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Evaluation and Simulation of Performance, Environmental and Economic Aspects of 1MW Photovoltaic Powerplant and Comparison with an Operational Powerplant

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In the current study, an operational method for feasibility study of a photovoltaic powerplant connected to the grid with total capacity of 1MW provide. This method first uses the geographical conditions of the powerplant's location to determine the arrangement for photovoltaic arrays with the conditions of minimized space use and suitable distance between photovoltaic strings to facilitate maintenance and repair and preventing modules from casting shadows on each other. The innovation of the current article is using the empirical data to compare the simulated powerplant and an actual powerplant from economic, performance and environmental pollutant aspects. The error analysis between the actual powerplant and simulated model is used to determine the accuracy of the simulation results. Furthermore, the amount of CO2 emission reduction due to the construction of this powerplant is investigated. The results indicated the importance of the geographical location and indicated which locations in Iran provide the highest efficiency for construction of photovoltaic powerplants. Furthermore, the other innovation is to determine the number of residential apartment units whose electricity was provided by this powerplant.

Keywords: Photovoltaic Cell, Photovoltaic Powerplant, Environmental pollutant, CO_2 emission, Empirical data, Casting shadows

1 Introduction

For years, environmental researchers have considered the use of renewable energy both as an alternative to potentially depleting oil reservoirs and to counteract oil dependence. Severe environmental pollution due to the use of fossil fuels is another factor to change the use of conventional fossil energy sources to renewable energy sources [1].
In recent years, due to the reduction of other energy sources such as fossil fuels and their harmful effects on the environment by creating harmful gases such as carbon dioxide and

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sulfur dioxide, researchers are paying attention to the use of other renewable energy sources. Permeability has increased like solar cells. Reducing the use of fossil fuels is one of the most important steps in helping to control global warming [2, 3].

The spread of clean energy such as solar and wind energy has reduced the use of oil and coal in power plants. The use of public transportation and cars with non-fossil fuels has a significant impact on reducing greenhouse gas emissions [4]. Also Simultaneous triple power generation systems have become to an attractive option to meet energy demand Consumers.

Yaghoubi et al. in [5], after introducing these systems an appropriate procedure for designing triple energy generation systems for use in tropical regions and extraction, an optimal exploitation model has been presented.

Renewable energy sources such as solar, wind, tidal and geothermal energies are limitless and offer no limitations. In contrast, non-renewable resources such as petroleum, gas and coal are limited with dwindling reserves. Furthermore, the use of fossil fuels and non-renewable energies result in emission of significant amounts of environmental pollutants including CO_2 which is the main contributor in climate change. Among renewable energies, solar energy is known as a source of free and clean energy without significant detrimental environmental effects. Therefore, the energy crisis has resulted in many countries changing their methods related to renewable energies.

The annual energy consumption worldwide was estimated at 13TW in year 2000. This number, considering the increase in population and energy consumption will reach the annual amount of 28TW by year 2050. Therefore, many researchers round the world have aimed to use renewable energy resources such as wind turbines and photovoltaic cells to replace current energy sources [1].

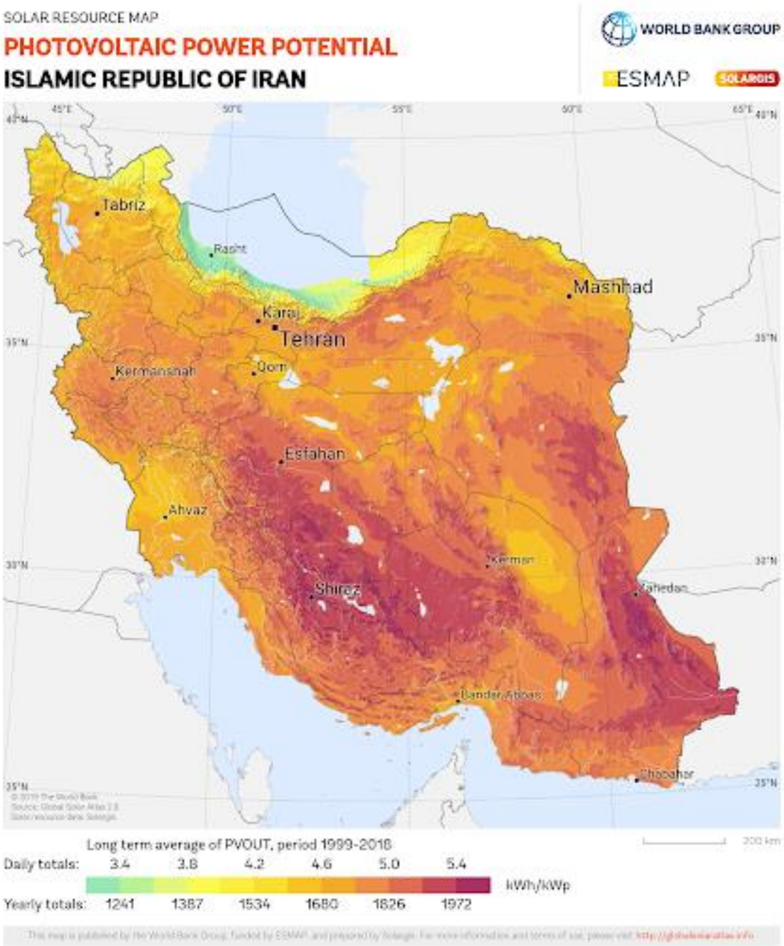


Figure 1 Map of solar irradiation amount in Iran

The photovoltaic technology is the most direct method of converting solar energy to electrical energy without any CO_2 emissions of greenhouse effects. The annual potential usable solar energy is estimated to be 600TW [2, 3].
Iran is located between the latitudes of 22ºN and 440ºN and is ranked among the locations with the highest solar input worldwide.
The most important advantages of solar energy include its unlimited and renewable supply, accessibility, free use, environmentally friendly nature, its compatibility with sustainable development and the possibility of electricity production at the place of use.
Since Iran has on average a total of 280 sunny days per year, it can be placed among the countries with high access to solar energy. According to the data provided by Iran Meteorological Organization, the average solar irradiation in Iran is between 1800 to 2200 KW/m^2 which is approximately twice the amount of irradiation in Europe [4].
Direct conversion of solar energy to electrical energy is often carried out using photovoltaic cell using photovoltaic effect. This effect is based on the interaction between photons with energies equal or higher than that of the band gap of photovoltaic compounds with these materials. These photovoltaic modules can convert solar energy to electrical energy without noise, pollution or variation in electrical output. However, solar energy has a low density and therefore photovoltaic modules require large surface area to produce relatively small amounts of electrical energy. Photovoltaic systems used in power grids must also use suitable DC to AC coverts to match the electrical output of photovoltaic arrays to that of the electricity distribution grid. Solar electricity is also the main source of power in spacecrafts and various space missions.
The structure and performance of photovoltaic systems are very important in proper use of these systems [5].

2 Various parts of photovoltaic powerplants

The equipment necessary for production of solar electrical energy include [6]:

- Photovoltaic arrays;
- Solar tracking systems;
- AC/DC inverters or electronic power converters;
- Power storage units;
- Maximum power trackers;
- Other necessary utilities;

Photovoltaic arrays
Photovoltaic arrays are created by combining several photovoltaic panels, each made from several photovoltaic modules. Each photovoltaic module includes several photovoltaic cells which convert solar energy to electrical energy [7].
Solar Tracking systems
Photovoltaic arrays can be installed using stationary method or using solar tracking systems which change their angle to the sun based on the season. Sometimes the arrays can also be installed using seasonal stationary method. The most important parameter during installation of photovoltaic arrays is their angle with the solar irradiation since irradiation angle can significantly affect the electricity production in these photovoltaic arrays. However, due to change in solar irradiation angle during various times of day as well as in different seasons, the received solar irradiation in these arrays can change depending on the time of day and time of year. The seasonal stationary installation method is used to improve the solar irradiation input of the arrays. In this method, solar trackers are used to rotate the arrays along one or two of their axes in order to create a constant angle with the solar irradiation, thus increasing the output of solar panels [8]. In the stationary solar panels, the panels are installed with a constant angle

facing the sun. In the northern hemisphere including in Iran, photovoltaic panels are installed with their irradiation sensitive side facing southward since the sun is at the southern angle during the year. However, in order to maximize solar irradiation adsorption, it is recommended that the installation slope be equal to the latitude of the installation location. For example, in the city of Isfahan, Iran, solar panels should be installed with the slope of 32 degrees facing southward in order to maximize their solar input over the year.

AC/DC inverters or electronic power converters

These inverters receive DC power of the photovoltaic array and convert it to standard AC current used for home applications or power transfer with characteristics such as AC frequency determined by the user. In general, photovoltaic units can be divided into two main categories of arrays connected and detached from the main power grid. This can affect the types of inverters and converters used in these arrays [6].

Power Storage Units

Power storage units in photovoltaic arrays are often batteries and can include some or all of the following parts [10, 11, 12]:

- Battery case;
- Battery charge control unit;
- Separate panels for critical circuits;

These batteries are used to store the produced electrical energy and can also power critical units during power outages. In case of lack of power in the power grid, the solar unit is removed from the grid and is only used to provide power for predetermined critical units.

The main factor for selection of batteries in photovoltaic systems is their charging and discharging ability for numerous cycles without significant damage to the battery’s operations. Serial or parallel configurations are also used in order to produce higher capacities.

Batteries are used in both attached and detached photovoltaic systems and store the produced energy when the production is higher than the load. Then, when solar irradiation is unavailable or when the solar energy production is lower than the load, batteries are used to make up for the difference. Therefore, these batteries should be able to be charged and discharged for numerous cycles.

Maximum power trackers

Figure (1) shows the current – voltage curve of a solar panel. As can be seen, each location on the curve provides a voltage and current value which is not necessarily the maximum possible voltage or current.

For example, point E has the maximum voltage but the current value of zero while B has maximum current but the voltage is lower than the maximum amount. In order to optimize the use of photovoltaic panels, it is necessary to select the point with maximum possible current and voltage. This point is determined using maximum power trackers. For example, point C has the highest possible current and voltage. The next graph shows the output power versus the voltage for an electrical panel [9].

In 2013, Mohammad hossein Shams, Mohsen Kiya an Behdad Mahdavi, carried out the design optimization studies of a 100KW grid-connected photovoltaic powerplant in Tehran using PVSyst software and provide the optimum implementation method for the photovoltaic powerplant considering boundaries such as output voltage and power of modules, voltage range and inverter input currents.

In 2014, Mohammadali Mahdiyan, Amir Sayemi & Vali Kalantar carried out a simulation of photovoltaic powerplant in university of Yazd and validated the results using empirical data. The result of their comparison between simulation results of the powerplant performance using PVSyst software and empirical data showed very small errors, indicating that this software can be reliably used for simulation of photovoltaic powerplants.

In 2017, Reza Pasaaei Mohammadi & Ali Hatani carried out a study on optimal design and performance of a 5-KW grid-connected solar powerplant in Shahid Beheshti University of Tehran using 250W Yangly panels. In this study, a solar powerplant with high yield was designed for a residential complex using PVSyst software. The results lead to recommended methods for selecting optimal width and length of the photovoltaic powerplant. Furthermore, the simulation results were used to recommend the optimal angle of 40 degrees and azimuthal angle of zero degrees for the panels, resulting in annual output of 8422 KWh.
Pi Shiva Kumar et.al. in 2015 investigated the performance of a 10-MW grid-connected solar powerplant in Bapal University of India using PVSyst software and conclded that the highest energy input at the geographical location occurred in the month of December and was equal to 1589MW electricity; with the annual electricity production being 16047 MW [10].
In 2015, Y.M. Irvin and R.A. Amelia et.al. evaluated grid-independent photovoltaic systems using PVSyst software and concluded that this software is capable of predicting optimal design and configuration of photovoltaic systems. Furthermore, the output energy was calculated based on the simulation results which was significantly dependent on the geographical location.
In 2015, Tobias Gertsmier et.al. carried out a large and length set of experiments for photovoltaic systems in the University of Freiburg. In these experiments, small power plants were tested for a few days and large powerplants were tested for several weeks and the results indicated that all three tested powerplants has higher than expected energy outputs. Furthermore, two methods were identified for optimizing the energy modeling of large-scale powerplants using central inverters [11].
In 2017, an investigation on degradation of grid-connected photovoltaic systems was carried out in University of Salento, Italy by Mariya Malouni et.al. using PVSyst software. In this work, for the first time, the expected energy production per hour measure was used for performance comparison of photovoltaic systems and the results indicated that the reliability of photovoltaic systems depends on their operational conditions and is not directly related to weather changes. Furthermore, a good compatibly was observed between theoretical and empirical output, indicating a reliability of approximately 85% I photovoltaic system. Furthermore, annual degradation after 5 years of exposure to sunlight was estimated as 1.12% per year [12].
In 2016, Shazad Ehsan et.al. in University of Deli, India, carried out a design and cost analysis of 1-KW photovoltaic systems based on their actual performances in India using PVSyst software. Their results indicated that the photovoltaic system is capable of producing up to 3101.2 KWh of electrical energy but actually produces only 2933.4 KWh of energy, resulting in 167.8 KWh unused potential which can be due to battery problems or lower energy demand during daytime hours. In this study, the produced photovoltaic energy was calculated on a monthly basis [13].
In 2018, Elham Baghdadi et.al. investigated the performance of grid-connected photovoltaic systems in Morocco which linked 2.04KW monocrystal cells with 2.04KW polycrystalline cells and 1.86KW amorphous cells using PVSyst software. Their results indicated a large difference between these technologies and showed that monocrystalline cells have better performance compared to polycrystalline cells which are in turn better than amorphous cells [14].
In 2020, Rahim Balmahdi & Abdolmajid Albouradi, carried out an investigation of potential photovoltaic performance in the northern regions of Morocco using PVSyst software. They investigated the performance of a 1MW powerplant and investigated different installation conditions. The results indicated that optimal operation could be achieved using the angle of 33 degrees for constant angle configuration and 15-degree summer angle and 48-degree winter angle for seasonal angular adjustment configurations. The overall performance results indicated that the constant angle configuration as 77.3% better performance compared to seasonal angular adjustment configurations [15].
Diptiman Dey and Bidyadhar Subudhi performance a simulation and feasibility study on grid-connected 90KW systems in 2020 in India. They suggested using 9 photovoltaic systems of

10KW each for a grid-connected configuration and showed that this powerplant can result in 2199.6 metric ton reduction of CO_2 emission in 20 years and provides good economic feasibility [16].

Yen Yang et.al. analyzed the potential of rooftop solar powerplants in 2020 in Sweden. Their results indicated a high potential for rooftop solar powerplants which can be used in residential, business and industrial buildings [17].

Panj Kumar et.al. in 2020 carried out an analysis and evaluation of 10 KW solar photovoltaic array for remote islands of Andaman and Nicobar and investigated 5 different geographical locations for solar arrays [18].

Reference [19] mentions the feasibility of solar PV based on the approach of environmental and economic analysis in five locations in Malaysia using 7 E evaluation frameworks. Solar radiation and weather data for each location were collected from the meteorological database using RETSCP software, and the results show that the proposed solar PV system will work well enough for all selected locations with a minimum yield rate of 8%.

Reference [20] for determining the optimal location for the development of solar power plants in Ghana states that the selection of suitable locations for the development of solar farms by combining analytical hierarchical process and density-based clustering using the GIS. In recent years, some researchers study Photovoltaic Systems in different Different climate zones for example, Design these systems, Simulation and Economic Evaluation [21], Potential Analysis of a Solar Photovoltaics [22] and Performance Analysis and Evaluation of the Solar Photovoltaic Array [23]. These studies maybe focoused on analysis of a conceptual utility-scale [24] or Optimizing photovoltaic power plant site [25].

Based on the previous studies, the current study aims to simulate a 1MW photovoltaic powerplant using PVSyst in Iran and evaluate the results based on structure, performance, feasibility and environmental effects. The innovation of the current article is using the empirical data to compare the simulated powerplant and an actual powerplant from economic, performance and environmental pollutant aspects. Furthermore, the amount of CO_2 emission reduction due to the construction of this powerplant is investigated. Furthermore, the other innovation is to determine the number of residential apartment units whose electricity was provided by this powerplant.

3 Results and discussion

3.1 Determination of Panel and Azimuthal angles

The base of solar panels can use various configurations including stationary, seasonal-stationary, vertically adjustable, horizontally adjustable and adjustable in both axes and in the current study, based on economic reasons and feasibility, the stationary configuration is used. This is due to the fact that adjustable panel bases must be replaced in average every 5 to 6 years, resulting in an average of 5 replacements in 25 years, thus increasing the operational costs of the project.

In regard to the angle of solar panels, based on the latitude principle, the angle should be equal to the installation latitude in order to maximize the solar irradiation which is equal to 30.7 degrees in this study. Therefore, the angle of 30 degrees was selected. As can be seen in figure (2), the azimuthal angle indicates the direction facing the solar panels with azimuthal angle of zero showing that the panels are facing directly southwards. This is in line with the known principles for countries located in the northern hemisphere including Iran, in which solar panels should face southward to maximize solar irradiation which in southern hemisphere, the panels should face northward.

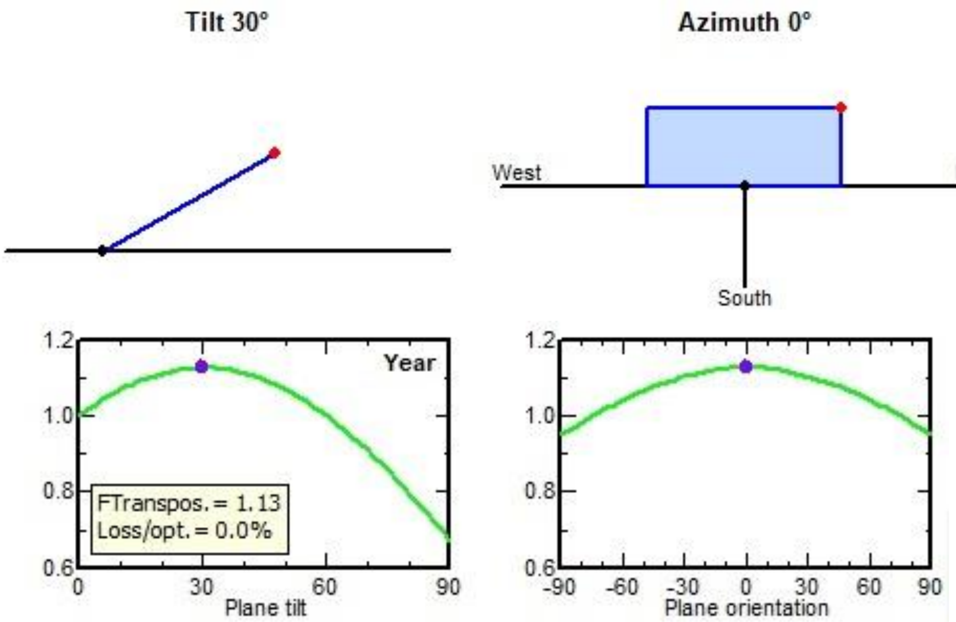


Figure 2 Determination of solar panel angles

Countries such as Iran, which are located in the northern hemisphere, should place their photovoltaic panels to the south and install them. Solar panel is usually fixed in Iran (latitude * .9). For example, for Isfahan, solar panel angle is common to consider between 29 and 32 degrees, which is finally in this work is considered at 30 degrees.

As can be seen in figure (2), the panels' base angle is 30 degrees, resulting in zero irradiation loss, with other angles resulting in loss in received solar irradiation.

This simulation must to do between December 20 and 22 in each year, which is a geographical rule, which says the shadow and the yield that these days enters the system throughout the year. It should be noted that the software extracts all days of the year in accordance with geographical data.

3.1.1 Determination of Type of Panels

Since the powerplant is designed for the output of 1000KW or 1MW, the cell output is set to 250W at peak output. Due to feasibility reasons, polycrystalline cells are used which means a total of 4000 solar panels are needed for the entire powerplant. Based on provided yields and price range, CHSM6610P-250 model of solar panels made by Astronergy – Germany was selected which offers a yield of 17.23%.

This solar panel has the length of 1652mm, width of 994mm and thickness of 45mm. The weight of each solar panel is 20Kg and includes 60 parallel cells covering a total area of 243.3cm^2.

The I-V graph of this panel is presented in figure (12) and shows its operational current and voltage.

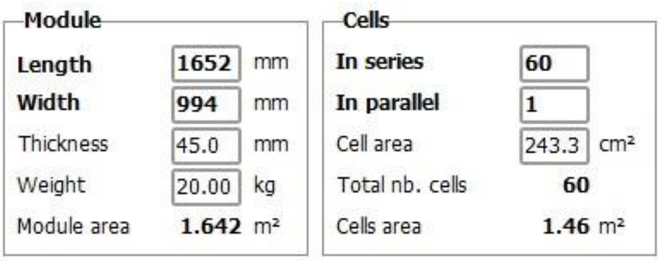


Figure 3 Dimensions and size of solar panels

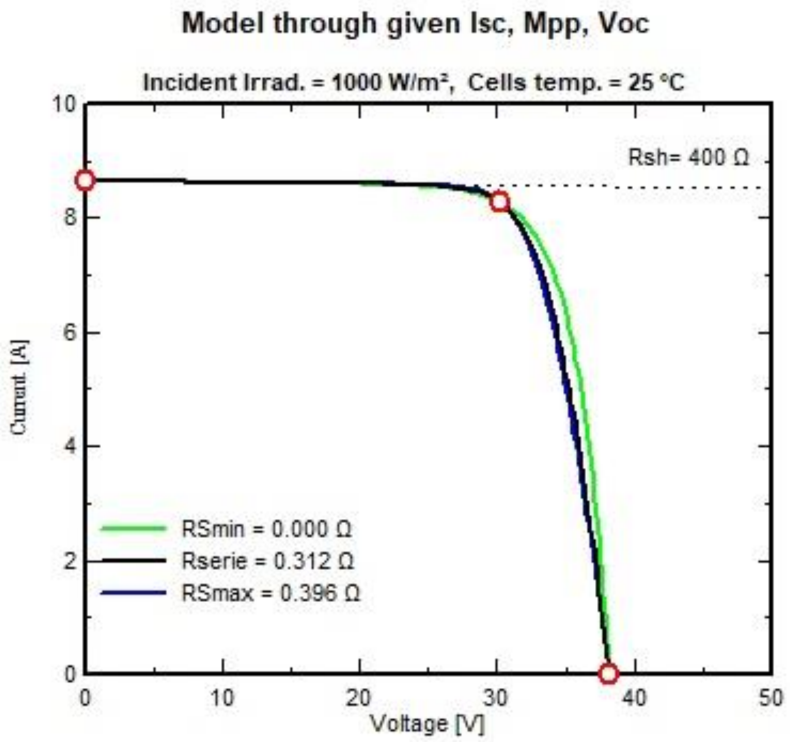


Figure 4 The I-V diagram of the solar panel

In this diagram, the first point at the voltage of 0, is the short-circuit current of 8.65 A while the voltage at the current of zero is equal to 38.19V. The point at the voltage of 30.3V and current of 8.27 has the highest power output. The graph for parallel resistance configuration is shown with greed, graph for serial resistance configuration is black and the graph for highest series resistance is shown with blue.

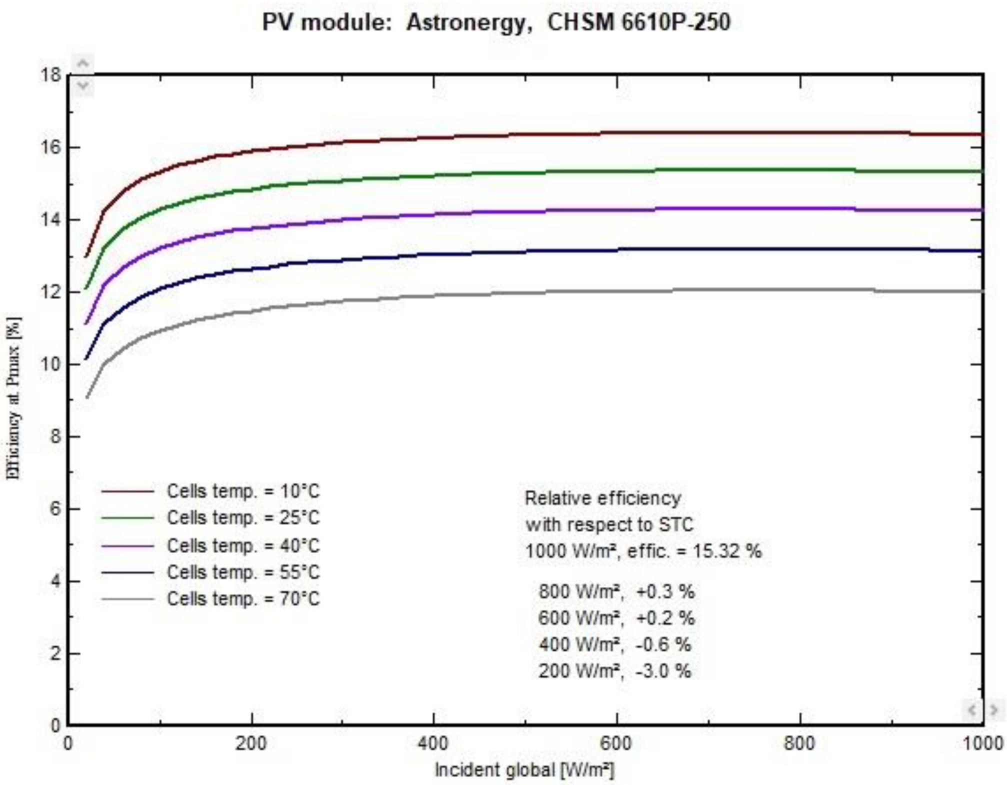


Figure 5 Yield at maximum power versus power input per surface area

3.1.2 Determination of yield at maximum power

The following diagram shows the yield at maximum power versus overall power input per surface area at different temperatures. The graph for temperature of 10℃ is shown in red, graph for 25℃ is greed, the graph for 40℃ is violet, the graph for 55℃ is blue and the graph for 70℃ is shown in gray color. The results indicate that the output power of the solar panel changes with the temperature, with higher temperatures resulting in lower solar panel output powers. Therefore, the geographical location selected for installation of solar panels should have a suitable temperature range.
The most suitable location for installation of photovoltaic powerplant must have a maximum annual temperature of less than 40℃ which means that the city of Isfahan is suitable for its installation and maximizing energy output.
It is worth nothing that this diagraph is drawn for Astronergy CHSM6610P-250 and the results will vary depending on the brand and model of solar panels used.

3.1.3 Inverter selection

After selecting and evaluating the solar panels, it is also necessary to select and evaluate the inverter data. Since the photovoltaic powerplant has a power output of 1MW, the best inverter requires a nominal power of 500KW. To this end, Sunny Cenral 500 CP-US inverter made by SMA, Germany was selected which has minimum voltage of 430V, maximum voltage of 820V, and maximum yield of 96.8%.
Figure (16) shows changes in power at different temperatures. As can be seen, output power is directly proportional to the temperature, with the maximum power of 550KW observed at temperature of 25℃, the nominal power of 500KW at 55℃ and a sharp decline in output power at higher temperatures. This emphasizes the importance of the temperature at the photovoltaic powerplant's location and the important of predicting temperature variations at the powerplant's location due to its direct effects on powerplant performance.

3.1.4 D simulation of solar powerplant

After selecting proper solar panel and inverters and entering necessary data, the "Near Shadings" option is used to provide a 3D model of the powerplant location. To this end, some parameters must be considered including the array arrangements and the position of panels. These are used to provide a 3D model of the 1MW photovoltaic powerplant for which the shade test is carried out for different months of the year in order to determine the loss in power (figure 7).

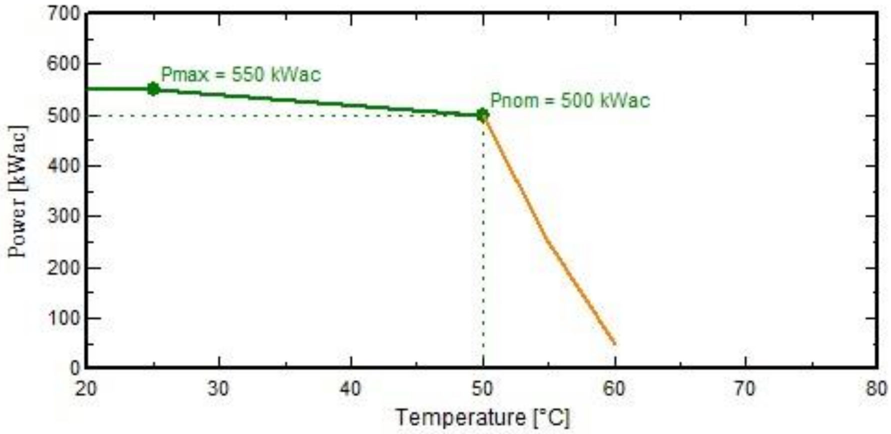


Figure 6 The Power vs temperature diagram for the inverter

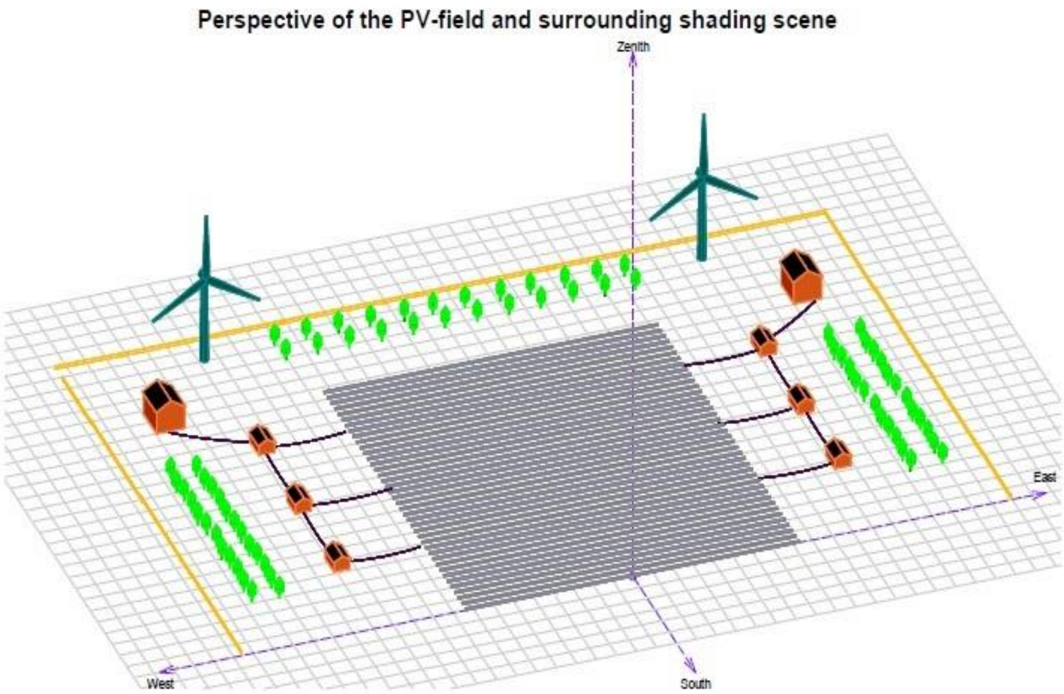


Figure 7 The 3D design of 1MW photovoltaic powerplant

3.1.5 Loss and shade percentages

As seen from the above 3D model, the panels are installed in 40 set of 100 panels for a total of 4000 solar panels. After confirming the distances and repeating the simulation several times, shade test was carried out and the resulting animation was stored. As can be seen in figure (19), on average shading loss starts decreases from 7:30AM and reaches zero at around 8:00AM. This trend continues until 16:30 after which the shading loss increases. According to these results, the total shading loss is less than 0.5% which is an acceptable amount.

After completion of 3D design, the daily input – output diagram is created based on geographical location and solar beam intensity in different months. A large deviation in this diagram indicates an imprecise design while a compact diagram is a sign of correct design with elements fully matching a system. As can be seen, the diagram presented in figure (20) is close to a straight line which indicates good simulation and design quality.

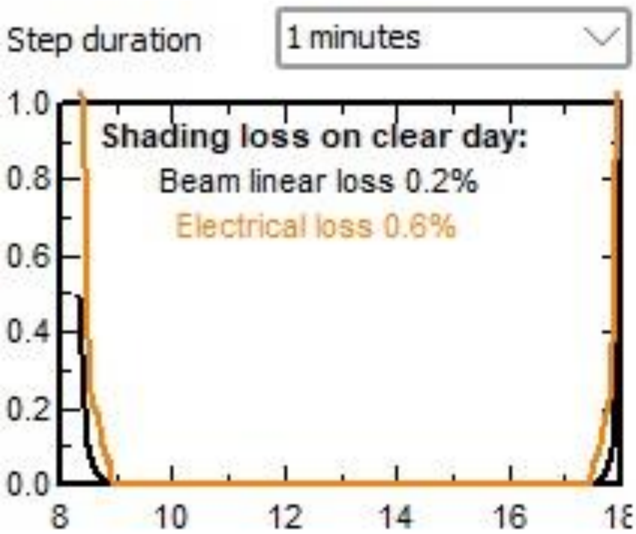


Figure 8 The shading loss diagram for the photovoltaic powerplant

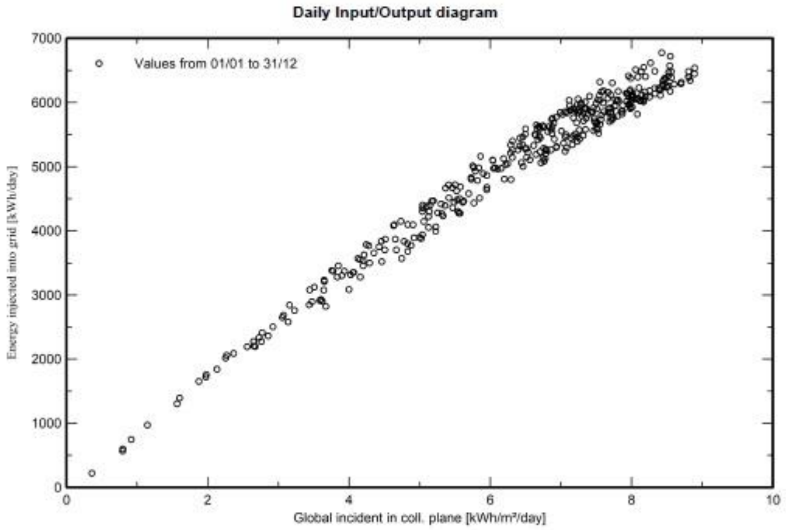


Figure 9 Daily input – output diagram

3.1.6 Estimation of land area needed for construction of photovoltaic powerplant

Finally, the software uses the input data along with calculations to provide a final printout similar to that of figure (10). This report includes details such as the name of designer, geographical specifications such as longitude and latitude, elevation from sea level and time difference with Greenwich Mean Time for a grid-connected system. This report also includes the nominal output power of the powerplant and the required land area, based on panel dimensions and distance required to prevent shading, which is equal to 6568 square meters. Finally, inverter specifications including brand, model and nominal power are presented at the end of the report.

3.1.7 Sun's Movement Path in the Region

Figure (11) shows the sun's movement path in the region with the x-axis showing the azimuthal angle of the panels and the y-axis sh5
owing the sun height.
The lines indicated with numbers 1 to 7 in the yellow section show the sun's movement path in seven-time period indicated in the graph's legend. As can be seen, number 1 is for June 22, 2 for May 22 to July 23, 3 is for April 20 to August 23, 4 is for March 20 to September 23; 5 is for February 21 to October 23, 6 is for January 19 to November 22 and 7 is for December 22. The dashed lines show different shading loss percentages.

3.1.8 Annual electricity output of Photovoltaic powerplant

After calculating overall losses due to angles and shading, the annual production of the powerplant is calculated as 1828MW.
Figure (12) shows the output of the power plant in a year, the annual performance, the cost per kilowatt hour, annual costs and the amount of cost required to invest in this project.

3.1.9 Powerplant Losses in various months

Figure (13) shows that the highest amount of losses in solar panels occurs in the month of August while the highest amount of useful energy production is also seen in the month of August.

3.1.10 Powerplant's Performance Ratio

Although power generation increases during the summer months, the system suffers more losses at ambient temperatures above 40 ° C, resulting in lower performance ratios. So that the higher the temperature, the lower the temperature of the power plant. In general, two factors, ambient temperature and humidity, are very important in having proper efficiency

Figure (14) shows the system performance in different months by which we can estimate the rate of return on investment from the project, in this chart we have the highest performance in January and the lowest performance in August.

Project summary

Geographical Site		**Situation**		**Project settings**	
Isfahan		Latitude	30.70 °N	Albedo	0.20
Iran		Longitude	34.45 °E		
		Altitude	1590 m		
		Time zone	UTC+3.5		

Meteo data
isfahan
Meteonorm 7.1 (2006-2011), Sat=100% - Synthetic

System summary

Grid-Connected System		**Sheds, single array**			
PV Field Orientation		**Near Shadings**		**Shadings of thin objects**	
Fixed plane		According to strings		According to strings	
Tilt/Azimuth	30 / 0 °	Electrical effect	100 %	Electrical effect	40 %

System information

PV Array		**Inverters**	
Nb. of modules	4000 units	Nb. of units	2 units
Pnom total	1000 kWp	Pnom total	1000 kWac
		Pnom ratio	1.000

User's needs
Unlimited load (grid)

Results summary

Produced Energy	1828 MWh/year	Specific production	1828 kWh/kWp/year	Perf. Ratio PR	79.10 %

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Astronergy	Manufacturer	SMA
Model	CHSM 6610P-250	Model	Sunny Central 500CP-US
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	250 Wp	Unit Nom. Power	500 kWac
Number of PV modules	4000 units	Number of inverters	2 units
Nominal (STC)	1000 kWp	Total power	1000 kWac
Modules	200 Strings x 20 In series	Operating voltage	430-820 V
At operating cond. (50°C)		Max. power (=>25°C)	550 kWac
Pmpp	887 kWp	Pnom ratio (DC:AC)	1.00
U mpp	545 V		
I mpp	1630 A		
Total PV power		**Total inverter power**	
Nominal (STC)	1000 kWp	Total power	1000 kWac
Total	4000 modules	Nb. of inverters	2 units
Module area	6568 m²	Pnom ratio	1.00
Cell area	5840 m²		

Figure 10 The final output report of PVSyst software

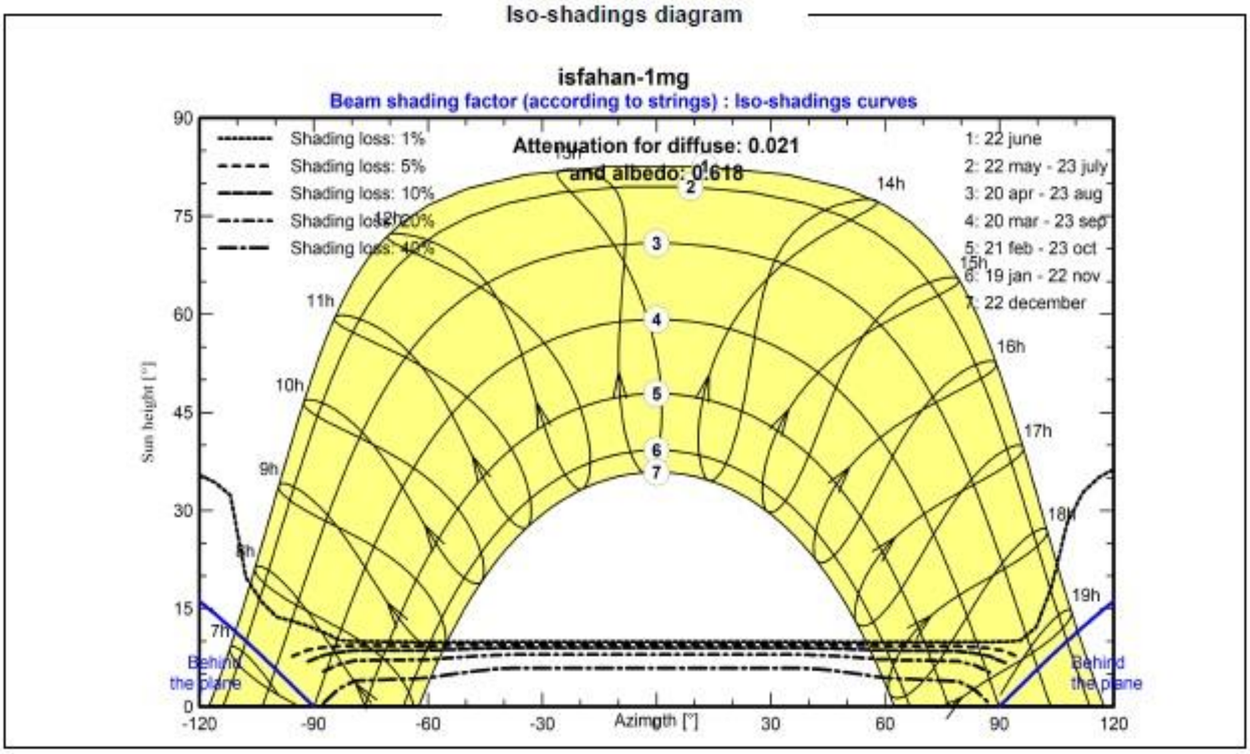


Figure 11 Graph of Sun's movement

Main simulation results				
System Production	Produced Energy	1827934165 W/year	Specific prod.	1828 kWh/kWp/year
	Performance Ratio PR	79/1 %		
Investment	Global incl.taxes	834500 US$	Specific	0/83 US$/Wp
Yearly cost	Annuities (Loan 5/0%, 25 years)	59210 US$/yr	Running Costs	10000 US$/yr
Energy cost		0/04 US$/kWh		

Figure 12 the output power of the powerplant in a year

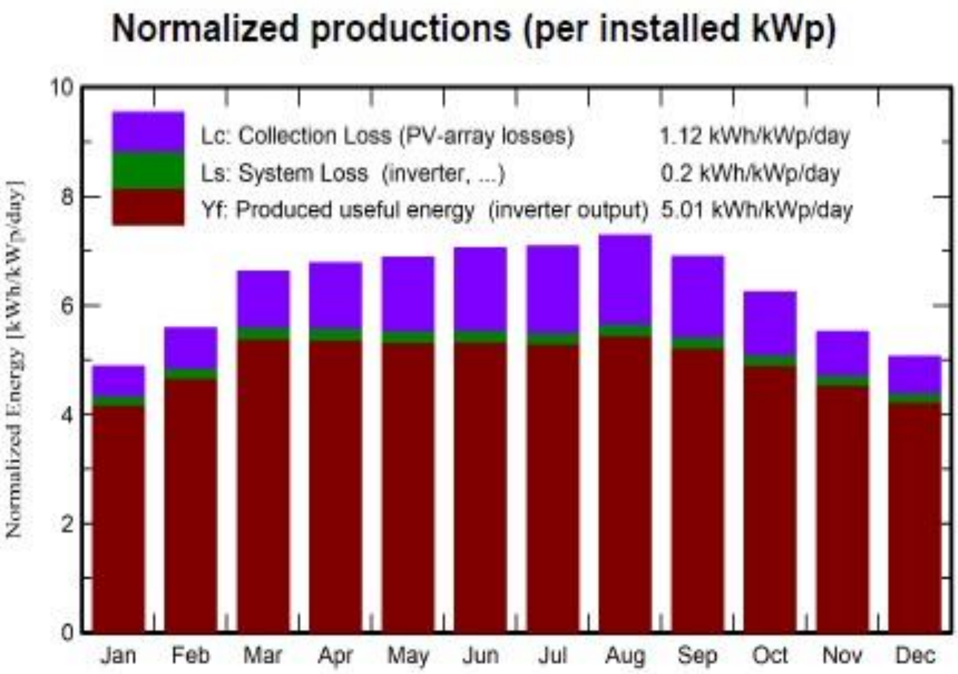


Figure 13 YF, LC and LS graphs

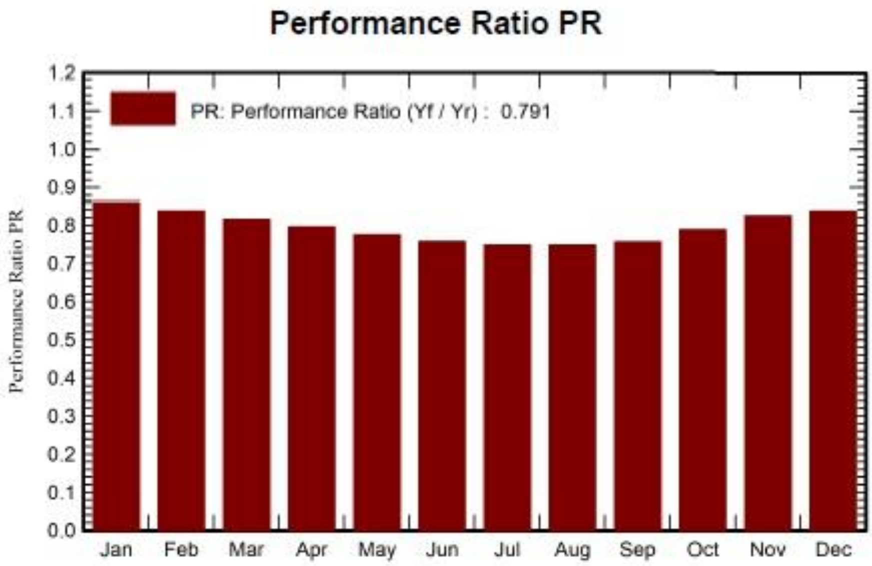


Figure 14 Powerplant's Performance Ratio in different months

3.1.11 Photovoltaic Powerplant Yield in Different months

The following table (1) shows various parameters of the powerplant including global horizontal irradiation, ambient temperature, global irradiation per square meter, global irradiation per square meter after calculating various effects, effective energy output of the array, energy introduced to the power grid, effective yield at array's output and energy injected into the power grid for different months of the year. As can be seen, the final yield for the entire year is equal to 12.04%.

3.1.12 Changes in the output power of the powerplant

Figure (15) shows that the horizontal global irradiation at the powerplant's region is equal to 2090 KW.h/m^2 which increases by 10.4 by angling the solar panel while shading loss and irradiation ratio decrease. By multiplying these numbers to the total area of the solar panels, it is possible to calculate the total energy input for the powerplant. However, since the solar panels have a yield of 15.3%, this yield should also be considered, resulting in the input energy of 2230 MW.h.

This 2230 MW.h input energy decreases due to various losses and finally leads to energy output of 1828 MW.h.

Table 1 Final simulation results and overall powerplant yield

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 ratio
January	104.7	38.39	4.75	151.5	146.2	135.3	130.0	0.858
February	118.9	39.69	6.76	156.4	150.7	136.3	130.9	0.837
March	172.8	53.34	11.27	205.4	197.6	174.2	167.6	0.816
April	197.3	62.99	15.25	203.2	194.4	168.1	161.7	0.796
May	228.8	69.64	19.16	213.4	203.5	172.3	165.7	0.776
June	239.9	62.35	22.62	211.8	201.6	167.0	160.5	0.758
July	244.8	55.89	24.66	219.8	209.6	171.2	164.7	0.749
August	229.2	57.24	24.57	226.0	216.2	175.9	169.2	0.749
September	186.5	46.35	21.51	207.2	199.4	163.2	157.0	0.758
October	152.5	49.60	17.65	193.6	186.8	158.5	152.6	0.788
November	113.8	35.73	10.71	165.7	159.4	142.2	136.8	0.826
December	100.4	29.66	6.64	156.9	150.9	136.8	131.3	0.837
Year	2089.7	600.85	15.51	2310.9	2216.2	1900.8	1827.9	0.791

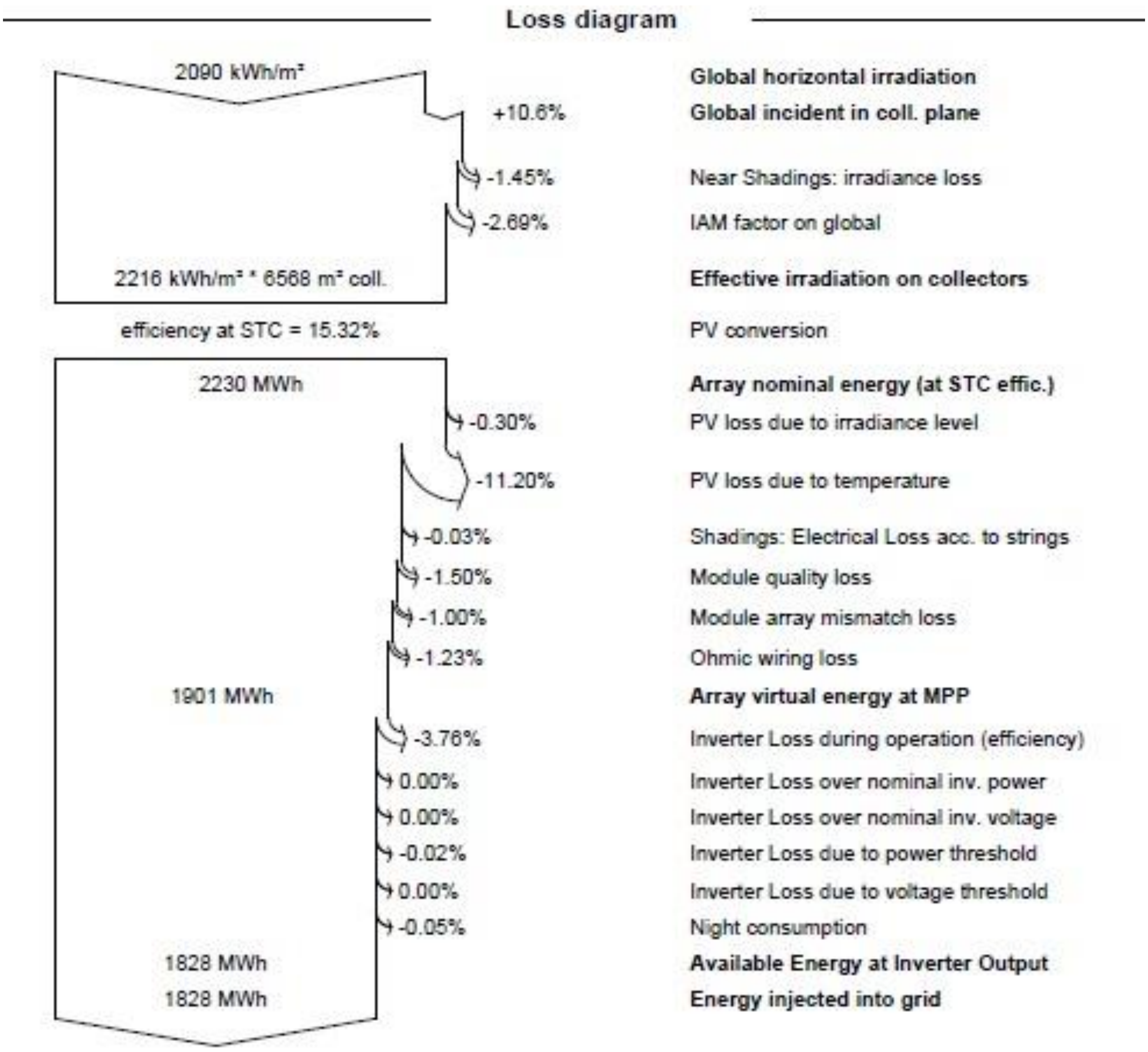


Figure 15 Various losses in the input energy resulting in the final output of the powerplant

3.1.13 Feasibility

Based on the available data and it is observed in figure (16), each solar panel costs 138USD which adds up to 550,000USD for a total of 4000 solar panels. The cost for each inverter is also equal to 62500USD which means a total of 125,000USD for two, 500kW inverter units. Adding the additional costs of wiring, commissioning and batteries plus tax adds to an investment of 834,500USD for the entire photovoltaic powerplant. Since the powerplant requires an area of 6568 square meters and considering the incentives provided by Renewable Energies Organization of Iran which provide free land area for renewable energy projects from Natural Resource Management Organization of Iran, the cost of land is calculated at IRR 300,000 per square meter, resulting in a total land cost of IRR 1,970,000,000 or, using IRR to USD conversion rate of IRR42000:1USD is equal to 47,000USD. By considering 10% additional investment for unpredictable costs, the total investment for the powerplant is equal to 834,500USD equipment cost, 47,000USD land cost and 10% or 88,150USD unpredictable costs, resulting a total investment of 969,650USD or IRR 40,725,300,000. Based on the approved price list for electricity from Renewable Energies Organization of Iran of IRR 49,000 per KW energy, and a total energy production and sale of 1,828,000 kW.h per year, the total annual sales of the produced electricity are equal to IRR 8,957,200,000, resulting in a full return of investment after 4 years and 6 months. Therefore, this powerplant project is fully feasible, resulting in a total income of IRR 223,930,000,000 over a period of 25 years of operation.

Cost of the system

Installation costs	
PV modules	4000 units
	137.50 US$/Unit
	550'000.00 US$
Inverters	2 units
	62'500.00 US$/Unit
	125'000.00 US$
Settings	
	50'000.00 US$
Transport and assembly	
	5'000.00 US$
Engineering	
	5'000.00 US$
Taxes	
	110'250.00 US$
Total	845'250.00 US$
Depreciable asset	675'000.00 US$
Operating costs	
Maintenance	
	10'000.00 US$/year
Total (OPEX)	10'000.00 US$/year
System summary	
Total installation cost	
Operating costs	
Produced Energy	
Cost of produced energy (LCOE)	
	845'250.00 US$
	10'000.00 US$/year
	1828 MWh/year
	0.005 US$/kWh

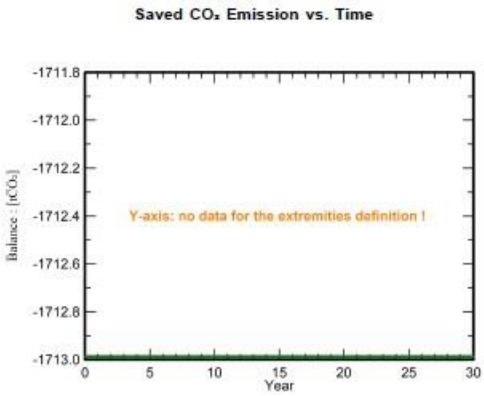
Figure 16 Price estimates for the output electricity of the powerplant

3.1.14 Reduction in CO_2 Emission

As it is illustrated in figure (17), in average, production of 1KW solar electricity prevents the emission of 1713Kg of CO_2. Considering the capacity of 1000KW for the powerplant, this results in 1713 metric tons reduction of CO_2 emission.

CO_2 Emission Balance

Total:	-1713.0 tCO_2
Generated emissions	
Total:	1712.99 tCO_2
Source:	Detailed calculation from table below:
Replaced Emissions	
Total:	0.0 tCO_2
System production:	1827.93 MWh/yr
Grid Lifecycle Emissions:	0 gCO_2/kWh
Source:	Custom value supplied by user
Lifetime:	30 years
Annual degradation:	1.0 %



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	1000 kWp	1712720
Supports	0.01 kgCO2/kg	40000 kg	267

Figure 17 The reduction in CO_2 emission in simulated photovoltaic powerplant

3.2 Power Supply Estimates

3.2.1. Supply of power for a 120-square meter apartment in cities of Isfahan or Tehran

In table (2) and based on the simulation results for the photovoltaic powerplant, the results are used to determine the number of apartments supplied by this powerplant considering the worst-case electricity usage. As can be seen, the power usage of various household appliances is provided in the following table including lights, fans, refrigerators, freezers, TV, water air conditioner systems, washing machine, irons, and other uses. This results in a daily power use of 23.52 KW.h for a 120-square meter apartment in cities of Tehran or Isfahan. Given the annual power production of 1,828,000 KW.h for the simulated photovoltaic powerplant, this means that the powerplant can supply the required electricity for 213 apartment units.

3.3. Comparison of the simulated powerplant with operational powerplant in Kerman province

The comparison with the empirical data was carried out with the help of Mehrdad Energy Avand Co., which is in charge of construction of 1200KW photovoltaic powerplant in Rafsanjan, Kerman province. This powerplant was selected since after numerous contacts with companies involved in construction of photovoltaic powerplants in Iran, only Mehrdad Energy Avand Co. agreed to provide us with the necessary operational data.

This 1200KW powerplant was completed in July 2017 in Rafsanjan county, Kerman province. This powerplant is made using KIOTO Solar Powerplants made in Austria with the nominal power of 265W per panel and uses 4596 solar panels. This solar panel has a yield of 16%. On the other hand, the simulated powerplant has the output of 1000KW and a total of 4000 solar panels. Furthermore, Refsanjan powerplant uses 38 Froniu, ECO inverters while simulated powerplant uses two 500KW inverters.

The total land area of Rafsanjan powerplant is 1.8 Hectares, some of which includes unused areas and makes up 6.5% of project investment while the land area of the simulated powerplant is 6568 square meters.

Since the power output of the Rafsanjan powerplant is 200KW higher than the simulated powerplant, the difference in cost resulting from this higher power was deducted during calculations.

The investment cost of the 1200KW powerplant in July 2017 along with land cost is around IRR 50,000,000,000 which based on IRR to USD exchange rate of IRR 38,000 = 1USD is equal to 1,315,789 USD. Adjusting the cost for a 1000KW powerplant, the initial investment is equal to 1,025,219USD which, adding the land cost of 71,217USD, results in total investment of 1,096,490USD. On the other hand, the investment for the simulated 1MW powerplant is 969,650USD which is 11.567% lower that the investment of Rafdanjan powerplant adjusted for difference in power output which is an acceptable amount.

The output electricity of 1200KW powerplant in 12 months is equal to 2300 MW.h per year or 1916 MW.h adjusted for the output power of 1000KW. On the other hand, simulated 1MW powerplant has total electricity output of 1828 MW.h in 12 months which is 4.6% lower that the Rafsanjan powerplant.

Furthermore, in regards in decrease in CO_2 emission, according to the data from the operating company, the decrease in CO_2 emission is equal to 1600 metric tons per year for the 1200KW powerplant or 1333 metric tons per year adjusted for the power output of 1000KW. On the other hand, the amount of decrease in CO_2 emission for the simulated powerplant is 1713 metric tons per year which is 22% higher than the real powerplant. This difference can be, in part, due to the calculations being carried out differently in different regions.

Table 2 Average electricity usage per day in an apartment unit

No.	Household appliance	Power usage (W)	Usage data		
			Duration (hours)	W.h.	KW.h
1	Lamps	70	12	840	0.84
2	Fans	35	8	280	0.28
3	Refrigerator	100	24	2400	2.4
4	Freezer	150	24	3600	3.6
5	LCD 40” TV	200	10	2000	2
6	Water AC System	530	10	5300	5.3
7	Washing Machine	1500	1	1500	1.5
8	Iron	2000	1	2000	2
9	Others (averaged)	1400	4	5600	5.6
Total energy usage in KW.h					23.52

4 Conclusion

After design and simulation of photovoltaic powerplant and investigating its various parameters, it can be concluded that the design of photovoltaic systems is fully dependent on their place and geographical location.

Since Iran is one of the countries in favorable locations for use of solar energy, various locations including Kerman, Fars, Sistan & Baluchistan, Isfahan, Yazd, Southern Khorasan and Semnan provinces are among best locations for construction of solar powerplants.

The system’s performance indicate that production of photovoltaic electricity is a suitable method for Isfahan province and analyses have shown that it is possible to design larger photovoltaic systems with higher capacity in this province.

The current study simulated a photovoltaic, grid-connected powerplant and investigated its various aspects including geographical location, technology and type of photovoltaic systems, and system losses among other aspects.

The results indicated that temperature can directly affect the performance of the powerplant and higher ambient temperatures result in decreased powerplant performance. This decrease should be considered for both solar panels and inverters.

Economic evaluations indicated that the 1MW photovoltaic powerplant requires an investment of approximately IRR 40,725,300,000. Considering the sale price for the produced electricity, full return of investment occurs after 4 years and 6 months, after which the system is profitable.

As an innovation, simulation results for the powerplant indicate that this powerplant is capable of producing enough electricity for 212 residential units with average area of 120 square meters in city of Isfahan under worst usage conditions which is equal to the electricity for 22 3-story educational units.

Another innovation is about the given power output of 1000KW for the powerplant, which is calculated and indicated that construction of this powerplant can result in an annual 1713 metric tons decrease in CO_2 emission.

Since the current study used two 500KW inverters for the simulated 1MW photovoltaic powerplant but an actual solar powerplant used 37 inverters, it is suggested that future studies increase the number of inverters in order to distribute the required power. This, in practical situations, helps reduce the power outage scale of the powerplant in case of problems in any of the inverters.

To satisfy the results, the results obtained from PVSyst software and the empirical data compared from an operational powerplant with similar size indicates a small difference with each other between the results which indicates the remarkable accuracy of this software for simulation of photovoltaic powerplants.

Due to the incentive plans by Ministry of Power for investment and use of small and large-scale photovoltaic powerplants, expanded use of this technology can be considered in the future in order to prevent the emission of CO_2 and other environmental pollutants.

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