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Economic Analysis and Energy Utilization of Renewable Energy to Supply Electric Charge with Approach of Storage Resources

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Abstract
In this research work, the technical and economic analysis of the use of storage devices in a hybrid wind/solar system is performed in order to provide a maximum electrical load of the residential buildings. For this aim, the two scenarios of grid-connected and off-grid systems are studied. The two parameters of high reliability and cost per production capacity are used. According to these two parameters due to the low cost of the grid energy and the high cost of purchasing, the second scenario cell is selected with the grid-connected system approach. Based on this system, the final generation that has a surplus of production sells the energy to the network, and uses the network to supply the load when there is a lack of power to supply the load. According to the cases mentioned in the second scenario, more than 50% of the requested load is supplied by the photovoltaic cell, which indicates the high potential of the studied area. For the selected system, the return on investment is 7.53 years, considering that the cost of energy is 0.13 $/kWh.

Keywords: *Technical and economic analysis, connected and disconnected from network, storage system, reliability.*

1. Introduction

With the industrial development of the world, the increasing demand for energy, on the one hand, the limited and necessary preservation of fossil fuel resources for the future generations and the prevention of environmental damage caused by their use and, on the other hand, there is no other way but to use the renewable energy resources [1, 2]. Currently, the use of these energy sources in replacement with fossil fuels due to the environmental and economic characteristics is the main concern of the energy policy-makers [3, 4]. One of the most important renewable energy sources is the solar energy systems, which have made significant progress. Iran is one of the countries with a high energy consumption, especially in the residential building sector, and has a high potential for solar energy so the use of solar systems can be a big step, in the long run, to achieve the sustainable development goals, reduce fossil fuel consumption, and thus reduce environmental pollution [5-7]. Solar energy has advantages such as an easier access and enormous capacity of this resource [8, 9]. The amount of solar energy received by the earth is several thousand times the current consumption of electricity around the world. Due to the importance of using the renewable energy sources in the energy supply, the use of these resources is increasing rapidly. Renewable energies have a different energy structure than the conventional energy production technologies since the development process in renewable energies has high initial investment costs and, in contrast, the cost of maintenance is low [10-12]. However, the benefits that have boosted the use of this energy include the emission of pollutants from combustion and the increase in CO_2 in the atmosphere and its wastes including the rising temperatures, climate change, rising sea levels, and a sharp decline in the material cost. Renewable energies such as wind and solar has become very important due to the nonrenewability of the fuels such as oil and coal [13, 14]. The use of wind and solar energy can be used in order to provide the power required to generate electricity. However, one of the most important problems in using this type of energy is the variability of the parameters such as the wind speed and solar radiation. Also due to the government's approach to the production of a clean and green energy and financial and economic support for such projects, it is expected that the prices of important components of the hybrid system such as wind turbines and solar panels will change a lot [15-17]. Table 1 shows some research works on the supply of electrical energy by renewable energy.

Table 1. some research works on the supply of electrical energy by renewable energy

Reference	Location	Renewable energy	Wind turbine type	Connection	Electrical load (kWh/day)	COE ($/kWh)
[18]	Iran	Wind, Solar	Vertical	Off-grid	54	0.636
[19]	KSA	biogas, Solar	-	On-grid	250	0.21
[20]	Turkey	Solar	-	On-grid	25108	0.05
[21]	Ethiopia	Solar	-	Off-grid	77	0.359
[22]	India	Solar	-	Off-grid	220	0.11
[23]	Malaysia	Solar	-	On-grid	22128	0.022

One of the major problems with renewable energy is the variability of this energy during the day and during different seasons, which has led the researchers to think of overcoming this problem to maximize the use of storage resources at times when these types of energy sources are not available to do research so in this work, in order to analyze these storage resources as much as possible economically and energetically for a hybrid wind and solar system will be evaluated for the most appropriate type of storage according to two economic factors and maximum supply should be selected. Since in most research works, the storage resources are considered as a presumption, the study of storage resources in the renewable systems by considering economic and energy factors is the innovative aspect of this research work.

2. Materials and methods

2.1. General description of model

There are different systems to supply electricity to residential buildings; in this research work, a hybrid wind and solar system has been considered. The configuration of this system is such that first, the photovoltaic-wind turbine cell starts to generate electrical energy, and then in cases where the production is more than the consumption, it will be transferred to the back-up system, which is the storage system. In this research work, the focus is more on the storage system with the aim to provide the maximum load required in the building under study. In this regard, how to choose the appropriate storage system taking into account the economic parameters and system reliability, the HOMER renewable energy simulator software is used, which requires the intensity of solar radiation and bio-electricity. The amount of solar radiation intensity for the studied area (Saveh city) was obtained from the NASA site. In the next step, the amount of electrical power for a sample building was calculated according to the relevant standards received from the Ministry of Energy. Due to the variability of the amount of solar radiation and the amount of utilization of this energy in supplying the electrical power, the sensitivity analyzes have also been performed.

A flowchart of the software performance is shown in figure 1. The type and number of inputs required to perform the simulation, optimization and economic ranking calculations are shown in the flowchart. Also the technical-economic-energy-environmental outputs show the high ability of the software to analyze the issues related to renewable energy.

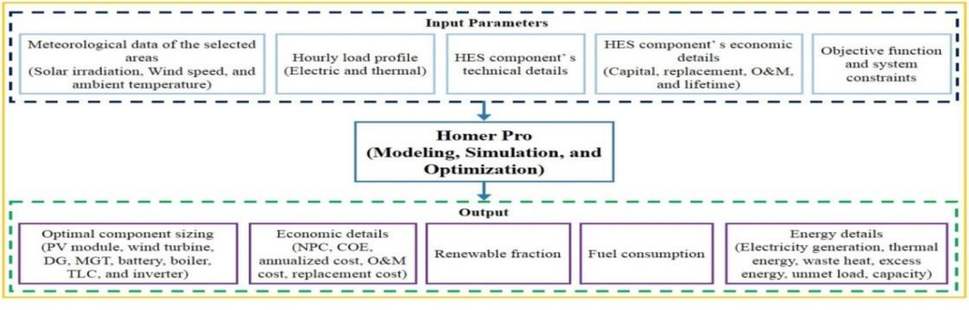

Figure 1. A flowchart of HOMER software performance [24].

Amount of sunlight: In October, the solar radiation intensity of the Saveh city was collected from the functions of the Markazi province for the years 2019-2020 from the NASA site, and then this information was considered as the input for the Homer software. Based on this, the average amount of solar radiation in this region was 4.84 kWh/m^2/d, whose diagram can be seen in figure 2.

Figure 2. Monthly average solar radiation intensity for Saveh city.

Wind rate: Figure 3 shows the amount of wind for a period of one year at a height of 50 m for the studied area.

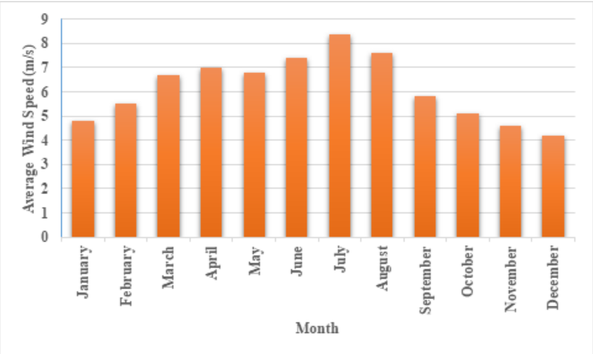

Figure 3. Wind rates for Saveh city.

According to figure 2, the highest wind intensity is related to July at 8.38 m/s, and the lowest in November is 4.59 m/s. For the above diagram, the Weibull coefficient is equal to 2, and the peak hour is related to the 15th hour of July. Accordingly, the average wind in this area is 4.99 m/s.

Electrical load: In order to simulate more accurately and to achieve more realistic results, the required electric charge for a residential unit is required. For example, the load with the specifications mentioned in the table was calculated and used in the simulation. The total amount of electrical power required per day is 11.26 kWh/d, and the peak load is 2.09 kWh, which can be seen with all the details in table 2 and figure 4.

Table 2. Evaluation tablet of daily load of a residential unit.

Equipment	Time	Consumption rate (kW)
Air conditioner	4-1 a.m.	12 kW
Television	10 a.m. to 4 p.m.	2 kW
Indoor lamps	18-17 p.m.	0.51 kW
Lamps inside yard	20-19 p.m.	1.05 kW
Washing machine	22-21 p.m.	5 kW
Iron	9-7 p.m.	1 kW
Computer	1-19 p.m.	0.1 kW
Refrigerator	1-24 p.m.	3.6 kW
Vacuum cleaner	24-19 p.m.	1 kW

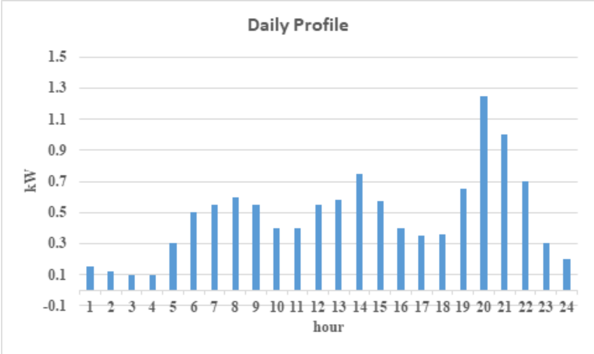

Figure 4. Electrical load of desired residential unit.

2.2 Simulation of wind and solar hybrid system with different types of storage

First scenario for system in question: The photovoltaic cell and the battery storage system are connected to the DC load bus due to DC power generation, and the wind turbine is connected to the AC bus due to the AC power generation, and by a DC/AC converter, the total power produced by these units is connected to AC power. The consumer usage is connected to the AC bus. By applying the above information to the software and the cost of the devices used in the hybrid system, the configuration can be considered as follows.

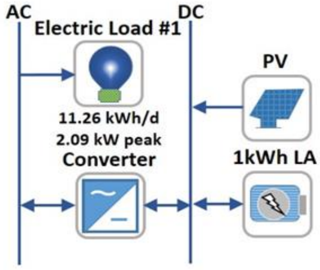

Figure 5. General scheme of solar system with battery storage.

Second scenario for system in question: In this scenario, no power storage system is used, and excess and shortage of power will be exchanged with the national grid. The photovoltaic cell is connected to the DC load bus due to DC power generation, and the wind turbine is connected to the AC bus due to the AC power generation, and by a DC/AC converter, the total power generated by these units is connected to the AC power for the consumer use in the bus. AC is connected. By applying the above information to the software and the cost of the devices used in the hybrid system, the configuration can be considered as follows.

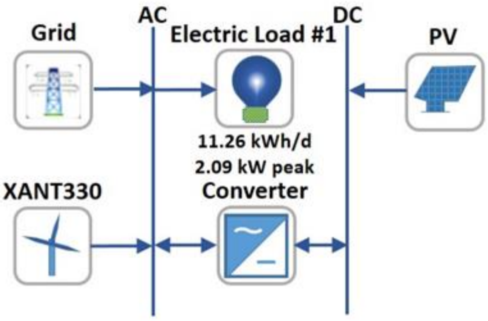

Figure 6. General scheme of a solar/wind hybrid system connected to a grid.

3. Results

3.1. First scenario

After simulating the system mentioned in the above section in the Homer software, the results obtained for each scenario, considering the two objectives of the lowest investment cost along with achieving high reliability, were as follow. It is worth noting that the lifespan of this system is 20 years.

Table 3. Results from HOMER software for first scenario.

Equipment	Quantity
Solar cell	7.2 kw
Battery	43kwh
Invertor	4.46 kw
Initial capital ($)	35829
Operating cost ($/y)	1300
Total NPC ($)	52630
COE ($/kWh)	0.991

According to the results obtained, the total investment cost of the solar/wind system with battery storage is $52630, and the cost of maintenance during the year is equal to $1300 during the 20-year period of operation of the system. The cost of energy per kilowatt-hour for this system was $0.991, which required 7.2 kW of photovoltaic cells and 43 kWh of batteries with 4.46 kW of converters to supply the required load.

Investment cost of components of desired hybrid system: For the operation of the hybrid solar power plant, the total construction cost will be $52630 during the 20-year operation period. The investment cost for photovoltaic cells, batteries, and converters is $22,523, $28,310, and $1797, respectively, as shown in figure 7.

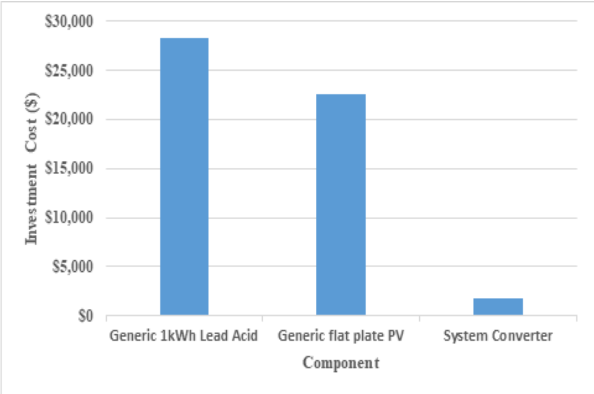

Figure 7. Investment cost by each component of hybrid system for first scenario.

Utilization rate of studied hybrid system equipment: Considering that in the independent mode of the network, the only source of power generation is the photovoltaic cell, the amount of power generation of this equipment after 12 months can be seen in figure 8.

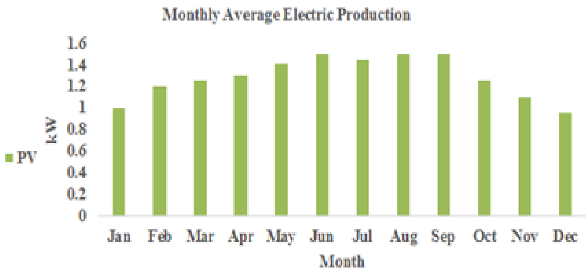

Figure 8. Electricity generation rate during a year.

According to Figure 8, the production capacity per year is equal to 11377 kW, which is the same amount of the total load required by the system. For a more detailed analysis, the production capacity of photovoltaic cells for different days of the year can be seen in figure 9.

Since the solar radiation is not always available, it is necessary to have a battery system that can work as a production source, and the amount of charge and discharge power by the battery is very important, which can be seen in figure 10.

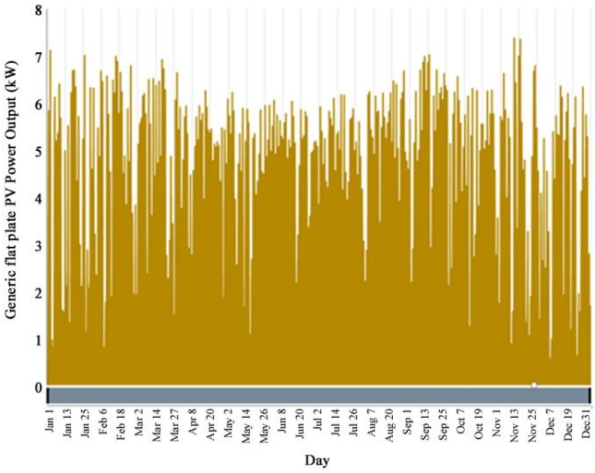

Figure 9. Photovoltaic cell power generation per day.

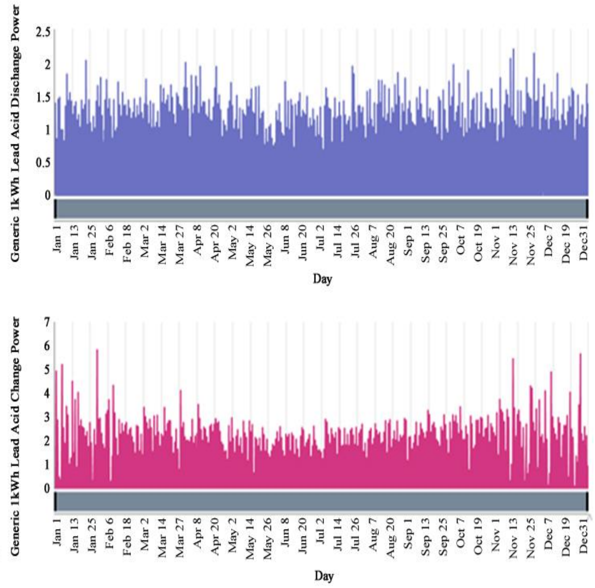

Figure 10. Battery charge and discharge rate during a year.

The operating hours of the converter can also be seen in figure 11.

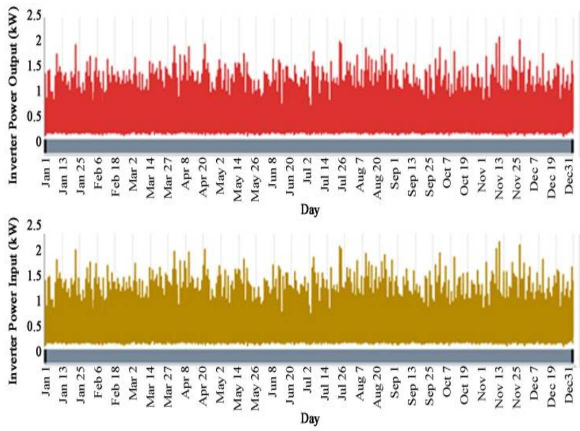

Figure 11. Converter operating hours during a year.

3.2. Second scenario

After simulating the system mentioned in the above section in the Homer software, the results obtained for the second scenario, considering the two objectives of the lowest investment cost along with achieving a high reliability, were as follows. It is worth noting that the lifespan of this system is estimated at 20 years.

Table 4. Results of HOMER software for second scenario.

Equipment	Quantity
Solar cell	1.69 kW
Grid	-
Invertor	1.4 kW
Initial capital ($)	5501
Operating cost ($/y)	233.46
Total NPC ($)	8519
COE ($/kWh)	0.13

According to the results obtained, the total investment cost of the solar system with battery storage is $8519, and the maintenance cost during the year is $233.46 during the 20 years of operation of the system. The cost of energy per kilowatt-hour for this system was $0.13, which required 1.69 kW of photovoltaic cells with a 1.4 kW converter to supply the required load.

Investment cost of components of desired hybrid system: For the operation of the hybrid solar/wind power plant, the total construction cost will be $8519 during the 20-year operation period. The investment costs for a photovoltaic cell and a converter are $5300.21 and $563.22, respectively, as shown in figure 12.

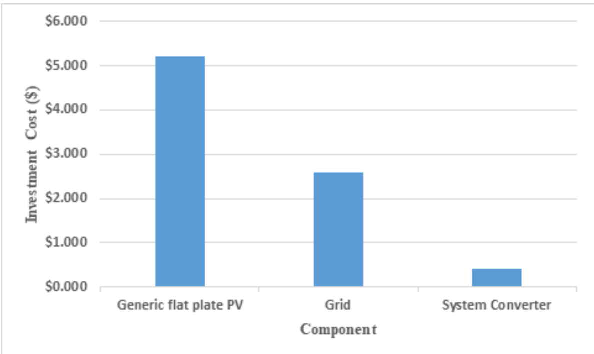

Figure 12. Investment cost for each component of hybrid system considering third scenario.

Utilization rate of studied hybrid system equipment: Since in the grid-connected state, photovoltaic cell power generation is not the only source, the amount of required generation for the load can be seen in Figure 13 after 12 months.

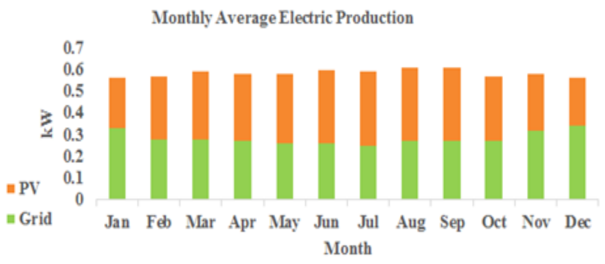

Figure 13. Amount of electricity generated during a year based on different sources.

According to figure 13, the production capacity per year is equal to 5212 kW, which is the same as the total load required by the system.

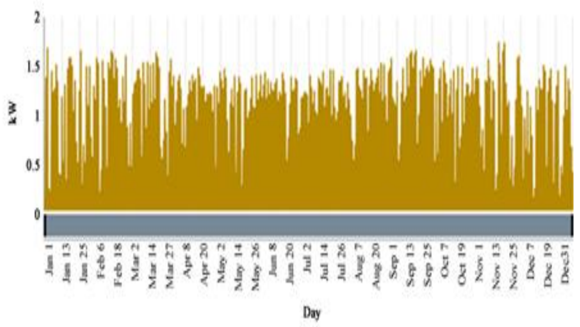

Figure 14. Power generation by photovoltaic cells per day.

Given that the solar radiation is not always available, the times when the network enters the circuit as a back-up system and acts as a production source must be also available, which can be seen in figure 15.

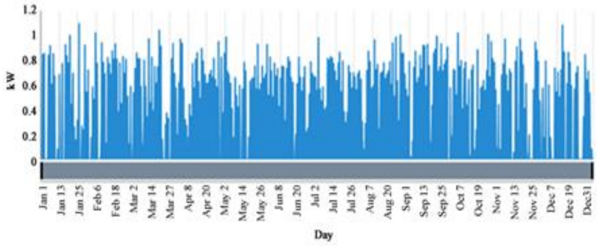

Figure 15. Network utilization rate during a year.

The operating hours of the converter can also be seen in figure 16.

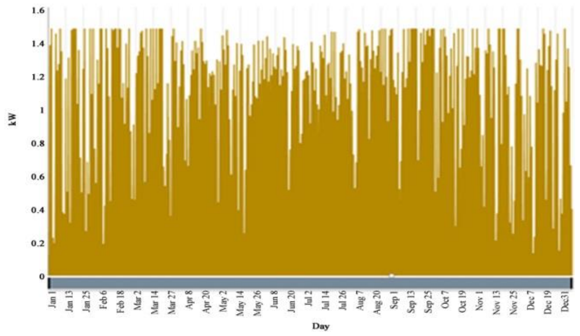

Figure 16. Converter operating hours during a year.

Sensitivity analysis for selected scenario (second scenario)

Solar: Since the intensity of solar radiation may be different in the coming years, and this average value will change, in order to achieve a system with a high reliability, the sensitivity analysis on the intensity of radiation in the region was performed, and the results obtaied were shown in table 5.

Table 5. Results of sensitivity analysis on solar radiation intensity.

Architecture					Cost				System
PV (kW)	XANT330	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating Cost ($)	Initial Capital ($)	Ren Frac (%)
1.69	-	999,999	1.40	CC	$0.130	$8,519	$233.46	$5,501	50.0
-	1	999,999	-	CC	$0.0358	$235,695	-$18,125	$470,000	99.8
0.0156	1	999,999	0.00521	CC	$0.0358	$235,734	-$18,125	$470,048	99.8

Considering the two economic indicators and the reliability of electricity supply, the program was implemented for different situations; the best case is related to the average radiation intensity of 4.84 according to the results obtained in table 6.

Table 6. Results of sensitivity analysis for most optimal solar radiation intensity.

Sensitivity	Architecture					Cost				System
Solar scaled average (kWh/m^2/day)	PV (kW)	XANT330	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating Cost ($)	Initial Capital ($)	Ren Frac (%)
4.84	1.69	-	999,999	1.40	CC	$0.130	$8,519	$233.46	$5,501	50.0
4.00	2.12	-	999,999	2.46	CC	$0.157	$10,269	$246.25	$7,086	50.0
5.50	1.48	-	999,999	1.62	CC	$0.121	$7,922	$232.90	$4,911	50.0
5.00	1.63	-	999,999	1.49	CC	$0.127	$8,360	$233.40	$5,343	50.1

For the above system, the effective economic indicators in selecting the equipment for interest-free return on investment are equal to 7.01 years, and for return on investment, considering that the interest is 7.53 years. The optimum for the intensity of solar radiation can be seen in figure 17.

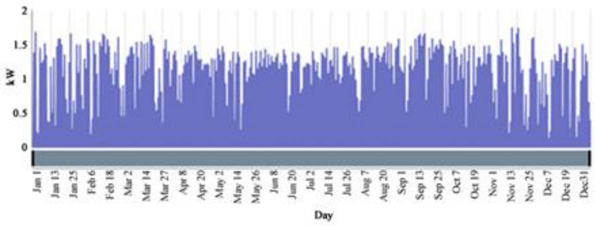

Figure 17. Amount of power produced by a photovoltaic cell for optimal radiation intensity.

4. Conclusion

The use of renewable energy-based electricity generation systems is expanding and developing, and in the meantime, one of the main problems of these systems is the lack of access at all hours of the day and night. In order to solve this problem, there are various solutions such as using it connected to the network or using the electrical energy storage systems, and finally, using several sources in one system. In the present work, three schemes were examined, and the following can be mentioned as the important results:

- Considering that the average intensity of radiation in the studied area is higher than the global average, it is a good option for using the solar systems in the buildings and public and commercial facilities.
- According to the first scenario, it was observed that the solar systems were not yet an economically viable and competitive option to supply electricity to a building.
- In both scenarios, the photovoltaic cell can supply the entire load, i.e. although the reliability of power supply in this system is 100%, there is also a surplus of generating power. If the system is connected to the network, one can also earn money from selling it.
- Due to the second scenario, where on-grid, the cost of energy was much lower than the first one, this is due to the low cost of the grid.
- Given the second scenario, despite the high cost of the photovoltaic cell and the low cost of the grid energy, it can be seen that more than 50% of the building energy is supplied by the solar cell, and this shows the high potential of the area. Various works can be done to complete the research work; among these works, the followings can be mentioned:
  Utilizing mathematical optimization.
  Use different storage systems in one scenario for a better comparison.
  Exergy-environmental analysis of the studied system.

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