar power systems, whether for home, commercial, or industrial use, may be tailored to fulfill a variety of energy requirements. Because of its adaptability, it is a versatile option for a wide spectrum of consumers.

To summarize, solar energy adoption is critical for a sustainable and greener energy future. Its cleanliness, abundance, energy independence, cost savings, job creation, and scalability make it an appealing option as we work to shift away from fossil fuels and toward renewable energy sources.

1.2 Solar Energy?

1.2.1 Solar Energy Capacity

Solar energy will never run out since, according to NASA, the Sun still has 6.5 billion years to live. Solar technology in certain nations has advanced to compete with traditional methods of power generation in a relatively short period. It will make up a sizable portion of the global sustainable energy system in only a few decades.

Additionally, the environment is ideal for the development of solar energy since the Sun provides the Earth with enough heat and light on an hourly basis to meet all of the planet's needs for a whole year or 4,000 times more energy than we require. According to the estimations of Renewable Energies Info the Earth's surface gets 120,000 Terawatts of solar radiation, which is 20,000 times more energy than the globe requires. [1] The projected commercial solar capacity in Azerbaijan is 23,000 MW.

1.2.2 Development of Solar Energy

Solar power systems' history is a wonderful narrative of technological advancement and environmental needs. It is crucial to examine the historical and contextual elements that have influenced the creation and uptake of solar power systems as we stand on the cusp of an energy revolution. This article examines the history and current state of solar power systems, charting their progression from an exciting concept to an essential part of our future energy supply.

1.2.3 The 1970s Energy Crisis

The 1970s energy crisis served as the impetus for the solar power revolution. Geopolitical tensions and supply interruptions caused an abrupt rise in oil prices during this turbulent time, which was seen across the world. This crisis exposed the weakness of our reliance on fossil fuels by sending shockwaves through markets. Solar energy emerged as a possible option when governments and energy experts started looking for alternatives.

1.2.4 Technological Advancements

Modern photovoltaic (PV) technological advancements have been crucial to the creation of solar power systems. Solar panels were made possible by the discovery of the photovoltaic effect, which turns sunlight directly into power. Solar panels are becoming more efficient and affordable as a consequence of sustained research and development efforts throughout time. These technical advancements have increased the number of people who can receive solar energy.

1.2.5 Environmental Awareness

Growing interest in clean and renewable energy sources has been considerably boosted by increasing awareness of environmental challenges, notably air pollution and the impending threat of climate change. The principles of environmental preservation and a more sustainable future are perfectly compatible with solar electricity, which is emissions-free and sustainable. Solar energy has risen to the top of the global energy transition as a result of the pressing need to combat climate change.

1.2.6 Governmental Incentives

Governments all around the globe are taking advantage of solar power systems' ability to fight climate change and improve energy security. Many nations have used a variety of laws and incentives to encourage adoption. These include tax incentives, rebates, feed-in tariffs, and net metering programs, which all work to reduce the upfront costs and increase the financial appeal of solar systems.

Solar power systems' history and context provide a stirring tale of adaptability, creativity, and shared responsibility. Solar energy has risen as a ray of light from the gloom of energy crises and environmental problems, shining the way to a cleaner and more sustainable energy future. As we take stock of the incredible development of solar power systems, it becomes abundantly evident that they are not simply a scientific marvel but also a monument to our creativity and our ability to meet today's urgent energy and environmental concerns. Solar power systems continue to motivate us in our search for a world that is brighter and more sustainable since the sun is our continuous companion.

CHAPTER TWO

RESEARCH METHODOLOGY

2.1 Meteorological Conditions in Baku

The Caspian Sea coast city of Baku, the capital of Azerbaijan, is renowned for its distinctive fusion of modernism and history. Baku's geographic position, which affects its temperature, weather patterns, and seasonal fluctuations, shapes the city's meteorological conditions. Here is a thorough description of the weather in Baku that you might anticipate:

(Köppen climatic classification: BSk) Baku has a semi-arid climate that is categorized as a cold desert climate. This indicates that the city has distinct seasons, with hot, dry summers and somewhat moderate winters. The Caspian Sea influences temperature and humidity levels, moderating the environment to some extent.

The performance and effectiveness of solar power systems established in the city of Baku are significantly influenced by the local weather conditions. Baku's climate and weather patterns are important concerns for anyone wishing to harvest solar energy since solar power systems, especially photovoltaic (PV) solar panels, are heavily dependent on sunlight and environmental conditions. Following are some effects of Baku's weather on solar power systems: [2]

2.1.1 Sunlight and Irradiance

Baku has year-round high levels of sunlight, which is beneficial for the production of solar electricity. Every year, the city receives 2,200 to 2,500 hours on average of sunlight. The energy production of solar panels is favorably impacted by the availability of sunshine, enabling them to produce electricity effectively.

An overview of the possibilities for producing solar photovoltaic (PV) power is given in this map of solar resources. It shows the average daily/yearly total electricity production from a grid-connected solar PV power plant with a peak power of 1 kW, computed during 20 years (1999-2018).

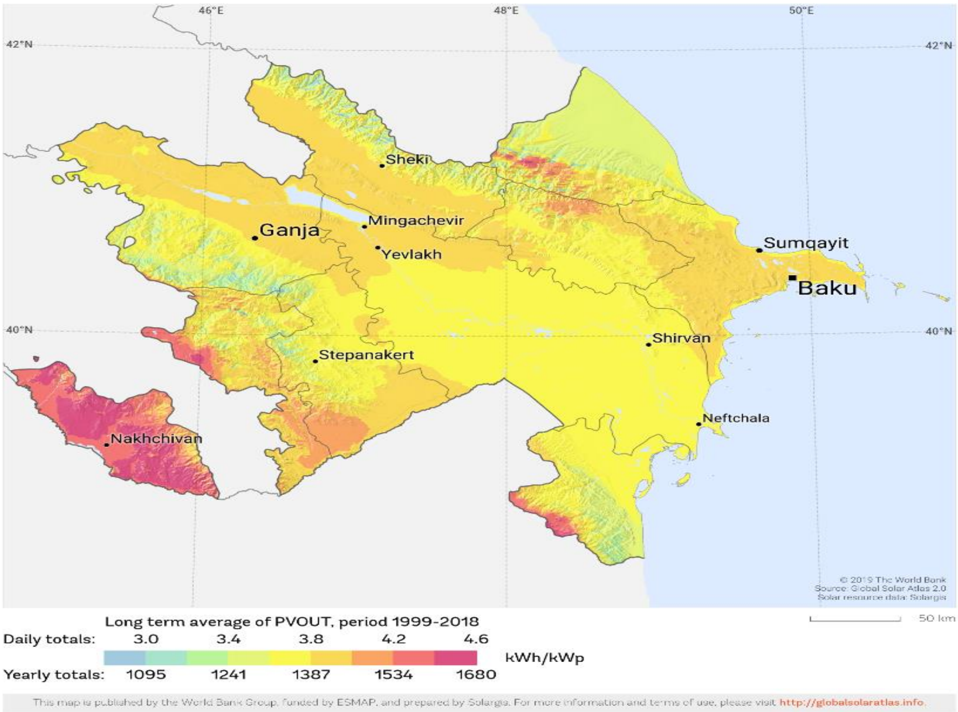


Figure 2.1 Azerbaijan irradiation map [3]

The PV system configuration is made up of free-standing, ground-based structures with crystalline silicon PV modules fastened in place and tilted to the maximum degree possible to maximize the annual energy yield. The ideal tilt is between 27° and 38° in the direction of the equator. High-efficiency inverter use is expected. High-resolution solar resource data and PV modeling software from Solargis serve as the foundation for the computation of solar electricity. To estimate the energy conversion and losses in the PV modules and other parts of a PV power plant, the simulation takes into account solar radiation, air temperature, and terrain. 3.5% of the simulation's losses were attributed to soiling and dirt. It is estimated that the total impact of additional conversion losses, such as inter-row shading, mismatch, inverters, cables, transformers, etc., is 7.5%. There is a 100% availability of the power plant.

With a 30-minute time step and a 1000-meter geographical resolution, atmospheric and satellite data are used to build the underlying solar resource database.

To assist in the expansion of solar energy in our client nations, the World Bank Group created this map of solar resources using information from the Global Solar Atlas (GSA). The Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund managed by The World Bank with funding from 18 donor partners, is responsible for funding this activity. It is a component of the global Renewable Energy Resource Mapping Program

(ESMAP) that includes wind, solar, hydropower, and biomass. Based on a database of solar resources that Solargis owns and maintains, this map was created by Solargis under contract with The World Bank. [3]

To obtain additional maps and information, please visit: (http://globalsolaratlas.info)

2.1.2 Temperature

Temperature: As temperatures rise, solar panels' efficiency declines. Solar panels may become less effective overall due to Baku's scorching summers. Solar panels may perform less effectively and gradually deteriorate at high temperatures. However, Baku's often mild winters assist in minimizing this problem by enabling the panels to cool down and retain greater efficiency throughout the winter. Here are the specific temperatures for the corresponding season:

Summer (June to August): Baku experiences hot, dry summers with frequent afternoon highs of 30°C (86°F). Heat waves are frequent at this time of year, with sporadic highs over 40°C (104°F) and even the mid-30s.

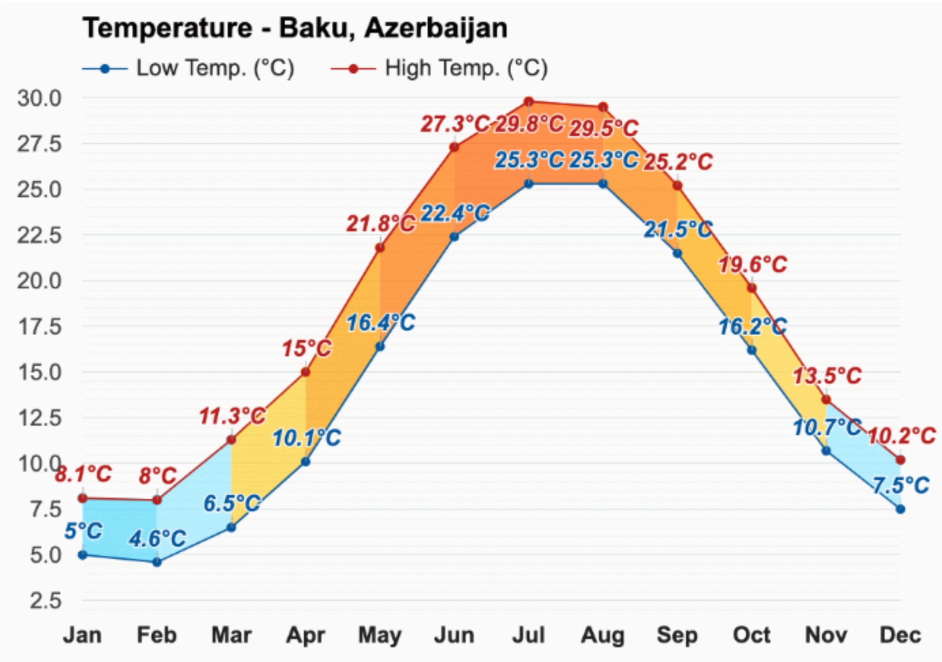


Figure 2.2 Temperature in Baku [4]

Autumn (September to November): Daytime highs in the fall often range from 10 to 25 °C (50 to 77 °F). As the season goes on, the nights get chilly and the rain starts to come more frequently.

Winter (December to February): In comparison to other inland towns at comparable latitudes, Baku's winters are quite moderate. Nighttime lows can reach 0°C (32°F), and daytime temperatures typically vary from 5 to 10°C (41 to 50°F). In the winter, snowfall is uncommon but not unheard of.

Spring (March to May): Gradual temperature increases define spring. By May, daytime highs are in the high teens to low 20s Celsius (high 60s to low 70s Fahrenheit), up from the low teens to mid teens Celsius (mid-50s to mid-50s Fahrenheit). Rainfall occurs often throughout the spring. [4]

2.1.3 Pollution and dust

Baku is prone to dust storms, particularly in the spring and early summer. Solar panels are susceptible to dust and pollutant buildup, which decreases their effectiveness by obstructing sunlight. Solar panels must be cleaned and maintained regularly in these circumstances to work at their best. Baku occasionally receives dust storms, commonly referred to as "gazob." When dry winds from desert regions to the southwest blow in, these storms are most frequent in the spring and early summer.

2.1.4 Wind

The windy weather in Baku may have both good and bad impacts on solar power installations. On the one hand, wind may assist in clearing away dirt and debris from solar panels, possibly increasing their effectiveness. Strong wind gusts, on the other

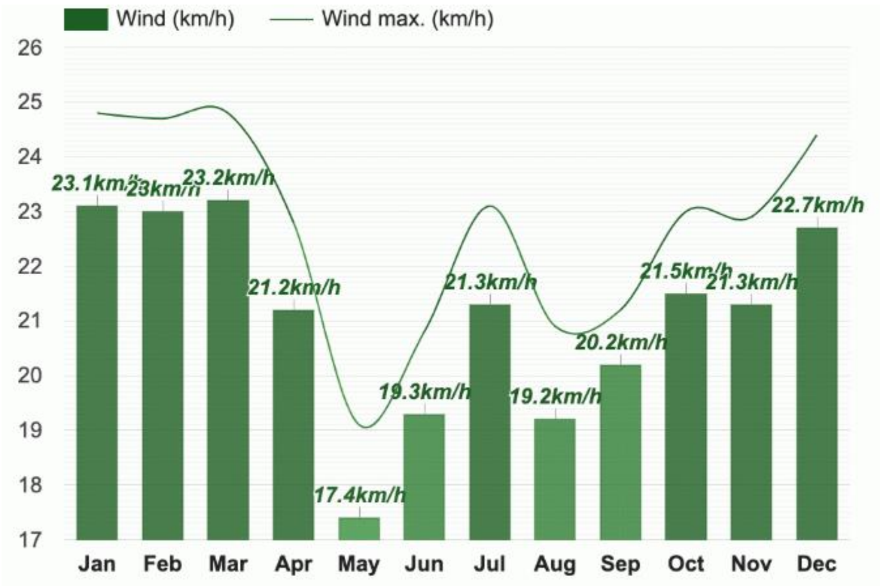


Figure 2.3 Wind data for Baku [4]

hand might raise the possibility of physical damage to solar panels or mounting infrastructure. To endure the city's winds, proper installation, and strong anchoring systems are essential.

2.1.5 Precipitation

The two seasons with the most precipitation in Baku are spring and fall. The yearly average rainfall in the city is about 250–300 mm (10–12 inches), which is modest. Rain is the most common kind of precipitation, however, winter months can occasionally see snowfall. While Baku's rainfall is generally mild, may be used to clean solar panels by eliminating built-up dust and enhancing their effectiveness.

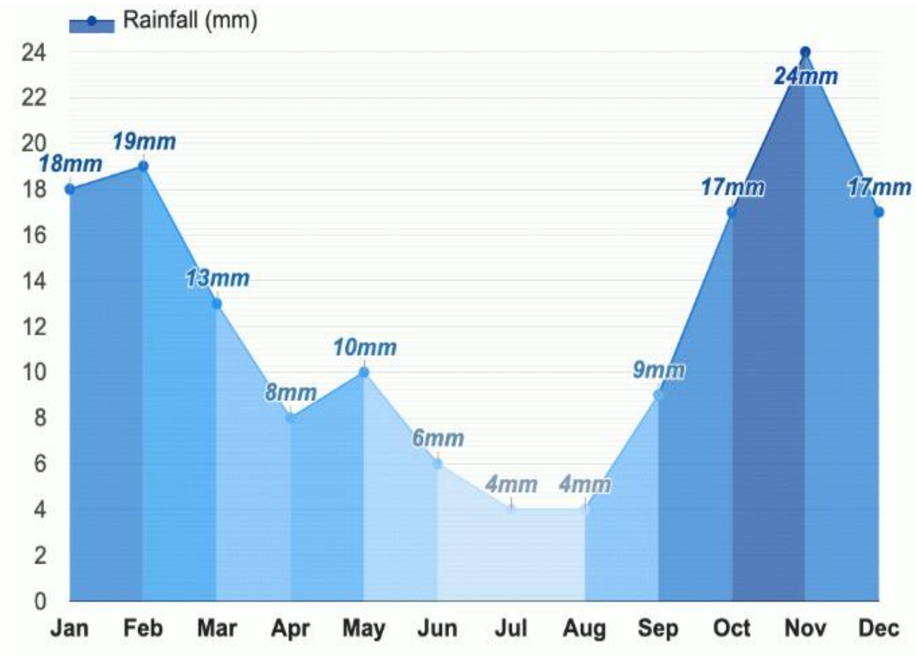


Figure 2.4 Precipitation data for Baku [5]

During sweltering summer days, rain also assists in cooling the panels, momentarily enhancing their efficacy. [5]

2.1.6 Seasonal Variations

The climate of Baku has four distinct seasons, each with a different length of day. As a result, the amount of energy produced by the sun changes throughout the year, with energy output being higher during the long summer days and lower during the briefer winter days. These seasonal fluctuations should be taken into consideration when designing and sizing solar power systems.

2.1.7 Cloud Cover

The amount of sunlight that reaches solar panels may be considerably impacted by cloud cover. Throughout the year, Baku is covered with clouds to varied degrees, which can cause variations in the production of solar electricity. Solar panels may still generate power on overcast days but at a lower rate.

2.1.8 Humidity

Baku has a rather high amount of humidity because of its closeness to the Caspian Sea. Summertime is when humidity is most noticeable, frequently surpassing 60-70%, which makes heatwaves uncomfortable.

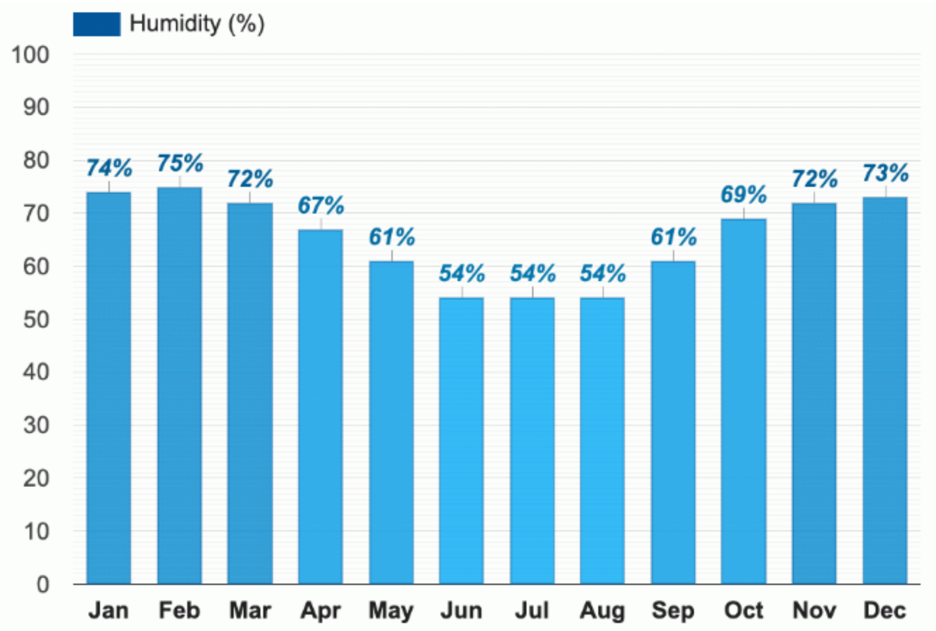


Figure 2.5 Humidity data for Baku [5]

The weather in Baku both benefits and difficulties for solar power installations. Although the city's plentiful sunshine is a valuable resource, it must be controlled together with other elements including temperature, wind, dust, and cloud cover. To improve the effectiveness and lifetime of solar power systems in Baku's variable environment, proper system design, frequent maintenance, and consideration of seasonal fluctuations are necessary. Despite the difficulties, solar energy is still a practical and sustainable energy source for the city, supporting its sustainability objectives.

2.2 Solar Power Technologies

The photovoltaic (PV) solar cells that comprise a solar panel are connected in both series and parallel. Cells often include two or more layers of semiconductor material, such as B and P injected into pure SI. There is a positive charge on one layer and a negative charge on the other. Atoms of semiconductors release electrons when sunlight hits a solar panel, which absorbs photons from the light. An electrical current is generated when electrons transition from negative to positive layer of a semiconductor. A source of direct current (DC) is a device that produces energy by allowing current to flow in only one direction, like a battery. [6]

Many different types of solar system layouts exist. But before you start designing, there are three things you should think about:

1. Grid connected
2. Off-the-grid
3. Independent

Grid-connected photovoltaic (PV) systems are invariably equipped with a link to the public electrical grid through an appropriate inverter. This is because solar panels or arrays, being the primary power source, exclusively generate direct current (DC) electricity. In addition to the use of solar panels, a grid-connected photovoltaic (PV) system has supplementary components that distinguish it from a standalone PV system. [7]

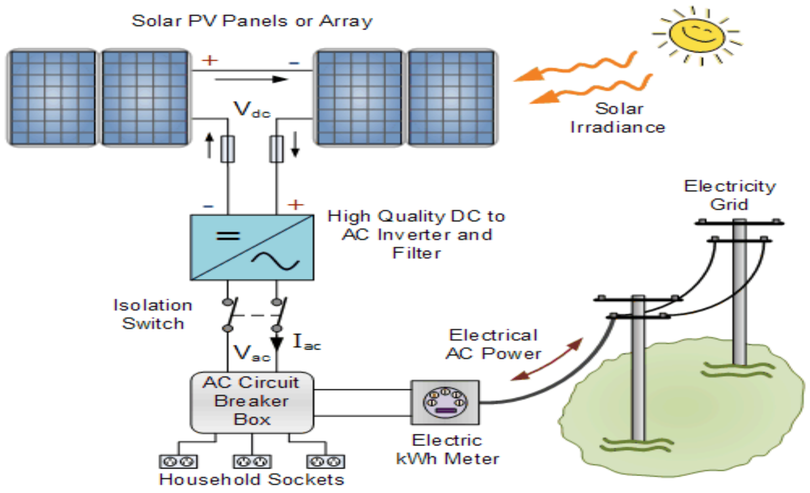


Figure 2.6 Grid-connected PV plant. [7]

2.3 Components of grid-connected solar power plant

2.3.1 PV Module

There has been an uptick in the development and release of solar power technologies to meet the rising demand. We may broadly categorize solar photovoltaic cells into four categories:

1. Monocrystalline or single crystalline
2. Multi-crystalline or polycrystalline
3. Thick film
4. Silicon amorphous

Monocrystalline**:** In terms of efficiency and availability, it is the cell material of choice. In terms of power production per unit area of module, they are unmatched. A single crystal is sliced to make each cell. The wafers are cut into rectangular cells to boost the solar panel's cell density.

Polycrystalline cells are made from the same silicon material as monocrystalline cells, but they are shaped into several crystals by melting and molding the material. The end product is a square block rather than a circular one, making it easier and more efficient to cut into square wafers. [8] The difference between mono and polycrystalline is represented in the picture.

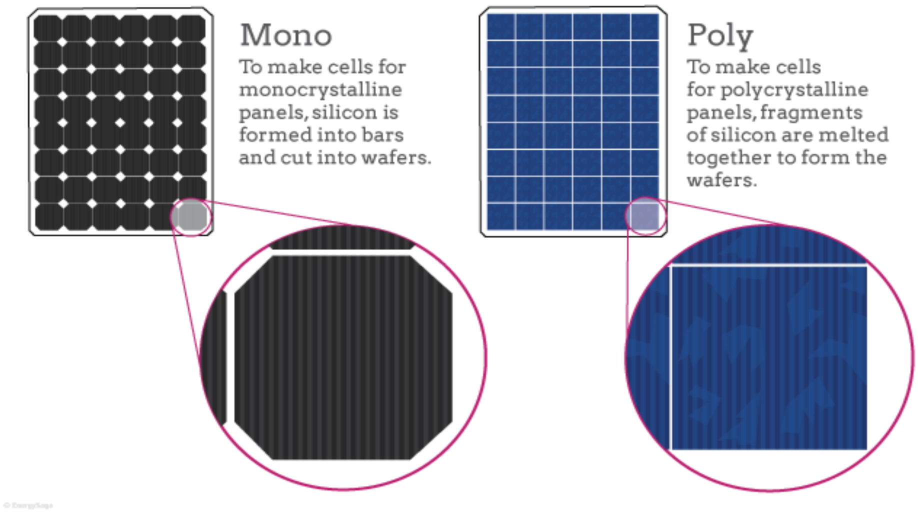


Figure 2.7 Monocrystalline and polycrystalline solar cells. [8]

In addition, the technical differences between these two modules are shown in the table below:

Table 2.1 Comparison of mono and polycrystalline solar panels

	Monocrystalline Solar Panels	Polycrystalline Solar Panels
Material:	Single Pure Silicon Crystal	Different Silicon Fragments Molten Together
Appearance:	Uniform dark squares with rounded edges	Blue squares with no rounded edge
Conversion Efficiency:	**15% to 20%**	**13%** to **16%**
Space Efficiency:	Efficient	Less Efficient
Temperature Coefficient:	**-0.3% / c** to **-0.5% / c**	**-0.3% / c** to **-1% / c**
Lifespan:	Around **40 years**	Around **35 years**
Recyclability:	Yes	Yes
Cost:	**$$$**	**$$**

Thin film panel - The latest innovation in solar cell technology is the thin film panel. Materials such as GaAs, CdTe, and Cd are used to make thin films. They are set directly on substrates. Some of them are better than crystalline modules in low-light conditions. A few micrometers are the minimum thickness required to describe a thin film.

Amorphous Silicon**:** Amorphous silicon is the most recent advancement in thin film technology. Amorphous silicon vapor is deposited on a few micrometer thick amorphous films on stainless steel rolls in this process. This method uses only 1% of the material that crystalline silicon does.

2.3.2 Inverters

Grid-connected photovoltaic (PV) systems encompass three fundamental categories of inverters: central, string, and micro-inverters. Central inverters are primarily employed in utility-scale photovoltaic (PV) systems due to their large-scale capacity. These inverters possess capabilities above 1 MWAC, thereby enabling the aggregation of the power generated by thousands of photovoltaic (PV) modules.

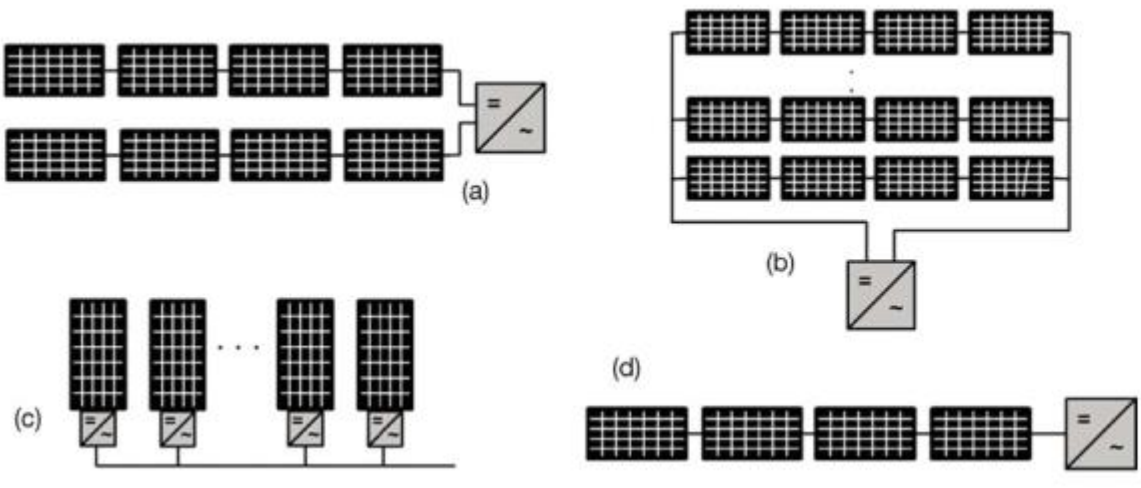


Figure 2.8 Types of solar inverters [9]

The prevalent form of an inverter, known as the string inverter, establishes connections between a very limited number of modules, often with a collective capacity of less than 100 kWAC. The primary distinction between central inverters lies in their rated capacity, which consequently affects the level of granularity in maximum power point (MPP) tracking (Deline, 2016). As a result, string inverters are better suited for photovoltaic (PV) plants that anticipate variations in irradiance across different sections of the facility, such as complex terrains where module tilt and orientation differ throughout the field. [9]

2.3.3 Other necessary components

The electricity meter - commonly referred to as a Kilowatt-hour (kWh) meter, serves the purpose of documenting the movement of electrical energy to and from the power grid. Dual kilowatt-hour (kWh) meters can be employed, with one meter serving to indicate the amount of electrical energy being consumed, while the other meter is utilized to record the quantity of solar-generated electricity being transmitted to the grid.

A solitary bidirectional kilowatt-hour meter can also serve the purpose of quantifying the overall electricity consumption from the grid. The integration of a grid-connected photovoltaic (PV) system has the potential to impede or cease the rotation of the aluminum disc within the electric meter, perhaps resulting in a reversal of its spin direction. This phenomenon is commonly known as net metering.

The AC breaker panel and fuses - refer to the standard fuse box found in residential electrical systems, with the inclusion of extra breakers for inverter and/or filter connections.[10]

Safety Switches and Cabling - To facilitate maintenance or testing, it is imperative to have the capability to disconnect a solar array from the inverter, as it consistently generates a voltage output in the presence of sunshine. It is necessary to ensure that isolator switches, which are capable of handling the highest DC voltage and current of the array and inverter safety switches, are installed independently. Additionally, these switches should be easily accessible to allow for the disconnection of the system.

Additional safety measures required by the electrical company may encompass the implementation of earthing systems and the installation of fuses. It is imperative to ensure that the electrical cables employed for interconnecting the different components are appropriately rated and sized.

The electricity grid - is an essential component for a Grid Connected PV System, since it provides the necessary infrastructure for connection. Without the presence of the utility grid, the system cannot be considered grid-connected.

A grid-connected system lacking batteries is the most straightforward and cost-effective solar power configuration. Additionally, the absence of battery charging and maintenance contributes to enhanced efficiency. It is imperative to acknowledge that a grid-connected solar power system does not function as an autonomous power source, in contrast to a stand-alone system. In the event of an interruption to the mains supply originating from the electrical grid, it is possible for the illumination provided by electric lights to cease, irrespective of the presence of sunlight. One potential strategy for addressing this challenge is incorporating a mechanism for short-term energy storage inside the architecture. [11]

CHAPTER THREE

PLANT SIZING CALCULATION

3.1 Geographical situation

Solar panels will be installed at ADA University which is in Baku, Azerbaijan. The location-related data can be found below.

Table 3.1 ADA University location data

Time zone	UTC+04:00
Latitude	40°23'40"N
Longitude	49°50'56"E
Altitude	32m

ADA University is situated in the center of Baku. However, the university is not surrounded by high buildings which creates a proper condition for the usage of solar energy since high buildings create shading which is not suitable for solar panel application.

Figure 3.1 Satellite view of ADA University

ADA University consists of five primary buildings, namely A, B, C, D, and the Library. Based on the conducted surveys, the overall load of the aforementioned five buildings is

8.75MVA. Due to the inadequate overall area, it has been determined that the supply of 8.75MVA will be limited to only A building. The areas of the five buildings are as follows.

Table 3.2 ADA University building rooftop areas

A building	1264.8 m^2
B building	1937.17 m^2
C building	1663.01 m^2
D building	2572.75 m^2
L building	742 m^2
Overall	8179.73 m^2

According to the information above we can estimate the approximate consumption of building A.

$$X \cdot Area_{total} = Power_{total}$$
$$X = Power_{total} / Area_{total}$$
$$X = 8.75 / 8179.73\ m^2 = 0.00106971746$$
$$Power_A = Area_A \cdot 0.00106971746$$
$$Power_A = 1.35MVA$$

3.2 Determining components

We need to determine 2 components: solar panel and inverter.

- The power rating of a solar panel shows how much power it produces under Standart Test Conditions.

- Power withstand: This reveals the potential deviation between the actual power output and the suggested power rating. If you want to be sure of your power tolerance, go with a lesser number.

- The efficiency of the module is a measure of how well solar energy can be converted into usable electricity.

- Temperature coefficient. A solar panel's output power is reduced when exposed to high temperatures. How much this capacity is reduced is shown by the temperature index. As the temperature rises over 21ºC, the power capacity decreases, as shown by this test's methodology. For that reason, it is preferable to choose a panel with a low-temperature index.

- Solar panels' quality. Choosing a product with ISO 9001 certification is a good way to evaluate it in this regard. The International Organization for Standardization (ISO) developed this standard to ensure product quality in the industrial industry. [12]

- You can evaluate how well a solar panel will last a long time by looking at its durability feature. If the manufacturer's claims are to be believed, the panel in question must adhere to the criteria laid down by the International Electrotechnical Commission's IEC 61215.

- Warranty on solar panels. If the panel develops an issue after installation, the manufacturer will cover the cost of the necessary repairs thanks to the robust guarantee. [13]

The aforementioned characteristics allow us to conclude that Jinko Solar panels are an appropriate choice for our setup. Data for both kinds of panels are necessary for our comparisons since we will be looking at both monocrystal and polycrystal cells.

Based on the above features, we can say that Jinko Solar is a suitable panel for our installation. Since we will compare panels with monocrystal and polycrystal cells we need to include data for both panel types.

Table 3.3 Technical data for Jinko Solar panels

Manufacturer	Jinko Solar	Jinko Solar
Model	JKM340M-72	JKM340PP-72
Country	China	China
Cell Type	Mono-crystalline	Poly-crystalline
No. of cells	72	72
Dimensions	1956x992x40mm	1956x992x40mm
Weight	22,5 kg	22,5 kg
Maximum Power (W)	340W	340W
Maximum Power Voltage (Vmp)	38,7V	38,2V
Maximum Power Current (Imp)	8,79A	8,91A
Open-circuit Voltage (Voc)	47,1V	47,5V
Short-circuit Current (Isc)	9,24A	9,22A
Module Efficiency STC	17,52%	17,52%
Operating Temperature Range	-40°C~+85°C	-40°C~+85°C
Maximum system voltage	1000 VDC(IEC)	1000VDC(IEC)
Maximum series fuse rating	20A	20A
Power tolerance	0~+3 %	0~+3 %
Temperature coefficients of Pmax (%/°C)	-0,40 %/°C	-0,40%/°C
Temperature coefficients of Voc (%/°C)	-0,29 %/°C	-0,31 %/°C
Temperature coefficients of Isc (%/°C)	0,048 %/°C	0,06 %/°C
Nominal operating cell temperature (NOCT) (°C)	45±2°C	45±2°C
Price (€)	75,65	66,57

Inverters are the second main component and the main cause of THD (Total Harmonic Distortion) which is not desirable. So, we need to find an inverter with less than 3% THD and with relevant data. After searching for a while, I figured out that Power Electronics FreeSun FS1390 HE/HEC 360V is suitable for our installation. Here is the technical information about the inverter that we get from PVSYST. [14]

Table 3.4 Technical data for inverter

Inverter - FreeSun FS1390 HE/HEC 360V

Manufacturer	Generic
Model	FreeSun FS1390 HE/HEC 360V

Commercial data

Availability :	Prod. Since 2012	Data source :	Manufacturer 2012
Remarks		**Sizes**	
Technology: Transformerless, 8 kHz, IGBT		Width	5260 mm
Protection: -20 - +50°C, IP 21/54		Height	2150 mm
Control: Touch display, 10"		Depth	1020 mm
HEC outdoor IP65:		Weight	4500.00 kg
HxWxD = 2270x5600x1144mm			

Input characteristics (PV array side)

Operating mode	MPPT		
Minimum MPP Voltage (Vmin)	565 V	Nominal PV Power (Pnom DC)	1390 kW
Maximum MPP Voltage (Vmax)	820 V	Maximum PV Power (Pmax DC)	1668 kW
Absolute max. PV Voltage (Vmax array)	1000 V	Power Threshold (Pthresh.)	600 W
Behaviour at Vmin/Vmax	Limitation		
Behaviour at Pnom	Limitation		

Output characteristics (AC grid side)

Grid voltage (Imax)	Triphased 360 V	Nominal AC Power (Pnom AC)	1390 kWac
Grid frequency	50/60 Hz	Maximum AC Power (Pmax AC)	1390 kWac
		Nominal AC current (Inom AC)	2230 A
		Maximum AC current (Imax AC)	2230 A

Efficiency defined for 3 voltages

		Maximum efficiency	European average efficiency
	V	%	%
Low voltage	565	98.6	98.4
Medium voltage	650	98.2	98.1
High voltage	750	97.9	97.8

3.3 DC input and AC output power of an Inverter

We know that the apparent power of an inverter is P_{AC} =1500kW. Look the formula below.

$$P_{DC} = \frac{P_{AC}}{\eta} \tag{3.1}$$

P_{DC} – DC input power for an inverter.
P_{AC} – AC power of an inverter.
η - Efficiency of inverter.

$$P_{DC} = \frac{1390kW}{0.9855} = 1410.45 \text{ kW}$$

3.4 Nominal Power Ratio

The inverter's and the PV array's direct current power are related in this ratio. You should not oversize the inverter since its performance is at its best with a certain amount of absorbed power and degrades at lower-than-usual levels.

$$\text{NPR} = \frac{P_{DC}}{P_{DCsolar}} \tag{3.2}$$

NPR – nominal power ratio
P_{DC} – is an inverter DC power
$P_{DCSolar}$ – maximum power of PV arrays

$$\text{NPR} = \frac{1410.45}{1390} = 1.01$$

3.5 Voltage sizing

It is obvious that the main barrier between voltage and current is temperature so let’s look at the dependence between current voltage and temperature

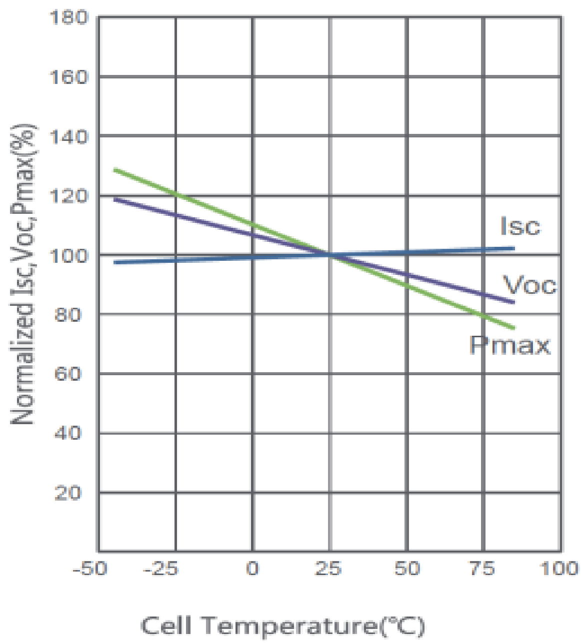


Figure 3.2 Relationship between P, V_{OC}, I_{SC} [15]

3.5.1 Panels max open circuit voltage

High temperature is not desirable in electrical circuits due to high resistance. As we can see from the diagram above V_{OC} and P are decreasing by increasing temperature. The following formula shows the relationship between voltage and temperature at the PV panel.

$$V_{DCmaxPanel} = V_{DCmaxppPanel} = V_{OpenCircuitMax} \cdot \left(1 + \frac{T_{min} \cdot \Delta T}{100\%}\right) \quad (3.3)$$

$V_{DCmaxPanel}$ – max voltage of 1 panel
$V_{OpenCircuitMax}$ – max open circuit voltage of 1 panel (given in the technical data)
T_{min} – coefficient of temperature at min temperature (given in the technical data)
ΔT – the difference between standard and min temperature

According to the Bureau of Hydro-meteorological Forecasts of the National Hydrometeorology Department of the Azerbaijani Ecology and Natural Resources Ministry, the lowest temperature in Baku was (-11) degrees recorded 6:00-7:00 on the morning of February 8, 2012. So, we will take the minimum temperature as -11 degrees. Additional data we will be taken from the technical parameters table of solar panels. Using formula 3.3 lets compute voltages for both technologies.

For monocrystalline:

$$V_{DcmaxPan} = V_{DcmaxppPan} = 47.1 \cdot \left(1 + \frac{-0.29\%°C \cdot (-11°C - 25°C)}{100\%}\right) = 52.01V$$

for polycrystalline:

$$V_{DcmaxPan} = V_{DcmaxppPan} = 47.5 \cdot \left(1 + \frac{-0.31\%°C \cdot (-11°C - 25°C)}{100\%}\right) = 52.8V$$

3.5.2 Minimum MPP Voltage

For calculating the minimum MPP voltage we need to know the maximum recorded temperature for the installation area. According to Turan.az the hottest day in Baku for the last 120 years was on 1 July 2018 about 45 degrees. [16]

However, since the operation temperature of solar cells is 45-70 °C. So, for reaching minimum voltage, we will consider 70°C as a working temperature.

$$V_{DcminPanel} = V_{DcmaxppPanel(maxT)} = V_{mpp} \cdot \left(1 + \frac{T_{max} \cdot \Delta T}{100\%}\right) \quad (3.4)$$

$V_{DCminPanel}$ – min voltage of a panel
V_{mpp} – Max peak power voltage of a panel (given in the technical data)
T_{max} – coefficient of temperature at max temperature (given in the technical data)
ΔT – the difference between STC and maximum temperature in the area

Now like we did above, using formula 3.4 let us compute min voltages for both technologies. Since at maximum temperature resistance is high our voltges will be be less that voltages in min temperature.

for monocrystalline:

$$V_{DCminPan} = V_{DCmaxppPan} = 37.8V \cdot \left(1 + \frac{-0.29\%°C \cdot (70°C - 25°C)}{100\%}\right) = 33.65V$$

for polycrystalline:

$$V_{DCminPan} = V_{DCmaxppPan} = 38.2V \cdot \left(1 + \frac{-0.31\%°C \cdot (70°C - 25°C)}{100\%}\right) = 32.871V$$

3.6 Maximum PV panel current

Now we can leverage the relationship between current and temperature to our advantage. The maximum temperature is used again in the graph to determine the maximum current.

$$I_{DCmaxSTR} = I_{DCscPanel(maxT)} = I_{sc} \cdot \left(1 + \frac{T_{max} \cdot \Delta T}{100\%}\right) \qquad \textit{(3.5)}$$

$I_{DCmaxSTR}$ – max current of the string
$I_{DCscPanel(maxT)}$ – SC current of a panel (given in the technical data)
T_{max} – coefficient of temperature at max temperature (given in the technical data)
ΔT – the difference between STC and maximum temperature in the area

for monocrystalline:

$$I_{DCmaxSTR} = I_{DCscPan(maxT)} = 9.24A \cdot \left(1 + \frac{0.048\% \cdot (70°C - 25°C)}{100\%}\right) = 9.44A$$

for polycrystalline:

$$I_{DCmaxSTR} = I_{DCscPan(maxT)} = 9.22A \cdot \left(1 + \frac{0.06\% \cdot (70°C - 25°C)}{100\%}\right) = 9.469A$$

The following table 3.5 shows the calculation results:

Table 3.5 Calculation results for panel voltage and current

Type	Monocrystalline	Polycrystalline
V_{OCMAX}	52.01V	52.8V
V_{MPPMIN}	33.65	32.871V
$I_{DCmaxSTR}$	9.44A	9.469A

3.7 String size

3.7.1 Maximum number of panels per string

String voltage should not be too high compared to what an inverter can handle. For us, the range is 560-220V. Therefore, determining the total number of modules in a string is necessary for calculating its voltage. [17]

$$n_{max} = \frac{V_{maxInv}}{VmaxPan} \quad (3.6)$$

n_{max} – max number of panels per string
V_{maxInv} – inverter's max working voltage
V_{maxPan} – panel's maximum voltage

for monocrystalline:

$$n_{max} = \frac{V_{maxInv}}{VmaxPan} = \frac{1000V}{52.01V} = 19.22 \approx 19$$

for polycrystalline:

$$n_{max} = \frac{V_{maxInv}}{VmaxPan} = \frac{1000V}{52.8V} = 18.93 \approx 18$$

3.7.2 Minimum number of panels per string

Now let's calculate the minimum number of panels per string

$$n_{min} = \frac{V_{minInv}}{VminPan} \quad (3.7)$$

n_{min} – min number of panels per string
V_{minInv} – inverter's min working voltage
V_{minPan} – panel's minimum voltage

For determining minimum value for both technologies we need formula 3.7.

for monocrystalline:

$$n_{min} = \frac{V_{minInv}}{VminPan} = \frac{565V}{33.65V} = 16.79 \approx 17$$

for polycrystalline:

$$n_{min} = \frac{V_{minInv}}{VminPan} = \frac{565V}{32.871V} = 17.18 \approx 18$$

n should be between the n_{max} and n_{min} values. This condition we need to satisfy when we design our array.

$$n_{min} \leq n \leq n_{max} \quad (3.8)$$

for monocrystalline:

$$17 \leq n \leq 19 \quad n = 18$$

for polycrystalline:

$$18 \leq n \leq 18 \quad n = 18$$

3.8 Maximum and minimum string voltage

So far, we know how many panels make up a string. The following formulae are used to calculate the maximum and lowest string voltage.

$$V_{DCmaxSTR} = n \cdot V_{DCmaxPan} \quad (3.9)$$

$$V_{DCminSTR} = n \cdot V_{DCminPan} \quad (3.10)$$

V_{minPan} – panel’s minimum voltage
V_{maxPan} – panel’s maximum voltage
$V_{DCmaxSTR}$ – string’s maximum voltage
$V_{DCminSTR}$ - string’s minimum voltage
n – number of panels per string

for monocrystalline:

$$V_{DCmaxSTR} = 18 \cdot 52.01 = 936.18V$$

$$V_{DCminSTR} = 18 \cdot 33.65 = 605.7V$$

for polycrystalline:

$$V_{DCmaxSTR} = 18 \cdot 52.8 = 950.4V$$

$$V_{DCminSTR} = 18 \cdot 32.871 = 591.7V$$

3.9 Maximum and minimum number of strings

The inverter's input current limits how many strings can be utilized and how many can be used at once. The formula for determining how many strings exists is shown below.

$$n_{maxSTR} = \frac{I_{DCinv}}{I_{DCmaxSTR}} \quad (3.11)$$

$$n_{minSTR} = \frac{P_{DCarray}}{P_{DCmaxPAN} \cdot n} \quad (3.12)$$

n_{maxSTR} – max number of strings
n_{minSTR} – min number of strings
I_{DCinv} – max inverter input current
$I_{DCmaxSTR}$ – max string current
$P_{DCmaxPAN}$ – power of a panel
P_{array} – array power

for monocrystalline:

$$n_{maxSTR} = \frac{2500}{9.44} = 264.83 \approx 264$$

$$n_{minSTR} = \frac{1390}{0.340 \cdot 18} = 227.12 \approx 227$$

for polycrystalline:

$$n_{maxSTR} = \frac{2500}{9.469} = 264.01 \approx 264$$

$$n_{minSTR} = \frac{1390}{0.340 \cdot 18} = 227.12 \approx 227$$

for both we will choose 230 strings.

The table contains the results of calculations for array sizing.

Table 3.6 Calculation results for string number and voltage

Type	**Mono**	**Poly**
Number of panels per string	18	18
Maximum string voltage	936.18V	950.4V
Minimum string voltage	605.7V	591.7V
Number of strings	230	230

3.10 Number of modules for PV plant

It is obvious that to find the number of modules we need to multiply the string number and panel per string.

For monocrystalline:

$$n_{modules} = n_{str} \cdot n_{PANperSTR} \cdot n_{inv} = 18 \cdot 230 \cdot 1 = 4140 \quad (3.13)$$

for polycrystalline:

$$n_{modules} = n_{str} \cdot n_{PANperSTR} \cdot n_{inv} = 18 \cdot 230 \cdot 1 = 4140 \quad (3.14)$$

3.11 Annual energy production of PV plant

Finally, let’s calculate the yearly DC energy production of our system.

$$E_{DC} = P_{DC} \cdot (PSH) \cdot \eta_{inv} \quad (3.15)$$

P_{DC} – inverters DC power
(PSH) – number of hours when solar irradiance is average 1000 W/m^2
η_{inv} – number of inverters

first, let's calculate PSH

$$PSH = \frac{Yearly\ irradiation\ (\frac{kWh}{m^2})}{1000\ W/m^2} = \frac{1446.8\ (\frac{kWh}{m^2})}{1000\ W/m^2} = 1446.8\ h \qquad (3.16)$$

DC energy production will be:

$$E_{DC} = P_{DC} \cdot (PSH) \cdot n_{inv} = 1410.45\ kW \cdot 1446.8\ h \cdot 1 = 2040.64\ MWh/year$$

For calculating AC energy production of PV plant we need the efficiency of the inverter:

$$E_{AC} = E_{DC} \cdot \eta_{inv} = 2040.64 \cdot 0.982 = 2003.907\ MWh/year$$

3.12 PR calculation

PR is a main indicator of performance of the plant and this value is being calculated after establishing the plant.

$$PR_{meas} = \frac{\sum_j (E_{meas,j})}{E_{calc,j}} \qquad E_{alc,j} = P_{nom} * \sum_j [\left(\frac{G_j}{G_{stc}}\right)\left(1 - \frac{\beta}{100} * (Tmod_n - Tmeas_j)\right)] \qquad (3.17)$$

P_{nom} - the nominal power of the Plant in kWp,
G_j - the irradiation in kWh/a per m² measured per each metering interval j
PR_{meas} - the average Plant Performance Ratio during the testing period;
T_{measj} - the average PV module temperature measured during each metering interval j by the temperature sensors placed on the reverse side of the PV modules (in °C);
T_{modn} - the average monthly PV module temperature expected
G_{stc} - the irradiance at standard test condition in (kW/m²), and is equal to one;
β - the temperature coefficient from the PV modules' data sheet (in %/°C) as defined in the PV module's datasheet.

CHAPTER FOUR

SIMULATION AND RESULTS

4.1 Simulation tool

In order to size the PV system, the primary calculations are presented in the preceding chapter. To get more precise results, however, you'll need to construct a simulation using software. The PV SYST V7.4 application was used to execute the simulations for this project. Depending on the user's needs, the program may either provide a preliminary estimate for a PV installation or a detailed plan after extensive research and analysis. [18] Project Design Grid-Connected and the software's database have been utilized for precise sizing. Data about the elements of PV Plants and the weather are included in the database.

Firstly, let's take a look at the meteorological data computed by the simulation

Table 4.1 Meteorological data computed by simulation

	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/mth	kWh/m²/mth	°C	m/s	[-]	%
January	61.0	29.8	4.5	5.10	3.822	86.4
February	68.7	39.6	4.3	5.49	4.608	88.1
March	111.8	60.3	7.3	6.09	5.356	85.4
April	138.6	86.0	11.5	5.50	7.001	80.8
May	183.1	95.9	18.6	4.79	6.228	72.1
June	200.6	95.0	24.1	5.50	6.012	65.5
July	191.6	102.3	28.0	5.60	6.949	60.0
August	166.8	96.2	28.1	4.80	6.358	62.4
September	126.6	67.3	22.6	4.80	6.080	73.0
October	85.5	48.8	16.6	4.70	5.201	82.0
November	59.2	35.2	10.7	4.89	4.341	85.1
December	53.3	25.8	6.7	4.99	3.962	85.8
Year	**1446.8**	**782.2**	**15.3**	**5.2**	**5.493**	**77.2**

Initially, it is important to make adjustments to the plane tilt and azimuth of the aircraft to minimize losses and achieve an optimal outcome with zero percent deviation.[19]

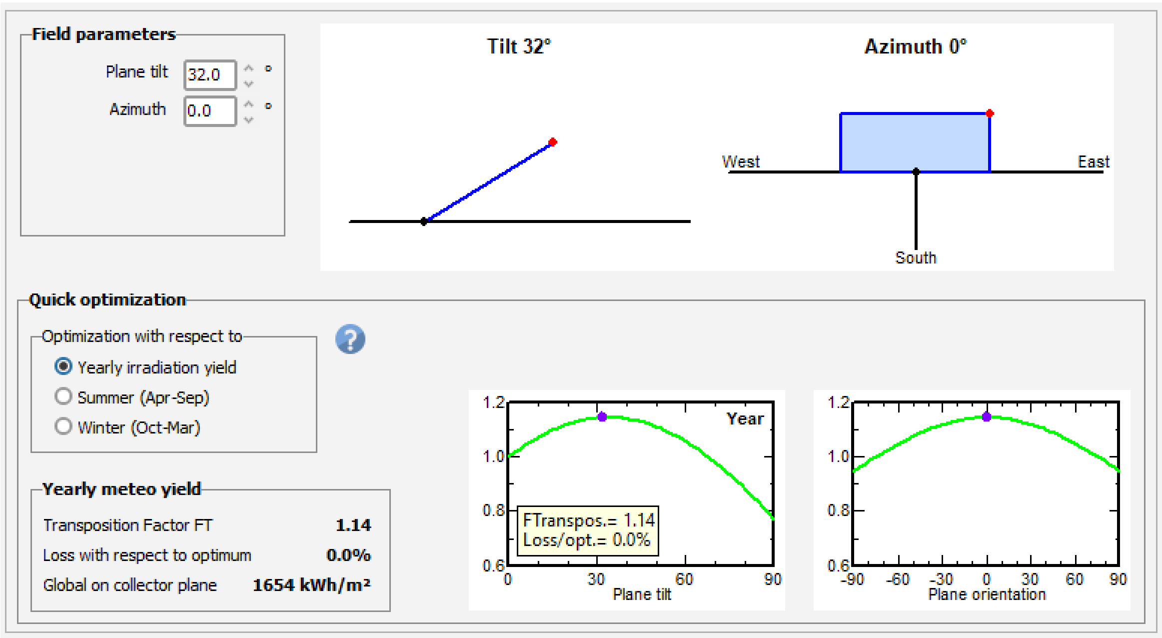


Figure 4.1 Plant orientation

Then coming to the system configuration, we need to include planned power, inverter, and panel type and company. After this system will automatically calculate output voltage, power, n_{string}, and n_{panel}.

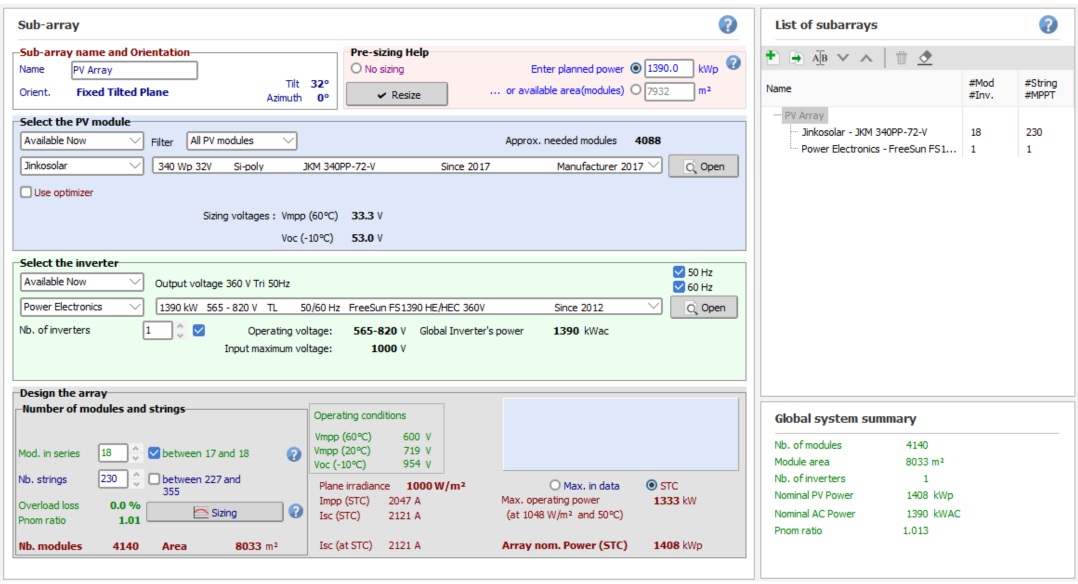


Figure 4.2 System parameters

As we can see, the outcomes of my simulation and calculation are identical, except for a few minor distortions. Now let's compute the results.

4.2 Simulation results for monocrystalline technology

PVsyst offers a thorough analysis of the setup of your photovoltaic system. This encompasses specific information on the quantity and kind of modules, inverters, and other constituent elements. Comprehending the system configuration is imperative for the purpose of developing and enhancing the efficiency of the solar array. Table 7.2 represents the general parameters and main PV array characteristics. Here you can find nearby shadings, total number of PV module per string, tilt, azimuth, and electrical parameters of array at STC and MPP. In addition, all losses related to array and equipment are given in this table. However, detailed information about losses you can find in Figure 4.3. Now let us go through general parameters of array which represented in table 4.2

Table 4.2 General parameters of PV plant (monocrystalline)

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	JKM 340M-72	Model	FreeSun FS1390 HE/HEC 360V
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	340 Wp	Unit Nom. Power	1390 kWac
Number of PV modules	4140 units	Number of inverters	1 unit
Nominal (STC)	1408 kWp	Total power	1390 kWac
Modules	230 string x 18 In series	Operating voltage	565-820 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.01
Pmpp	1271 kWp		
U mpp	629 V		
I mpp	2019 A		
Total PV power		**Total inverter power**	
Nominal (STC)	1408 kWp	Total power	1390 kWac
Total	4140 modules	Number of inverters	1 unit
Module area	8033 m²	Pnom ratio	1.01
Cell area	7075 m²		

PVsyst offers a thorough assessment of the energy generation of your photovoltaic (PV) system. This encompasses comprehensive projections for the yearly, monthly, and daily energy production. These estimations are derived from many characteristics, including location-specific solar irradiation, ambient temperature, and module temperature.

The Performance Ratio (PR) is a crucial measure that signifies the effectiveness of your PV system. The term refers to the ratio between the actual energy output and the anticipated energy production in optimal circumstances. PVsyst determines the performance ratio (PR) by considering many factors that contribute to energy losses, including module mismatch, shading, soiling, and other environmental conditions.

Table 4.3 Main results of PV plant (monocrystalline) 2

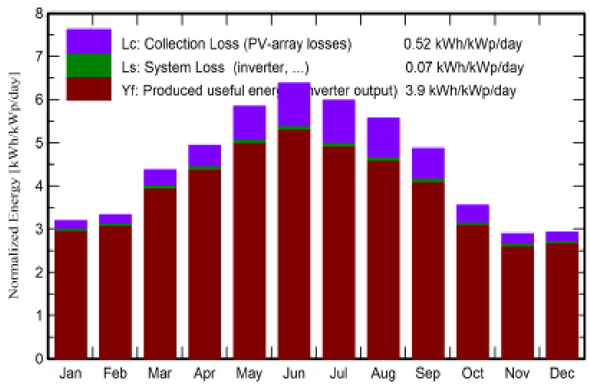
System Production

Produced Energy	2005293 kWh/year	Specific production	1425 kWh/kWp/year
		Perf. Ratio PR	86.84 %

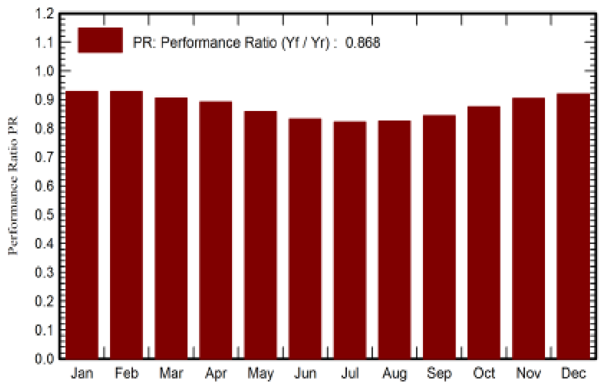
Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	1 322 100.00 AZN	Annuities	0.00 AZN/yr	Energy cost	0.05 AZN/kWh
Specific	0.94 AZN/Wp	Run. costs	45 189.12 AZN/yr		
		Payback period	8.3 years		

Normalized productions (per installed kWp)



Performance Ratio PR



All the components, including the inverter, wiring, shading, and others, are given with comprehensive information on losses. These losses are broken down by PVsyst, which provides a detailed picture of the precise locations inside the system where energy losses occur. This information is helpful for a variety of purposes, including maintenance, optimization, and troubleshooting processes. You can find information about losses in the figure below.

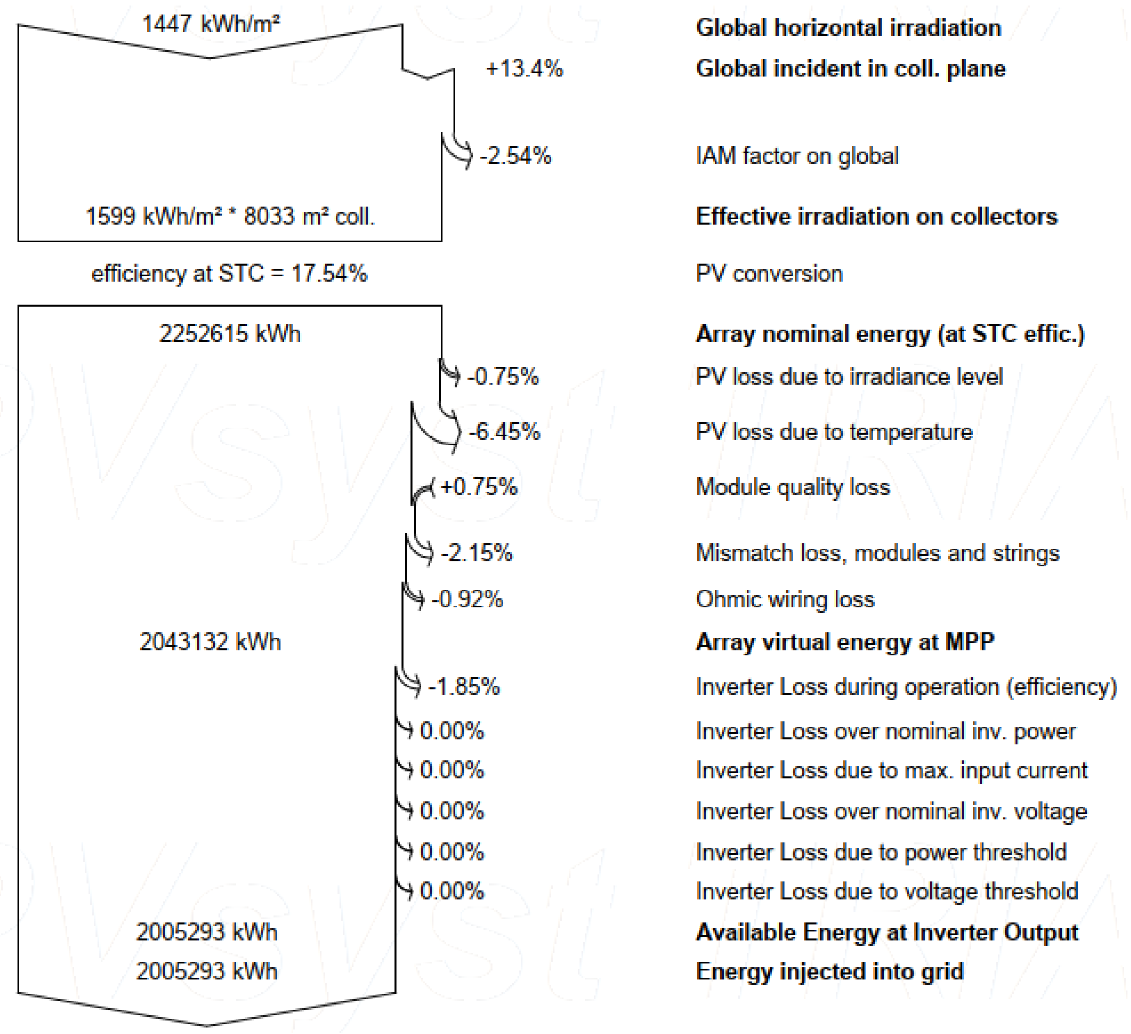


Figure 4.3 Loss diagram of PV plant (monocrystalline)

4.3 Simulation results for polycrystalline technology

Now that we have looked at the data, let us talk about polycrystalline. Nearly identical outcomes can be seen regarding the properties of the array and the electrical parameters. The fundamental factors that influence energy output, public relations, and payback period, on the other hand, are not significantly different from one another. When compared to monocrystalline technology, the overall system that utilizes polycrystalline technology is more advantageous.

Table 4.4 General parameters of PV plant (polycrystalline)

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	JKM 340PP-72-V	Model	FreeSun FS1390 HE/HEC 360V
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	340 Wp	Unit Nom. Power	1390 kWac
Number of PV modules	4140 units	Number of inverters	1 unit
Nominal (STC)	1408 kWp	Total power	1390 kWac
Modules	230 string x 18 In series	Operating voltage	565-820 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.01
Pmpp	1274 kWp		
U mpp	630 V		
I mpp	2021 A		
Total PV power		**Total inverter power**	
Nominal (STC)	1408 kWp	Total power	1390 kWac
Total	4140 modules	Number of inverters	1 unit
Module area	8033 m²	Pnom ratio	1.01
Cell area	7254 m²		

Table 4.5 Main results of PV plant (polycrystalline) 2

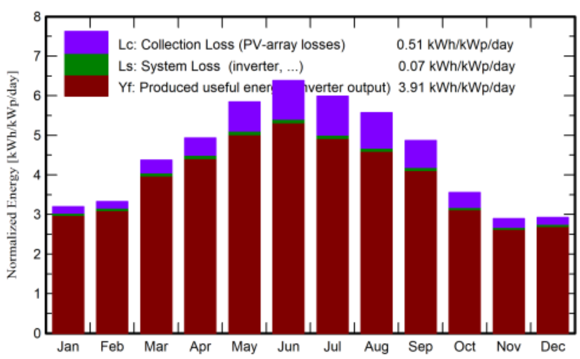
System Production

Produced Energy	2011129 kWh/year	Specific production	1429 kWh/kWp/year
		Perf. Ratio PR	87.09 %

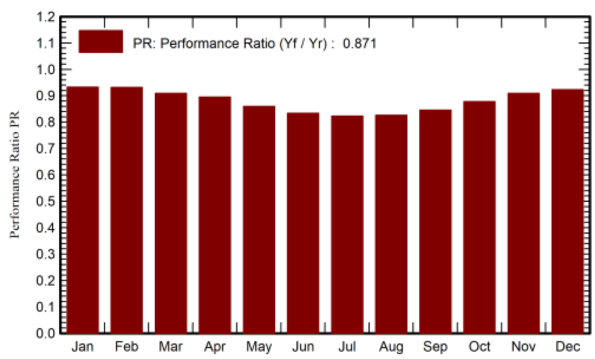
Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	1 322 100.00 AZN	Annuities	0.00 AZN/yr	Energy cost	0.05 AZN/kWh
Specific	0.94 AZN/Wp	Run. costs	45 189.12 AZN/yr		
		Payback period	8.3 years		

Normalized productions (per installed kWp)



Performance Ratio PR



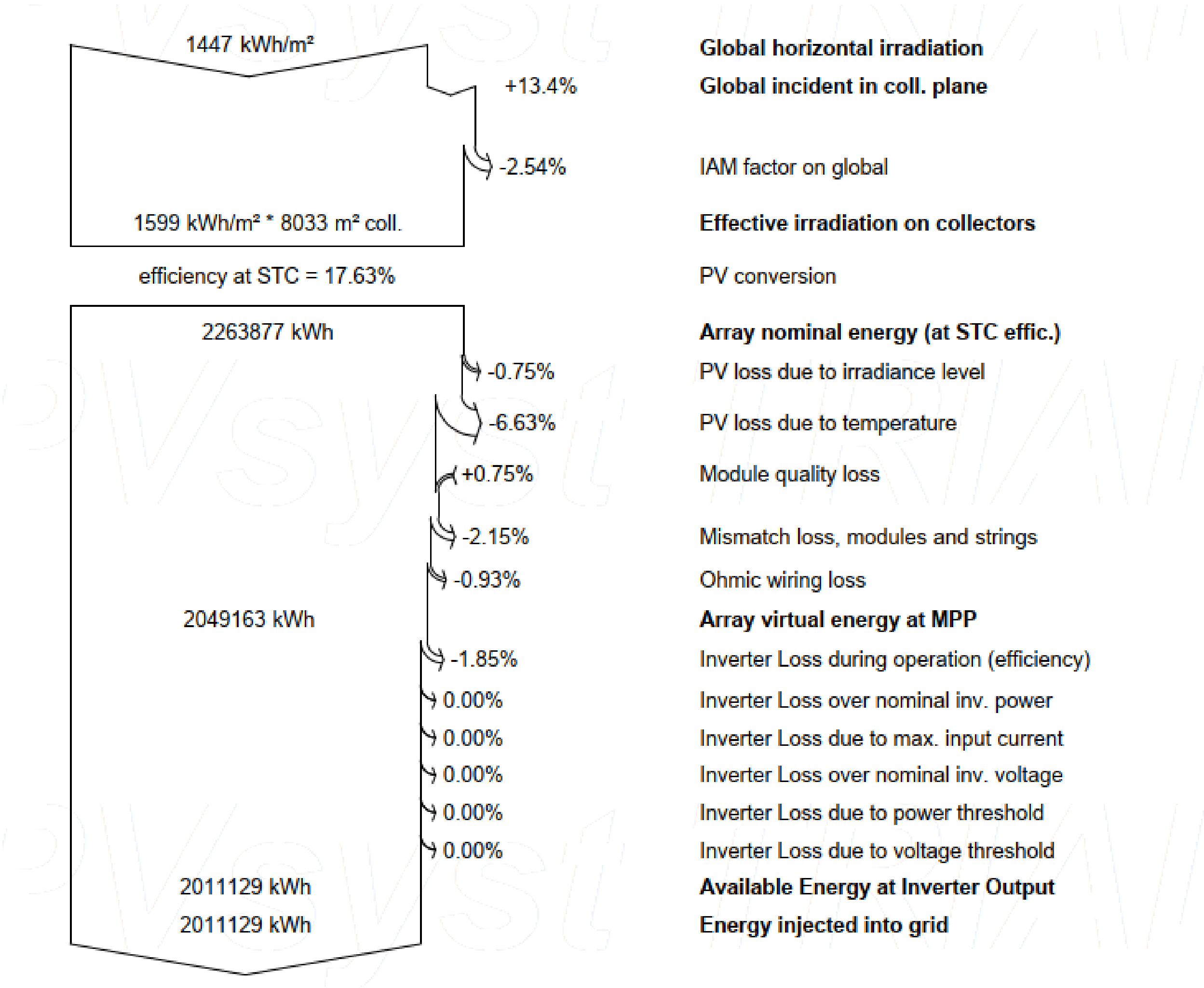


Figure 4.4 Loss diagram of PV plant (polycrystalline)

4.4 Economic analysis of PV plant

PVsyst may incorporate financial indicators to evaluate the economic feasibility of the photovoltaic system. These factors encompass the Levelized Cost of Electricity (LCOE), the time it takes to recoup the investment, and the financial internal rate of return (IRR). These indicators aid in assessing the economic viability of the solar project and projecting the long-term return on investment. According to statista.com CAPEX amount for a PV plant is 0.61$/W≈1AZN. Since our system is 1390kW CAPEX for our PV plant will be 1 322 100.00 AZN. In addition, OPEX according to the world standard will be 45 189 AZN. [20]

Table 4.6 Cost of the PV plant (monocrystalline)

Item	Quantity units	Cost AZN	Total AZN
PV modules			
JKM 340M-72	4140	200.00	828 000.00
Supports for modules	4140	15.00	62 100.00
Inverters			
FreeSun FS1390 HE/HEC 360V	1	20 000.00	20 000.00
Other components			
Wiring	10	3 000.00	30 000.00
Combiner box	10	3 000.00	30 000.00
Monitoring system, display screen	10	3 000.00	30 000.00
Measurement system, pyranometer	5	3 000.00	15 000.00
Installation			
Global installation cost per module	4140	50.00	207 000.00
Global installation cost per inverter	1	50 000.00	50 000.00
Grid connection	1	50 000.00	50 000.00
		Total	1 322 100.00
		Depreciable asset	910 100.00

Operating costs

Item	Total AZN/year
Maintenance	
Provision for inverter replacement	4 000.00
Salaries	12 000.00
Repairs	12 000.00
Cleaning	12 000.00
Total (OPEX)	40 000.00
Including inflation (1.00%)	45 189.12

System summary

Total installation cost	1 322 100.00 AZN
Operating costs (incl. inflation 1.00%/year)	45 189.12 AZN/year
Produced Energy	2005 MWh/year
Cost of produced energy (LCOE)	0.0489 AZN/kWh

The years that did not generate any profits are represented by the red hue, as can be seen. The gain from the system will cover all expenditures and begin to generate a profit when 8.3 years have passed. A total return on investment (ROI) of 193.7% has been achieved.

Table 4.7 Financial analysis of PV plant (monocrystalline)

Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
0	0	1 322 100	0	0	0	0	0	-1 322 100	0.0%
1	200 529	0	40 000	45 305	115 224	0	160 529	-1 161 571	12.1%
2	200 529	0	40 400	45 305	114 824	0	160 129	-1 001 441	24.3%
3	200 529	0	40 804	45 305	114 420	0	159 725	-841 716	36.3%
4	200 529	0	41 212	45 305	114 012	0	159 317	-682 399	48.4%
5	200 529	0	41 624	45 305	113 600	0	158 905	-523 493	60.4%
6	200 529	0	42 040	45 305	113 184	0	158 489	-365 004	72.4%
7	200 529	0	42 461	45 305	112 764	0	158 069	-206 936	84.3%
8	200 529	0	42 885	45 305	112 339	0	157 644	-49 292	96.3%
9	200 529	0	43 314	45 305	111 910	0	157 215	107 923	108.2%
10	200 529	0	43 747	45 305	111 477	0	156 782	264 705	120.0%
11	200 529	0	44 185	45 305	111 039	0	156 344	421 050	131.8%
12	200 529	0	44 627	45 305	110 598	0	155 903	576 952	143.6%
13	200 529	0	45 073	45 305	110 151	0	155 456	732 409	155.4%
14	200 529	0	45 524	45 305	109 701	0	155 006	887 414	167.1%
15	200 529	0	45 979	45 305	109 245	0	154 550	1 041 965	178.8%
16	200 529	0	46 439	45 305	108 786	0	154 091	1 196 055	190.5%
17	200 529	0	46 903	45 305	108 321	0	153 626	1 349 682	202.1%
18	200 529	0	47 372	45 305	107 852	0	153 157	1 502 839	213.7%
19	200 529	0	47 846	45 305	107 378	0	152 683	1 655 522	225.2%
20	200 529	0	48 324	45 305	106 900	0	152 205	1 807 727	236.7%
21	200 529	0	48 808	800	150 922	0	151 722	1 959 449	248.2%
22	200 529	0	49 296	800	150 434	0	151 234	2 110 683	259.6%
23	200 529	0	49 789	800	149 941	0	150 741	2 261 424	271.0%
24	200 529	0	50 287	800	149 443	0	150 243	2 411 666	282.4%
25	200 529	0	50 789	800	148 940	0	149 740	2 561 406	293.7%
Total	**5 013 234**	**1 322 100**	**1 129 728**	**910 100**	**2 973 406**	**0**	**3 883 506**	**2 561 406**	**293.7%**

Table 4.8 Return on investment

Payback period	8.3 years
Net present value (NPV)	2 561 406.38 AZN
Internal rate of return (IRR)	11.05%
Return on investment (ROI)	193.7%

Taking into consideration the data, polycrystalline technology is more advantageous than monocrystalline technology from an economic standpoint. The difference, on the other hand, is not that significant. For polycrystalline technology, the return on investment is 194.8%. In terms of net presented value (NPV), the increase is 14587.78 AZN.

for polycrystalline:

Table 4.9 Cost of the PV plant (polycrystalline)

Item	Quantity units	Cost AZN	Total AZN
PV modules			
JKM 340PP-72-V	4140	200.00	828 000.00
Supports for modules	4140	15.00	62 100.00
Inverters			
FreeSun FS1390 HE/HEC 360V	1	20 000.00	20 000.00
Other components			
Wiring	10	3 000.00	30 000.00
Combiner box	10	3 000.00	30 000.00
Monitoring system, display screen	10	3 000.00	30 000.00
Measurement system, pyranometer	5	3 000.00	15 000.00
Installation			
Global installation cost per module	4140	50.00	207 000.00
Global installation cost per inverter	1	50 000.00	50 000.00
Grid connection	1	50 000.00	50 000.00
		Total	1 322 100.00
		Depreciable asset	910 100.00

Operating costs

Item	Total AZN/year
Maintenance	
Provision for inverter replacement	4 000.00
Salaries	12 000.00
Repairs	12 000.00
Cleaning	12 000.00
Total (OPEX)	40 000.00
Including inflation (1.00%)	45 189.12

System summary

Total installation cost	1 322 100.00 AZN
Operating costs (incl. inflation 1.00%/year)	45 189.12 AZN/year
Produced Energy	2011 MWh/year
Cost of produced energy (LCOE)	0.0488 AZN/kWh

Table 4.10 Financial analysis of PV plant (polycrystalline)

Year	Electricity sale	Own funds	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
0	0	1 322 100	0	0	0	0	0	-1 322 100	0.0%
1	201 113	0	40 000	37 025	124 088	0	161 113	-1 160 987	12.2%
2	201 113	0	40 400	37 025	123 688	0	160 713	-1 000 274	24.3%
3	201 113	0	40 804	37 025	123 284	0	160 309	-839 965	36.5%
4	201 113	0	41 212	37 025	122 876	0	159 901	-680 064	48.6%
5	201 113	0	41 624	37 025	122 464	0	159 489	-520 576	60.6%
6	201 113	0	42 040	37 025	122 047	0	159 072	-361 503	72.7%
7	201 113	0	42 461	37 025	121 627	0	158 652	-202 851	84.7%
8	201 113	0	42 885	37 025	121 202	0	158 227	-44 624	96.6%
9	201 113	0	43 314	37 025	120 774	0	157 799	113 175	108.6%
10	201 113	0	43 747	37 025	120 340	0	157 365	270 540	120.5%
11	201 113	0	44 185	37 025	119 903	0	156 928	427 468	132.3%
12	201 113	0	44 627	37 025	119 461	0	156 486	583 955	144.2%
13	201 113	0	45 073	37 025	119 015	0	156 040	739 994	156.0%
14	201 113	0	45 524	37 025	118 564	0	155 589	895 584	167.7%
15	201 113	0	45 979	37 025	118 109	0	155 134	1 050 717	179.5%
16	201 113	0	46 439	37 025	117 649	0	154 674	1 205 392	191.2%
17	201 113	0	46 903	37 025	117 185	0	154 210	1 359 601	202.8%
18	201 113	0	47 372	37 025	116 716	0	153 741	1 513 342	214.5%
19	201 113	0	47 846	37 025	116 242	0	153 267	1 666 609	226.1%
20	201 113	0	48 324	37 025	115 764	0	152 789	1 819 398	237.6%
21	201 113	0	48 808	33 920	118 385	0	152 305	1 971 703	249.1%
22	201 113	0	49 296	33 920	117 897	0	151 817	2 123 520	260.6%
23	201 113	0	49 789	33 920	117 404	0	151 324	2 274 844	272.1%
24	201 113	0	50 287	33 920	116 906	0	150 826	2 425 671	283.5%
25	201 113	0	50 789	33 920	116 403	0	150 323	2 575 994	294.8%
Total	**5 027 822**	**1 322 100**	**1 129 728**	**910 100**	**2 987 994**	**0**	**3 898 094**	**2 575 994**	**294.8%**

Again, the years that did not generate any profits are represented by the red hue, as can be seen. The gain from the system will cover all expenditures and begin to generate a profit when 8.3 years have passed. A total return on investment (ROI) of 194.8% has been achieved.

Table 4.11 Return on investment

Payback period	8.3 years
Net present value (NPV)	2 575 994.16 AZN
Internal rate of return (IRR)	11.10%
Return on investment (ROI)	194.8%

4.5 Environmental impact

Solar plants play a crucial role in reducing carbon dioxide (CO_2) emissions. By harnessing sunlight to generate electricity, solar plants help displace the need for fossil fuel-based power sources, such as coal and natural gas. This shift to clean, renewable energy sources contributes to a decrease in greenhouse gas emissions, particularly CO2, mitigating the environmental impact associated with traditional power generation. The capacity to produce energy from an endless source is what sets photovoltaic energy production apart. Producing energy in an eco-friendly manner is made possible by this attribute. The benefits of PV plants compared with various energy sources are as follows:

- We can power our homes and more efficiently by using less petroleum and natural gas.
- Minimize or eliminate emissions of carbon dioxide and other harmful gases.
- Ensure that operating waste is minimized.

Greenhouse gas emissions will go down if a 1390 kW PV facility is installed. We can readily calculate the amount of decreased CO_2 using simulation software. We were able to conserve 19572.5 metric tons of carbon dioxide.

for monocrystalline:

Table 4.12 CO_2 emission balance (monocrystalline)

CO_2 Emission Balance

Total: 19572.5 tCO_2

Generated emissions

Total: 2303.16 tCO_2

Source: Detailed calculation from table below

Replaced Emissions

Total: 24615.0 tCO_2

System production: 2005.29 MWh/yr

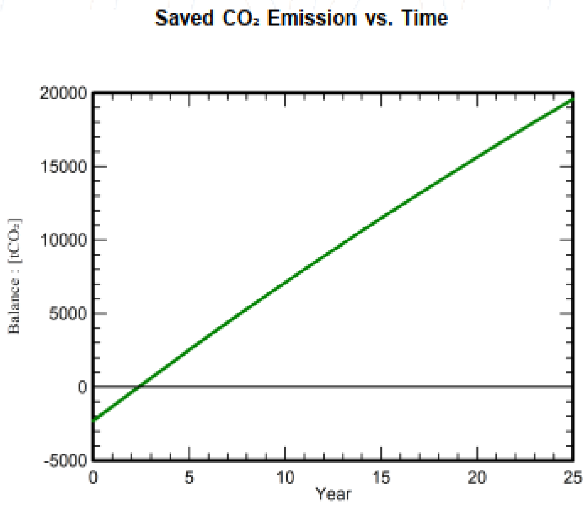
Grid Lifecycle Emissions: 491 gCO_2/kWh

Source: IEA List

Country: Azerbaijan

Lifetime: 25 years

Annual degradation: 1.0 %



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	1273 kWp	2180224
Supports	3.27 kgCO2/kg	37440 kg	122615
Inverters	324 kgCO2/units	1.00 units	324

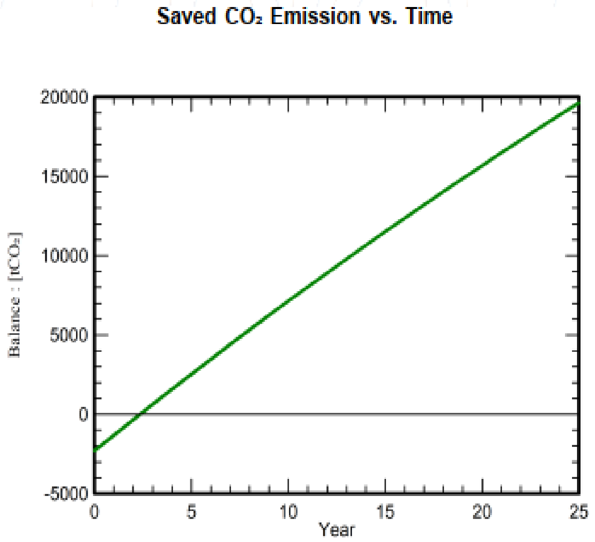
When compared to monocrystalline technology, polycrystalline technology conserves 19636.2t of emission, which is 63.7 t more than monocrystalline technology.

for polycrystalline:

Table 4.13 CO_2 emission balance (polycrystalline)

CO_2 Emission Balance

Total:	19636.2 tCO_2
Generated emissions	
Total:	2303.16 tCO_2
Source: Detailed calculation from table below	
Replaced Emissions	
Total:	24686.6 tCO_2
System production:	2011.13 MWh/yr
Grid Lifecycle Emissions:	491 gCO_2/kWh
Source:	IEA List
Country:	Azerbaijan
Lifetime:	25 years
Annual degradation:	1.0 %



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal [$kgCO_2$]
Modules	1713 kgCO2/kWp	1273 kWp	2180224
Supports	3.27 kgCO2/kg	37440 kg	122615
Inverters	324 kgCO2/units	1.00 units	324

Table 4.12 and 4.13 illustrate the correlation between greenhouse gas savings and the lifespan of the plant. The accompanying graph indicates a consistent annual increase in emission savings. In addition, you can see carbon saving per each element and subtotal for all equipments.

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

5.1 Conclusion

This research compared the performance of a 1.39 MW photovoltaic (PV) system installed on the ADA University rooftop with that of a system using polycrystalline solar cells. The cells were monocrystalline. The goal of the component selection process was to provide a fair assessment of the two technologies' capabilities. Because polycrystalline cells in grid-connected solar systems do not do as well at high temperatures as monocrystalline cells, more modules and more surface area are needed to make up for it.

All costs and annual energy output are some of the financial issues included in the second PV SYST sizing and simulation study. According to the results, the amount and surface area of modules needed by the two systems are equal. Although monocrystalline photovoltaic (PV) systems are more expensive, they generate more energy, according to the modeling results. For the purpose of making an accurate comparison, an extensive economic analysis was carried out to determine the LCOE, amortization schedule, and payback duration for both technologies. Results in terms of payback time, amortization, and levelized cost of electricity (LCOE) show that a polycrystalline grid-linked photovoltaic (PV) system is the best fit for the power plant model at ADA University. Compared to the monocrystalline system, the polycrystalline system has a shorter payback period, greater benefits throughout plant operation, and a cheaper cost per kilowatt-hour. The difference, on the other hand, is not that significant. For polycrystalline technology, the return on investment is 194.8%. In terms of net presented value (NPV), the increase is 14587.78 AZN. We were able to conserve 19572.5 metric tons of carbon dioxide. When compared to monocrystalline technology, polycrystalline technology conserves 19636.2t of emission, which is 63.7 t more than monocrystalline technology.

5.2 Future Work

Improving the efficiency of the rooftop solar power system at ADA University Campus might be part of future plans, along with incorporating smart grid technology, energy storage options, and improving the system's layout. The solar project's long-term viability and success may depend on measures such as ongoing performance data monitoring and analysis and educational campaigns to increase public awareness. To enhance the influence of the solar power system, it will be vital to collaborate with academic and industrial partners for research possibilities, involve the community, and conform to shifting rules and policies.

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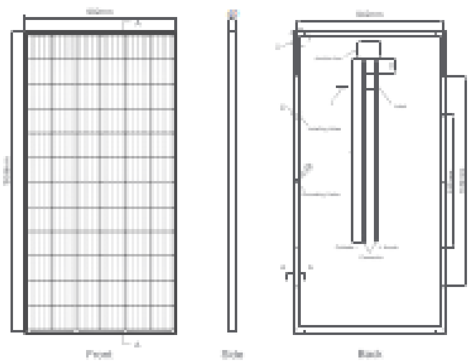
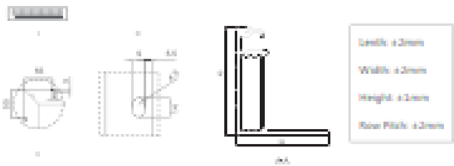
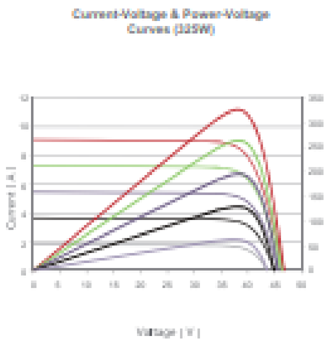
APPENDIX A

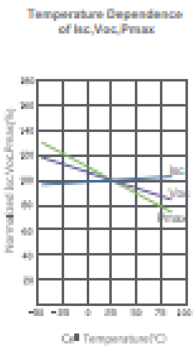
Engineering Drawings





Electrical Performance & Temperature Dependence





Packaging Configuration

(Two pallets=One stack)

27pcs/pallet, 54pcs/stack, 648 pcs/40'HQ Container

Mechanical Characteristics

Cell Type	Poly-crystalline 157×157mm (6 inch)
No.of cells	72 (6×12)
Dimensions	1956×992×40mm (77.01×39.05×1.57 inch)
Weight	22.5 kg (49.6 lbs.)
Front Glass	3.2mm, Anti-Reflection Coating, High Transmission, Low Iron, Tempered Glass
Frame	Anodized Aluminium Alloy
Junction Box	IP67 Rated
Output Cables	TÜV 1×4.0mm², Length: 1200mm or Customized Length

SPECIFICATIONS

Module Type	JKM320PP-72 JKM320PP-72-V		JKM325PP-72 JKM325PP-72-V		JKM330PP-72 JKM330PP-72-V		JKM335PP-72 JKM335PP-72-V		JKM340PP-72 JKM340PP-72-V	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	320Wp	237Wp	325Wp	241Wp	330Wp	245Wp	335Wp	249Wp	340Wp	253Wp
Maximum Power Voltage (Vmp)	37.4V	34.7V	37.6V	35.0V	37.8V	35.3V	38.0V	35.6V	38.2V	35.9V
Maximum Power Current (Imp)	8.56A	6.83A	8.65A	6.89A	8.74A	6.94A	8.82A	6.99A	8.91A	7.05A
Open-circuit Voltage (Voc)	46.4V	43.0V	46.7V	43.3V	46.9V	43.6V	47.2V	43.8V	47.5V	44.0V
Short-circuit Current (Isc)	9.05A	7.35A	9.10A	7.40A	9.14A	7.45A	9.18A	7.52A	9.22A	7.58A
Module Efficiency STC (%)	16.49%		16.75%		17.01%		17.26%		17.52%	
Operating Temperature(℃)	-40℃~+85℃									
Maximum system voltage	1000/1500VDC (IEC)									
Maximum series fuse rating	20A									
Power tolerance	0~+3%									
Temperature coefficients of Pmax	-0.38%/℃									
Temperature coefficients of Voc	-0.31%/℃									
Temperature coefficients of Isc	0.06%/℃									
Nominal operating cell temperature (NOCT)	45±2℃									

APPENDIX B

freesun
SOLAR INVERTER

HE | Technical Characteristics 360VAC

		360VAC - MPPt Window 510Vdc-900Vdc								
		FRAME 1 - FS		FRAME 2 - FS			FRAME 3 - FS			
	NUMBER OF MODULES	2	3	4	5	6	7	8	9	10
	FREESUN HE	FS0280IH	FS0420IH	FS0560IH	FS0700IH	FS0830IH	FS0970IH	FS1110IH	FS1250IH	FS1390IH
OUTPUT	Nominal AC Power(kVA) at 50°C	280	420	560	700	830	970	1110	1250	1390
OUTPUT	Nominal AC Current (A) at 50°C	444	667	889	1111	1333	1555	1778	2000	2222
OUTPUT	Operating Grid Voltage(Vac)	360Vac								
OUTPUT	Operating Range, Grid Frequency	50Hz - 60Hz								
OUTPUT	Voltage Ripple, PV Voltage	< 3%								
OUTPUT	Current Harmonic Distortion (THDi)	< 3% at nominal power								
OUTPUT	Power Factor (cosi phi)[1]	0.0 leading...0.0 lagging / Reactive power injection at night								
OUTPUT	Number AC connections per pole	4x240mm²xM12		4x240mm²xM12			8x240mm²xM12			
INPUT	MPPt Voltage Window (VDC)[2]	510V-900V								
INPUT	MPPt window @full power (VDC)[2]	568V-820V								
INPUT	Max. permissible DC voltage (Vdc)	1000V								
INPUT	Rated DC current (A)	500A	750A	1000A	1250A	1500A	1750A	2000A	2250A	2500A
EFFICIENCY & AUX. SUPPLY	Maximum Efficiency Pac, nom (η)	98.6%		98.6%			98.6%			
EFFICIENCY & AUX. SUPPLY	Euroeta (η)	98.2%		98.3%			98.4%			
EFFICIENCY & AUX. SUPPLY	Maximum Standby Consumption (Pnight)	< approx. 120W		< approx. 240W			< approx. 400W			
EFFICIENCY & AUX. SUPPLY	Control Power Supply	3 x 400V, 50/60Hz, (VRT compatible inverters equipped with internal UPS)								
CABINET	Dimensions [WxHxD] mm	2100x2080x1020		3372 x 2080 x 1020			5260 x 2080 x 1020			
CABINET	Weight (kg)	1650		2900			4500			
CABINET	Air flow	Intake through rear lower part blown out through upper side								
CABINET	Type of ventilation	VSD temperature controlled, Air-cooled								
ENVIRONMENT	Degree of protection	Indoor IP21								
ENVIRONMENT	Permissible Ambient Temperature	-20°C ...+50°C								
ENVIRONMENT	Relative Humidity	10% to 95% Non condensing								
ENVIRONMENT	Max. Altitude (above sea level)	1000m; >1000m power derating 1% Sn (kVA) per 100m								
ENVIRONMENT	Noise level[4]	< 79 dBA								
CONTROL INTERFACE	Interface	Alphanumeric Display / Optional Freesun App Display or Freesun Web Display								
CONTROL INTERFACE	Communication	RS232 / RS485 / USB / Ethernet, (Modbus RTU Protocol, Modbus TCP/IP) Optional GSM/GPRS								
CONTROL INTERFACE	Analogue Inputs	1 programmable and differential inputs; (0-20mA or ± 10mV to ± 10V) and PT100								
CONTROL INTERFACE	String Supervisor Communication	RS485 /Modbus RTU								
CONTROL INTERFACE	Plant Controller Interface	Ethernet / Modbus / TCP/IP								
CONTROL INTERFACE	Digital Outputs	2 electrically-isolated programmable switched relays (250Vac, 8A or 30 Vdc, 8A)								
PROTECTIONS	Ground Fault Monitoring[5]	Standard built in								
PROTECTIONS	Humidity Control	Active Heating / Optional Heating Resistors								
PROTECTIONS	Emergency Stop	Optional								
PROTECTIONS	General AC Protection & Disconn.	Circuit Breaker / Optional AC fuses & disconnectors								
PROTECTIONS	General DC Protection & Disconn.	Optional: Integrated in empty modules or external								
PROTECTIONS	Module AC Protection & Disconn.	AC circuit breaker & contactor								
PROTECTIONS	Module DC Protection & Disconn.	Motorized MCCB								
PROTECTIONS	Overvoltage Protection	AC, DC Inverter and Auxiliary Supply type 2 - Internal Standard								
PROTECTIONS	Lightning Protections	Optional (Integrated in the inverter)								

NOTES
[1] [1] Consult P-Q charts available: $Q(kVAr)=\sqrt{S(kVA)^2-P(kW)^2}$
[2] Values at 1.00Vac nom and cos Φ = 1.
Consult Power Electronics for derating curves.
[3] Values at 1.00Vac nom and cos Φ = 1 and T_{amb}=50°C.
[4] Sound pressure level at a distance of 1m from the rear part.
[5] In cases where the installation has the positive pole or the negative pole earth connected, this protection will be disconnected.