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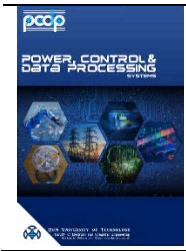

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Designing a Grid-Connected Hybrid Micro-Grid: A Case Study in Hamedan

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ABSTRACT

Energy plays a critical role in the growth and development of societies, and universities are recognized as key drivers of economic progress. In light of declining fossil fuel reserves and global warming, adopting renewable energy sources, such as photovoltaic (PV) systems, has become increasingly essential. Furthermore, the advantages of distributed generation are now more apparent than ever. Many countries have developed various scenarios to eliminate fossil fuels from electricity generation, an approach that warrants serious consideration in Iran as well. This study investigates the techno-economic feasibility and optimal design of a hybrid photovoltaic/diesel/battery power system intended to supply electricity to an academic center located in western Iran. The technical aspects and economic viability of implementing such a system were evaluated using the HOMER (Hybrid Optimization of Multiple Energy Resources) simulation tool. Various configurations combining solar energy, battery storage, and diesel generators were analyzed and compared. The simulation results presented in this study demonstrate that, given the subsidized nature of energy carriers in Iran, the implementation of hybrid energy systems is not highly recommended at this time.

Keywords: HOMER analysis tool, hybrid power system, net present cost, on-grid, Renewable energy, techno-economic optimization.

1 Introduction

At the end of 2016, around 24 % of the world "s electricity was produced from renewable energy sources (RESs). This amount increased to 2.5 % (i.e. 26.5 %) in 2017 [1]. The availability and utilization of energy sources are key factors that determine the country's assets and growth. For example, the study reported in [2] showed 277 potential sites for large-scale hydropower applications with an estimated output of 734 MW. At the same time, the amount of energy produced from solar sources per year is about 27 times the amount of energy produced from regular energy sources [3], with an average of 6.5 hours of sunlight per day [4]. The modern world is still hard to compensate for the maximum renewable energy sources (RESs) to compensate for the disadvantages of conventional energy sources due to the emission of greenhouse gases, non - service areas, non - service areas, voltage quality issues, and distribution power losses. Table 1 shows the typical renewable generation capacity used for small remote residential loads [5].

Table 1: Renewable Generation Capacity

Type	Size	Typical load
Large	>100Kw	Regional loads
Medium	5Kw up to 100Kw	Isolated off-grid communities
Small	<5Kw	Remote households

According to the UN-Energy Report 2014, about 17.8 % of the world's population does not have electricity. Moreover, last decade data suggests that 40 % of the total energy is used in buildings, recorded as universal consumption [3]. Conventional energy sources are scarce and emit dangerous gases [4], the main causes of climate change [3]. Moreover, the cities contribute to the production of human greenhouse gases by about 65 - 75 % [3]. Furthermore, network outage is often caused by natural disasters, while conventional sources (diesel, gas) cannot address these worst-case scenarios [3]. Considering the above issues, normal and intensive energy sources can be subsequently replaced with renewable energy sources to simultaneously improve the technical and economic standards of the energy system [2]. Therefore, the hybrid renewable energy system (HRES) can be used as a stable, reliable, low carbon, and cost-effective system for load demand [3]. HRESs can be dense as a combination of renewable energy sources such as photovoltaic (PV), wind turbines (FC), hydroelectric (FC), hydroelectric power systems, which are used to provide an electric charge is reliable, economical, and environmental demand in reliable, economic and environmental applications [6], [7]. To achieve the highest use of HRERs, the system should be optimally designed and planned. Also, proper and adequate power management implementation is a key necessity to ensure that the maximum amount of energy is extracted from the sources of energy. In recent years, the data show rapid growth and high reliability in the wind energy system technology [5]. Energy is an important factor in economic growth and development in many countries in the world. [8] Because of the growth of industry and the development of cities, demand for energy in the world is increasing, and the energy consumption is predicted to increase by 33 % from 2010 to 2030 [9]. According to the International Energy Agency, in April of 2021, energy consumption is projected to increase 4.5 % this year, particularly in emerging economies such as China [10]. This paper is organized as follows: Section 1 provides the introduction, followed by a review of related literature. Section 2 presents the management of energy consumption in Iran. Section 3 presents the research history. Case study Proposed in section 4. methodology. System design specifications Proposed in section 5. Sections 6 and 7 offer a technical and economic evaluation of the optimal system. While Section 8 discusses the simulation results.

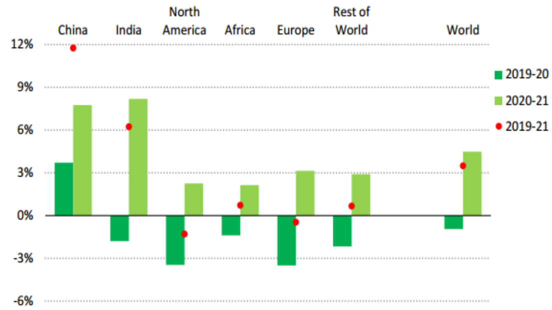

Figure 1: Changes in electricity consumption by 2020 and 2021 by regions

2 THE MANAGEMENT OF ENERGY CONSUMPTION IN IRAN

Iran is one of the rich countries of fossil fuels such as oil and gas. Iran has 10 % of the world's crude oil and 17 % of world gas. Iran is one of the most widely used countries in the world so that the per capita energy consumption in Iran is 15 times more than Japan and ten times the EU [13]. According to data released in the Ministry of Energy in April 2020. In Iran, the highest consumption in industry is by 36.3 % compared to other areas, the rise of consumption in the domestic industry hit 32.4 %, 14.4 % general, and 6.8 % other uses up 6.8 %, and the lighting of passages is 1.6 %.

Meanwhile, the share of electricity produced by renewable energies in Iran has been only 1 % by the end of April 2020. The share of distributed production has been 2.4%. But fossil fuels carry out the highest power generation in Iran. Also, the total number of subscribers in the country has grown by 2.7 % compared to the same year [14]. But CO2 production in Iran by the end of 2019 shows an increasing development in various fields in Iran, which has caused many environmental problems in Iran over the last few years. Figure 2 shows the carbon dioxide emissions in different parts of Iran [15]. Figure 3 shows CO2 emissions in return for power generation and heat in some countries in the world [15].

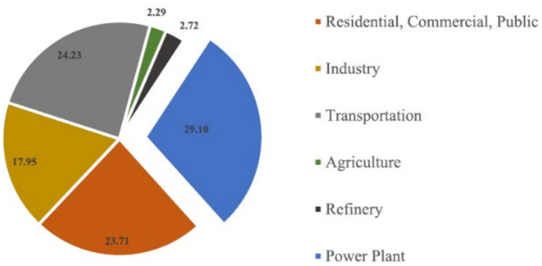

Figure 2: Carbon dioxide emissions in different parts of Iran

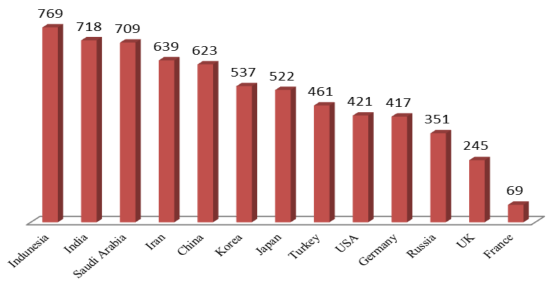

Figure 3: CO2 emission (10^6 ton/year) versus electrical production in some countries in the world

As shown in Figure 3, pollution in electricity generation in Iran is higher than in many countries such as China, the USA, Germany, and France. Therefore, it is necessary for all countries, including Iran, to choose appropriate policies.

2.1 Energy policy in the world and Iran

According to the study of energy consumption and demand models in more than 160 countries globally, it has been using 100% renewable energy sources [16]. Following the Treaty of Paris, Germany has set a target of achieving a 100% reduction in emissions by transitioning its entire energy system to renewable sources-excluding even the use of nuclear energy [17]. But with the current policy on energy production, Iran is expected to emit 188 million tons of CO2, in 2050 [18]. However, some scenarios suggest that Iran will use renewables by 2030 or 2050 to supply most of its electricity from such sources. [18] [19]. One of the strategies of CO2 reduction can be the use of natural gas that is well experienced in Iran. However, the best strategy is still to use renewable energies [20]. In Iran, solar energy is the best option for non-hydro renewable energy, so that Iran can install only one percent of its area and with an efficiency of only 10 percent to produce 9 Mw of solar electricity [13].

2.2 The importance of energy-matter at universities

Today, governments use universities as powerful tools for economic development, and economic development is virtually impossible without the alignment of universities and industry. Therefore, it is necessary that universities, as sensitive centers of the country, have sustainable energy and do not have power outages as much as possible. In this paper, power consumption of Payame Noor University of Hamedan from 2016 to the end of 2020 was extracted separately in low load, medium load, and high load hours, and their average was calculated and entered as Homer software as primary information of the university load. Due to problems in Iran's electricity network in the field of production in June 2021, it was observed that Tavanir manages the university during the peak load of the day, which shows the importance of this project. In this project, using Homer software, consumption management and the economics of using renewable energy, and distributed generation in the Payame Noor University of Hamadan has been evaluated.

3 RESEARCH HISTORY

Numerous researches have been done in the field of technical-economic and environmental feasibility of a renewable power plant. The optimal size of a hydroelectric power plant has been studied in various studies [1], [13], [14], [15]. The optimal design of renewable energies and the combination of renewable and conventional energies have been investigated in other studies. In addition [14], a hydro / PV / wind/diesel power system has been proposed for the development of clean energy, the development of electricity generation, and the improvement of rural life in remote areas. This type of hybrid energy system (hydropower) is better than a system based on fossil fuels because less money is spent on oil and pollutant emissions, and it is better managed with the help of RESs. Previous studies have focused only on the optimal size of a system using renewable energy sources such as solar and wind energy with diesel systems and storage devices for grid power supply [21], [22], [23], [24]. Several previous studies, such as [25], have focused solely on the technical aspects of hybrid energy systems, while neglecting their economic implications. Others, like [26], have concentrated primarily on the technological details of renewable energy systems, addressing only their economic viability without a comprehensive technical analysis. In contrast, this paper presents a novel approach that simultaneously considers both the technical and economic dimensions of hybrid energy system design. Table 2 provides a comparative summary of previous studies and the proposed work presented in this paper.

The purpose of this paper is to fill this research gap with the detailed design and economic feasibility of the PV / battery/diesel system using HOMER simulation software. In this paper, the optimal design of HRES has been done so that the optimization of HRES design has been done based on the comprehensive technical-economic approach of simulation and optimization analysis for different hybrid scenarios of diesel, battery, and converter. The optimal hybrid system has been proposed taking into account the actual load demand data and up-to-date meteorological information to supply the energy required by a university unit located in Iran.

Table 2: comparative summary of previous studies and the proposed work

Ref	Economic Analysis	Technical Analysis	Equipment Details	Using geographic data
[1,13-15]	✓	✓	-	-
[21-24]	-	✓	-	-
[25]	-	✓	-	✓
[26]	✓	-	✓	✓
Proposed work	✓	✓	✓	✓

4 CASE STUDY ANALYSIS

4.1 Selected site

The Payame Noor University of Hamedan is located in the northeast of Hamadan with 34.8352 ° E and 48.5209 ° N. Also, the exact position of the University for Further Calculations is marked in Homer software according to Figure 4.

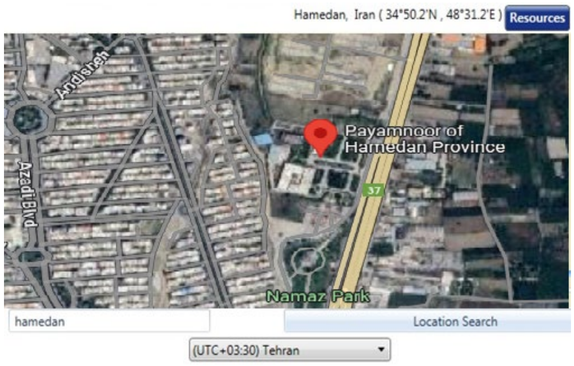

Figure 4: Geographical coordinates of the selected site

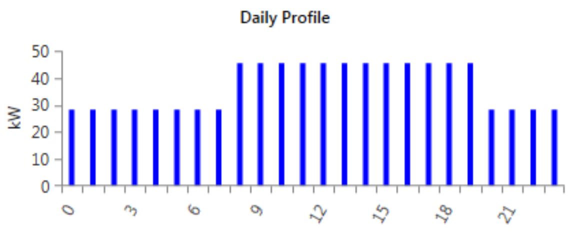

Figure 5: Daily load consumption for February

4.2 Load profile

The proposed hybrid system meets the 24-hour load demand of an academic center in Hamadan province. Conventional loads include public lighting, coolers, computer systems, elevator, and workshop spaces for any academic center. Hence, the total demand for the total energy of the university in HOMER is calculated as demand data for an hourly load to obtain a monthly and annual load profile. Generally, most daily loads work for several hours, while a high percentage of electricity demand in academia is attributed to workshop equipment, cooling, and ventilation. Low electricity demand in the morning is from 24 to 8 and also from 19 to 24. However, it peaked from 8 pm to 17, as most practical classes were arranged during these hours. Of course, this pattern may be slightly different in odd and even terms.

The load profile of the February of this academic center is given in Figure 5. The load curve is also presented monthly and annually respectively in Figs . 6 and 7; as shown in Fig . 8, the university's average charge is 37.3 kW.

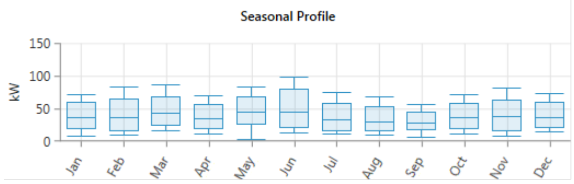

Figure 6: Load curve by months of the year

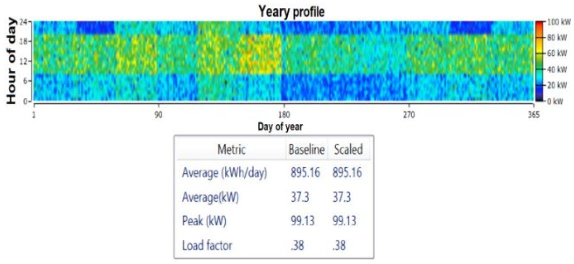

Figure 7: Annual load curve

5 SYSTEM DESIGN SPECIFICATIONS

The monthly average of global solar radiation data shown in Figure 8 is from NASA and is considered in HOMER as the input of solar sources. The period from April to September has reported a high amount of solar radiation and a clearness Index due to a decrease in the wet period leading to the high potential for PV power supply. However, the radiation levels in other months are not high enough to produce significant power due to the mountainous area of the region and the coincidence with the rainy season and less radiation.

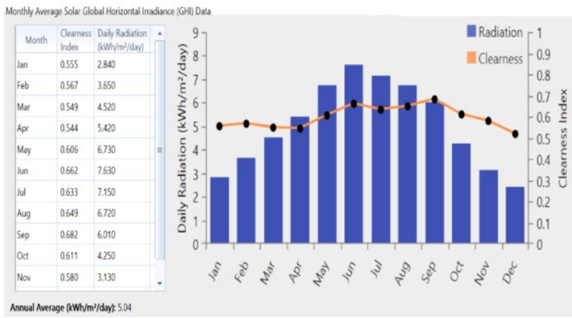

Figure 8: Average solar radiation

Although wind energy is not used in the hybrid system of this article, since the amount of wind will affect the movement of clouds and thus the amount of solar radiation, in this article, the amount of wind is also considered. The wind speed data shown in Figure 9 were obtained from HOMER software through the NASA website at the height of 10 meters [27]. The average annual wind speed is 5.26 m/s, and the minimum wind speed is 4.m/s in September. And the maximum speed is 5.82

m/s in March. Moreover, the high wind speed observed between February and April can confirm the low potential of PV applications in this period. The fluctuations observed in the wind pattern are often due to topographical characteristics [27]. Moreover, other parameters that were considered for wind sources during the simulation were an automated correlation coefficient of an hour (0.85), the daily pattern stretch (0.25), and the Weibull factor (2).

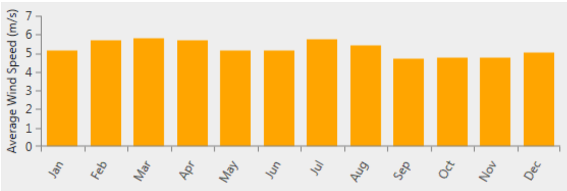

Figure 9: Annual wind rate

Moreover, the ambient temperature affects the performance of PV as well as its energy production levels. Therefore, it was necessary to consider changes in the ambient temperature of the selected location. The average ambient temperature is shown in Figure 10. However, the average temperature from April to October exceeded 10 ° C and the maximum temperature occurred in July. The average annual temperature was about 11.62 ° C.

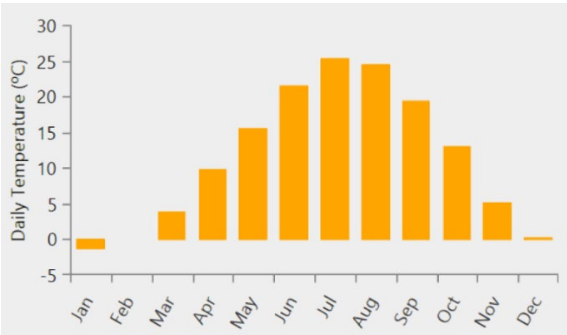

Figure 10: Average annual temperature of the study area

5.1 System components data

The cost and size data of the main components used in this analysis are presented in detail in Table 3. Different sizes of system components were analyzed to determine the optimal size to fit in the selected position. Pricing of components and technical details was obtained from [1], [2], [28].

6 PROPOSED HYBRID SYSTEM CONFIGURATION

The hybrid energy configuration proposed in this paper consists of a solar system with a battery, and a DG (diesel generator), the general schematic of which is shown in Figure 11, and its composition in Homer space is shown in Figure 12. The system components are interconnected in HOMER, and their technical and economic specifications were provided for simulation.

Table 3: Hybrid System Component Specification

Component parameter	Specification
PV module	
Efficiency under standard test condition	13%
Temperature coefficient	-0.48%/°
Capital cost	20000000 Rials/Kw
Cost of replacement	18000000 Rials/Kw
O&M cost	10000Rial/KW/year
D-rating factor	80%
Ground reflation	20%
Lifetime	25 years
Batteries	
Model	Kinetic
Nominal voltage	12V
Nominal capacity	1 Kwh
Capital cost	4000000 Rials
Cost of replacement	4000000 Rials
O&M cost per year	10000 Rials
Lifetime throughput	800kwh
Converter	
Capital cost	4000000 Rials/kw
Cost of replacement	3000000 Rials/kw
Efficiency	98%
O&M cost per year	200000 Rials
Lifetime	5 years
Diesel generator	
Capital cost	120000000 Rials
Cost of replacement	110000000 Rials
Lifetime	15000h
Maintenance cost	0.05$/kw/h
Minimum load ratio	25%

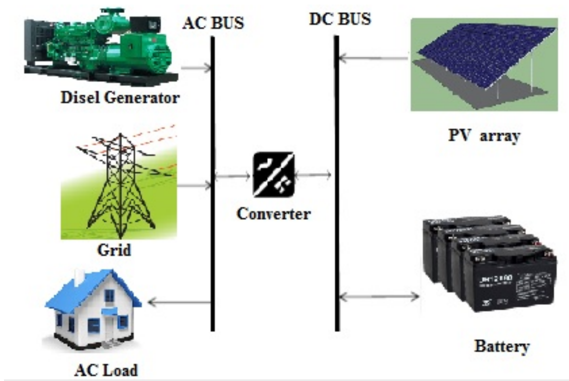

Figure 11: The proposed hybrid system includes a solar system with a battery and a DG (diesel generator) connected to the grid

The priority of the control strategy is to supply the required energy from the distribution network to meet the energy demand and charge the solar energy of the storage unit. It is also expected that the diesel generator will be active only when the connection to the distribution network is disconnected and the renewable energy sources can't meet the load demand, and the battery charge mode is less than 40%, i.e., the use of diesel will be in storage or emergency mode. This strategy leads to a reduction in the Net Present Cost (NPC) and additional energy production. In addition, the amount of carbon dioxide emissions produced in this strategy is better managed. However, it should be noted that this system is connected to the distribution network, and if it provides the required load to the unit, it can sell overproduction to the network.

Power generating units, including AC and DC, are combined with a bilateral converter to maintain power flow between the following components: PV panel and battery (DC bus) and diesel generator (AC bus). In this study, a feasibility study was performed along with a comparative analysis of some other system models to obtain an optimal system and evaluate the validity of the design connected to the proposed network.

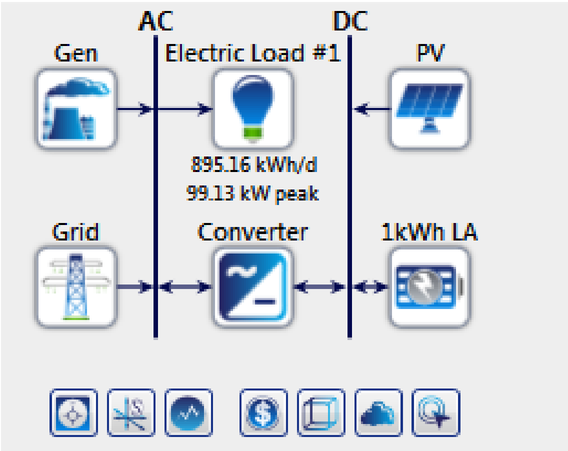

Figure 12: The proposed hybrid system includes a solar system with a battery and a DG connected to the grid in the Homer software

6.1 PV modeling considering the effect of temperature

Equation (1) is used in HOMER software to calculate the PV output power: [29].

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{G_T}{G_{T,STC}}\right)\left[1 + \alpha_p\left(T_c - T_{c,STC}\right)\right] \quad \text{Eq 1}$$

Where Y_{pv} is the PV output power in Kw under standard test conditions (STC), α_p is the power temperature coefficient in percent. f_{pv} represents the PV rating factor in percentage. $G_{T,STC}$To solar radiation under STC conditions one (kW / m2), G_T refers to solar radiation hitting the photovoltaic panel (kW / m2).

Equation 2 shows the relationship between PV cells and ambient temperatures: [29].

$$T_c = T_\alpha + (0.0256{*}G) \quad \text{Eq 2}$$

Where G is solar radiation (W/m2).

6.2 Battery energy storage system

Battery backup is an essential part of HRES to maintain system reliability, especially during the night and unwinds weather. In this study, the KINETIC battery model was used. The selected battery has 1 kWh nominal capacity, roundtrip efficiency of 80%, and a lifetime of 3 years and an operating power of 800 kWh. The capital and replacement costs were supposed to be 4000000 Rials/unit, while O&M costs were 10000 Rials/yr. The minimum SOC of the battery was 40%, and the maximum value was 100% which has a fast-charging capability.

Battery size calculation can be determined as follows: [5].

$$Ah_{bat} = \frac{Wh_{load}}{(DoD).(V_{bat})} \quad \text{Eq 3}$$

$$Wh_{load} = \frac{Wh_{night}}{\eta B} + \frac{(Wh_{day} + Wh_{night}).n_a}{\eta B} \quad \text{Eq 4}$$

Figure 13 shows the battery controller while the battery charging and discharging can be controlled to stabilize load voltage and frequency [31]. The equations for the battery terminal voltage and SOC are as follows: [32].

$$V_{bat} = V_o + i_b R_b - K\frac{Q}{Q - \int i_b d_t} + Ae^{(-B\int i_b d_t)} \quad \text{Eq 5}$$

$$SOC = 100\left(1 - \frac{\int i_b d_t}{Q}\right) \quad \text{Eq 6}$$

$$20 \le SOC \le 80 \quad \text{Eq 7}$$

$$-\frac{P_{bat}}{V_{bat}} \le I_{bat} \le \frac{P_{bat}}{V_{bat}} \quad \text{Eq 8}$$

Where P_{bat} and V_{bat} are battery rated power and nominal voltage, respectively. Conventional droop control for the battery is used [31]. The battery inductor (L_{bat}) is designed according to the following relationship [32].

$$L_{bat} = \frac{V_{DC}(1-D)}{2.f_{min}.\Delta I_B} \quad \text{Eq 9}$$

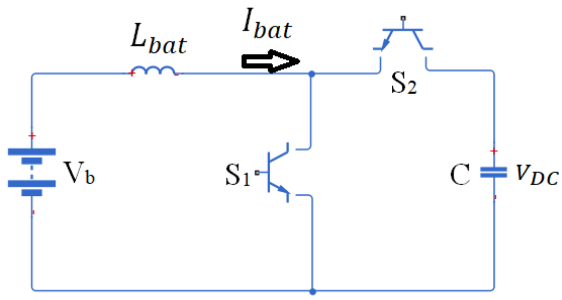

Figure 13: The battery controller

6.3 Power converter

The converter is used to exchange power between the AC and DC buses. The utilized converter has capital and replacement costs of 4000000 Rials/kW and 200000 Rials/year O&M cost [36]. The chosen converter has a lifetime of 15 years and an efficiency of 95%. Power capacity levels of the converter can be determined according to the following equation.

$$C = (3 \times L_i) + L_r \quad \text{Eq 10}$$

Where L_i and L_r are inductive and resistive loads. AC side mathematical model for inverter voltage vector is [32]:

$$V_i = V_g + R_f I_f + L_f \frac{dI_f}{d_t} \quad \text{Eq 11}$$

WhereV_g, R_f, I_f, L_f is grid side load voltage vector, filter resistance, inverter output current, and filter inductance, respectively. Inverter powers are related as [32]:

$$P = Re\left\{V_g I_f\right\} = \frac{3}{2}\left(V_{g\alpha} I_{f\alpha} + V_{g\beta} I_{f\beta}\right) \quad \text{Eq 12}$$

$$Q = Im\left\{V_g I_f\right\} = \frac{3}{2}\left(V_{g\beta} I_{f\alpha} - V_{g\alpha} I_{f\beta}\right) \quad \text{Eq 13}$$

LC Filter equation and inverter model with capacitor voltage V_c and load current I_L are expressed as follows:

$$C_f \frac{dV_c}{d_t} = I_f - I_L \quad \text{Eq 14}$$

$$V_i = R_f I_f + L_f \frac{dI_f}{d_t} + V \quad \text{Eq 15}$$

6.4 Diesel generator

Generally, a diesel generator is used as a backup source during high demand to reduce the power deficit during high load consumption. The cost of installing the diesel generator in this article was 120,000,000 Rials, while the cost of service and maintenance is 10,000 Rials. The price of diesel fuel per liter according to the Iranian market was 600 Rials. The lifetime of the diesel was 15000 hours, with the minimum load ratio of the diesel generator being 25%. The diesel fuel consumption depends on the DG output power, and it can be calculated as follows [34]:

$$Fuel_{c,DG} = a.P_{DG,n} + b.P_{DG,g_c} \quad \text{Eq 16}$$

Where, $Fuel_{c,DG}$ is the fuel consumption rate (L/h), $P_{DG,n}$ and $P_{DG,g}$ is the nominal power and generated power of the DG (kW). While a=($\frac{0.0140}{kw}\frac{L}{hr}$) and b= ($\frac{0.2440}{Kw}\frac{L}{hr}$).

7 ECONOMIC MODELING

In this paper, minimization of total NPC and COE is the main objective of the optimization problem, which can be expressed as follows [37, 38]:

$$C_{NPC} = \frac{TAC}{CRF(i,N)} \quad \text{Eq 17}$$

Where the total annual cost ($ / year) is determined by the TAC. N (year), and 'i' refers to the actual annual discount rate (%). The capital recovery factor (CRF) is defined as follows:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N-1} \quad \text{Eq 18}$$

Also, Leveled cost of energy (COE) is obtained From Eq. (19) as follows [36]:

$$COE = \frac{TAC}{E_{anloadserved}} \quad \text{Eq 19}$$

Where $E_{anloadserved}$ represents the total annual load (kWh) supplied by the system.

8 PROPOSED HYBRID SYSTEM CONFIGURATION

The simulation performed in this study examines the load profile and the resources available in the selected area. HOMER simulation tool has been used to find the optimal configuration in hybrid energy sources based on technical-economic and environmental analysis by the selected academic center in Hamedan, Iran. Comparative analysis of different energy source combinations, including a DG alone, has been performed. In this paper, in addition to electrical and economic performance, the environmental aspects of the optimized system are also considered. It should be noted that in this article, the project life is 25 years.

8.1 Optimization results

The simulation results presented in Table 4 indicate the optimal configuration with other possible configurations. From the sensitivity analysis results, it is clear that the cost of balanced energy varies from 50.24 Rials per kilowatt-hour to 172.36 Rials per kilowatt-hour. It was also found that the DG / Grid scheme was the cheapest configuration without Unmet Electric Load and consumed approximately 14,668 liters of fuel, resulting in an emission of 232,234 kg of CO2 per year. It may be expected that Plan number two may be predicted to have lower carbon emissions due to the use of renewable sources, and it is (231822 kg per year). However, the relatively large difference in NPC does not justify this small difference, and plan number One is accepted as the optimal design.

8.2 Technical evaluation of the performance of the optimal hybrid system

The layout of the system was such that the load requirement was met by combining a diesel with the grid. Figure 14 shows the monthly electricity generated by each component of the optimal system. It also shows the percentage of energy consumption of the initial AC load. From this figure, we inferred that a large portion of the electricity generated was purchased from the grid (85.5% of total production). The second major source of electricity generation was diesel, in which diesel produced 14.5 % of the total production.

Table 4: Summarized Optimization Results of the System

Energy Sold (Kw/h)	Energy Purchased (Kw/h)	Renewable fraction (%)	Fuel (L/yr)	COE (Rials/kw)	NPC (Rials)	Converter (KW)	Grid (KW)	Battery	DG (KW)	Pv (KW)
32220	306753	0	14668	50.24	509M	-	999999	-	100	-
32261	306102	0.193	14668	52.23	529M	0.194	999999	-	100	1
32220	306753	0	14668	68.91	698M	0.194	999999	5	100	-
32261	306102	0.193	14668	70.46	714M	0.194	999999	5	100	1
0	326733	0	-	150	1.38B	-	999999	-	-	-
0	326041	0.212	-	152.34	1.40B	0.194	999999	-	-	1
0	326733	0	-	170.51	1.57B	0.194	999999	5	-	-
0	326041	0.212	-	172.36	1.59B	0.194	999999	5		1

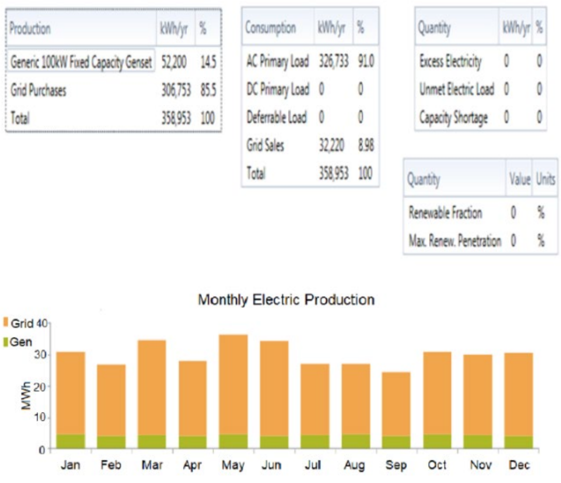

Figure 14: The result of the technical assessment of the proposed hybrid system

In addition, this system does not rely heavily on renewable energy systems for its operations, so that the renewable fraction shows zero percent. This configuration proved to be effective in the supply of electric charge since the excess energy value was zero as the surplus energy surplus was sold through the grid. Furthermore, because of the grid connection, the system has not any unmet load. It showed that the system could meet most of its load requirements and have a maximum capacity. The size, operation hours, electric output, and diesel capacity factor are shown in Table 5. This system had a low percentage of renewable systems penetration, which negatively impacted reducing greenhouse gas emissions. Also, the amount of energy exchanged with the grid during the twelve months of the year is shown in Table 6. This table shows how much the grid is connected to the system during all months of the year and how much energy is being exchanged with it.

Table 5: Absolute errors

Component	DG
Size (KW)	100
Annual hours of operation	522
Minimum Electrical Output (KW)	0
Maximum Electrical Output (KW)	100
Capacity Factor	5.96

Table 6: Amount of Energy Exchanged With the Grid during One Year

Month	Peak Load (KW)	Net Energy Purchased (Kwh)	Energy Sold (Kwh)	Energy Purchased (Kwh)	Peak Load (KW)
January	72	22,692	3,296	25,989	72
February	84	20,546	2,078	22,625	84
March	87	28,002	2,102	30,104	87
April	70	21,234	2,394	23,628	70
May	84	29,326	2,295	31,620	84
June	99	28,240	1,739	29,979	99
July	74	20,019	2,507	22,526	74
August	69	18,632	3,598	22,230	69
September	57	17,373	2,948	20,321	57
October	72	22,746	3,264	26,010	72
November	81	22,307	3,039	25,346	81
December	73	23,414	2,961	26,375	73
Annual	**99**	**274,533**	**32,220**	**306,753**	**99**

The fuel consumption summary presented in Figure 15 indicates that the combined diesel generator consumes a total of 14,668 liters, averaging 40.2 liters per day and 1.67 liters per hour to meet the system's load requirements.

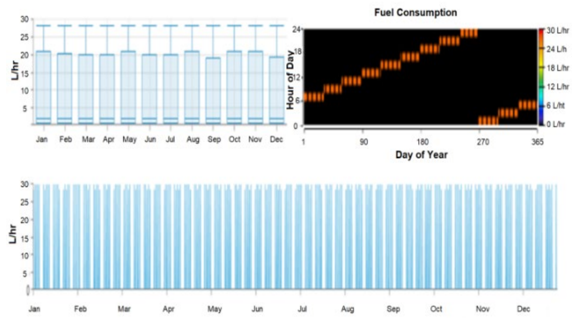

Figure 15: Summary of fuel consumption

8.3 Economic evaluation

The net percent cost (NPC) is estimated at 509 million Rials, while the operating cost and energy costs are 13.8 million Rials and 50.24 Rials per year, respectively. Figure 16 shows the system cost summary. We observed that fuel costs (248296075.93 Rials) and operating costs (158415847.79 Rials) were the most expensive components. A significant part of the operating cost is spent on the construction of the grid, and less than 10% of it is spent on the diesel system.

Figure 16: System cost summary

However, the replacement cost has been reported to be zero Rials due to the lack of replaceable components during the project review period because the life of these components is between 20 and 25 years, which is either corresponding to or higher than the project life. The nominal cash flow of the optimal system and the base case (grid system) for 25 years (project life) are presented in Figures 17 and 18.

The cash flow (nominal) sustained a continuous minimum value over the project lifetime for the optimal system as compared to the base case scenario where the cash flow kept a maximum constant value throughout the 25 years.

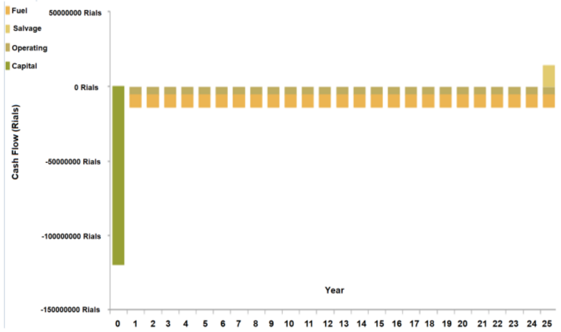

Figure 17: System cost summary

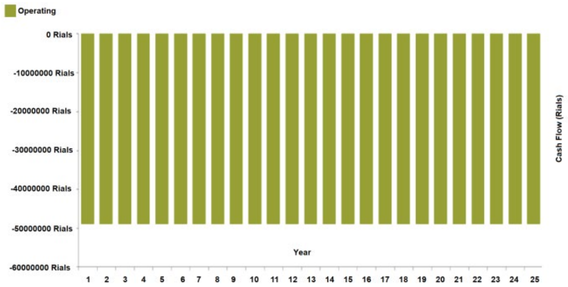

Figure 18: Nominal cash flow of the base case system

9 Conclusion

In this study, we designed an electrical energy generation system for deployment in an academic center in Iran, considering the available renewable energy sources while the system was connected to the grid. The HOMER optimization tool was used in the simulation and analysis of such a system, selecting the most optimal arrangement possible from a diesel generator system, a PV array, and a battery bank. From the simulation results, it can be concluded that:

- DG / Grid hybrid system in terms of investment cost (120 million Rials) in addition to having an acceptable electrical load (358953 kWh / year) and lack of capacity (zero kW / year) had better performance, but the maximum emission rate of pollutants is 232234 kg/year Had. This system requires a significant amount of cost (8800920 Rials) for fuel as well as high operating cost (158415847.8 Rials) and service and maintenance costs (522000 Rials/year). The high rate of pollutant emissions implemented in this system is an unacceptable option.
- Perhaps the best solution to reduce pollution was incorporating renewable systems such as PV into the GD / Grid system. But comparing the reduction of CO2 emissions from 232234 kg/year to 231882, which is a decrease of about 0.15%, in exchange for an increase of 20 million Rials NPC (approximately 3% increase) is not reasonable. Even the DG / Grid / PV / battery hybrid system did not significantly reduce emissions compared to the GD / Grid system. At the same time, it increased the amount of NPC from 509 million Rials to 714 million Rials (40.2% increase). Therefore, it can be concluded that the proposed GD / Grid system is the most optimal hybrid arrangement in terms of economics and considering the amount of pollution.
- In Iran, due to the illusory energy rate and the existence of subsidies in energy costs, the rate of purchase of energy from small producers is several times the rate of sale from the grid. In other words, buying directly from the network will be cheaper than producing it locally.
- As the simulation results showed, due to the cheaper cost of purchasing energy from the grid and the high cost of construction of renewable energy systems, distributed generation resources on a small scale is not economically justified. So the use of such resources is perhaps only with the use of a diesel; despite the amount of pollution seems reasonable.

Disclosure of Potential Conflicts of Interest

The Authors declare that there is no conflict of interest.

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