Feasibility Analysis of PV/Wind/Battery Hybrid Power Generation: A Case Study

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Abstract- Depletion of fossil fuel reserves, unpredictable fluctuation of diesel prices, and global warming issue have motivated numerous countries to produce new policies for energy that engorge the utilization of alternative energy sources. Renewable energy resources like solar, hydro, and wind are clean and have potency to be more widely used. Integration of these sources together with back-up units can produce a better clean, economic, and reliable power for all loads conditions as compared to single source systems. The feasibility study of using integrated energy system to supply electric energy for remote rustic school in the southern part of Iraq is investigated in this research paper. In order to carry out the feasibility study of the hybrid system, HOMER software is employed as a tool for the technical, economic, and environmental assessments. The analyses of the optimal energy systems are explained in details to find the most feasible off-grid system. Then, this system is compared with the options of extension to the grid and diesel generator system.

Keywords Solar, Wind, Hybrid, Diesel, Total cost

1. Introduction

The growth of world population and development of industrialization sector are the main reasons for the increasing the demand of electricity [1]. Non-renewable resources such as oil, coals, and gas are used in the conventional electricity generation systems. However, using of these sources gives a share in the increment of emissions, which are hazardous to the atmosphere. Consumption of fossil fuel has several negative effects such as air and coastal pollutions, deforestation, biodiversity loss and deterioration [2]. All these issues encourages nations to look for alternative sources of energy. Thus, researchers, environmentalist and makers of policy in the global are currently searching for potential renewable energy sources in order to minimize the utilizing of the conventional energy sources, which leads to reduce the emissions [3].

In Iraq, despite the availability of fossil fuels, electricity shortages initiated in 1991 as a result of the overall desolation of the country caused by the war [4]. Both people and government of the country are not quite aware of the importance of alternative energy sources. Therefore, the development of these technologies in the area is usually done by the organizations, which are nongovernmental, and also by individual efforts [5]. At the current time, the life in several remote rural positions is primitive and in a disordered status because of the unstable situation of the country as mentioned. In these places, people usually use off-grid diesel generators since it locates far away from the central grid. Besides the dangerous emissions of diesel fuel, its leakage from generator is found to increase the pollution levels of the natural underground [5]. Furthermore, there are difficulties in transmitting of the diesel from the far places. In such case, the only alternative of diesel is the using of new clean and silent energy resources [5].

Renewable sources of energy like solar and wind have many challenges since they are intermittent and unpredictable because they mainly depend on climate and weather conditions [6]. As a result, using only wind system or solar panels is capable of meeting the demand of the load only for the periods of time in which there is availability of high wind speed or massive solar irradiation. Thus, an energy storage system or a backup energy source is usually used when using renewable energy sources [7]. When the source of renewable energy (solar radiation/cut-in speed) is not available, storage or backup energy source supplies the load demand. Moreover, diesel generators power is independent of climate and predictable. By presenting the shortcomings of both conventional and renewable energy sources, various types of energy sources are utilized in order to supplement each other in perfect way. Accordingly, multi-source hybrid renewable energy system with properly designed, sized, and control have better possibility to achieve better reliability and higher quality as compared to single source of energy system [7].

Limited number of researches has been done on the applications and roles of renewable energy technology in Iraq. The authors in [5] presented an assessment of decentralized diesel/PV hybrid energy system as an alternative to the grid extension in Iraq. The authors found that that the integration of energy systems is a suitable choice for electrification in the selected site.

In [8], the authors evaluated the performance of the hydro/diesel energy system to provide electric power for a rural area in Iraq. They found that the hybrid energy system can minimize the noise and air pollution levels and reduce the of electric power cost (kW/hr) as compared to the off-grid diesel generators.

The performance analysis of the hybrid power generation which consists of PV and fuel cells for providing electricity to remote rural area in Iraq is reported in [9]. The results showed that PV/fuel cell system is able to produce a satisfactory outcome by using suitable components and proposed control strategies.

The present study aims to investigate the suitability of a hybrid PV/wind/batteries power generation system that does not emits any pollutants via simulation and mathematical modelling to supply electricity for a remote rural school in Alnasyria city southern of Iraq. The effects of important parameters such as ambient temperatures, load variations and rate of interest are considered in this research.

2. Materials and Methods

2.1. HOMER Software

HOMER is a software tool utilized to design and analyze the hybrid energy systems, originally developed at the National Renewable Energy Laboratory, United States. Simulations, optimizations and sensitivity analyses are the main 3 tasks which are performed in this software. HOMER models the performance of different integrated energy systems to investigate their techno-economic and environmental feasibility in the simulation process. While, in the process of optimization, simulation of several system configurations is done to obtain the best optimal feasible that satisfying the technical constraints with lowest net present cost [1, 10, 11]. Multiple optimizations with a range of inputs variables are performed in the sensitivity analysis [12].

2.2. Description of the Selected Site

In this study, a small remote rural school in Alnasyria, Iraq, has been chosen for the feasibility assessment. The area is not connected to the grid. Currently, electrification of the school is achieved by using diesel generators. Figure 1 shows one room in the selected school.

2.2.1. Load Profile

The selected school is small. Lighting and electrical apparatus in the school do not need large amount of electrical energy. Time-step-to-time-step and day-to- day random variability of 20% is considered in order to give more reliability. The daily load profile of the school is shown in Fig. 2.

2.2.2. Solar Radiation Resource

Data of solar radiation is determined from National Aeronautics and Space Administrative, NASA. Figure 3 shows the monthly average daily radiation of the selected school which is the average data in that area for many years. The data are collected according to the latitude and longitude of the position which are 31.02° N and 46.23° E respectively [13]. The highest daily radiation is recorded in June which is 7.940 kWh/m^2/day while 2.640 kWh/m^2/day is the lowest one which is recorded in December. The average amount of the annual radiation is found to be 5.16 kWh/m^2/day. Furthermore, the data shows that the summer season has highest solar radiation as compared to the other seasons.

In this research paper, the effects of ambient temperature on the output performance of the solar panels are taken into account. The average monthly air temperature of Alnasyria is presented in Fig. 4.

To calculate the output of the photovoltaic panels, HOMER uses the following equation [10, 14]:

$$P_{PV} = Y_{PV} \times f_{PV} \times \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) \times \left[1 + \alpha_P \times \left(T_C - T_{C,STC}\right)\right] \quad (1)$$

where Y_{PV} is the PV rated capacity (kW), meaning its output power under standard test conditions, f_{PV} is the de-rating factor of PV, $\bar{G}_T$ is the episode of the solar irradiation on the PV panels in the current time step (kW/m^2), $\bar{G}_{T,STC}$ is the incident irradiance at standard test conditions (1 kW/m^2), α_P is the temperature coefficient of power (%/°C), T_C is the temperature of PV cell (°C) in the current time step and $T_{C,STC}$ is the temperature of PV cell under standard test conditions (25 °C).

Fig. 1. One room in the selected primary school

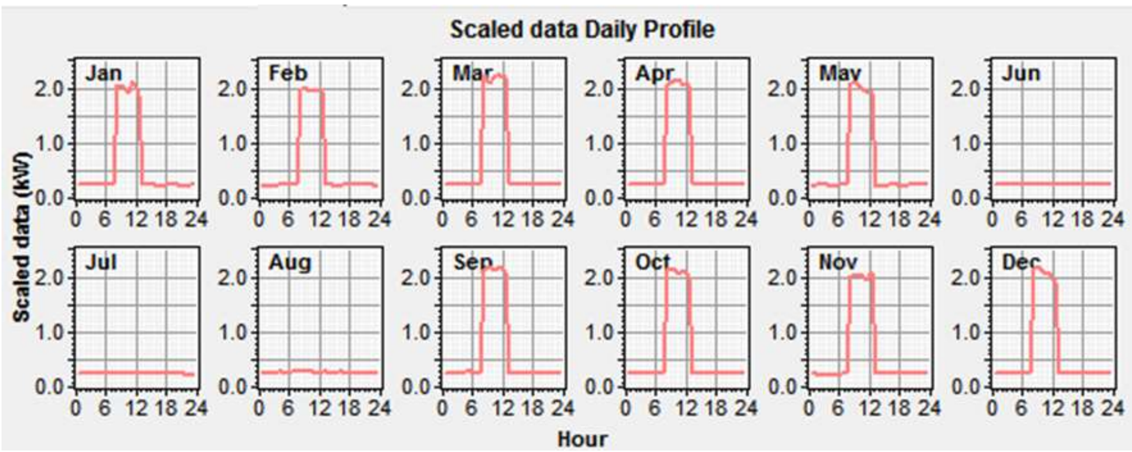

Fig. 2. Details of the daily load demand of the school

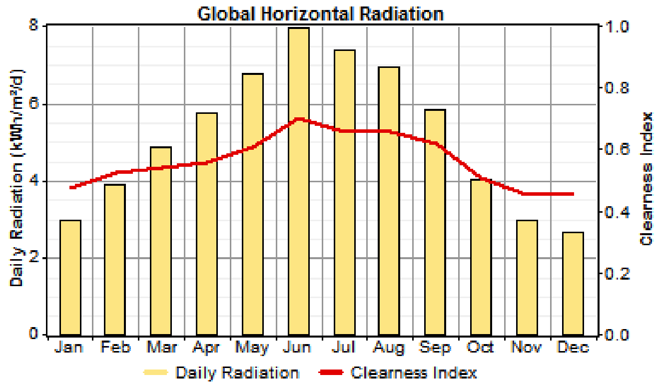

Fig. 3. Monthly solar radiation of the chosen area

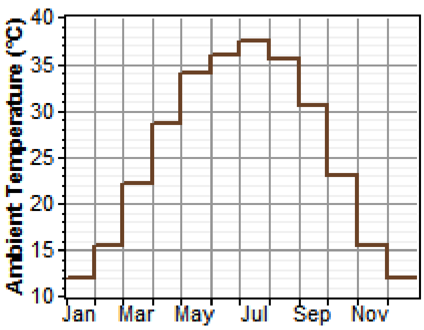

Fig. 4. The monthly average air temperature in Alnasyria

2.2.3. Wind Resource

All the wind speed monthly variation is shown in Fig. 5 [13]. The distribution of probabilities of wind speed in Alnasyria is calculated using the Weibull's function mathematical expressions, and the following formula is used for the definition [15, 16]:

$$f(v)=\frac{k}{c}\times\left(\frac{v}{c}\right)^{k-1}\times\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

where k is the Weibull shape parameter which depicts the data dispersion (unitless), c is the Weibull scale parameter measured in (m/s), and v is the speed of wind (m/s).

The relation between the Weibull's parameters and the average wind speed is described using the following formula [15]:

$$V_{ave} = c\times\Gamma\times\left(\frac{1}{k}+1\right) \quad (3)$$

where Γ is the gamma function.

Maximum likelihood method is used in HOMER because it offers a good fit with measured wind data as shown in Fig. 6.

2.3. System Components

2.3.1. System Description and Details of the Components

The main sources of the proposed hybrid energy system for the school are solar and wind energies. Solar panels, wind system, units of batteries, and rectifier are the major components of the system design. The specifications of PV, wind turbine, converter, and batteries are depicted in Tables 1, 2, 3, and 4 respectively. Different references [4, 15, 17, 18] are the sources of information of the inputs details for the components.

2.3.2. Operating Principle

Both PV and wind turbine work to feed the load demands. When the output power of these energy sources is enough to supply the load, the excess energy generated supplies the batteries to be totally charged after satisfying the load demand. When the energy of PV and wind turbine is not enough to supply the load in cases like low solar radiation or wind speed, the batteries work to compensate the shortfall of the energy. During the night hours, the output of the solar panels become zero, therefore, wind and/or batteries meet the load. Figure 7 shows the configuration of the proposed system. The system design in HOMER software is presented in Fig. 8.

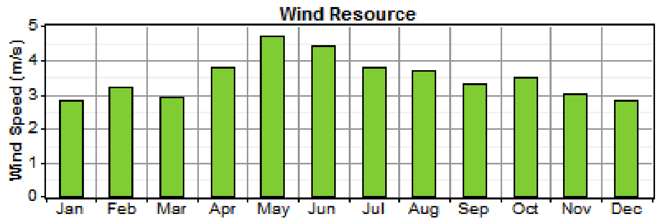

Fig. 5. Monthly wind speed in Alnasyria at 10 m height

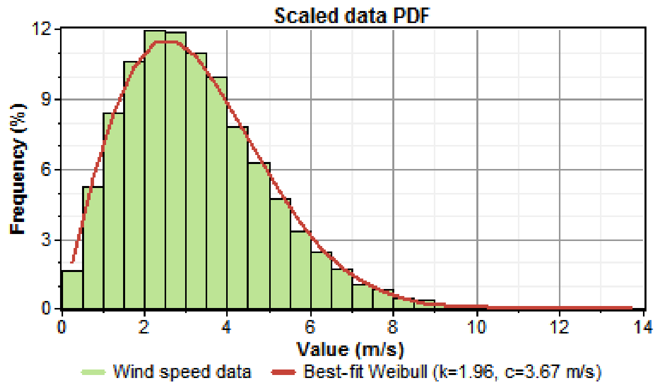

Fig. 6. Probability distribution of wind speed

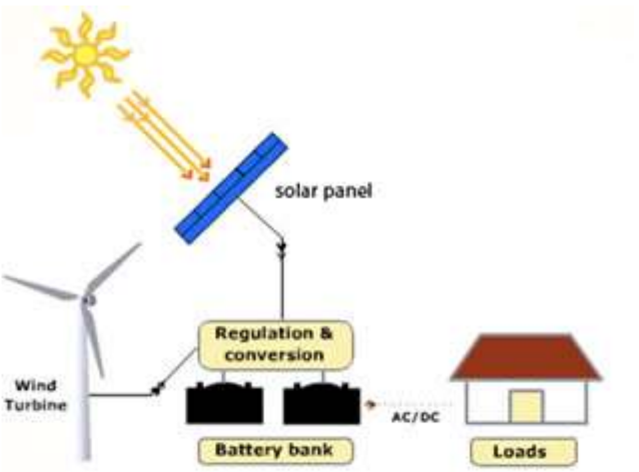

Fig. 7. Schematic diagram of the proposed system

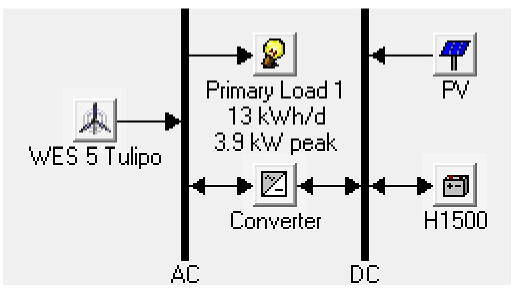

Fig. 8. The design of the system in HOMER software

Table 1. PV inputs details

Input	Data specification
De-rating factor	90 %
Nominal operating cell temperature	47 °C
Temperature coefficient	-0.48 % / °C
Efficiency at standard test condition	13 %
Ground reflectance	20 %
Cost of capital	$ 4000/kW
Cost of replacement	$ 2000/kW
Operating and maintenance cost	$ 5 /kW/year
Lifetime	20 years
Tracking system	Fixed

Table 2. Wind turbine inputs details

Input	Data specification
Type	WES 5 Tulipo
Diameter of rotor	5 m
Rated power	2.5 kW AC
Capital cost	$ 5000
Replacement cost	$ 4000
Operating and maintenance cost	$ 50/year
Lifetime	15 years
Hub height	25 m

Table 3. Converter inputs details

Input	Value
Capital cost	$ 550/kW
Replacement cost	$ 450/kW
Operating and maintenance cost	$ 5 /kW/year
Lifetime	15 years
Efficiency	90%

Table 4. Batteries inputs details

Input	Data specification
Type	Hoppecke 12 OPzS 1500
Nominal voltage	2V
Nominal capacity	1500 Ah (3 kWh)
Round trip efficiency	86 %
Capital cost	$ 508
Replacement cost	$ 475
Operating and maintenance cost	$ 18 /year
Minimum lifetime	5 years

2.4. System Description Economic Evaluation

The evaluation of the economic feasibility for the whole hybrid energy system is carried out by optimizing the net present cost (lifetime cost) of the systems. Lifetime of the project and annual real rate interest and are important input parameters. The yearly real rate interest can be defined as the rate of discount which is utilized to convert between the annual cost and one-time cost. The following equation hives the relation between the nominal interest rate and the annual real interest rate [1]:

$$i = \frac{i' - f}{1 + f} \quad (4)$$

where i is the real interest rate, f is the annual inflation rate, and i' is the nominal interest rate. The annual rate interest is considered to be 7.85 % in this analysis which is the average of rate interest in Iraq for many years [19].

The life-cycle cost of the system is represented by the net present cost (NPC), which includes the capital, replacement, operation and maintenance, and fuel costs where applicable over their useful lifetime, Equation below gives the mathematical equation of the net present cost [5, 20]:

$$\mathrm{NPC} = \frac{C_{tot}}{\mathrm{CRF}(i.n)} \quad (5)$$

where C_{tot} is the annual total cost ($/year) and n is the project lifetime which is considered to be 20 years in this study. The following expression is used to calculate the capital recovery factor (CRF) [5, 20, 21]:

$$\mathrm{CRF}(i.n) = \frac{i \times (1+i)^n}{(1+i)^n - 1} \quad (6)$$

HOMER takes into account the salvage cost (SC) to determine the total lifetime cost. By the ending of the project lifetime, the amount remaining in the components of the energy system is called the salvage value which can be obtained using the following equation [15, 20]:

$$\mathrm{SC} = C_{RC} \times \frac{T_{rem}}{T_{com}} \quad (7)$$

where C_{RC} is the cost of replacement ($), T_{rem} is the remaining life (year) and T_{com} is the lifetime of the components (year).

Furthermore, the levelized energy cost, which is the average cost per kWh of energy generated from the hybrid energy systems, can be determined using [5]:

$$\mathrm{COE} = \frac{C_{tot}}{E_{tot}} \quad (8)$$

where E_{tot} is the total yearly consumption of electricity (kWh/year).

3. Simulation and Results

3.1. Optimization Results

The feasibility of supplying electricity for rural school using hybrid renewable energy system is depend on the availableness of the energy resources in the location and total cost of the systems. In HOMER software, an hourly time series simulation for each feasible system on a yearly basis is performed in order to evaluate the characteristics of the operation like the excess electricity, annual load served, yearly electricity production, and renewable fraction. HOMER investigates the best feasible system configuration and the sizes of each component that is capable of meeting the load demand at the lowest net present cost (NPC) and then the results of the simulation is presented the in terms of optimum systems and sensitivity analysis.

Figure 9 shows the techno-economic optimization results of the all feasible options (PV/wind, PV/battery, and PV/wind/battery hybrid energy systems). It is found that integration of energy system which consists of 5 kW PV, 1 wind turbine, 19 units of batteries, and 4 kW converter is the cheapest system with a lifetime cost of $ 42205 and energy cost of 0.917 $/kW. It is able to reduce the net present cost about 10% and 14% as compared with wind turbine with batteries, and PV with batteries, respectively, Furthermore it has the same effect on cost of energy since COE is defined as the ratio of the annual electric generation cost (the difference between the total annual cost and the cost of the thermal load demand) and the total production of useful electrical energy. Figure 10 depicts the net present cost details of the optimized PV/wind/battery hybrid power generation.

Table 5 presents summary of important electrical output results, it is found that the annual electricity production is 12297 kW in which 63% electricity comes from solar panels array and 37% electricity comes from wind turbine. Excess electricity fraction is almost 58 percent which can be used to supply a deferrable load such as ice maker and water pumping. Moreover, there is no unmet electric load and capacity shortage is zero. The monthly average production of electricity is presented in Fig. 11.

PV (kW)	WES5	H1500	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
5	1	19	4	$ 36,852	539	$ 42,205	0.917	1.00
	4	28	4	$ 36,424	1,037	$ 46,724	1.015	1.00
8		20	4	$ 44,360	452	$ 48,845	1.061	1.00

Fig. 9. Techno-economic results of the optimum systems

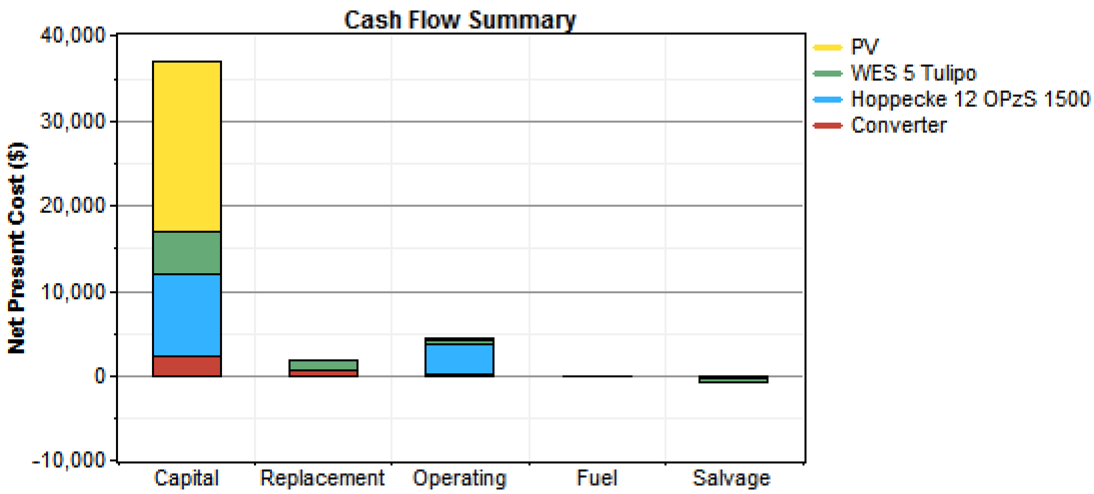

Fig. 10. Cash flow summery of PV/wind/battery hybrid energy system

Table 5. Summary of electrical output results

Quantity	Value	Units	Ratio
PV array production	7688	kWh/year	63%
Wind turbine production	4609	kWh/year	37%
Total production	12297	kWh/year	100%
Excess electricity	7127	kWh/year	58%
Unmet electric load	0	kWh/year	0%
Capacity shortage	0	kWh/year	0%
Renewable fraction	1	-	100%

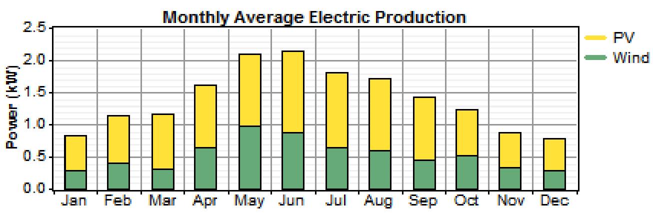

Fig. 11. Monthly average sharing of electricity production between PV and wind turbine

3.2. Impact of Variation of Real Interest Rate on Net Present Cost and Cost of Energy

In Iraq, the central bank provides data of real interest rate from 2004 to 2015. During these years, the average value is 7.85 % with a minimum of -14.28 % in 2005 and a maximum of 46.78% in 2015 as shown in Fig. 12 [19].

The relation between net present cost (NPC) and cost of energy (COE) of the proposed standalone PV/wind/battery hybrid system with annual interest rate variation from 1 % to 50 % is shown in Fig. 13. It is clear that the relation between them is just opposite to each other. In the annualization formula, the discount rate is used to convert the current capital cost into a cost that is spread out over years of the future in the lifetime of the project. Whilst the formula of net present cost is utilizing the discount rate to convert costs of future into today's cost. Increment of the discount rate results in increasing the annual costs (and subsequently higher cost of energy). On the other hand, the net present cost is the totality of initial capital cost and all of the discounted costs of the future. Therefore, the total NPC decreases with increasing interest rate. Moreover, both the increment of cost of energy and reducing of lifetime cost are not linear. This explains that in the hybrid energy system, solar panels and wind turbine is fuel free, so, the fuel cost change has no effect on the total cost. The intersection point of NPC and COE curves occurs at rate of interest 17 %, which means that at this point, the system works most economically.

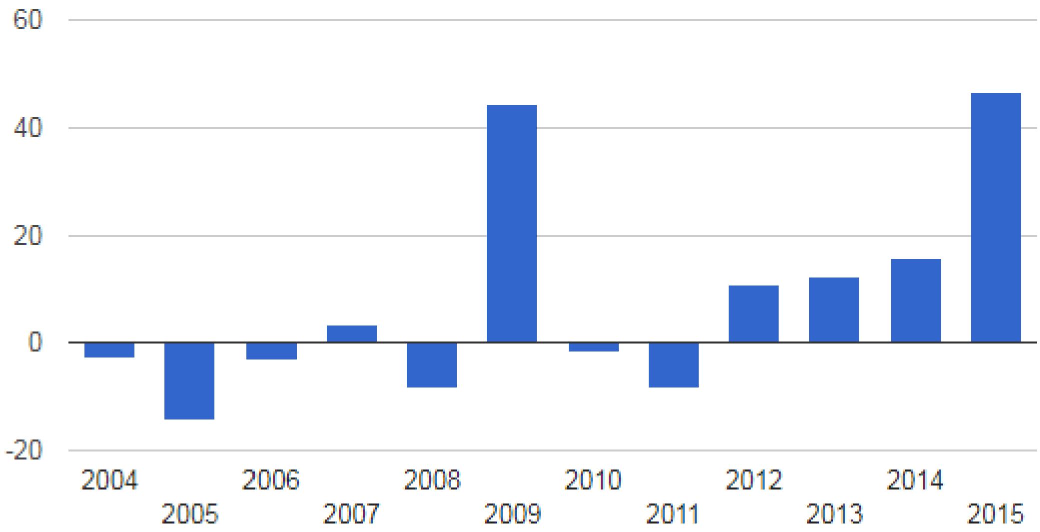

Fig. 12. Real interest rate in Iraq

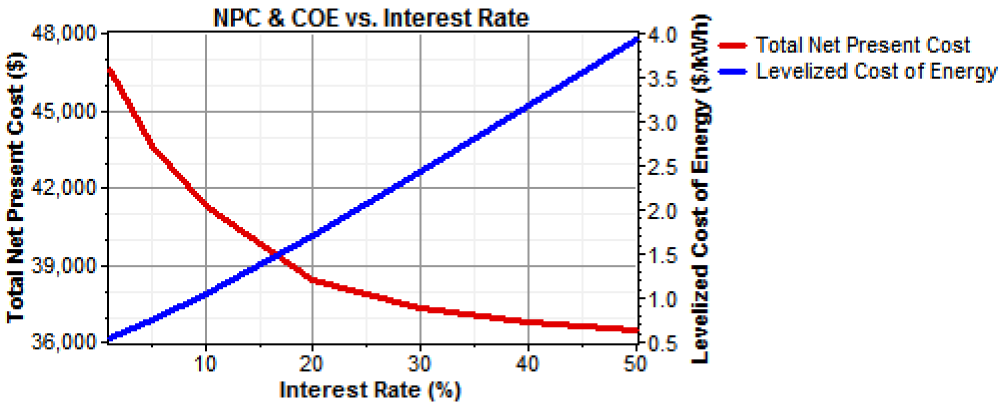

Fig. 13. Impact of real interest rate on net present cost and cost of energy

3.3. Extension to Grid

In this part of research, the cost of the expansion to the grid is compared with the cost of the standalone hybrid energy system. Proper inputs of the grid extension in HOMER software are presented in Table 6.

In this analysis, the distance of breakeven grid extensions is determined. This is the distance beyond which the total lifetime cost of grid expansion is higher than that of a stand-alone system. In other words, if the distance between the selected site and the grid site is less than breakeven distance, the extension to the grid is more cost-effective than the standalone system, and vice versa. Figure 14 presents a comparison between the costs of the both cases and presents that the breakeven grid extension is 3.59 km. Since the distance between the selected school and the grid is around 15 km, therefore, the off-grid system is less expensive as compared the grid expansion choice.

3.4. Standalone Diesel Generators

Currently, 2 diesel generators with capacity of 4 kW and 3.5 kW are utilized to feed the load of the school. In this part of simulation, the using of diesel generator is compared with the hybrid system and the grid extension. For the used generators, the capital cost is set to 500 $/kW while the replacement cost is considered to be and 400 $/kW. The cost of maintenance and operation is set to 0.02 $/hr/kW. In Iraq, the present price of diesel is around $ 0.6 per litre [5]. For sensitivity analysis, various diesel prices are considered. For the current price of diesel, the simulation results show that NPC and COE of the standalone diesel generator are cheaper than the costs of hybrid energy system and extension to the grid. From Fig. 15, it is can be seen that that for diesel price higher than $ 0.8/L, both the total lifetime cost and cost of energy of the diesel system become higher than these costs for the other two cases.

Table 6. Proper inputs of grid extension

Parameters/Costs	Value
Capital cost	8000 $/km
Operating and maintenance cost	160 $/year/km
Price of grid power	0.17 $/kWh

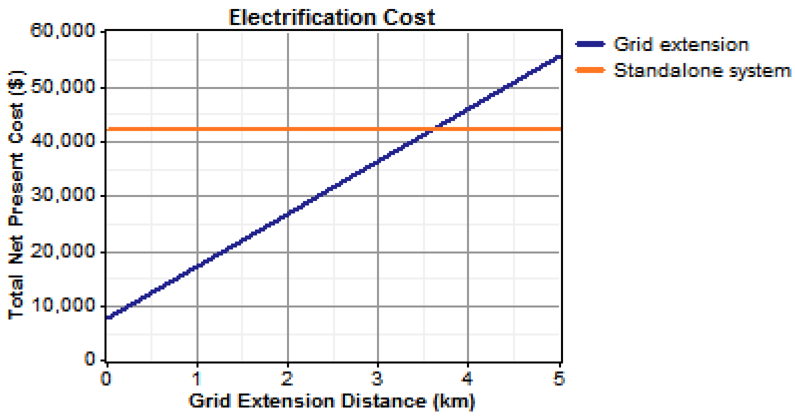

Fig. 14. Comparison between electrification costs of standalone energy system and grid expansion

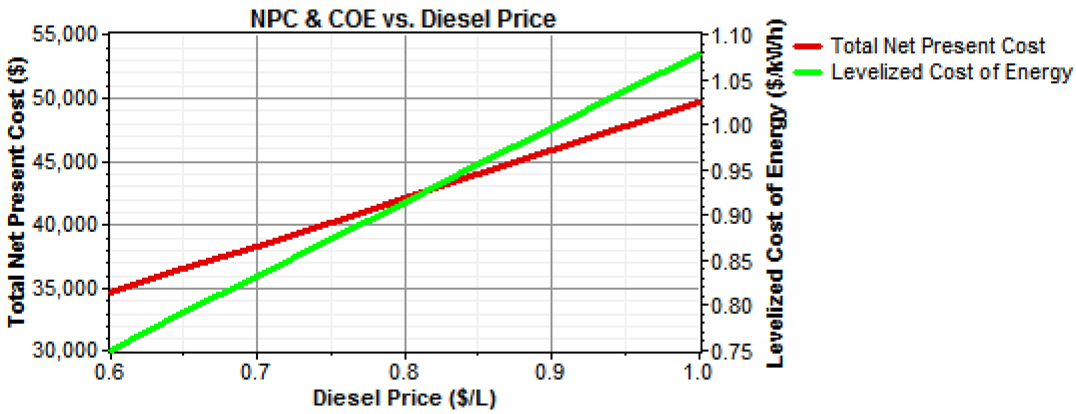

Fig. 15. Diesel generator system with different diesel prices

During the combustion of fossil fuels, several types of pollutants such as CO_2, CO, NO_1, NO_2, SO_2, and unburned hydrocarbon are emitted. These pollutants are negatively affected the life of human by causing pollution to the local environment [22]. The pollutants which are emitted from the two diesel generators system for the lifetime period the project are presented in Table 7.

3.5. Feasibility of the Proposed System in the Energy Development Context in Southern of Iraq

An important feature about the case study analyzed in this research paper is that the obtained results are meant to be generalizable to be applicable for all area with similar conditions and features as the studied position. Promising results of the proposed hybrid renewable energy systems utilized in this study can be applied at the many rural area southern of Iraq since the availability of wind and solar resource is very similar in that area. PV and wind turbine can be integrated together to meet the demands. This would reduce the use of depleted oil and the harmful emissions related to fossil fuel utilization. From the economic analysis of the study, it is obvious that with current price of diesel, use of diesel generators is cheaper than the proposed hybrid energy system. However, it is important to take into account that the price of diesel will increase in the future while the renewable energy system components decrease. The results also indicate that for small scale demands, it is not economically viable to extend the national grid to the remote rural areas.

Table 7. Amounts of different gaseous emissions of the off-grid diesel generator

Emission type	Value (kg/year)
Sulfur dioxide	20.1
Carbon dioxide	10027
Unburned hydrocarbons	2.74
Particulate matter	1.87
Carbon monoxide	24.7
Nitrogen oxides	221

3.6. Strength, Weaknesses, Opportunities and Threats of the Proposed Energy System in the Selected Site

Within several available methods to develop the strategy improvement process, the most commonly used one is the SWOT analysis [23]. This method examines the internal strengths and weaknesses on one side, and external opportunities and threats on another side. Furthermore, it is possible to be expanded to provide a framework for deriving strategies based on hopeful combination of discovered strengths, weaknesses, opportunities or threats. SWOT analysis is primarily applied as a tool for strategic of business planning. Moreover, currently, it is also successfully used as method for participatory planning [24]. In this section, the outcome of the technical, economic, social, and environmental analyses aspects is discussed.

3.6.1. Strength

- Suitable geographic location, the area enjoys a huge amount of solar radiation and suitable wind speed.
- Safe and environmentally friendly.
- Hybrid energy systems have a better reliability and higher quality as compared to the single energy source.
- Fuel transport infrastructure is not required.
- Low operation and maintenance cost.

3.6.2. Weaknesses

- Weak technical infrastructure.
- High capital costs of PV and wind turbine installations.
- Level of governmental support may be suddenly change, it is not easy to offer any long-term guarantees on purchases or prices.
- Transfer of technology from academic research to applied technologies is still not adequate.

3.6.3. Opportunities

- Opportunities of new jobs
- Diversification of corporations in sector of energy.
- Awareness programs about renewable energy will lead the people feeling easy regarding this energy.
- Capability of implementing clustering of small scale.

3.6.4. Threats

- Uncertainly of the futurity of renewable energy projects, especially after the fall of the oil prices in 2014.
- Instability of policy may dishearten some investors
- Limited practical expertise.
- Ineligible legitimate frame (standards regulations and permissions of installations).

4. Conclusion

The techno-economic and environmental feasibility study to find the optimal configurations of hybrid renewable system for standalone rural school electrification in Iraq is assessed in this paper. It is found from the results that the optimized wind/PV/battery hybrid energy system is more feasible as compared to PV/battery, and wind/battery. The analysis show that the hybrid energy system which consists of 5 kW PV, 1 wind turbine, 19 units of batteries, and 4 kW converter is the most optimum hybrid system. Furthermore, it is cheaper than grid extension and more expensive than diesel generator options. However, the proposed hybrid energy system is clean and has no pollutants while the off-grid diesel system causes too much air pollution besides many negative effects such as the noise and difficulties of transporting the fuel to the remote areas. Therefore, it can be concluded that the using of hybrid renewable energy system is a potential choice to supply electricity for the remote rural area in Alnasyria, Iraq.

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