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Potentiometric of the Renewable Hybrid System for Electrification of Gorgor Station

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Abstract- *In this paper, an optimal design of the renewable combustion plant has been investigated with the aim of ensuring the required load on the Gorgor station. The purpose of this study is to minimize the cost of the proposed hybrid unit during the period of operation of the designed system simultaneously. Information on the intensity of solar radiation and the intensity of wind blowing in the area are taken and applied in the simulation of the system. The intended target function includes the cost of investment, replacement cost and maintenance cost. After the design phase, the main objective is to check the economic benefits of the project's utilization from the grid and compare it with the renewable electricity system, as well as to calculate the initial investment return in renewable electricity. First, the initial cost of consuming electricity from this project is calculated using a renewable electricity system, and then the cost of project is determined using the national grid. Further, by calculating the annual current cost of each of these combinations, the investment return in each mode is obtained. Various options for the use of renewable energies are surveyed separately and in combination. The technical-economic analysis is done on each of these options and ultimately the best one is presented.*

Keyword: Gorgor station, Electrical energy audit, Optimization, Design, Economic analysis.

1. INTRODUCTION

Due to recent advances, the use of solar and wind power plants in the power distribution system is increasing. Distribution networks are now being used to add renewable power plants to power systems. And this transforms the previous meaning of distribution systems, because distribution systems in addition to delivering power to the consumer are used as a place for injection of power [1]. Although the addition of renewable power plants in the power system leads to challenges such as interconnection, voltage protection and regulation, but reliability enhancement and lower costs, encourages its use [2]. On the other hand, factors such as constraints on the structure of new transmission and distribution lines, increased subscriber demand for more reliability in power supply, electricity market, serious attention to environmental changes and economic constraints, the construction of large centralized power plants and transmission and distribution lines is difficult and almost impossible to service subscribers. Therefore, investors and system designers have always sought a solution to this problem. Providing peak power to reduce energy transmission and distribution costs, reduce environmental waste, combine heat and power, provide high levels of reliability and quality of power, and delay investment of transfer and distribution are the major benefits of using power plants renewable. The above points, all confirm that the future of the production is for renewable plants.

The design of hybrid renewable systems has been discussed in several references. In Ref. [3], it is noted that solar and wind power is complementary power. Hybrid solar and wind power Plant leads to reliability enhancement and less swing power. The design of energy storage system due to its heavy costs is an important problem in hybrid renewable systems. In this reference, a method for optimal capacity computation has been presented. A framework based on mixed integer linear programming for a hybrid renewable energy system with battery storage is presented in which demand response method has been considered in Ref. [4]. The framework involves the stochastic behaviour of renewable plant. This reference studies the effect of load elasticity on the sizing of system equipment's.

Ref. [5] discusses design, construction and hybrid system implementation to produce electric energy at a low cost. This reference presents the construction of a hybrid system for house applications. Ref. [6] employs a multi-objective genetic algorithm to optimize size, the cost of renewable system. Design of different equipment's of a

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hybrid renewable system based on modified PSO has been discussed in Ref. [7], to supply communication center in Egypt. Two states have been investigated; stand-alone system and network connected renewable system.

A design method based on cost, reliability and emission index has been developed in Ref. [8]. In this reference, wind turbine and solar panel have been considered and economic analysis has not been carried out to evaluate the efficiency of design method. Cost criterion is defined as objective function in Ref. [9] and SOC battery, loss of power supply probability, total energy lost and power different between generation and storage is assumed as problem constraints. In Ref. [10] the different reliability indexes has been studied. It is concluded that loss of load hours (LOLH) is a stricter design index compared with loss of power supply probability (LPSP).

Gorgor Sabalan waterfall is located in the village of Shayegh and 20 km from Sarein city to Alvares ski resort and 35 km from Ardabil. It is about 12 meters high and 200 m^2 and is located on the northern slope of the Sabalan mountain in the valley of Alvares or Ghezel Gollare.

Gorgor fountain is located at a height of 2420 meters above sea level. The discharge of this fountain is very high, and the water emerges from the cliffs of the rocky wall overlooking the valley. Due to the steep slopes of the route, the water reaches the river to the bed of the manifold waterfall. The geographic position of the Gorgor waterfall is 47 degrees, 56 minutes and 48.27 second east longitude (47.9467423), and latitude, 38 degrees and 9 minutes, and 24.25 second northern latitude (38.1567210).

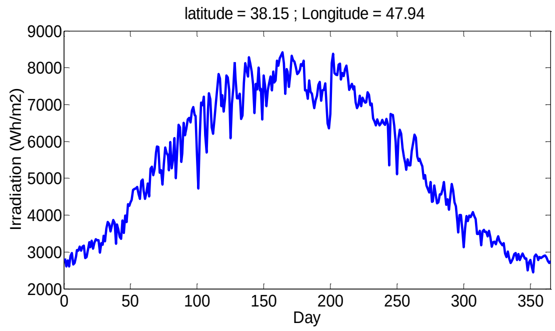
In this article, generalizations regarding to the geographical and natural location of the Gorgor station, solar energy and wind potential potentiometric pictures in the Gorgor station area, the potential of using wind and solar energy for the Gorgor station area and the study of the electric power consumption of the Gorgor station have been studied. An electric energy audit method has been used to estimate the station load. In this method, the estimation of Gorgor station load capacity is calculated by using the average power of electric equipment by utilizing electrical installation maps. The economic analysis of lighting system is based on the proposed scenarios and study of return on investment. The optimal technical-economic design of the renewable system along with the storage of the battery is done using an optimization algorithm. The purpose of this design is to minimize the overall cost of the system, which is presented at the cost of the present value of the system in terms of interest rate and inflation. Finally, the economic analysis of the plan is carried out in the previous stages. Efforts have been made to provide important economic-technical indicators after the initial estimation of the cost of a typical renewable system.

2. SOLAR AND WIND POTENTIOMETRIC ANALYSIS FOR GORGOR STATION AREA

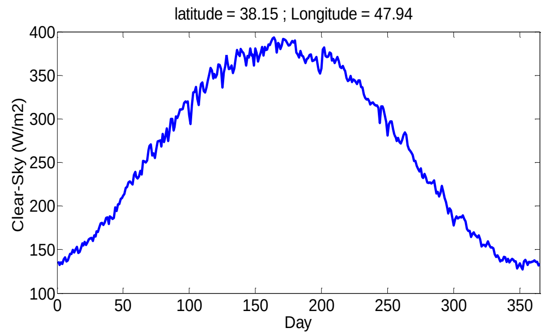
2.1. Study of solar intensity for the Gorgor station area

The intensity of solar radiation is considered as an important parameter in the discussion of optimal solar energy utilization and the design of solar energy systems in each location [11, 12]. In this section, we have tried to estimate the solar energy potential in the region by studying the intensity of the solar radiation for the Gorgor station. Radiation data are derived from ref. [13].

The radiation data in Fig. 1 to Fig. 2 show, respectively, the daily average of the energy received from the solar irradiation, the daily average of the clear sky solar irradiation, the daily average of the radiation at the high point of the atmosphere and the daily average of the radiation. As it is evident from these figures, the Gorgor station has the highest radiation in the sixth month, in June, and has the lowest radiation in January.

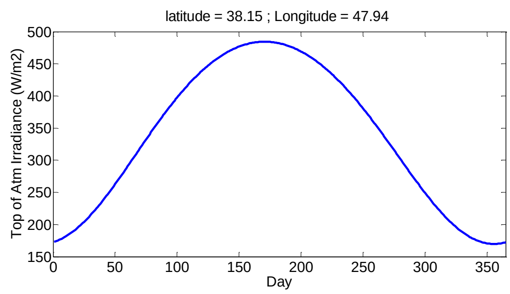


(a)



(b)

Fig. 1. (a) Average daily energy from solar radiation in (Wh/m^2), (b) Daily average of clear sky irradiance in (W/m^2)



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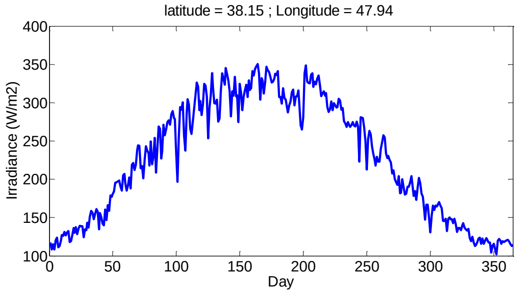


(b)

Fig. 2. The average daily radiation in the upper point of the atmosphere in (W/m²), (b) Average daily radiation in (W/m²).

The average solar energy in the Iran is 4.5 kWh/m². The Gorgor station area with annual average solar, 5.4374 kWh/m² has more radiation than the country average. The highest radiation is 8.4128 kWh/m² and the minimum radiation is 2.4419 kWh/m². The annual average irradiation energy in the region of Gorgor station for the six years from 2010 to 2015 is given in Fig. 3. According to this table, the average solar radiation for the years 2010 to 2014 has changed slightly compared to 2015.

2.2. Investigating the use of wind energy for the Gorgor station area

Average wind speed data in m/s, temperature, pressure and relative humidity are extracted daily from Gorgor station area and have been shown in Fig. 4 and Fig. 5 for Gorgor station area. By calculating the annual average of the region, which is about 3.2970 m/s, we conclude that the potential of wind power production in the region of Gorgor station is practicable. The maximum wind speed is 10.982 m/s.

According to Ref. [14], the average wind speed of less than 4.5 m/s is considered as a weak potential region. The wind power production potential in the Gorgor station region is weak, according to the standard provided in Ref. [14], So that average annual wind speed is 3.2970 m/s and maximum wind speed is 10.9820 m/s. The average annual temperature in the region is 9.6575 C°. The maximum temperature is 28.1158 C° and the lowest temperature is -9.6041 C°. The average wind speed, peak speed and annual average area temperature for the six years from 2010 to 2015 are given in Fig. 6. According to this figure, the average wind speed has been accompanied by a slight change in years.

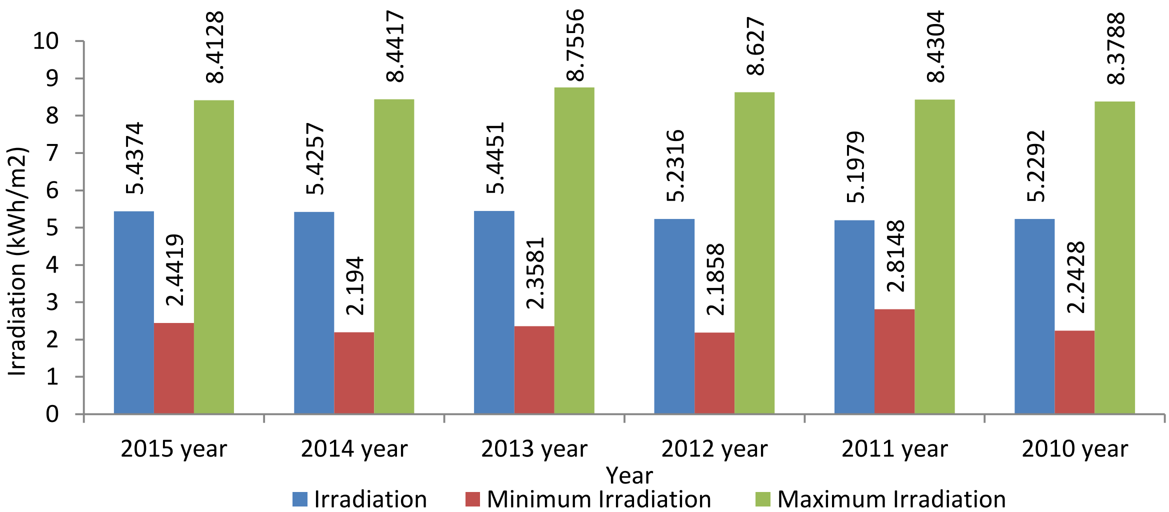
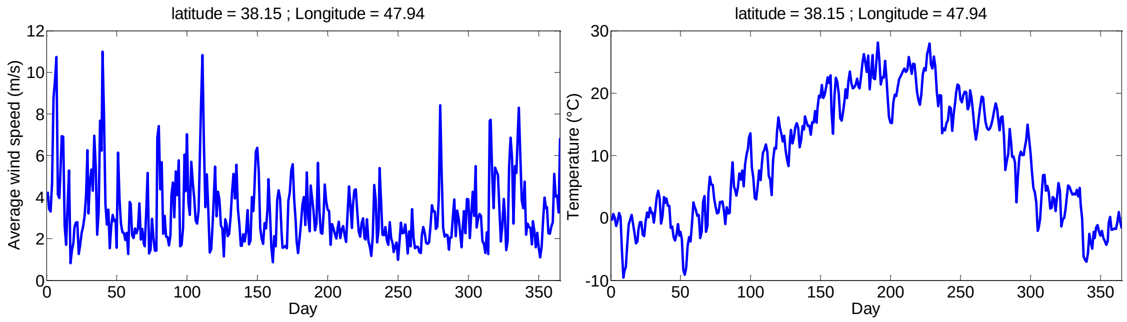


Fig. 3. The average annual solar radiation in the region of Gorgor station for 6 consecutive years



(a) (b)

Fig. 4. (a) Average wind speed daily for Gorgor station, (b) Temperature in C° for Gorgor station area

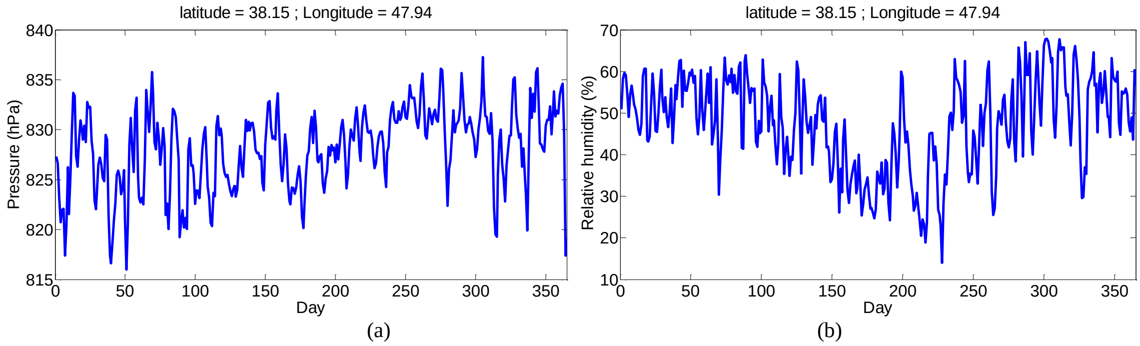


Fig. 5. (a) Pressure values daily for Gorgor station area, (b) Relative humidity daily for the Gorgor station area

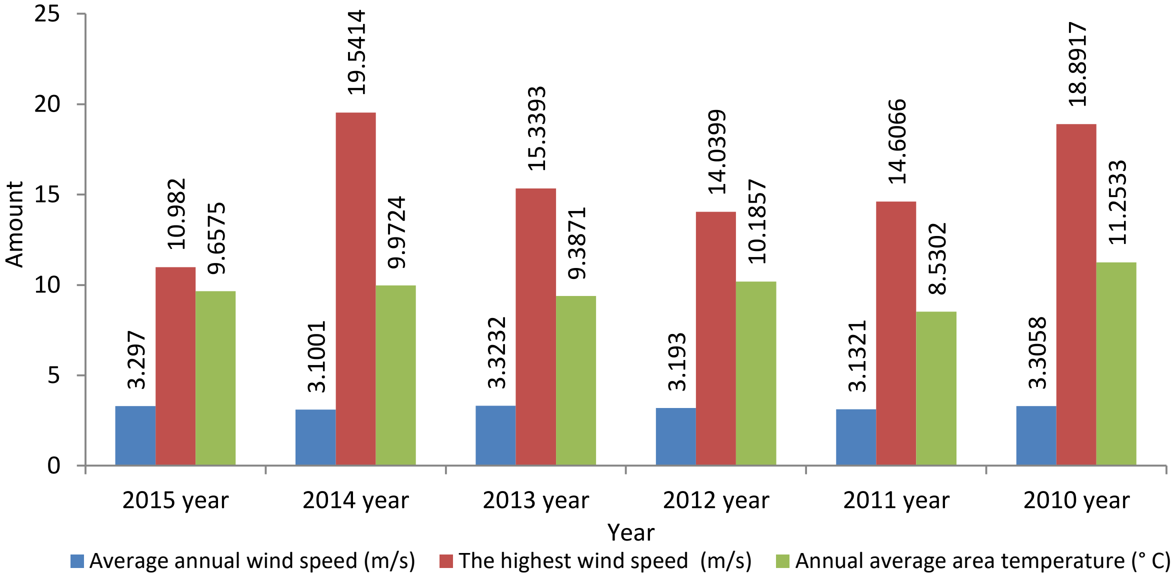


Fig. 6. Average annual wind speed, the highest wind speed and annual average area temperature for 6 consecutive years.

3. LOAD ESTIMATION OF LIGHT SYSTEM FOR GORGOR STATION

The area of the Gorgor station is 200 meters. To supply the lighting load of this area, by using a 150 W LED lamp, an LED is used for every 20 meters. Also, two spot lights with 12 lamps are used for indoor lighting in the station. Therefore, for station area lighting, twenty 150W LED lamps, and for the indoor lighting of the station, 24 LEDs with 150 watts are needed. According to the power consumption of the lights in Table 1, total power consumption for lighting the area around the station is 3 kW and 3.6 kW for lighting inside the station. The total power consumption of the station is 6.6 kW.

Energy consumption of station for lighting for the first and second six months of the year are extracted and recorded in Table 2, assuming an average of 10 hours in the first six months and an average of 12 hours for the lighting of ways (for the first six months, 6 hours low load and 4 hours peak load and for the second six months, 8 hours low load and 4 hours peak load are considered).

According to Table 2, from the total 29167.2 kWh used for lighting the station, 12060 kWh is related to the lighting of the area around the station and 17107.2 kWh is related to the lighting of the station.

The energy cost has been calculated based on Table 3 and has been given in Table 4. 17210952 Rials is for lighting of the area around the station and 25146158.4 Rials is for lighting inside the station. Taking into account the cost of demand, the total annual payment cost for lighting of Gorgor station is 44812310.4 Rials.

4. THE COMBINED RENEWAL SYSTEM DESIGN

It is assumed that the model of the photovoltaic panel, wind turbine and battery is presented in references [15, 16]. The system's performance strategy is shown in Fig. 7.

The optimal design model for an independent grid system is as follows:

Table 1. Estimated Gorgor station load

no	Type	LED with 150 W power		Total power (kW)
		Number	Power (kW)	
1	Area lighting around the station	20	3	3
2	Lighting inside the station	24	3.6	3.6
3	Sum	44	6.6	6.6

Table 2. Estimated energy consumption (kWh)

Estimated energy consumption (kWh)				Sum
The first six months		The second six months		
Daily	Monthly	Daily	Monthly	
30	930	36	1080	12060
43.2	1339.2	50.4	1512	17107.2
73.2	2269.2	86.4	2592	29167.2

Table 3. Energy price

Tariff code	With a power exceeding 30 kW				With a power of 30 kW or less			
	Power price (Rial/kW)	Energy price (Rial/kWh)			Power price (Rial/kW)	Energy price (Rial/kWh)		
		Mid-load hours	Peak hours	Low load hours		Mid-load hours	Peak hours	Low load hours
1	37200	1364	2728	682	-	1612	3224	806
2	31000	422	844	211	-	546	1092	273
3	14880	236	472	118	-	298	596	149

Table 4. Estimated cost of energy consumption (Rials)

Estimated cost of energy consumption (Rials)				Sum of years
The first six months		The second six months		
Daily	Monthly	Daily	Monthly	
45012	1395372	49104	1473120	17210952
66290.4	2055002	71200.8	2136024	25146158.4
111302	3450374	120305	3609144	42357110.4
			Demand cost	2455200
			Total amount (Rials)	44812310.4

1) Get technical-economic data of combined equipment and meteorological data
2) Create a Primary Population
3) Calculation of $\Delta P=P_{re}(i)-P_l(i)$
4) If ΔP> 0, the batteries are charged and the new SOC is calculated.
5) If ΔP <0, the batteries are charged and the new SOC is calculated. If SOC <SOCmin, then the batteries do not have the ability to supply load, and a new combination of combinations should be introduced.
6) The steps are executed for all 365 days.
7) The algorithm continues until the cost is minimized.

Fig. 7. The combined system design algorithm

$$F(x)=\min\sum_i N_i\times\{[IC_i+RC_i\times\sum_{n=1}^{y_i}\frac{1}{(1+ir)^{n\times L_i}}]\times(\frac{ir\times(1+ir)^R}{(1+ir)^R-1})+OMC_i\} \tag{1}$$

where x is the number of variables, including the number of photovoltaic panels, the number of wind turbines, the size of the water turbine, the number of inverters and charge controllers.

N, IC, RC and OMC represent the number, cost of investment ($/unit), replacement cost ($/unit) and annual performance in (year-$/unit). R is the lifetime of the project and the annual inflation rate.

The constraints used in the problem are as follows:

$$P_P(t)>P_L(t) \tag{2}$$

$$SOC_{\min}(t)\le SOC(t)\le SOC_{\max}(t) \tag{3}$$

$$0\le N_{PV}\le N_{PV,P}^{\max} \tag{4}$$

$$0\le N_{Bat}\le N_{Bat}^{\max} \tag{5}$$

$$0\le N_{WT}\le N_{WT}^{\max} \tag{6}$$

P_p is the power produced by the renewable system and P_L is the load power. SOC, N_{PV}, N_{Bat} and N_{wT} are battery charge parameter, number of photovoltaic panels, number of batteries, and number of wind units, respectively.

To obtain optimal design, according to Table 5, the design of renewable system has performed in 8 states. In the first one to third, wind turbines, solar panels and water turbines are used separately for design. In the state 4 to 6, the wind turbine, solar panel and water turbine will be used in dual mode and in the state of the 7 will be used jointly. State 8 is when we use photovoltaic panels, wind turbines and water turbine concurrently in network connection mode.

Table 5. Different design modes

Modes	Description
Mode 1	Wind turbine utilization
Mode 2	solar panel utilization
Mode 3	water turbine utilization
Mode 4	Simultaneous use of wind turbine and solar panel
Mode 5	Simultaneous use of wind turbine and water turbine
Mode 6	Simultaneous use of solar panel and blue turbine
Mode 7	Simultaneous use of wind turbine, solar panel and blue turbine
Mode 8	Simultaneous use of wind turbine, solar panel and blue turbine in network connection mode

The required parameters in the design process are given in Table 6. This data have been extracted from catalogs of each equipment. Photovoltaic panel, wind turbine, charge controller and inverter have been produced by Sharp, Hummer, xantrex and Sunny Island companies.

The proposed method is utilized to design a renewable hybrid system with grid independent structure to provide variable load power. The annual distribution of power required in one year is shown in Fig. 8.

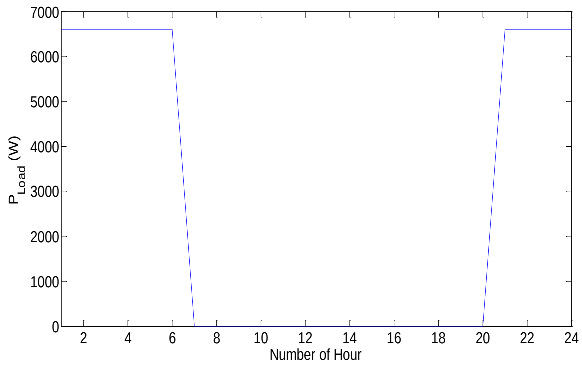


Fig. 8. Annual distribution of customer power daily per hour

The results of state 7 are followed as an example. The optimal design results of the system with the total cost of the system derived from the particle optimization algorithm are shown in Table 8.

As can be seen, for days with high power received from the sun and the wind, the power of the renewable system will be greatly increased. Fig. 11 (b) displays the input/output battery bank that indicates how to charge and discharge throughout the year. $P_b>0$ indicates battery charge, and $P_b<0$ indicates battery discharge.

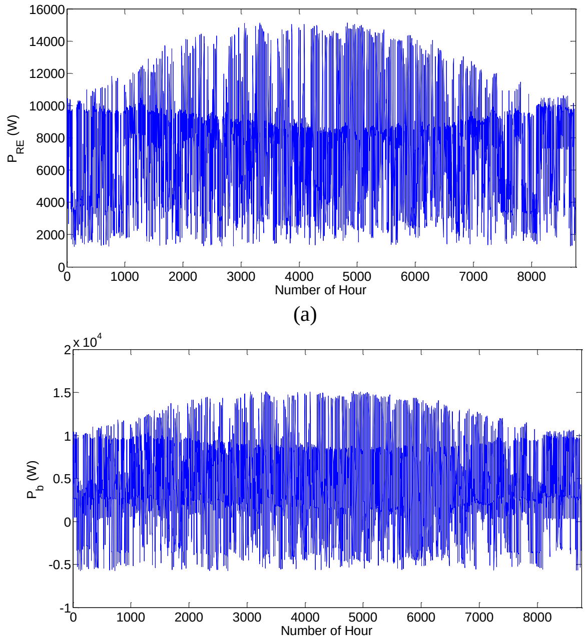


Fig. 9. (a) Generated power by renewable resources (P_{RE}), (b) Battery power input/output power during the year.

Fig. 10 (a) indicates the SOC battery, and it is observed that the SOC battery bank is between SOC_{max} (100% SOC) and SOC_{min} (40% SOC), which represents the correct functioning of the designed systems. The total power of the system is also given in Fig. 10 (b).

5. INVESTIGATING THE EFFECT OF DIFFERENT FLUXES ON THE DESIGN OF THE RENEWABLE SYSTEM

Five different water flows of 100, 200, 300, 400 and 500 lit/sec are investigated to study the effect of different fluxes in mode 7. The results of different fluxes are presented in Fig. 11 and Fig. 12.

As can be seen from figures, with the increase in water flow, the total cost of the design of the renewable system will be significantly reduced.

6. Economic analysis

Project scenarios that are survived in this section are:

Scenario 1: Power supply through the national electricity grid

Scenario 2: Power supply through a wind turbine disconnected from the network

Scenario 3: Power supply through solar panel disconnected from the network

Scenario 4: Power supply through water turbine disconnected from the network

Scenario 5: Power supply through wind turbine and solar

Table 6. The parameters of design

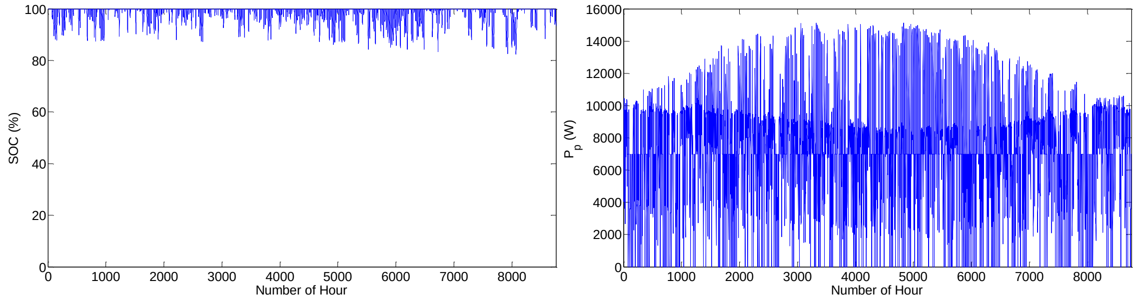
Equipment	Parameters	Value
Photovoltaic panel	$V_{OC}(V)$	37
	$I_{SC}(A)$	8.6
	$V_{max}(V)$	30
	$I_{max}(A)$	7.84
	$NCOT(^oC)$	47.5
	Life (year)	25
	Investment cost (million Rials)	13.63
	Replacement cost (million Rials)	12.24
	Operation and maintenance cost (million Rials/year)	0.1363
Battery	Nominal capacity (Ah)	200
	Nominal voltage (V)	12
	Maximum discharge depth (%) (DOD)	60
	Efficiency (%)	85
	Life (year)	5
	Investment cost (million Rials)	7.6
	Replacement cost (million Rials)	6.84
	Operation and maintenance cost (million Rials/year)	0.076
Wind turbine	Nominal power (kW)	3
	v_r (m/s)	10
	v_{ci}(m/s)	3
	v_{CO}(m/s)	25
	Investment cost (million Rials)	125.235
	Replacement cost (million Rials)	112.7115
	Operation and maintenance cost (million Rials/year)	12.5235
Water turbine	Nominal power (kW)	1
	Investment cost (million Rials)	20
	Replacement cost (million Rials)	18
	Operation and maintenance cost (million Rials/year)	0.2
Charge controller	Nominal capacity (A)	60
	Life (year)	15
	Investment cost (million Rials)	17.31
	Replacement cost (million Rials)	15.579
	Operation and maintenance cost (million Rials/year)	0.1731
Inverter	Life (year)	
	Investment cost (million Rials)	
	Replacement cost (million Rials)	
	Operation and maintenance cost (million Rials/year)	

Table 7. Results of different design modes

	Total number of panels	Total number of batteries	Total number of wind turbines	Water Turbine Capacity (kW)	Total controller charge	Number of inverters (Inverter capacity KW)	Total cost of target function (million Rial/year)
Mode 1	-	(4*31) 124	4	-	3	2 (10 kW)	1190.5
Mode 2	62	(4*7) 28	-	-	4	2 (10 kW)	515.76
Mode 3	-	(4*7) 28	-	6.3504	2	1 (10 kW)	132.69
Mode 4	46	(4*9) 36	5	-	7	3 (10 kW)	726.45
Mode 5	-	(4*8) 32	2	3.1752	3	1 (10 kW)	378.42
Mode 6	16	(4*6) 24	-	2.857	2	1 (10 kW)	299.56
Mode 7	32	(4*8) 32	2	1.27	4	2 (10 kW)	513.09
Mode 8	34	(4*7) 28	2	0.04	4	1 (10 kW)	286.91

Table 8. The results of optimal design

Optimal value	Renewable system
Total number of panels (number of series panels*Number of parallel panels)	32
Total number of batteries (number of series batteries*Number of parallel batteries)	32 (8*4)
Total number of wind turbines	2
Water Turbine Capacity (kW)	1.27
Number of charge controller	4
Number of inverters (inverter capacity kW)	2 (10 kW)
Total cost of target function (million Rial/year)	513.09



(a) (b)

Fig. 10. (a) SOC battery bank over the year, (b) Total generated power (*Pp*).

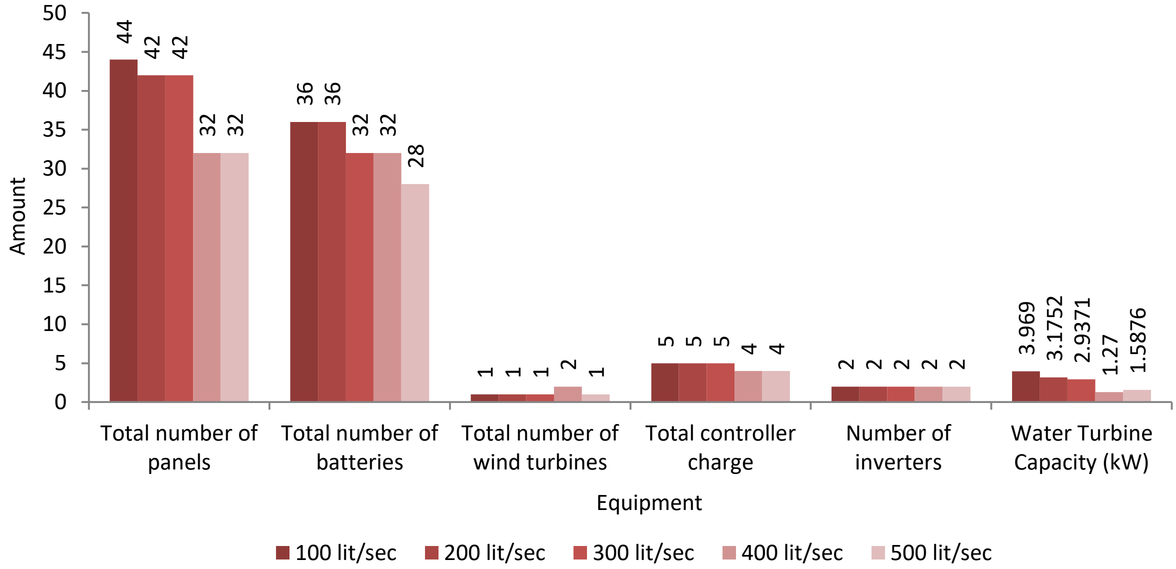


Fig. 11. Design results for different water flows

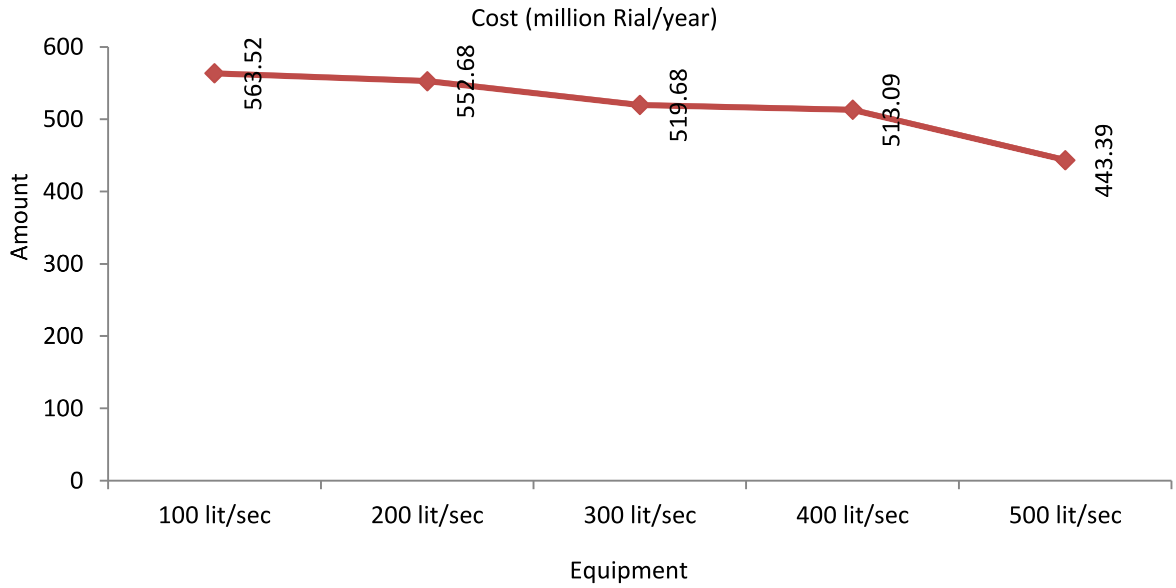


Fig. 12. Comparison of design costs for different water flows

panel disconnected from the network

Scenario 6: Power supply through wind turbine and water turbine disconnected from the network

Scenario 7: Power supply through water turbine and solar panel disconnected from the network

Scenario 8: Power supply through water and wind turbine and solar panel disconnected from the network

Scenario 9: Power supply through water and wind turbine and solar panel connected to

To supply Gorgor station power through the network (scenario 1), a 25-ampere three-phase power is required, which includes the following costs:

1. Cost of equipment and wages construction of one kilometer of 20-kV line with ACSR conductor type of mink with a 70 mm^2 equal to 400 million Rials (C1).
2. The cost of equipment and wages construction of an air substation (without calculating the transformer, cable, board and platform) with a 9 meter concrete beam equal to 77.5 million Rials (C2).
3. The cost of a transformer with a capacity of 25 kVA with an installation cost that total cost is 58.14 million Rials (C3).
4. Cost of Transformer cable connection to panel with cable score 3 × 25 + 16 equal to 4.95 million Rials (C4).
5. The cost of a distribution panel below transformer equal to 12.26 million Rials (C5).
6. The cost of distribution platform is 2.87 million Rials (C6).
7. The cost of other equipment for construction is 5 million Rials (C7).
8. The cost of 25 amps three phases demand is 25 million Rials (C8).
9. The cost of equipment and the cost of constructing a kilometer of a 400-volt air-line with a self-sustaining cable of 50 as 3×50+16+25 is 428.38 million Rials (we assume that we need to develop a low voltage network of 50 meters (C9).

According to this information, the initial cost of each above scenario is observed in Table 9 to Table 17.

Table 9. The cost of renewable electricity equipment designed according to scenario 1

Case	Cost
c1	200
c2	77.5
c3	58.14
c4	4.95
c5	12.27
c6	2.87
c7	5
c8	25
c9	21.4185
Sum (Million Rials)	407.1485

Table 10. The cost of renewable electricity equipment designed according to scenario 2

No.	Equipment	Total investment cost (Million Rials)	Total replacement cost (Million Rials)	Total maintenance cost (Million Rials/Year)
1	Wind turbine	500.94	400.752	5.0094
2	Solar panel (235 W)	0	0	0
3	Water turbine	0	0	0
4	Battery (200 Ah)	942.4	753.92	9.424
5	Charge controller (6 A)	51.93	41.544	0.5193
6	Inverter	200.368	160.2944	2.00368
Total cost		1695.638	400.752	16.95638

Table 11. The cost of renewable electricity equipment designed according to scenario 3

No.	Equipment	Total investment cost (Million Rials)	Total replacement cost (Million Rials)	Total maintenance cost (Million Rials/Year)
1	Wind turbine	0	0	0
2	Solar panel (235 W)	843.2	674.56	8.432
3	Water turbine	0	0	0
4	Battery (200 Ah)	212.8	170.24	2.128
5	Charge controller (6 A)	69.24	55.392	0.6924
6	Inverter	200.368	160.2944	2.00368
Total cost		1325.608		13.25608

Table 12. The cost of renewable electricity equipment designed according to scenario 4

No.	Equipment	Total investment cost (Million Rials)	Total replacement cost (Million Rials)	Total maintenance cost (Million Rials/Year)
1	Wind turbine	0	0	0
2	Solar panel (235 W)	0	0	0
3	Water turbine	127.008	101.6064	1.27008
4	Battery (200 Ah)	212.8	170.24	2.128
5	Charge controller (6 A)	34.62	27.696	0.3462
6	Inverter	100.184	80.1472	1.00184
Total cost		474.612		4.74612

Table 13. The cost of renewable electricity equipment designed according to scenario 5

No.	Equipment	Total investment cost (Million Rials)	Total replacement cost (Million Rials)	Total maintenance cost (Million Rials/Year)
1	Wind turbine	626.175	500.94	6.26175
2	Solar panel (235 W)	625.6	500.48	6.256
3	Water turbine	0	0	0
4	Battery (200 Ah)	273.6	218.88	2.736
5	Charge controller (6 A)	121.17	96.936	1.2117
6	Inverter	300.552	240.4416	3.00552
Total cost		1947.097		19.47097

Table 14. The cost of renewable electricity equipment designed according to scenario 6

No.	Equipment	Total investment cost (Million Rials)	Total replacement cost (Million Rials)	Total maintenance cost (Million Rials/Year)
1	Wind turbine	250.47	200.376	2.5047
2	Solar panel (235 W)	0	0	0
3	Water turbine	63.504	50.8032	0.63504
4	Battery (200 Ah)	243.2	194.56	2.432
5	Charge controller (6 A)	51.93	41.544	0.5193
6	Inverter	100.184	80.1472	1.00184
Total cost		709.288		7.09288

Table 15. The cost of renewable electricity equipment designed according to scenario 7

No.	Equipment	Total investment cost (Million Rials)	Total replacement cost (Million Rials)	Total maintenance cost (Million Rials/Year)
1	Wind turbine	0	0	0
2	Solar panel (235 W)	217.6	174.08	2.176
3	Water turbine	57.14	45.712	0.5714
4	Battery (200 Ah)	182.4	145.92	1.824
5	Charge controller (6 A)	34.62	27.696	0.3462
6	Inverter	100.184	80.1472	1.00184
Total cost		591.944		5.91944

Table 16. The cost of renewable electricity equipment designed according to scenario 8

No.	Equipment	Total investment cost (Million Rials)	Total replacement cost (Million Rials)	Total maintenance cost (Million Rials/Year)
1	Wind turbine	250.47	200.376	2.5047
2	Solar panel (235 W)	435.2	348.16	4.352
3	Water turbine	25.4	20.32	0.254
4	Battery (200 Ah)	243.2	194.56	2.432
5	Charge controller (6 A)	69.24	55.392	0.6924
6	Inverter	200.368	160.2944	2.00368
Total cost		1223.878		12.23878

Table 17. The cost of renewable electricity equipment designed according to scenario 9

No.	Equipment	Total investment cost (Million Rials)	Total replacement cost (Million Rials)	Total maintenance cost (Million Rials/Year)
1	Wind turbine	250.47	200.376	2.5047
2	Solar panel (235 W)	435.2	348.16	4.352
3	Water turbine	0.8	0.64	0.008
4	Battery (200 Ah)	243.2	194.56	2.432
5	Charge controller (6 A)	86.55	69.24	0.8655
6	Inverter	100.184	80.1472	1.00184
Total cost		1116.404		11.16404

In the renewable electricity system, the current cost is the cost of replacing the system components after their useful life and the annual maintenance cost. Also, the current cost of using electricity from network is the cost paid to the electricity company for every kilowatt-hour of electricity consumed. Electricity tariff is based on the tariffs provided in the previous sections. With regard to the initial and current costs of each scenario, the annual cost of the various scenarios for Gorgor station is calculated for the period of 25 years. The annual cost growth process of each scenario is presented in Fig. 13 to Fig. 20.

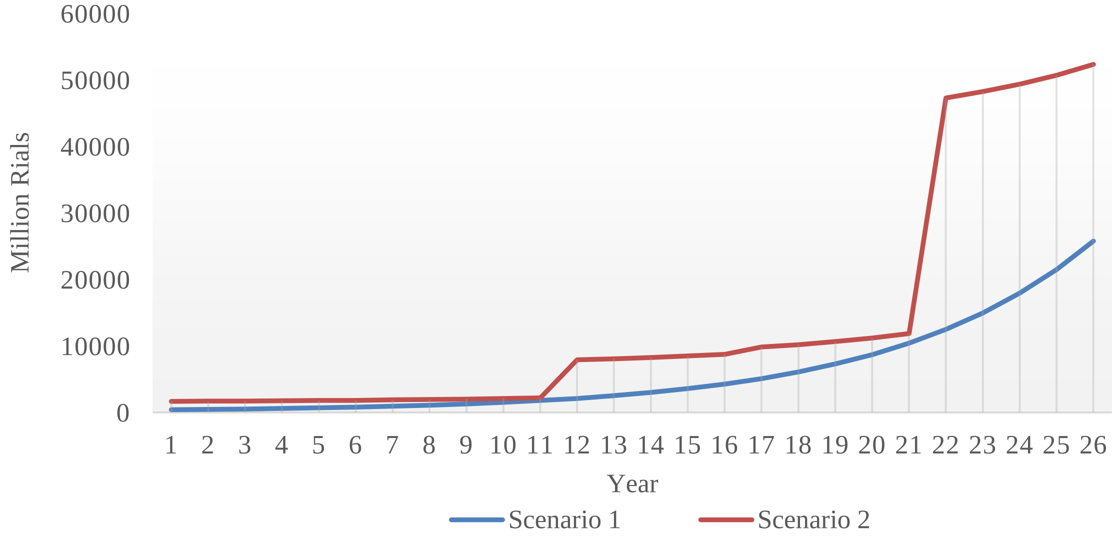


Fig. 13. Annual growth scenarios 1 and 2

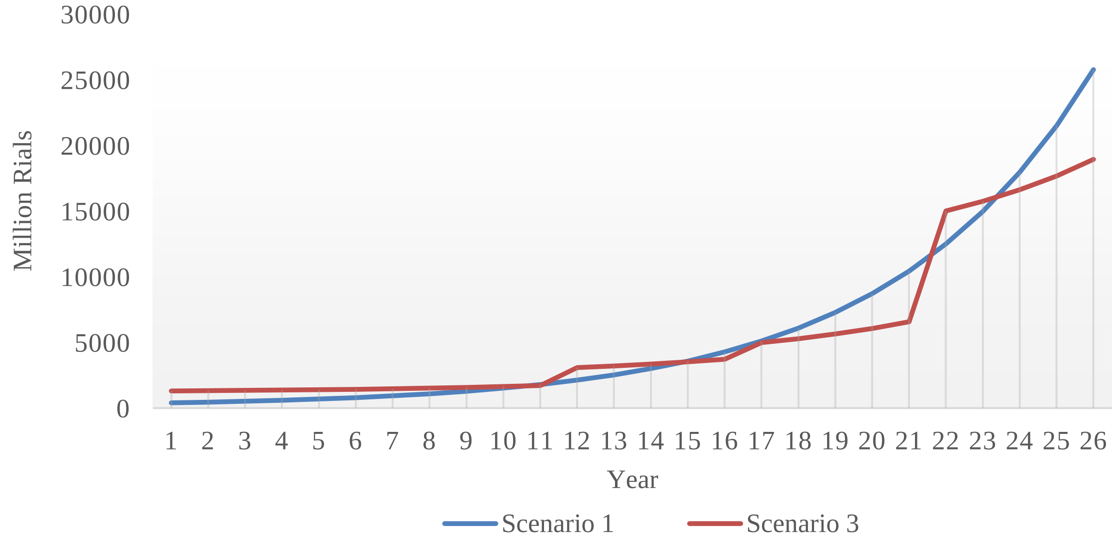


Fig. 14. Annual growth scenarios 1 and 3

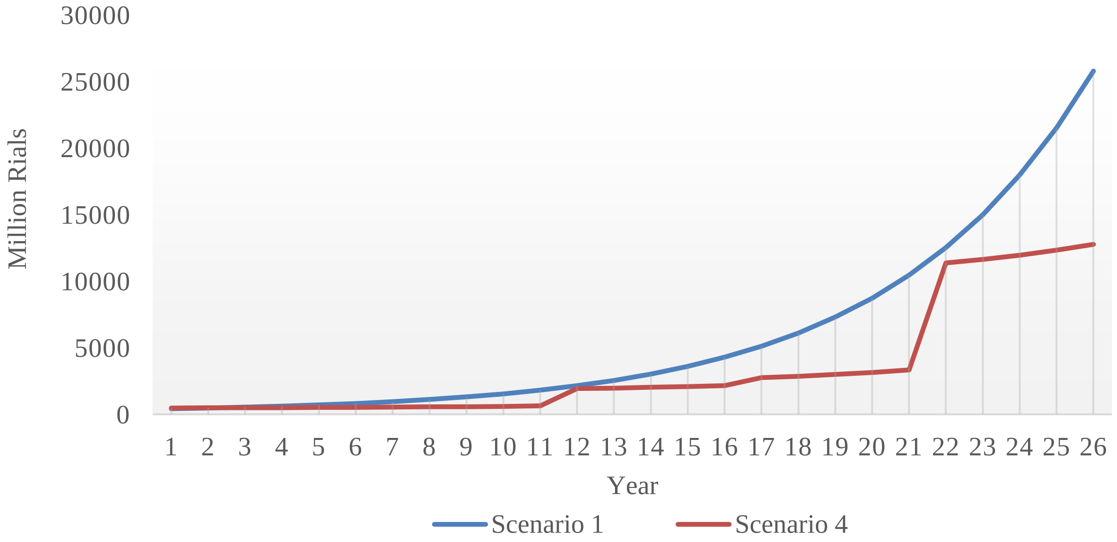


Fig. 15. Annual growth scenarios 1 and 4

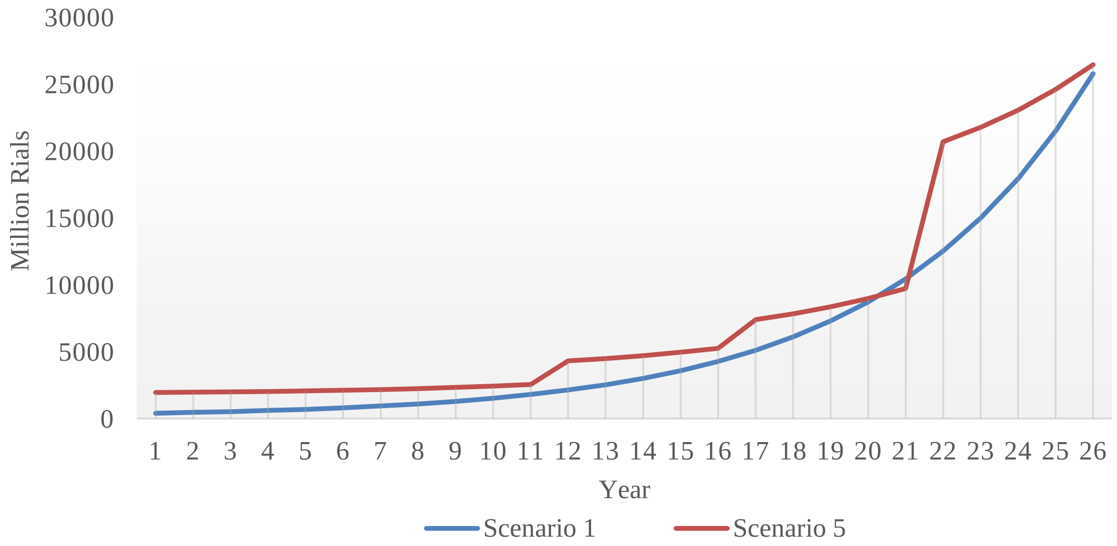


Fig. 16. Annual growth scenarios 1 and 5

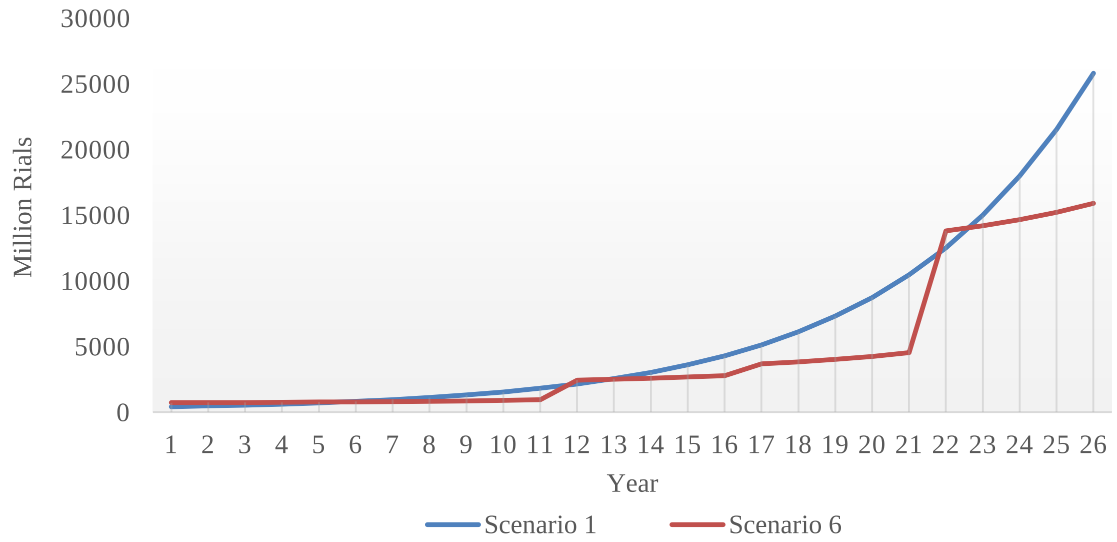


Fig. 17. Annual growth scenarios 1 and 6

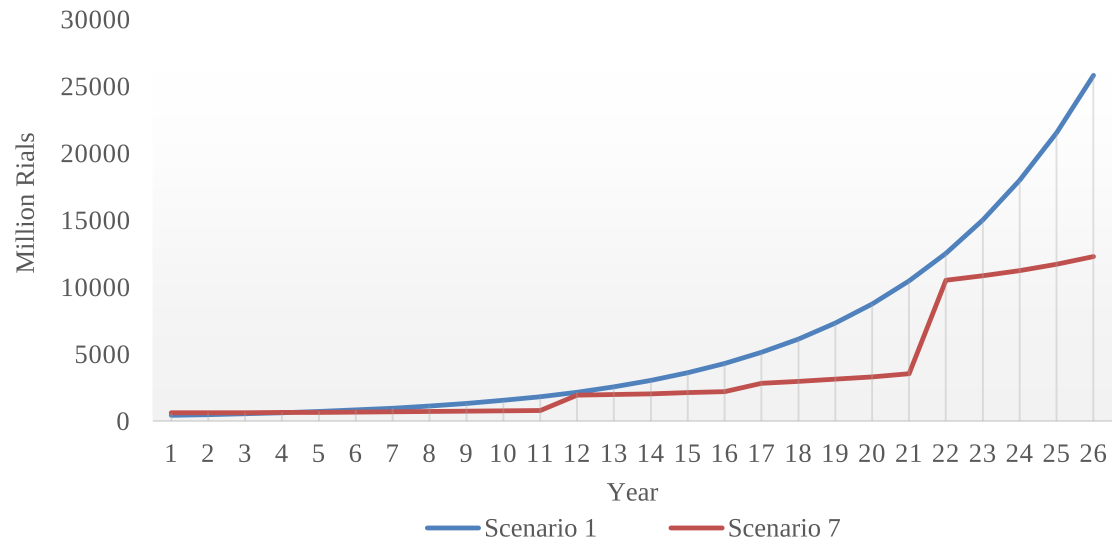


Fig. 18. Annual growth scenarios 1 and 7

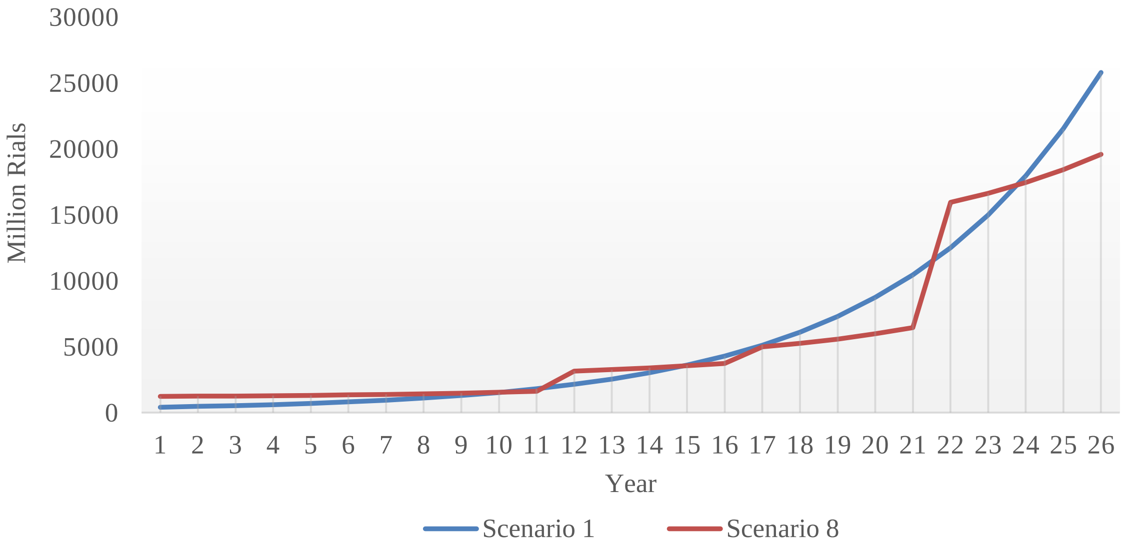


Fig. 19. Annual growth scenarios 1 and 8

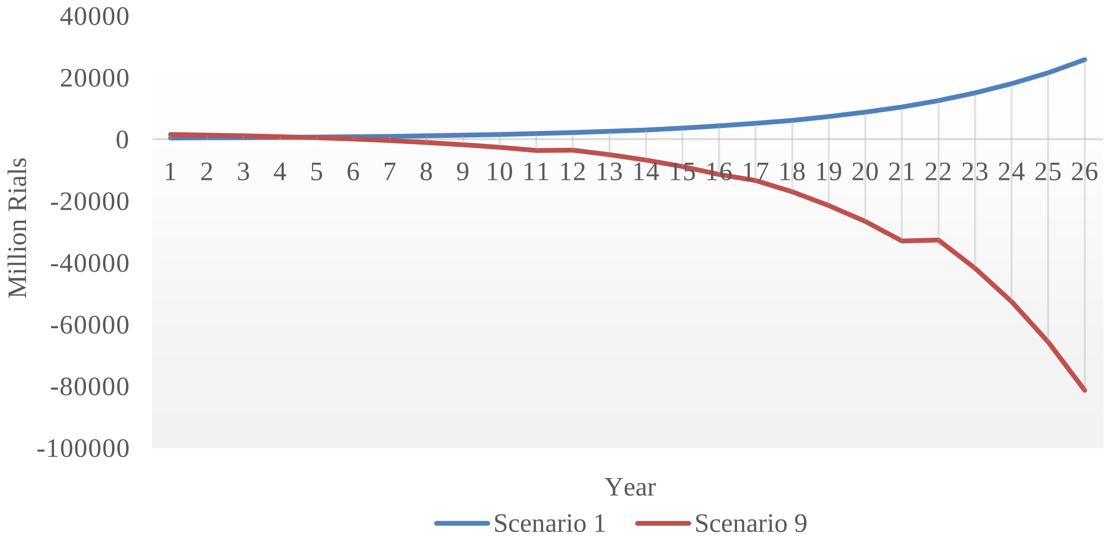


Fig. 20. Annual growth scenarios 1 and 9

7. Conclusion

From the topics discussed for the renewable power system, the following conclusions can be presented:

1. Initial and maintenance costs are given in Table 18. According to this table, the highest cost of the investment is related to Mode 4 or mode of use of the wind turbine and solar panel with a cost of 1947.07 million Rials. After this, mode 1 with the cost of 1695.638 million Rials is in the next row. Also, the highest maintenance cost is related to mode 4 and 1, respectively.

2. The values of the target function are given in Table 18 for different modes. According to this table, the highest value of the target function is related to Mode 1 with 1190.5 million Rials. After this, mode 4 is located with 726.45 million Rials in the next row.

3. With regard to the growth rate of various scenarios, the following cases can be deduced:

- The cost of scenario 2 is more than scenario 1.
- The cost of scenario 3 is more than scenario 1 for less than 23 years and costs less than 23 years later. So the return point for capital cost would be 23rd year.

Table 18. Initial costs and annual maintenance costs for different design modes

Mode/cost	Investment cost (million Rials)	Annual operation and maintenance cost (million Rials)	The value of the target function (million Rials)
Mode 1	1695.638	16.95638	1190.5
Mode 2	1325.608	13.25608	515.76
Mode 3	474.612	4.74612	132.69
Mode 4	1947.097	19.47097	726.45
Mode 5	709.288	7.09288	378.42
Mode 6	591.944	5.91944	299.56
Mode 7	1223.878	12.23878	513.09

- The cost of scenario 4 is less than scenario 1 for the year more than 1 year. The return point in this scenario is the first year.
- For all 25 years of study, less than about 21, the 5th scenario has more cost.
- For scenario 6, for all 25 years, except 12 and 21, the cost is greater than scenario 1.
- The cost of scenario 7 is less than the cost of scenario 1, so that in the first year we will have an investment return.
- The cost of scenario 8 also is more than scenario 1, except at some intervals.
- Overall, it can be said that the two scenarios 4 and 7 have a better situation, comparing the scenarios 4 and 7, we conclude that scenario 7 is the best scenario for designing the Gorgor station's renewable system.

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REFERENCES

[1] R. Afshan and J. Salehi, "Optimal scheduling of battery energy storage system in distribution network considering uncertainties using hybrid monte carlo-genetic approach," *J. Oper. Autom. Power Eng.,* vol. 6, pp. 1-12, 2018.

[2] M. Majidi and S. Nojavan, "Optimal sizing of energy storage system in a renewable-based microgrid under flexible demand side management considering reliability and uncertainties," *J. Oper. Autom. Power Eng.,* vol. 5, pp. 205-214, 2017.

[3] M. Khalid, M. AlMuhaini, R. P. Aguilera, and A. V. Savkin, "Method for planning a wind–solar–battery hybrid power plant with optimal generation-demand matching," *IET Renew. Power Gener.,* vol. 12, pp. 1800-1806, 2018.

[4] R. Atia and N. Yamada, "Sizing and analysis of renewable energy and battery systems in residential microgrids," *IEEE Trans. Smart Grid,* vol. 7, pp. 1204-1213, 2016.

[5] J. P. Castillo, C. D. Mafiolis, E. C. Escobar, A. G. Barrientos, and R. V. Segura, "Design, construction and implementation of a low cost solar-wind hybrid energy system," *IEEE Latin America Trans.,* vol. 13, pp. 3304-3309, 2015.

[6] M. B. Shadmand and R. S. Balog, "Multi-objective optimization and design of photovoltaic-wind hybrid system for community smart DC microgrid," *IEEE Trans. Smart Grid,* vol. 5, pp. 2635-2643, 2014.

[7] A. Hassan, M. Saadawi, M. Kandil, and M. Saeed, "Modified particle swarm optimisation technique for optimal design of small renewable energy system supplying a specific load at Mansoura University," *IET Renew. Power Gener.,* vol. 9, pp. 474-483, 2015.

[8] L. Wang and C. Singh, "Multicriteria design of hybrid power generation systems based on a modified particle swarm optimization algorithm," *IEEE Trans. Energy Convers.,* vol. 24, pp. 163-172, 2009.

[9] H. Bakhtiari and R. A. Naghizadeh, "Multi-criteria optimal sizing of hybrid renewable energy systems including wind, photovoltaic, battery, and hydrogen storage with ε-constraint method," *IET Renew. Power Gener.,* vol. 12, pp. 883-892, 2018.

[10] P. P. Vergara, J. M. Rey, L. C. P. Da Silva, and G. Ordóñez, "Comparative analysis of design criteria for hybrid photovoltaic/wind/battery systems," *IET Renew. Power Gener.,* vol. 11, pp. 253-261, 2016.

[11] J. A. Merrigan, "Sunlight to electricity: prospects for solar energy conversion by photovoltaics," *Cambridge, Mass., MIT Press, 1975. 172 p.,* 1975.

[12] G. Boyle, "Renewable energy," *Renewable Energy, Edited by Godfrey Boyle, pp. 456. Oxford University Press, May 2004. ISBN-10: 0199261784. ISBN-13: 9780199261789,* p. 456, 2004.

[13] Z. Miao, L. Fan, D. Osborn, and S. Yuvarajan, "Control of DFIG-based wind generation to improve interarea oscillation damping," *IEEE Trans. Energy Convers.,* vol. 24, pp. 415-422, 2009.

[14] A. Mostafaeipour, "Feasibility study of harnessing wind energy for turbine installation in province of Yazd in Iran," *Renew. Sustain. Energy Rev.,* vol. 14, pp. 93-111, 2010.

[15] R. Belfkira, L. Zhang, and G. Barakat, "Optimal sizing study of hybrid wind/PV/diesel power generation unit," *Solar Energy,* vol. 85, pp. 100-110, 2011.

[16] A. Kornelakis and E. Koutroulis, "Methodology for the design optimisation and the economic analysis of grid-connected photovoltaic systems," *IET Renew. Power Gener.,* vol. 3, pp. 476-492, 2009.