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Cost Effective Design of a 200 kW On-grid Rooftop Photovoltaic System Using PVsyst Software in Shiraz

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ABSTRACT

Solar energy is a clean and nonrenewable energy provided by photovoltaic systems, and its use is increasing daily. In Iran, due to the diversity of the climate and the need to supply electricity on a large scale, the use of solar energy to supply the electricity needed by industrial and household units is considered. In this research, the economic design of a 200 kW on-grid power plant was demonstrated by PVsyst software using 364 modules (550 W) on a rooftop in Shiraz. Taking into account the geographical location of Shiraz (which is located at a latitude of 29.82 N and longitude of 52.60 E) and shading and the maximum use of sunlight, an angle of 30° was considered suitable for installing solar panels. The results showed that the total energy received by the panels was equal to 480.4 MW/h per year; after deducting the system losses, the amount of energy injected into the national grid was equal to 413.2 MW/h per year. The annual global irradiance on the horizontal plane was 2199.1 kWh/m^2, while the global incident in the collector plane and effective global irradiance after optical losses were 2467.3 kWh/m^2 and 2396 kWh/m^2, respectively. The annual DC energy produced from the PV array and the annual AC energy injected into the grid were 427.81 and 413.2 MWh, respectively. The cumulative cash flow rate showed that after 20 years, the income of this power plant was 7000 billion IRR.

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Introduction

The conventional sources of electricity are mainly coal, hydropower and nuclear power. Among these three sources, the share of electricity from coal energy is significantly greater [1]. Most of the energy produced by burning limited amounts of fossil fuels will eventually run out [2]. Therefore, different natural sources of energy used to generate electricity need to be examined. Some common sources of energy include solar, wind, sea, fuel, and nuclear energy. Due to its location, solar energy is one of the useful sources in this field. Electrical energy can be generated by converting various energies found in nature [3]. Iran has 450 MW of solar electricity, which is less than one per cent of the installed capacity. This difference is insignificant compared to the difference in electricity demand between neighbouring countries. Iran has an average annual solar radiation of 2200 $KWh/m^{2,}$ and 90% of the country has enough sunlight to produce solar energy in 300 days of the year. Demographic trends and intensifying industrialization have caused electricity demand to increase by 8% per year [4].

Solar energy will likely become an economical method in the coming years because it has better technology in terms of application and cost. In addition, the sun is a free and unlimited source of energy. Sunlight can be directly used to generate electricity [5]. This is accomplished by a photovoltaic (PV) cell. Here, sunlight hits the surface of the voltaic cell directly. PV cells are semiconductor junction cells [6]. A potential difference or voltage appears at the junction of the cell due to sunlight. This potential or voltage difference causes electricity in the circuit to connect to the solar panel system. Today, solar panels have become popular due to the limitations of other conventional sources of electricity generation. Therefore, considering all these facts, alternative sources of energy should be sought [7]. Generating electricity from solar PVs is one of the preferred methods. Solar PVs generate direct DC electricity in a single step without the need for additional power [8]. A significant advantage of solar energy over other traditional power generators is that sunlight is directly converted into solar energy using a solar PV system [9].

In the performance of PV cells, factors such as radiation, temperature, and the angle of the PV cell relative to the sun affect the performance and efficiency of these cells. To maximize the output power, PV cells must receive maximum solar radiation to increase the output power produced. Renewable energies have experienced significant growth in recent years, and in developed and developing countries, electricity generation has become a more vital type of energy [10]. Among these technologies, solar energy is considered a positive type of energy because it is growing faster. Clean electricity is produced from the sun, which is a sustainable and efficient energy technology [11]. Due to the increase in electricity demand in recent years, it has become necessary to reduce electricity consumption [12].

Iran has already started several plans to use solar energy potential and produce the required amount of electricity. However, there is still no determination on the potential of solar energy in the country. One of the most important issues is obtaining suitable land for a solar farm. As Iran is mainly a fertile country for agriculture, acquiring land for major solar power installations is very challenging [13]. On the other hand, residential, industrial, commercial, and government buildings can all provide large areas on roofs for solar power generation. As a result, installing a solar power plant on the roof is the best alternative approach to achieve the objectives and alleviate the current energy crisis [14]. During the last decade, the use of green energy has greatly increased for many reasons, including a reduction in the use of fossil fuels, a rise in the use of pollutants, economic reasons, and energy demand. Solar energy has potential over other green energy sources in domestic and urban areas of Iran for many reasons including its installation. Compared with wind energy or biofuel, the PV system is considered easy to install and maintain [15]. In addition, PV systems are environmentally friendly and inexhaustible. Compared to traditional energy sources, PV systems have disadvantages including initial costs, solar panels, inverters, batteries, wiring, and installation costs. However, the use of PV system technology is growing rapidly and the initial cost is decreasing [16].

In this paper, PVsyst software was used to design a fixed PV system on a grid. Additionally, the effects of weather conditions including temperature and radiation on the selected system in the selected area were investigated; these two important parameters affect the power output of the network. The findings determine the efficiency of the system and its reliability and determine the efficiency of each PV system. The design and simulation of an energy production system connected to a solar PV network using the roof of a selected business unit in Shiraz City are presented in this article. The technical, economic, and annual performance of the solar PV system are also presented. PVsyst software was used to test and simulate the project, determine the best size and parameters of the solar PV system on-grid, and generate electricity. This project provided a brief financial analysis of a solar PV plant as well as operation and maintenance costs. The module orientation, close shading, and row spacing are all essential design elements that were evaluated. The performance ratio was obtained after considering several types of losses such as temperature, internal network, shadows, and mismatch losses. The findings of this experiment should encourage business owners to consider installing a solar PV system on their roofs to reduce the load and the cost of powering their facilities. In addition, solar power plants save fuel and have a negligible environmental impact.

Methodology

Panel characteristics

The solar panel required for the construction of this power plant was selected from the PVsyst software database. The panel was a product of the SUNTECH Company and had a rated power of 250 W; the features of this panel are listed in Table 1. The electrical data were applied under standard test conditions (STC) and an irradiance of 1000 W/m^2 with a spectrum AM of 1.5 and a cell temperature of 25 °C.

Table 1. Specifications of the 530 W SUNTECH panel under standard conditions.

Parameters	Unit	Value
Nominal Max. Power	Pmax (Wp)	550
Maximum power voltage	Vmp (V)	41.7
Maximum power current	Imp (A)	12.71
Open-circuit voltage	Voc (V)	49.65
Short-circuit voltage	Isc (A)	13.47
Module efficiency	(%)	20.53
Cell Type	Mono-crystalline	182 X 91 mm
No. of cells	144 Cells	72 Full Cells

Detailed purpose and technical module

To arrange the selected panels according to the simulation results in PVsyst software, 72 550-W panels were used to construct a power plant with a power generation capacity of 200 kW. It is noteworthy that if a power plant with a capacity of 200 kW is designed in an integrated manner with a 200 kW array, there is a possibility of reducing the production power due to shadowing on the panels or electrical problems in the panels. In case of failure of the whole system, to increase reliability, this power plant was designed with two separate roofs; the arrangement of each array is according to 2 strings of 13 modules (Figure 1). A total of 28 strings and 364 modules of 550 W constituted a 200 kW power plant.

Results and discussion

Site selection

To design a 200 kW solar power plant, the best area for installing the structure must be selected. To maximize the use of solar energy, the panel was installed according to the latitude. In this plan, due to the location of Shiraz city at 30° latitude, the panels were installed at an angle of 30° to the horizon. After modelling the power plant with PVsyst software, the results were extracted (Figure 2). This diagram illustrates the loss diagram of the entire system from the time of receiving radiant energy per unit of horizon level at the power plant site to the amount of energy injection into the grid during one year. The amount of total radiation energy that can be received from the sun on a horizontal level is equal to 2199 kWh/m2 per year; this expression means that by installing a 1 kW system horizontally in a location measuring 1 m2, it is possible to receive 2199 kWh of energy from the sun in a year. By determining the right angle for installing the panels, as shown in the diagram, the amount of energy that can be received from the sun increased by 12.2% compared to installing the panels horizontally. The optimal angle for installing solar panels to receive as much sunlight as possible was determined by PVsyst software according to Figure 1 to be 30° relative to the horizon. The total energy received by the panels, as shown in Figure 2, was equal to 480.4 MW/h per year. After deducting the system losses, the amount of energy injected into the national grid was equal to 413.2 MW/h per year. Figure 3 shows the path of the sun at the location.

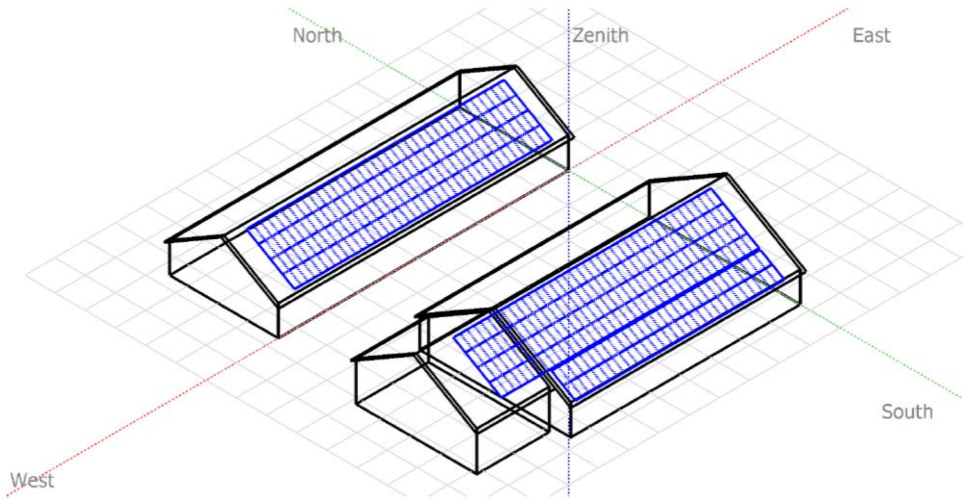


Figure 1. Arrangement of modules.

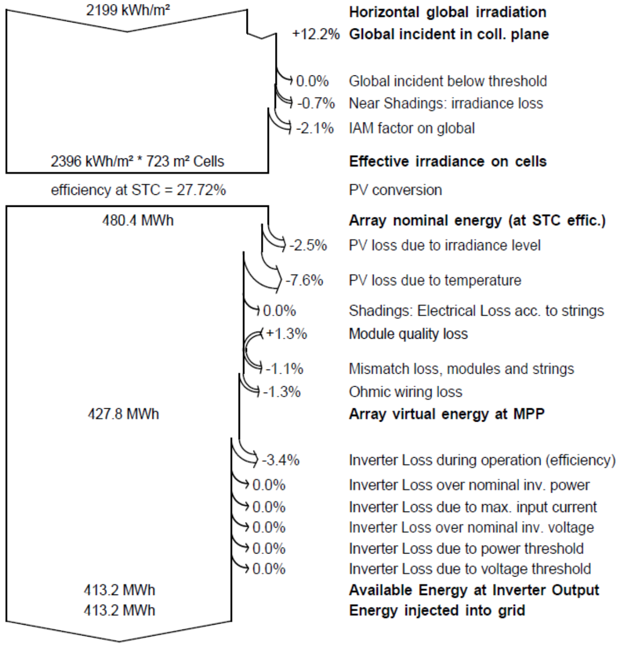


Figure 2. Loss diagram of the entire power plant from radiation to injection.

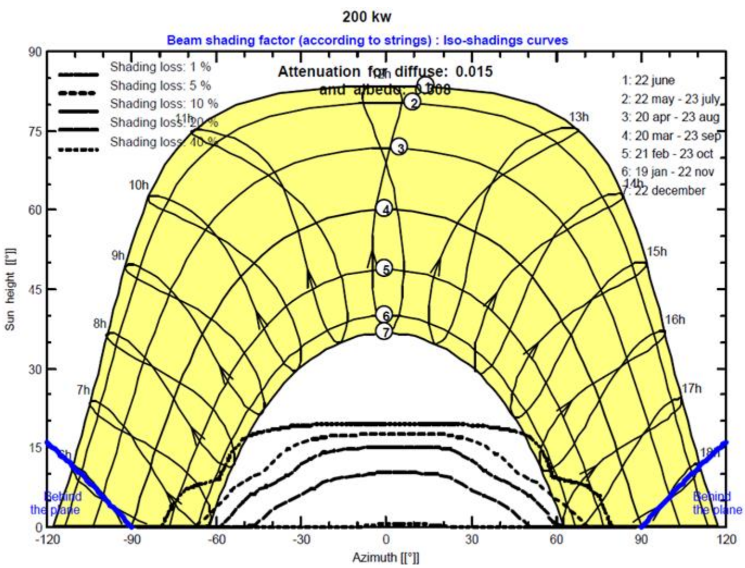


Figure 3. Iso-Shading Diagram.

Another parameter that is important to mention is the performance factor of the system. Based on the results obtained from the simulation of the performance factor of this system as per Figure 4, is equal to 83.7% annually. In general, the best system performance factor is between 80 and 84%, which is obtained by dividing the amount of energy injected into the network by the amount of energy received by the panels.

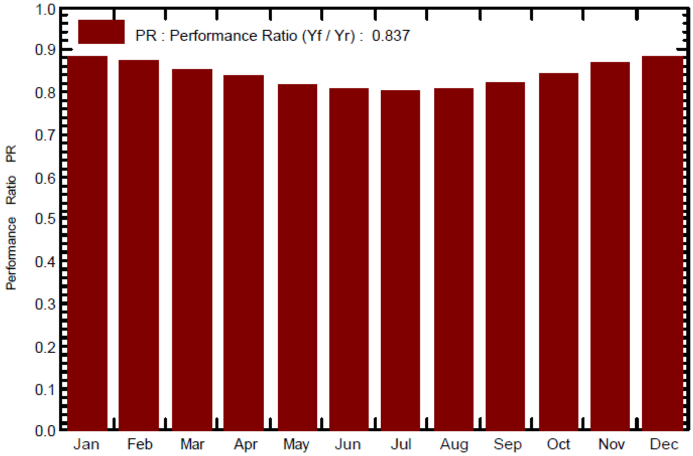


Figure 4. Performance ratio (PR)

The normalized production of the PV power plant is depicted in Figure 5. This approach provides PV array collection losses, system losses, and important inverter outputs. The table displays the monthly usable energy production and losses per kWh. The International Energy Committee (IEC) norms establish these normalized products, which are standardized variables for evaluating PV system performance. 0.91 kWh/kWp/day Lc is the collection loss or PV array capture loss. The system loss is 0.2 kWh/kWp/day, and the solar energy produced is 5.65 kWh/kWp/day.

Table 2 describes the balances and key results, which include variables such as global irradiance on the horizontal plane, ambient average temperature, global incidence in the collector plane, and effective global irradiance after soiling and shading losses. In addition to these factors, the DC energy generated by the monocrystalline solar array, the energy injected into the grid after accounting for photovoltaic array losses, the electrical components, and the system efficiency were also simulated. Each of the variables specified in the balances was simulated, and the major findings were acquired monthly and yearly. Figure 5 shows the new variant of the simulation. As averages for temperature and efficiency and as a summation of irradiance and energy, yearly values of the variables are possible. The annual worldwide irradiance on the horizontal plane for the research location is 2199.1 kWh/m2, while the global incident in the collector plane and effective global irradiance after optical losses are 2467.3 kWh/m2 and 2396 kWh/m2, respectively. The annual DC energy produced from the PV array and the annual AC energy injected into the grid are 427.81 MWh and 413.2 MWh, respectively, for this effective global irradiation value. Figure 6 shows the simulated values of cumulative cash flow. The diagram shows that the cumulative income after 20 years is more than 7000 billion IRR.

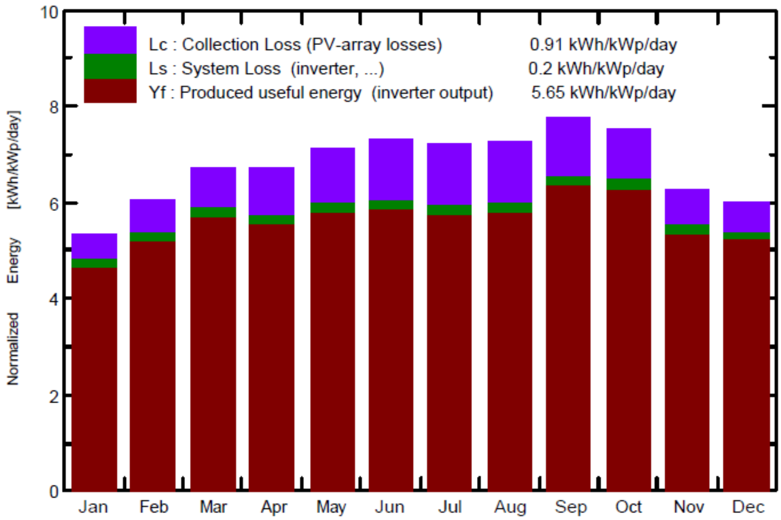


Figure 5. New simulation variant.

Table 2. Normalized productions.

	GlobHor kWh/m2	DiffHor kWh/m2	T_Amb °C	GlobInc kWh/m2	GlobEff kWh/m2	Earray MW/h	E_rid MW/h	PR
January	111.6	33.08	5.66	165.3	161.4	30.16	29.11	0.879
February	126.9	38.22	9.11	168.3	164.1	30.32	29.28	0.869
March	178.3	46.56	13.34	207.7	202.0	3.73	35.46	0.853
April	195.1	58.24	17.83	201.2	194.4	3487	33.67	0.836
May	237.8	58.83	24.46	220.6	212.6	37.34	36.07	0.816
June	246.5	55.73	28.34	218.3	210.5	36.48	35.22	0.806
July	227.3	55.83	29.74	224.0	215.3	37.03	35.77	0.801
August	207.3	55.83	29.74	224.0	216.5	37.34	36.10	0.805
September	207.3	35.97	25.29	232.8	226.4	39.61	38.26	0.821
October	178.8	29.40	20.03	232.8	227.8	40.52	39.14	0.840
November	126.5	26.64	12.32	187.5	183.6	33.59	32.45	0.864
December	116.4	26.45	7.56	185.6	181.5	33.82	32.67	0.879
Year	2199.1	522.15	18.76	2467.3	2396.0	427.81	413.20	0.837

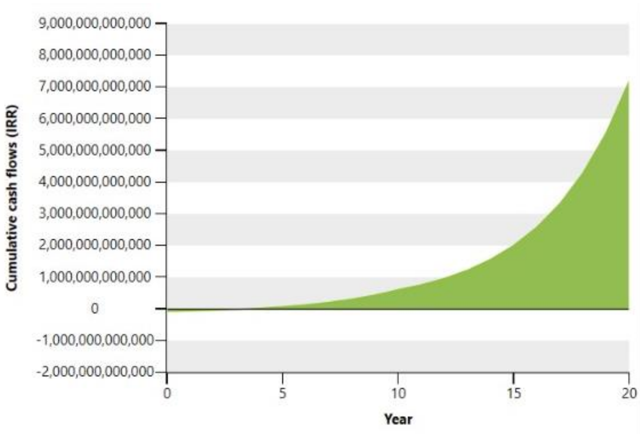
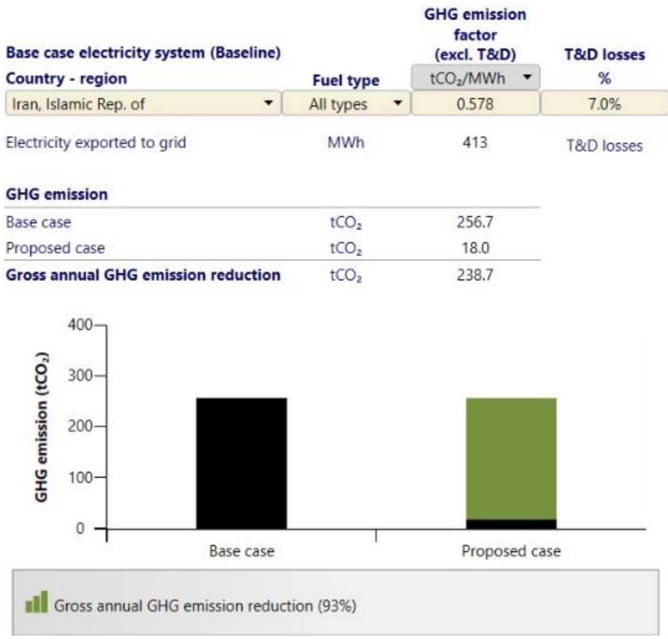


Figure 6. Cumulative cash flow rate per year.

CO_2 Emission Balance

Figure 7 shows the simulated values of the CO_2 emission balance. The emission factor (EF) is a coefficient that describes the rate at which a given activity releases greenhouse gases (GHGs) into the atmosphere. These factors are also referred to as conversion factors, emission intensity, and carbon intensity. Using this solar power plant removes 238 tons of CO_2, which is equivalent to using 22 hectares of forest absorbing carbon, 551 barrels of crude oil not consumed, 102558 litres of gasoline not consumed, and 44 cars and light trucks not used per year. This demonstrates that solar energy will greatly help the environment.



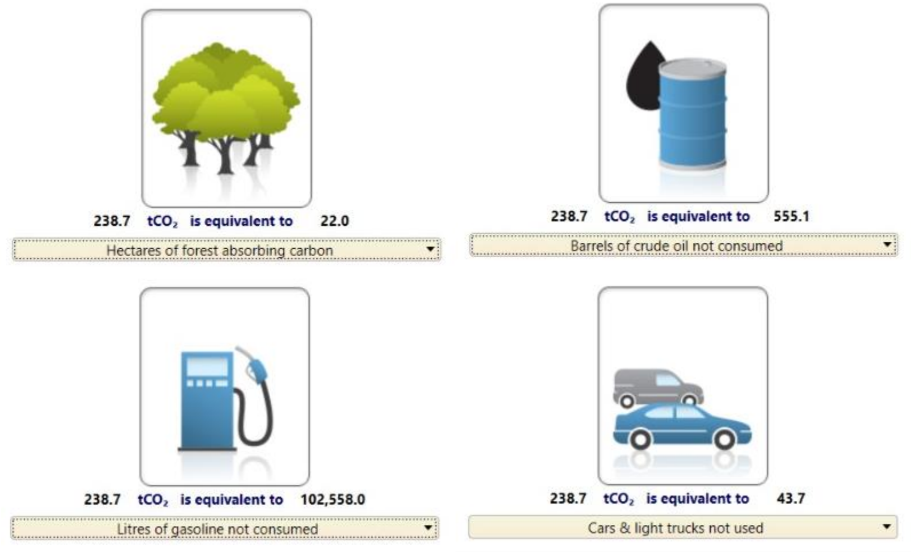


Figure 7. CO_2 emission balance.

Conclusion

Using PVsyst simulation software, the design and techno-economic feasibility of a new large-scale solar power plant type were evaluated for a geographical site in Shiraz, located at a latitude of 29.82 N and longitude of 52.60 E. The study revealed that a 200 MW solar power plant can potentially generate 413 MWh of renewable power per year. The performance ratio was approximately 80%. The present research presented the design modelling and simulation as well as the technical and economic potential of a solar PV grid-connected electricity generation plant with a monthly capacity of 200 kW in Shiraz. The maximum energy injected into the grid occurred in October and was equal to 40.52 MWh, and the minimum energy occurred in January and was equal to 30.16 MWh. The average PR of the monocrystalline PV system was 83.7% in the simulation for the planned location. This project demonstrated the effect of temperature variation on the performance of PV modules on a daily and yearly basis. The efficiency was more sensitive to temperature than to solar irradiation. During the morning, plant efficiency was high until the afternoon, after which it started to decrease until sunset. Therefore, cooling solar modules may be advisable for increasing efficiency. The system was designed and the inverters were chosen based on the worst-case of the maximum deviation from the MPP and the average temperature and irradiance during the year. The results revealed a proportional relationship between the MPP and irradiance since the short-circuit current increases rapidly with irradiance due to the dramatic increase in electron mobility and kinetic energy with irradiance.

Conversely, there was a reverse relationship between the temperature and the MPP; as the temperature increases, the domains in the polysilicon materials start to reorient themselves, and some of the voltage is cancelled at the module terminals. This study helps normal users design their own PV system to match their requirements by allowing them to choose the correct elements including PV strings and inverters, thus reducing power mismatching losses and improving the system's lifetime and efficiency.

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