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Economic Evaluation of Solar Electricity (Photovoltaic) Based on the Space Available in the Building in Different Climates of Iran

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Abstract

Solar energy is one of the most significant renewable energy sources. In this study, Camphor software is used to develop and assess residential PV power plants linked to the roofs of buildings in three climates: cold and mountainous (Tabriz), moderate and humid (Sari), and hot and arid (Semnan). In the design concepts, climatic elements like the influence of temperature rise on the surface of the panel, the effect of pollution, the average urban temperature, and the amount of sunlight have been included. The discount rate is estimated at 17.3%, and the escalation rate at 20.7%. Semnan with an internal rate of return of 32.13% has the highest economic return and Sari with a higher average temperature than Tabriz is the lowest return city. The normal payback of the investment period of the project is in the sixth year. The dynamic payback of investment period, Semnan is in the ninth year, but Tabriz and Sari are in the tenth year. In the sensitivity analysis to increase the internal rate of return efficiency, the effect of reducing fixed costs, which includes the cost of equipment, is more tangible than increasing the selling price of photovoltaic electricity.

Keywords: Economic Evaluation, Kamfar software, Photovoltaic Electricity, Renewable Energy

1. Introduction

Energy defines and maintains the main force in the world and life [1] ,and providing it is one of the basic needs in the economic and social development of countries and human societies. Population development and urbanization, inefficiencies in production, transmission, distribution, and consumption, and a shortage of energy supply from dependable and clean sources have led to a rise in energy demand and a fast consumption of its resources[2]. The depletion of fossil and non-renewable energy sources and the increase in pollution caused by their consumption are among the most important crises in the field of energy and the environment [3].

Increasing population and land occupation, lack of access to large and suitable spaces, or economic problems are obstacles to the expansion of solar power generation. Therefore, the solution for overcoming these problems is constructing and operating small home power plants, but in large numbers, on the roofs of buildings. Investigating the economic feasibility of using Kamfar software in the construction and operation of photovoltaic systems on the roof of building in the design model based on the space available in three climatic climates, cold and mountainous (Tabriz city), temperate and sultry (Sari city) and hot and dry (Semnan city) was studied. Climatic factors, such as the effect of temperature, the effect of pollution and the average temperature of the city, along with the amount of sunlight were applied in the assessment.

1.1. Principles of design

The general design criteria are: 1. Design to provide annual energy. 2- Design according to available budget. 3- Design based on available space[4].

By determining the design criteria of the photovoltaic system based on the available space, the required information is prepared.

These criteria mainly affect the capacity selection stage and the arrangement of photovoltaic array.

The steps of designing a photovoltaic system based on present space pattern are:

Determine the available area

Determine the maximum number of photovoltaic modules that can be installed in the available space

Determine how the module is arranged

Determine the output energy of photovoltaic array

Determine the amount of energy delivered to the grid

2. Research Methods

2.1. Design of photovoltaic system

To design a photovoltaic system based on the amount of space in the building, the following stages are required for capacity selection and layout of the photovoltaic array [4].

Step 1: The area of space in the building that has the least shade or, if possible, no shade at all, is measured in square meters.

Step 2: According to the dimensions of modules provided by the manufacturer, the maximum number that can fit in the measured area of the first step is calculated.

In designing study sample, a 450 watt monocrystalline module AE SOLAR is used.

The area of each module should be calculated as follows:

$2.094\,m \times 1.034\,m = 2.3860\ m^2$

Considering the distance of 10 mm between the modules, the area is calculated as follows:

$2.104\,m \times 1.134\,m = 2.3860\ m^2$

An area of 80 square meters of rectangular roof, for the average of each building that is exposed to sunlight is considered for calculations.

Step 3: Typically, the modules are rectangular with two dimensions (length and width). The modules may be put in length or breadth order. In order to establish the maximum real number of modules in each area, it is necessary to inspect the module installation in the two specified directions. These calculations are as follows to design the sample under study:

Mode A: Transverse installation

$10\,m \div 2.104\,m = 4.76 \sim 4$

$8\,m \div 1.134\,m = 7.06 \sim 7$

The total number of transverse modules can be multiplied by two and equal to 28.

Mode B: Longitudinal installation

$10\,m \div 1.134\,m = 8.82 \sim 8$

$8\,m \div 2.104\,m = 3.81 \sim 3$

The total number of modules which can be installed longitudinally is equal to the product of two and equal to 24.

A maximum of 28 panels can be installed. Using the access space to the roof (truss) and the space of 12 square meters, 6 panels will be deducted from the maximum panel capacity. Therefore, in the study sample, the maximum number of installable modules is equal to 22.

Step 4: Determine the output of photovoltaic arrays The average amount of output energy that is obtained daily from the photovoltaic system can be calculated using the following formula:

$$E_{array} = P_{stc} \times f_{man} \times f_{temp} \times f_{dirt} \times H_{tilt} \times N \quad (1)$$

In equation 1, E_{array}; Average energy output from photovoltaic array, P_{stc}; Module output power in STC (watt) conditions, f_{man}; The factor of reduction due to constructive tolerance (without units) is considered to be $0.95 f_{temp}$,; Temperature reduction factor (no units), f_{dirt}; Contamination reduction factorH_{tilt},; Radiation at peak hours for specific orientation and angle of impact & N; The number of modules in the array.

Temperature effect: According to AS 4059.2 standard, the average cell temperature inside the photovoltaic module can be estimated based on the following formula:

$$T_{cell,eff} = T_{a.day} + 25 \quad (2)$$

which in relation 2, $T_{cell,eff}$; Mean effective daily cell temperature in degrees Celsius, $T_{a.day}$; The average temperature during the day (in the desired month) is degrees

For $T_{cell,eff}$, The average daily temperature of photovoltaic cells according to the data of Meteorological Organization of Iran, for Tabriz, Sari and Semnan, respectively 44.8; 48.2 and 50 ° C are obtained.

The energy temperature coefficient is a quantity that indicates how much the photovoltaic module's production capacity increases for each degree of temperature increase above 25 ° C. For single crystal modules, for each degree of temperature increase above 25 ° C, the output power is reduced by 0.45%.

The amount of power reduction due to temperature can be calculated as follows:

$$f_{man} = 1 - (\gamma \times (T_{cell,eff} - T_{stc})) \quad (3)$$

Based on the results of Equation 3 and temperature of 25 ° C, the standard conditions for power reduction coefficient due to temperature for the cities of Tabriz, Sari and Semnan are 0.9109, 0.8956 and 0.8875, respectively.

According to the meteorological information of the provincial centers of the Meteorological Organization of Iran [5], the number of days with dust for the three cities of Tabriz, Sari and Semnan are 28, 1 and 27, respectively.

To calculate the pollution reduction factor, the ratio of the number of unpolluted air days to the total day of the year has been considered, which for the cities of Tabriz, Sari and Semnan has been 0.9233, 0.9973 and 0.9261, respectively.

H_{tilt} , which is considered in PSH calculations [4], according to the Geographical Atlas of Iran and NASA data for Tabriz, Sari and Semnan are applied 4.32, 3.99 and 4.79 kW, respectively.

For the sample of studied designs, the amount of daily energy produced according to Equation 1 is calculated as follows:

$$E_{array} = 450 \times 0.95 \times 0.9109 \times 0.9233 \times 4 \times 22 = 34.170kwh \quad Tabriz$$

$$E_{array} = 450 \times 0.95 \times 0.8956 \times 0.9973 \times 3.99 \times 22 = 33{,}517\ kwh \quad Sari$$

$$E_{array} = 450 \times 0.95 \times 0.8875 \times 0.9261 \times 4.79 \times 22 = 37.027\ kwh \quad Semnan$$

Step 5: Determining the amount of energy delivered from the photovoltaic system to calculate the energy delivered to the grid by the photovoltaic array, the effect of converter efficiency and losses should be taken into account. For this purpose, Equation 4 is used:

$$E_{system} = E_{array} \times \eta_{inv} \times L_s \quad (4)$$

Which in equation 4, E_{system}; Average daily amount of energy output from the photovoltaic system connected to the mains, η_{inv}; Converter efficiency (without units) and

L_s; Loss coefficient in system cables (without units).

For the studied designs, assuming 92% efficiency for the converter and considering losses equal to 5%, the amount of energy delivered from the photovoltaic system according to Equation 4 is calculated as follows:

$E\_system = 34170 \times 0.92 \times 0.95 = 29.865 kwh\ Tabriz$
$E_{system} = 33517 \times 0.92 \times 0.95 = 29.294 kwh \quad Sari$
$E\_system = 37027 \times 0.92 \times 0.95 = 32.362 kwh\ Semnan$

2.2. Data required for economic evaluation

Fixed cost: includes the purchase of 22 panels, inverters, cables and fittings and installation cost which is 1646.7 million rials

Care and maintenance costs: for two working days a year, a total of five million rials per year.

Length of construction period: The estimated time for operations related to the construction phase of project is one month

Operating life: The useful life of the solar system is equal to 30 years.

Escalation rate: The inflation rate considered in this section based on the average inflation rate in the last 11 years, from 2009 to 1398 was equal to 20.7 percent, which in this study is the same rate [6-7].

Discount rate: The discount rate considered in this study based on the average long-term deposit interest rate in the last 11 years, from 1388 to 1398 was equal to 17.3%, which is considered in this study [6-7].

3. Results and Discussion

NPV[1] balances investment payments with investment income, considering the time adjustment of money[8].

If the NPV of projects is positive, it is selected for economic activity. For three cities of Tabriz, Sari and Semnan with a discount rate of 17.3%, the net present value of the plan is positive and 5757.13 million rials, 5611.28 million rials and 6397.09 million rials (million rials), respectively.

IRR[2] is the condition for accepting the project that IRR is higher than the cost of capital. IRR is the discount rate at which the net present value of the project is zero. According to Table 4, the project has an economic value up to a discount rate of more than 30%. So at the project discount rate, the NPV is positive and the project is economical in all three cities. The cities of Semnan, Tabriz and Sari have the highest current value, respectively[8].

The normal payback of investment period is: Net cumulative cash flow of the project during operation and The dynamic payback of investment term is as follows: In calculating the payback period, the time value of money is considered, and the calculations are based on discounted data. Table 1 displays all the findings of the economic examination. To consider the unforeseen factors or the risk of factors that jeopardize the project efficiency, the sensitivity of the internal rate of return index to the changes in the selling price of generated electricity and changes in the fixed cost price of photovoltaic electricity is estimated. In the normal capital return period, all three cities are in the sixth year. The results of sensitivity analysis are shown in Table 2.

Table 1. Results of economic evaluation

	Tabriz	Sari	Semnan
Net present value of total investment	5757.13	5611.28	6397.9
Internal rate of return	31.00	30.74	32.13
Normal capital return period	5.60 years 1406	5.67 years 1406	5.33 years 1406
Dynamic payback of investment period	9.31 Years 1410	9.47 years 1410	8.66 years 1409

Table 2. Results of economic sensitivity

	Percentage of changes	Tabriz	Sari	Semnan
Increasing changes in electricity sales prices	- 25	34.3	33.99	35.36
	- 30	36.20	35.86	37.65
	- 50	37.44	37.08	38.98
	- 75	40.48	40.08	42.25
Reduce fixed cost price changes	+ 20	34.20	33.89	35.53
	+ 30	36.38	36.04	37.87
	+ 40	39.22	38.83	40.91
	+ 50	43.10	42.64	45.09

4. Conclusions

This study's primary objective is to evaluate the economic viability of solar systems based on the typical climates of Iran and the available roof space. In the research of variables influencing production, the average temperature, the impact of pollution, and the impact of temperature on the quantity of solar energy received were examined. Tabriz, which has a lower average temperature than Sari, produces more than Sari. In reality, it demonstrates that photovoltaic systems are advantageous in all climates,

[1]Net present value

[2]Internal rate of return

even cold and mountainous regions. NPV is a positive project which has economic value in all three cities. The internal rate of return of Sari is 30.74, Tabriz 31 and Semnan 32.13%, which confirms the superiority of Semnan. The normal return on investment period of all three cities is in the sixth year of operation but the mobile return period of Semnan capital is 8.66 years in the ninth year and for Tabriz and Sari in the tenth year. The results in general are superior to Semnan, Tabriz and Sari in economic evaluation of solar power generation, respectively. To examine the results of sensitivity rate, to achieve a 40% domestic rate of return requires a reduction of less than 50% in fixed production costs, but for the same rate of internal rate of return, a 75% incremental change in the selling price would be desirable. Therefore, comparing the effect of domestic rate of return index on changes in the fixed cost price of photovoltaic electricity with the impact of changes in the selling price of generated electricity, it is evident that reducing the price of photovoltaic equipment is more effective than increasing changes in sales prices. Price changes and costs are more effective than climate change.

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