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Design and Economic Study for Use the Photovoltaic Systems for Electricity Supply in Isfahan Museum Park

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ABSTRACT

Electricity production is one of the country's economic strength foundations. Therefore, it has been considered to increase electricity production and it's value-added in recent decades. In this respect, with the orientation and access to advanced technology, application and use of clean energy and renewable systems has considerable development for human energy needed. Ease of access and use of solar energy has placed it in proper position. The sun is the largest source of earth's energy supply which energy issued from it, is used by different ways to provide energy needed (fossil fuels and non-fossil). When we know that the solar radiation energy using photovoltaic systems directly and without intermediates is converting into electrical energy, it will be more important in the energy conversion systems. In this paper theduring introducing of photovoltaic systems as a new energy systems, they are described types of photovoltaic cells and its applications. Also It examines the economic issues in the power supply in Isfahan Museum Park.

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1. INTRODUCTION

Iran is among countries that is hot and dry in terms of geographical area and receive the most sunlight in all months of the year. Except Caspian Sea coast, there is 63 to 98 percent of sunny days across Iran. Figure 1.Shows the amount of received energy in Different regions of the country [1]. Solar energy as a clean energy source can used to provide energy in the form of heat or electricity. Due to the increasing price of energy derived from fossil fuels, energy production costs decreased by using new and renewable energy as progress of science and technology and will be closer to economy. Given that the lifetime of PV systems is 20 years its technology as one of the most important and effective tool in the application of new energy and referring to international experience can be proper accountability for providing electrical energy in areas outside the network. Also there is approximately 20 years' experience using photovoltaic systems in Iran as an energy source in telecommunication stations in remote areas there. In this paper in addition to introduction of photovoltaic systems, it will be economical evaluation using photovoltaic systems for the supply electricity in Isfahan Museum Park compared with electricity supply through a national network.

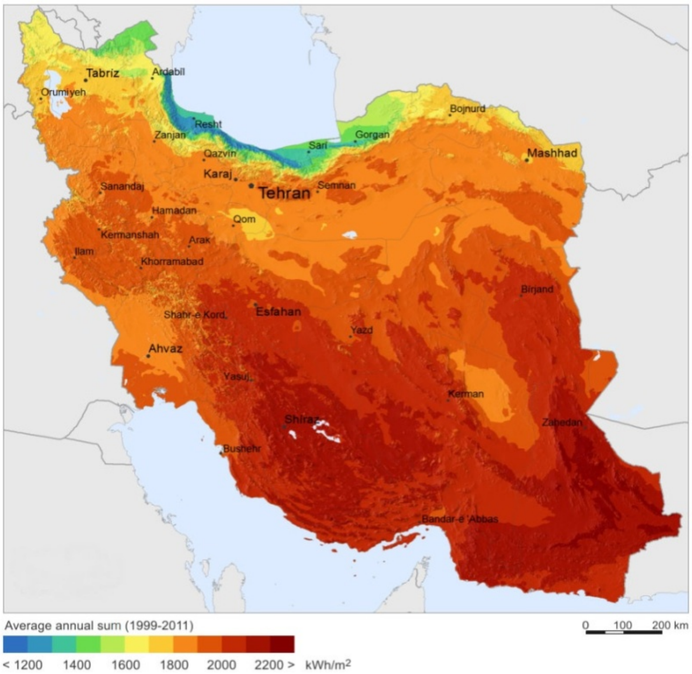

Figure 1. Map of the average of the received energy in Iran

2. Introduction to Photovoltaic systems

To understand the electronic behavior of a solar cell, it is useful to create a model which is electrically equivalent, and is based on discrete electrical components whose behavior is well known. An ideal solar cell may be modeled by a current source in parallel with a diode; in practice no solar cell is ideal, so a shunt resistance and a series resistance component are added to the model. The resulting equivalent circuit of a solar cell is shown on the Figure 2.

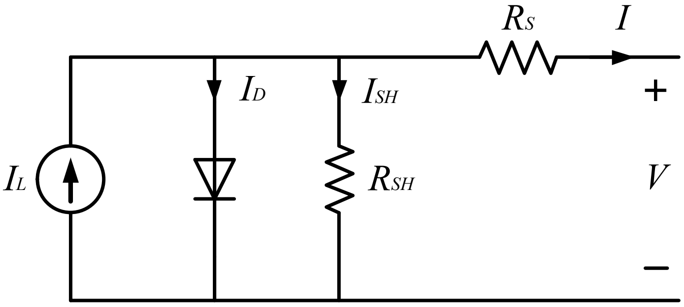

Figure 2. The equivalent circuit of a solar cell

From the equivalent circuit it is evident that the current produced by the solar cell is equal to that produced by the current source, minus that which flows through the diode, minus that which flows through the shunt resistor:

$$I = I_L - I_D - I_{SH} \tag{1}$$

Where

- I = output current ;
- I_L = photogenerated current ;
- I_D = diode current ;
- I_{SH} = shunt current.

The current through these elements is governed by the voltage across them:

$$V_j = V + IR_s \qquad (2)$$

Where
- V_j = voltage across both diode and resistor R_{SH} ;
- V = voltage across the output terminals ;
- I = output current ;
- R_S = series resistance.

By the Shockley diode equation, the current diverted through the diode is:

$$I_D = I_0 \{\exp\left[\frac{qV_j}{nkT}\right] - 1\} \qquad (3)$$

Where
- I_0 = reverse saturation current ;
- n = diode ideality factor ;
- q = elementary charge ;
- k = Boltzmann’s constant ;
- T = absolute temperature ;
- At 25°C, $kT/q \approx 0.0259$ volts.

By ohm’s law, the current diverted through the shunt resistor is:

$$I_{SH} = \frac{V_j}{R_{SH}} \qquad (4)$$

Where
- R_{SH} = shunt resistance (Ω).

Substituting these into the first equation produces the characteristic equation of a solar cell, which relates solar cell parameters to the output current and voltage:

$$I_D = I_L - I_0 \{\exp\left[\frac{q(V+IR_S)}{nkT}\right] - 1\} - \frac{V+IR_S}{R_{SH}} \qquad (5)$$

An alternative derivation produces an equation similar in appearance, but with V on the left-hand side. The two alternatives are identities; that is, they yield precisely the same results [2].

In principle, given a particular operating voltage V the equation may be solved to determine the operating current I at that voltage. However, because the equation involves I on both sides in a transcendental function the equation has no general analytical solution. However, even without a solution it is physically instructive. Furthermore, it is easily solved using numerical methods.

Since the parameters I_0, n, R_S, and R_{SH} cannot be measured directly, the most common application of the characteristic equation is nonlinear regression to extract the values of these parameters on the basis of their combined effect on solar cell behavior.

2.1 Effect of temperature on photovoltaic cell

Temperature affects the characteristic equation in two ways: directly, via T in the exponential term, and indirectly via its effect on I_0 (strictly speaking, temperature affects all of the terms, but these two far more significantly than the others). While increasing T reduces the magnitude of the exponent in the characteristic equation, the value of I_0 increases exponentially with T. The net effect is to reduce V_{OC} (the open-circuit voltage) linearly with increasing temperature. The magnitude of this reduction is inversely proportional to V_{OC}; that is, cells with higher values of V_{OC} suffer smaller reductions in voltage with increasing temperature. For most crystalline silicon solar cells the change in V_{OC} with temperature is about -0.50% per °C, though the rate for the highest-efficiency crystalline silicon cells is around -0.35% per °C. By way of comparison, the rate for amorphous silicon solar cells is -0.20% per °C to -0.30% per °C, depending on how the cell is made [3].

The amount of photogenerated current I_L increases slightly with increasing temperature because of an increase in the number of thermally generated carriers in the cell. This effect is slight, however: about 0.065% per °C for crystalline silicon cells and 0.09% for amorphous silicon cells. The overall effect of temperature on cell efficiency can be computed using these factors in combination with the characteristic equation. However, since the change in voltage is much stronger than the change in current, the overall effect on efficiency tends to be similar to that on voltage. Most crystalline silicon solar cells decline in efficiency by 0.50% per °C and most amorphous cells decline by 0.15-0.25% per °C. The figure 3.Shows I-V curves that might typically be seen for a crystalline silicon solar cell at various temperatures.

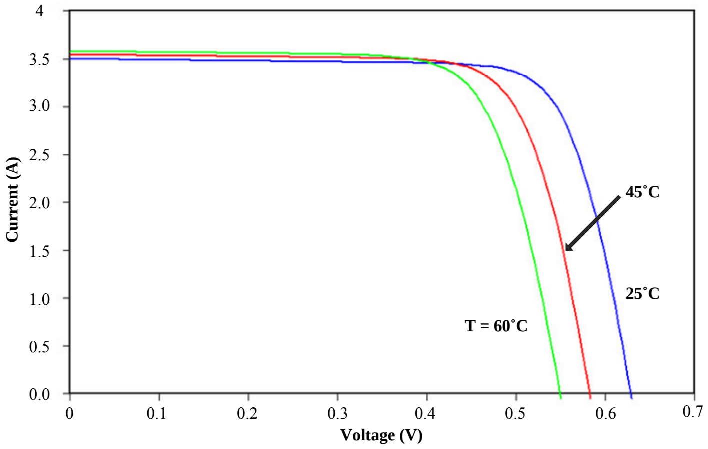

Figure 3. Effect of temperature on the current-voltage characteristics of a solar cell.

2.2 Photovoltaic effect on converts direct light to electrical energy

Photovoltaic system consists of solar cells, where they can convert direct sunlight to electricity, therefore more attention have been paid to them for producing electricity, New range of solar cells are based on semiconductors, they have P-N connections (light sensitive diodes) in vast surfaces. Photovoltaic effect that converts direct light to electrical energy, happen in three layers of energy conversions. First layer of these three layers is upper connection layer (N type semiconductor).

Second layer in this structure is core, where it is the absorption layer P-N connection. Third layer (P type semiconductor) is the lowest part of the three layers.

Photovoltaic cells are made by three methods namely: single crystal, multi crystal and amorphous (shapeless), where due to its crystal shapes, have different efficiencies. Table 1, shows efficiencies of various photovoltaic cells [4].

Table 1. Efficiency of various photovoltaic cells [4]

Type of structure	Practical efficiency (%)	Experimental efficiency (%)
single crystal	14-17	24
multi crystal	13-15	18
amorphous	5-7	13

In order to increase voltage the solar cells are connected in series. Panels at various sizes for different application are made. According to table2, panels are normally divided to three categories; low voltage panels or powers of less than 1.5-6 volt and few milli watt powers, small panels with 1-10watt power and 3-10V voltage, large panels with 10-60 watt power and 6-12V voltage [5].

Table 2. Technical properties of photovoltaic panels

Types of panels	Low voltage/power	Small	Large
Voltage (V)	1.5-6	3-10	6-12
Output Power (W)	Few milli watt	1-10	10-60

3. Applications of photovoltaic cells

Photovoltaic cells can be used to: provide lighting in remote areas, remote communication systems, water pumping, water filtration systems, electricity supply in rural areas, calculators, watches and toys, emergency systems, storage refrigerators to keeping vaccine and blood for remote areas, Ventilation systems for swimming pools, Satellites and space equipment… .

Generally, applications of photovoltaic cells can be classified into three categories:
1- Applications for connected to network
2- Applications for isolated from the network
3- Applications for Support systems.

3.1 Applications of photovoltaic cells for connected to the network

Photovoltaic systems connected to the network is designed so which will operate simultaneously and connected to the national grid. Converters are one of the main components of photovoltaic systems connected to the network, that convert DC electricity produced by solar cells (proportional to voltage and power the grid) to AC and will stop transmission automatically when it does not need. In general, there is bilateral communication between cells and photovoltaic systems so that if DC electricity produced by photovoltaic systems is more than needed, surpluses energy is added to the national grid and at night and when as a result of climatic, there is not the possibility of using sunlight, electrical load required will be provided by the national grid. Also in applications of connected to network if the PV system be outside from the circuit due to repairs, power requirements will be provided through the national grid. Figure 4 shows the system components connected to the network [6].

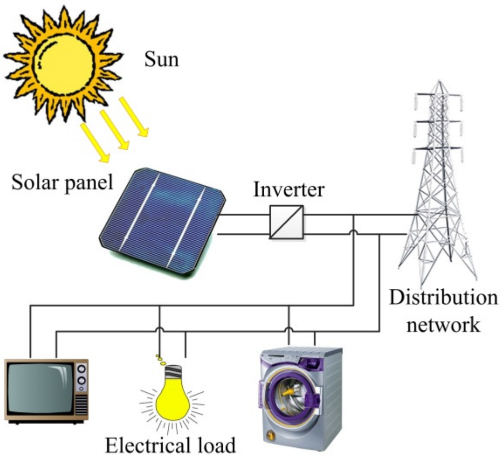

Figure 4. System components connected to the network

3.2 Applications of photovoltaic cells for isolated network

Photovoltaic systems Design connected to isolated network are operating independently from the national grid and often are designed to generate DC or AC electric load. In order to generate electricity systems for isolated network can be used an auxiliary force as wind turbines, generators or from the national grid.This system called photovoltaic hybrid. In isolated network systems in order to energy storage and using it at night or whenever sunlight is not enough, will be used the battery. Figure 5 shows the components of isolated network system [7].

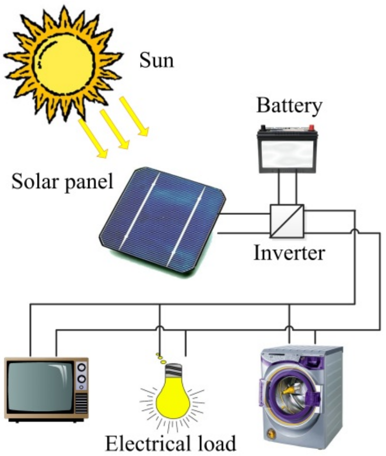

Figure 5. System components for isolated network

3.3 Applications of photovoltaic cells for Support systems

The most important use of photovoltaic support systems is in national network power outage period. A small photovoltaic support systems can supply power needed to equipment such as lighting, Computer, telephone, radio, fax and ... and larger systems can provide electricity needed for equipment such as refrigerators during power outages. Figure 6 shows the components of this system [8].

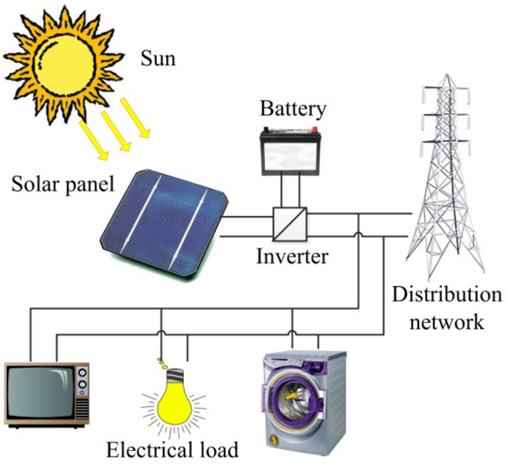

Figure 6. System components for Support systems

4. Evaluation of existing power grid in Isfahan Museum Park

Isfahan Museum Park with an area of approximately 130 hectares is located in the south-east Isfahan and distance of 11 km from the city center. A power requirement for this complex is supplied by substation 63/20 Road Shiraz (This substation is in proximity Highway ShahidDastjerdi). Power grid in this collection is very worn and outdated and length of existing network (20KV and 400 V) is much more than the standard. Due to a very large extent and mountainous region, it’s not possible to provide electricity to all parts of it. Figure 7 are show, status of power electricity grids in this collection.

5. Study and discussion on Issue

5.1 Mathematical Model

Solar radiation is the most important parameter in the design of solar energy conversion systems. Solar radiation data are commonly available in two forms, the monthly average daily global solar radiation on a horizontal surface (H) and the hourly total radiation on a horizontal surface (I) for each hour for extended periods such as one or more years.

The total solar radiation on a tilted surface (H_T) is made up of the direct or beam solar radiation (H_B), diffuse radiation (H_D), and ground reflected radiation (H_R). Thus, for a surface tilted at slope angle from the horizontal, the incident total solar radiation is:

$$H_T = H_B + H_D + H_R \tag{6}$$

The daily beam radiation received on an inclined surface may be expressed as:

$$H_B = (H - H_D)\, R_b \tag{7}$$

Where H and $H_D$are the monthly-average daily global and diffuse radiation on a horizontal surface, and $R_b$is the ratio of the average beam radiation on the tilted surface to that on a horizontal surface for each month. $R_b$is a function of the transmittance of the atmosphere, which depends upon the atmospheric cloudiness, water vapor, and particulate concentration.

However, have suggested that $R_b$can be estimated to be the ratio of extraterrestrial radiation on the tilted surface to that on a horizontal surface for each month. For a surface facing directly towards the equator:

$$R_b = \frac{\mathrm{Cos}(\varphi - \beta)\,\mathrm{Cos}\delta\,\mathrm{Sin}\omega'_s + (\pi/180)\omega'_s\,\mathrm{Sin}(\varphi - \beta)\,\mathrm{Sin}\delta}{\mathrm{Cos}\varphi\,\mathrm{Cos}\delta\,\mathrm{Sin}\omega_s + (\pi/180)\omega_s\,\mathrm{Sin}\varphi\,\mathrm{Sin}\delta} \tag{8}$$

a) The existing 20 kV network in Isfahan Museum Park

b) The worn existing network (400V) in Isfahan Museum Park

Figure 7. Status of power electricity grids in Isfahan Museum Park

Where ω'_s is the sunset hour angle for the tilted surface given by:

$$\omega'_s = \mathrm{Min}\begin{bmatrix} \omega_s = \mathrm{Cos}^{-1}\ (-\tan\varphi\ \tan\delta) \\ \mathrm{Cos}^{-1}\ (-\tan(\varphi - \beta)\ \tan\delta) \end{bmatrix} \tag{9}$$

Where "min" means the smaller of the two items in the bracket. Assuming isotropic reflection, the daily ground-reflected radiation may be written as:

$$H_R = H_\rho(1 - \cos\beta)/2 \tag{10}$$

Where β is the tilt of the surface from horizontal, and ρ is the ground reflectance (≈ 0.2). As a consequence, the monthly-average daily solar radiation on a tilted surface, H_T, may be expressed as follows:

$$H_T = (H - H_D)R_b + \frac{H_D}{2}(1 + \cos\beta) + \frac{H\rho}{2}(1 - \mathrm{Cos}\,\beta) \tag{11}$$

If we simplify to this equation, the equation:

$$H_T = R_H = RK_TH_o \tag{12}$$

5.2 Monthly Optimum Slope Angle

The daily mean values of solar radiation intensity on a flat plate for each month of the year are shown in Figure 8. The maximum and minimum values of solar radiation intensities are highlighted in the Figure. The monthly optimum slope angles are calculated for a collector faced to the south using Eqs. (8) to (11) and the solar radiation intensity on a horizontal plate. The monthly optimum slope angles are given for Isfahan city in Figure 8. The slope angles were calculated for different intensities of total radiation on the collector surface and the corresponding values for maximum total radiation were specified as the optimum slope angle.

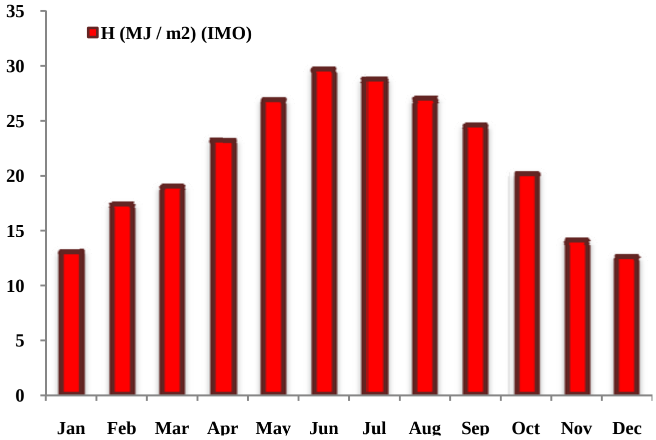

Figure 8. Average daily values of global solar radiation intensity on a horizontal collector (IMO) for the months of the year

The monthly optimum slope angle $\beta_{opt\,(m)}$, was calculated using daily mean values for each month of the year so that a solar collector could be adjusted accordingly. The maximum and minimum solar radiation intensities for Isfahan city are highlighted in the figure. It is noticed that the optimum slope angles are negative from May to July; the negative sign indicates that the solar collector should be faced to the north. A positive sign indicates that the solar collector is faced to the south. The optimum slope angle of each city in March is approximately equal to the site latitude. For each month the average global radiation intensity was found corresponding to the optimum slope angle, $\beta_{opt\,(m)}$. A comparison of the calculated solar radiation intensity on horizontal (H) and inclined surfaces ($H_{opt(m)}$) on monthly, seasonal and yearly basis is also given in Table 4. The preliminary results demonstrate that when a solar collector is fixed at a slope angle equal to $\beta_{opt\,(m)}$ there will be a significant gain in the solar energy intensity. The maximum and minimum percentages for this gain are highlighted in the corresponding column of the Table. These clearly indicate that the efficiency of solar collection at the monthly optimum slope angle is increased compared to the horizontal position. It should be stated that the optimum slope angle is increased in the beginning and at the end of each year (Table 3).

Table 3. The monthly optimum slope angle, $\beta_{opt(m)}$, and the average daily values of solar radiation intensity$H_{opt(m)}$(MJ/m^2)

Month	Optimum Slope Angle(°) $\beta_{opt(m)}$	Hopt(m) (MJ/m2)
January	57.40	21.32
February	48.11	23.56
March	32.14	21.215
April	14.63	23.02
May	0.058	26.09
June	**-6.58**	28.93
July	-3.10	27.91
August	9.17	26.53
September	27.45	26.44
October	45.18	26.58
November	55.40	22.16
December	**60.01**	20.65

Table 4. Percentage of heat gain under the monthly optimum slope angles at the monthly optimum angles, $\beta_{opt(m)}$

Month	Monthly	Seasonal	Yearly
January	69.41	41.073	26.159
February	40.17		
March	13.64		
April	3.116	**1.236**	
May	**0.01**		
June	0.583		
July	0.112	4.155	
August	1.164		
September	11.19		
October	34.28	**58.17**	
November	61.93		
December	**78.30**		

5.3 Economic Comparison of photovoltaic systems and national networks

This section will compare economically the cost of electrical energy from photovoltaic systems and national network for a load by 600 Kwh consumption per day that is the average consumption in the Isfahan Museum Park.

5.4 Estimated cost of photovoltaic systems

Table 5 shows photovoltaic system components and costs provide energy for the loadmentioned above.

Table 5. Components and cost of photovoltaic systems

Case	Unit price ($)	Number	total price ($)
Panel	267	3200	854400
Battery	84	1200	100800
Charge Control	417	100	41700
Inverter	665	100	66500
Structure	134	200	26800
Total			1090200

Although there are several acceptable methods to calculate the economic costs but it has been used from analyzing life-cycle cost method in this paper.The net present value formula is as follows [9]:

$$NPV = \frac{C}{(1+d)^y} \tag{13}$$

NPV: Net Present Value;
C: Cost in year;
d: Interest rate;
y: Year that costs in it occurs.

Interest rate 10% (in terms of inflation) usually used in the analysis of the return period. Economic estimates of photovoltaic systems are as follows:

A. The cost of constant investment

The initial investment cost is including equipment cost and installation of the system. The cost of installation and commissioning are usually equivalent to 10% equipment costs.

B. Variable costs

Variable cost is including the cost of battery replacement, and repair service. Battery life is usually considered 5 years, so the batteries will be replaced 3 times in the lifetime of the system.The annual service system fee is equivalent to 1% of the cost of photovoltaic systems equipment. It has been inserted list of twenty-year lifetime system costs with the LLC method In Table 6.Also, interest factor is obtained from the following formula:

$$D = \frac{1}{(1.1)^y} \tag{14}$$

Net present value obtains by multiplying total initial investment, replacement and repair, and maintenance costs and the interest factor for the same year. So the cost per Kwh of electrical energy is obtained as follows:

$$\frac{NPV - 12500}{20 \times 365 \times 600} = 0.325 \tag{15}$$

The cost of branch be considered 12500 $ in these calculations.

5.5 The estimated cost of national electricity networks

Economic estimation of power transmission by the national network with 20 KV line is as follows:

The average cost per km of 20 KV network equivalent of 14170 $, 400 LV network equivalent of 16710 $, Cost of 150 kVA transformer is 115000$. LV network length is usually considered about 1.5 km. Cost of release sales of electrical energy is 0.71 $/Kwh. The cost of branch be considered 12500 $ in these calculations. A distribution and branch cost of the Isfahan Museum Park is computed as follows:

(Cost of low voltage network × 1.5 + cost of the high voltage network × Distance of network + cost the transformer)

Unit cost of electrical energy consumption for the Isfahan Museum Park for 20-year lifetime is:

$$\frac{\text{Distribution costs}}{20 \times 365 \times 600} \tag{16}$$

Table 6. Total cost of photovoltaic systems

Year	The main costs	cost of battery replacement	cost of annual service	Interest factor	NPV
0	1398882		10883	1	1398882
1			10883	0.91	5672
2			10883	0.83	3235
3			10883	0.47	2056
4			10883	0.69	1328
5		100000	10883	0.62	9933
6			10883	0.57	723
7			10883	0.52	577
8			10883	0.47	497
9			10883	0.43	433
10		100000	10883	0.39	4116
11			10883	0.35	400
12			10883	0.32	387
13			10883	0.30	358
14			10883	0.27	382
15		100000	10883	0.24	4399
16			10883	0.22	450
17			10883	0.20	488
18			10883	0.19	473
19			10883	0.17	549
20			10883	0.15	662
		Total NPV			1436000

Table 7 presents the results of calculations made based on this method for cost of electricity transmission of national network and photovoltaic systems for Isfahan Museum Park According to distance Isfahan Museum Park from the network [10].

Table 7. Cost per kWh for the Isfahan Museum Park according to different distances from the network

Distance of network (km)	Costs of photovoltaic systems ($/Kwh)	Costs of national network ($/Kwh)
5	0.325	0.183
10	0.325	0.264
15	0.325	0.345
20	0.325	0.426

As can be seen, the cost of installing photovoltaic systems is independent of distance to network access. Obviously with increasing the distance, costs required to transmission network increases to rise. Figure 9 shows electrification compare economically by two methods is described.

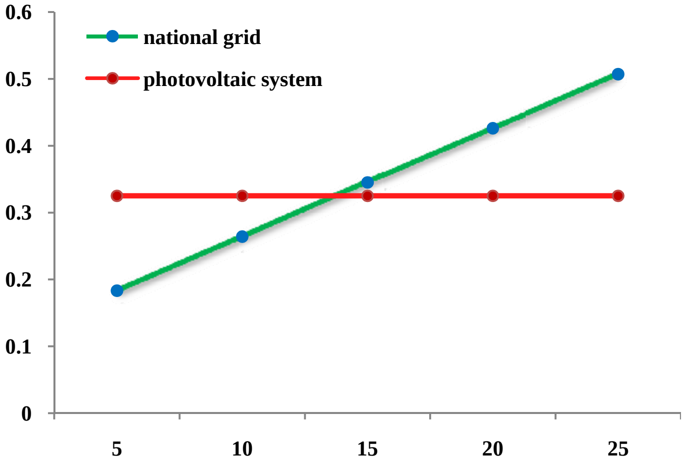

Figure 9. Comparison of cost each Kwh in the Isfahan Museum Park by the national network and photovoltaic System

Figure 9 shows that in Isfahan Museum Park, national network is affordable at distances less than 13 Km, and at more distances of 13 Km the photovoltaic systems are affordable. So in areas with low load and without of access to national electricity grid, the use of photovoltaic systems in addition to the technical feasibility, has the economic save.

6. Conclusion

At this paper, the cost of electricity supply to rural areas using of national network and photovoltaic systems were compared. The results show that cost of each kWh of energy using photovoltaic systems is 0.325$. While the costs by using the national grid according to the distance from the network is variable. So at specific distances from the national network, the photovoltaic system is affordable economically. In general can be concluded that in order to supply electricity at areas with low load and without of access to national electricity grid, using the photovoltaic systems are appropriate. Given the rapid growth of new technologies in fabricating solar cells at coming decades, the cost of photovoltaic systems reduced and it will be makes the development of photovoltaic systems.

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