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FEASIBILITY OF PV–WIND–DIESEL HYBRID RENEWABLE ENERGY POWER SYSTEM FOR OFF-GRID RURAL ELECTRIFICATION IN IRAQ: A CASE STUDY

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Abstract

Making electricity available in rural and particularly remote areas that cannot access grid connections remains a challenge in developing countries, such as Iraq. Currently, approximately 80% of the world's energy needs are supplied by fossil fuels, which are a major source of pollution. However, diminishing global fossil fuel resources, rising prices, and increasing energy requirements are good reasons to significantly minimize the dependence on fossil fuels. This study discusses the electrical needs of Zerbattiya, a city located in South-eastern Iraq near the Iranian border. The problem is that many remote areas in Iraq have randomly expanded in the past years, yet the generation stations have remained the same. The possibility of delivering electricity to these areas is time consuming and costly. The system's components are solar panels (PV), Wind Turbines (WT), Diesel Generators (DG), Batteries (BT), and Converters integrated according to compatibility with seven different scenarios. Wind and diesel (WT-DG) have the lowest Cost of Energy (COE), and Net Present Cost (NPC) values among all studied cases and is thus the most cost-effective design for Zerbattiya. The results showed that the NWT (39), NDG (5), NBT (351), Nconv (88), COE (0.123 US$/kWh), NPC (US$2.92 million), and IC (US$ 944,655).

Keywords: HOMER analysis, Hybrid system, Off-grid, Renewable energy sources, Rural electrification.

1. Introduction

Energy is a central index of any national socio-economic development. Currently, nearly 80% of the world's energy demand is satisfied by fossil fuels, which results in considerable adverse environmental impacts [1]. Greenhouse gas (GHG) emissions, the culprit responsible for global warming, and air pollution have created major concerns due to the continuous combustion of fossil fuels for generating electricity [2]. At the same time, significant reduction of fossil fuel resources globally and rapid escalation of energy requirements and fuel price help decrease the reliance on fossil fuels [3]. To positively address these issues associated with conventional energy generation and to meet the growing demand for energy, an energy generation system that is sustainable and environmentally friendly must be created [4]. Renewable Energy Sources (RESs) are abundant and can be potentially harnessed for generating energy that meets the global demand. Notably, these Renewable Energy Sources (RESs) are available at zero cost [5]. Even so, the massive potential of Renewable Energy (RE) is still underexploited due to economic and technical reasons and resource availability.

In the past few decades, Renewable Energy Sources (RESs) have been accepted as an important approach to energy generation. They have also been considered the ideal replacement for conventional ways of generating energy because they have no emissions, are safe for the environment, abundant, and free [6]. Moreover, a sizeable percentage of the global population is found in remote, difficult-to-access areas, which are partially or not even grid-connected at all [7], particularly in developing countries, such as Iraq. This inadequate distribution of such an essential resource as electricity is the result of several factors: difficulty of access due to challenging terrains; absence of electrical infrastructure, and exceptionally costly expenditure for installation of large grid connections that bring electricity to sparsely populated areas [8]. Consequently, distributed generation technologies built on renewable energy, referred to as independent or stand-alone hybrid renewable energy systems, are feasible solutions for remote and sparsely populated areas [9]. In the past few years, as a result of technological advancements and government policies that encourage the use of renewable energy sources, which saves substantial costs, these hybrid and independent systems offer commercial viability. renewable energies are attractive replacements for bringing electricity to remote areas not only in Iraq but also in other developing countries [10]. Unlike the predictability of conventional energy sources, that of renewable energy sources can be a critical issue because they are dependent on variances in the atmosphere, which can have a significant impact on the energy generation level [11]. To address this issue and ensure that the supply adequately meets the demand at all times, renewable energy systems can be integrated with non-renewable energy systems and/or energy storage systems [12].

Among all available types of Renewable Energy Sources (RESs), solar and wind energy systems hold great promise as renewable energy generating approaches because of their availability and topological benefits in inaccessible locations [13]. Such an alternative can comprise hybrid power systems, such as PV–DG, WT–DG, and PV–WT–DG [14-16], with or without a battery backup option, that will be discussed later in scenarios used, and in simulation results. Ongoing research and development have determined that an appropriately optimized hybrid system is cost effective and offers higher reliability than single-power-source systems. The irregular nature of solar and wind resources can be alleviated considerably by optimally integrating these resources to generate the required demand for prolonged periods. The use of solar and wind-based systems has significantly increased because of large savings in manufacturing costs and extensive advances from ongoing research. As a result, they are considered the most economically viable and technologically feasible [17].

2. Details of Selected Rural Region

2.1. Location and population

Zerbattiya, is a city located in South-eastern Iraq near the Iranian border Fig. 1 [18]. Located at N°33.26 and E°45.91 with a surface area of 170 km2 and an elevation of 95 m, it has a population of approximately 7,000 [19]. The number of households in Iraq without access to the grid network has increased in recent years. Many rural areas in Iraq, especially in the southern part, have limited access to the electricity grid. Thus, applying other optional energy sources, such as photovoltaic panels, wind turbines, and diesel generators, could help provide the electricity needs in such areas. The chosen population comprises communities in isolated areas near big cities. These remote areas are mostly populated by low-income communities that have no access to any grid connection. Data used are from the National Administration of Statistics in Iraq [20], and the figure below shows the location of Zerbattiya.

Fig. 1. Geographical location of Zerbattiya city.

2.2. Load estimation

Zerbattiya is not connected to electricity from the national grid. According to statistics from the Iraqi Ministry of Planning, Zerbattiya contains (83) small houses, (11) establishment buildings, (1) clinic, and (1) school as tabulated in Table 1 [21]. Its current population is obtained from the National Statistics Administration database, whereas the electricity and energy requirements in this city are estimates from the Iraqi Ministry of Electricity. Economically, the community mainly depends on agriculture. Therefore, the employed population is usually out of the house during daytime. The use of air conditioning is not considered in these communities because it is expensive and consumes high energy loads; such devices are rare in low-income communities. According to reports from the Iraqi Ministry of Electricity [22], the rates of energy consumption in the households is (36.41

kWh/d), the establishment buildings is (145.64 kWh/d), the clinic is (31.54 kWh/d), and the school is (35.96 kWh/d), as shown in Table 1. According to statistics from the Iraqi Ministry of Electricity, the demand for electricity grows by 1% every year. Moreover, the average life expectancy of the proposed system is 20 years, so it will be assumed that the supply of electricity is 1.2 of the loads today during the life of the proposed system. Therefore, the approximate average energy consumption in Zerbattiya is (4,691.61 kWh/d) Table 1. After 20 years the loads will be approximately (5,629.932 kWh/d), as shown in Fig. 2.

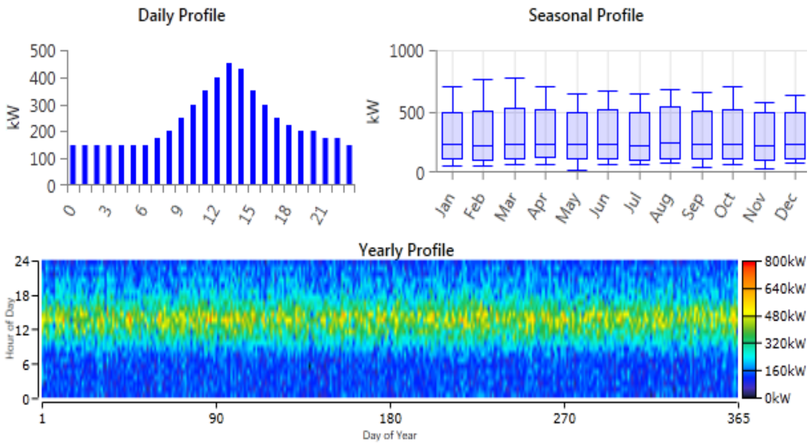

Fig. 2. Load profile [21, 22].

Table 1. Energy consumption of Zerbattiya city.

N	Load Equipment	Quantity	kWh/d	Total kWh/d
1	**Houses**	83	36.41	3,022.03
2	**Establishment Building**	11	145.64	1,602.08
3	**Clinic**	1	31.54	31.54
4	**School**	1	35.96	35.96
Total daily energy load				4,691.61 kWh/d
After 20 years				5,629.932 kWh/d

3. Major Components

Based on the availability of products in the market of Iraq, the components list was compiled, and their prices were determined from different distributors and contractors. Accordingly, the best options were selected in terms of operating and maintenance cost, lifetime, basic cost and additional expenses as tabulated in Table 2.

3.1. PV panel

Photovoltaics (PV) is the generation of electricity by conversion of solar energy to DC electricity [23]. As a result of Iraq's geographical location, the country is blessed with relatively abundant solar energy. The overall installation cost was US$ 1,250, the cost of replacement US$ 1,250, the annual operating and maintenance cost was US$ 10, 1,000 W, the lifetime for PV panel is 25 years, as tabulated in Table 2 [24]. Solar radiation, and temperature data were downloaded from NASA surface meteorology and solar energy database 2019. The average annual solar radiation was measured as (5.14 kWh/m^2/d), as shown in Fig. 3, while the average annual temperature was measured as (22.38 ºC), as shown in Fig. 4 [25].

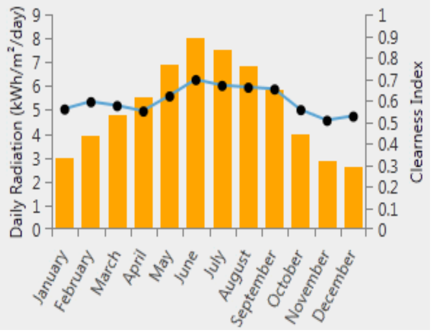

Fig. 3. Average annual solar radiation.

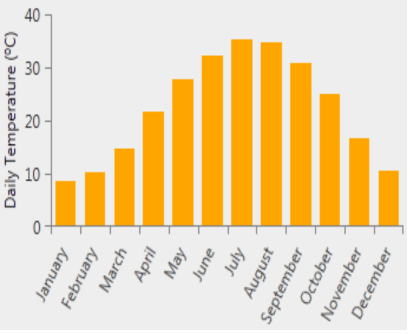

Fig. 4. Average annual temperature.

3.2. Wind turbine (WT)

Wind turbine is generation the electricity by conversion the wind kinetic energy to the electrical energy. Wind turbine farms have become significant providers of Renewable Energy (RE) and are utilized to lower dependence on fossil fuel therefore minimize pollutant emissions [26]. The cost of operating and maintenance appears to be closely related to the age of turbine, therefore the operation in the first few years, the manufacturer estimates a low level of operating and maintenance costs whereas from year 10 there would be higher repair costs so a certain level of additional investment should not be surprising. In this analysis, employed are wind turbine with a rated power of 10 kW and AC voltage output. The initial cost is US$ 17,000, the cost of replacement is also US$ 17,000, the annual cost of operating and maintenance is US$ 120, a turbine's lifetime is 20 years, as tabulated in Table 2 [27]. The data of wind speed was downloaded from NASA surface meteorology and solar energy database 2019. The average annual wind speed was measured as (5.36 m/s), as shown in Fig. 5 [25].

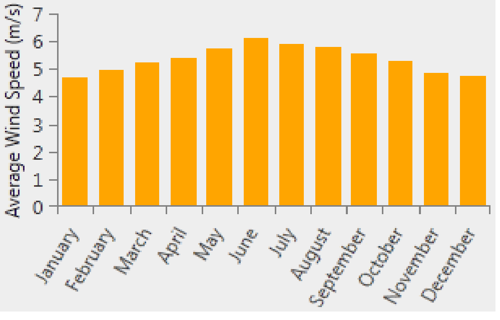

Fig. 5. Average annual wind speed.

3.3. Diesel generator (DG)

The PV-wind hybrid system is generally of not very reliable, and this is a significant obstacle to the development of these renewable energy systems market. As such, diesel generators have come to be suitable in enhancing the systems reliability [28]. The diesel generator (DG) selected with engine cooling by liquid and the estimated power 100 kW. The capital costs US$ 12,500, with the same cost for replacement, and the cost for operation & maintenance of US$ 0.25 / hour. The lifetime of this generator is 15,000 hours, as tabulated in Table 2 [29]. The current diesel price, taken from the Iraqi Ministry of Oil, is US$ 0.31/L [30].

3.4. Battery (BT)

Generally, batteries are among the costliest components in Renewable Energy (RE) production systems. Due to the fact that the solar, and wind energy are by nature irregular, a PV and WT system necessitates the use of battery storage capabilities to be able to supply power at a stable level. Therefore, the battery comes into play as a storage facility, with the battery making up any shortfall in power supply relative to demand. [31]. The battery involved is 1 kWh. The battery capital cost US$ 500, replacement cost US$ 500, and the annual operating and maintenance cost US$ 10. The selected battery has a life of 10 years, as tabulated in Table 2 [32].

3.5. Converter

The converter is among the major parts of the system as it is used for the conversion of the DC electricity generated by the PV modules into AC electricity and also for the conversion of the excess AC to DC for the purpose of storage in the battery to be utilized in case of lack of power processing. The capital cost is US$ 500, with a similar replacement cost of US$ 500, an annual cost for operating and maintenance of US$ 10; the efficiency of this converter is 90% and its lifetime is 20 years, with conversion rate of 1 kW used, as tabulated in Table 2 [33].

Table 2. The components list.

N	Capital Cost	Replace Cost	O&M Cost	Lifetime	Power	Type
1	$1,250	$1,250	$10/y	25 years	1 kW	PV
2	$17,000	$17,000	$120/y	20 years	10 kW	WT
3	$12,500	$12,500	$0.25/h	15,000 hours	100 kW	DG
4	$500	$500	$10/y	10 years	1 kWh	BT
5	$500	$500	$10/y	15 years	1 kW	Converter

4. Methodology

As has been stated earlier, Photovoltaic (PV), Wind Turbine (WT), and Diesel Generator (DG) are the components considered to generate power. As such, the total energy generated (ET) is defined as the sum of generated energy by photovoltaic (EPV), wind energy (EWT), and diesel generator (EDG). Therefore, a contribution of the individual sources of energy in the overall energy generated is as follows:

$$f_{pv} = \frac{E_{pv}}{E_T} \quad (1)$$

$$f_{WT} = \frac{E_{WT}}{E_T} \quad (2)$$

$$f_{DG} = \frac{E_{DG}}{E_T} \quad (3)$$

The three main economic indicators considered in the current analysis comprise the overall Cost of Energy (COE), Net Present Cost (NPC), and the Initial Capital Cost (IC). Net Present Cost (NPC) offers greater reliability in comparison with Cost of Energy (COE) as an economic factor as the value of Cost of Energy (COE) is subjective to a certain degree whereas Net Present Cost (NPC) is arrived at from a mathematical concept [1, 34].

Cost of Energy (COE) is defined as the average cost per kWh of useful electrical energy produced by the system. Cost of Energy (COE) is computed by dividing the total net present cost of generating electricity by the entire electric load served. The Cost of Energy (COE) equation is as shown below:

$$\text{Cost of energy (COE)} \left(\frac{\$}{\text{kWh}}\right) = \frac{\text{Total Net Present cost}}{\sum_{\text{H}-1}^{\text{H}-8760} \text{P}_{\text{Load}}} \text{CRF} \tag{4}$$

where, Total Net Present Cost (TNPC) is a sum of all component's costs, P-Load (h) is the hourly power consumption, CRF is the capital recovery factor.

The Capital Recovery Factor (CRF) equation is as shown below:

$$\text{CRF} = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{5}$$

where, i : Real interest rate [35], N: Lifetime of system (Amortization period).

The total Net Present Cost (NPC) of individual configurations can be computed as below:

$$\text{NPC (\$)} = C_{cap} + C_{Rep} + C_{O\&M} + C_f - C_{Salv} \tag{6}$$

where, C_{cap} : The total installation capital components cost at the onset of the project, C_{Rep} : The total replacement cost for all components, $C_{O\&M}$: The total operating and maintenance cost (O&M) for all components of the system, C_f : The total fuel cost, C_{Salv} : The salvage value of the system.

The salvage value, which is the representation of the remaining value of a power system component in the end of the project lifetime, which is assumed to go through a linear depreciation, suggesting a direct proportional relation with the remaining life. Furthermore, its basis is the replacement cost instead of the capital cost, and the value for individual components can be shown as follows:

$$\text{S} = C_{rep} \frac{R_{rem}}{R_{comp}} \tag{7}$$

where, C_{rep} are the replacement cost (US$), R_{comp} are the component lifetime (year), R_{rem} are the remaining costs of the component(US$).

When the best possible component mix for each area is finalized, the resulting environmental impact of the individual systems is also computed. The total carbon footprint was used for the evaluation of the related environmental impact. Moreover, for the best possible systems attained, the annual electrical energy production of individual components was also established [1, 36].

5. Scenarios, Results, and Discussions

This section discusses several possible scenarios for providing electricity to Zerbattiya using diverse energy sources. Toward this end, the total Cost of Energy (COE) and Net Present Cost (NPC) are determined for each scenario. However, the rent, taxes, and other costs are excluded from the simulation. This current study analyses the feasible sizing of a PV-WT hybrid system which comprises a battery unit to store power and a diesel generator for operational reliability, and auxiliary tools, as a means of compensating for power supply shortage. To determine the system's optimal setup and for the selection of appropriately sized components, renewable hybrid energy system may be shared by them is achieved by applying optimization in HOMER software. All variables and data for the location were inserted that concerned the Renewable Energy Sources (RES) and hybrid system (HS), like the solar radiation, temperature, wind speed, size of Photovoltaic (PV), Wind Turbine (WT), Diesel Generator (DG), and Battery (BT) available, the project lifetime, the location coordinates, all price details such as capital, replacement, and O&M costs.

All possible scenarios have been tested (single, double, triple sources). Also, the details of the operating patterns for all the proposed combinations were studied and quantified to indicate the advantages and disadvantages related to each system to reach the best design that also offers flexibility. For each scenario performs hundreds or thousands of hourly simulations over and over (to ensure best possible matching between supply and demand) in order to design the optimum system. The hybrid energy system is better than single energy system through the output results for all scenarios. As shown in Table 3, simulations are performed for the following.

The first case, diesel generators supply AC power to the load. These systems may be affected by costly maintenance, fuel supplies, and large amounts of polluting emissions. The second case uses solar panels for the provision of the energy that is then directed to the controller, which charges the batteries. AC converter is fed directly by the battery to supply high voltage energy (in AC) to the required devices.

In the third case, wind turbines supply AC power, which is converted into a DC to save it in batteries. The batteries in turn supply power to the load in several periods throughout the year. The first hybrid system (case 4) combines the PV and WT with the battery bank, which stores energy whenever excess solar and wind energies exist and gives it back on demand.

Table 3. The scenarios used.

Scenarios	DG	PV	WT	BT	Converter
1	✓	×	×	×	×
2	×	✓	×	✓	✓
3	×	×	✓	✓	✓
4	×	✓	✓	✓	✓
5	✓	✓	×	✓	✓
6	✓	×	✓	✓	✓
7	✓	✓	✓	✓	✓

In cases 5 and 6, the hybrid system consists of PV-DG, and WT-DG, respectively. Despite the capability of the diesel generator to provide endless power (depending on fuel availability), economic constraints prevent the system from total reliance on diesel generators. Case 7 combines PV, WT, DG, and battery storage to provide stability and reliability to the power supply and consider the economic viability of the system.

5.1. Scenario 1

Diesel generators are connected to the load direct, in this scenario, as shown in Fig. 6, and their simulation results is shown in Fig. 7.

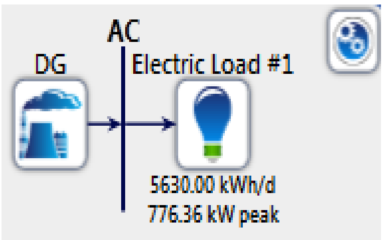

Fig. 6. System design (case 1).

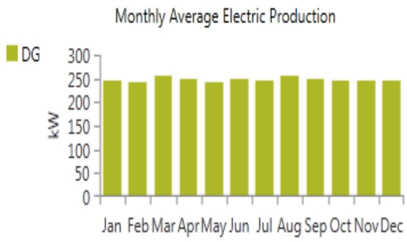

Fig. 7. Simulation results (case 1).

5.2. Scenario 2

Photovoltaic (PV), Battery (BT), and converter were the components included in this scenario, as shown in Fig. 8, and their simulation results is shown in Fig. 9.

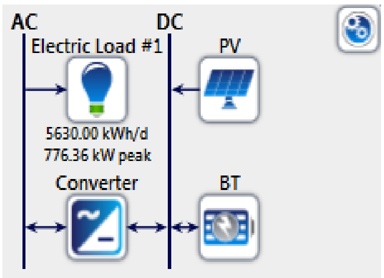

Fig. 8. System design (case 2).

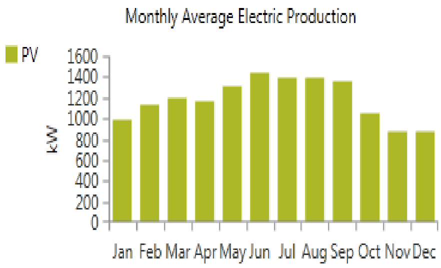

Fig. 9. Simulation results (case 2).

5.3. Scenario 3

Wind Turbine (WT), Battery (BT), and converter were the components included in this scenario, as shown in Fig. 10, and their simulation results is shown in Fig. 11.

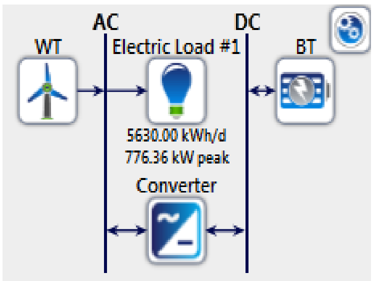

Fig. 10. System design (case 3).

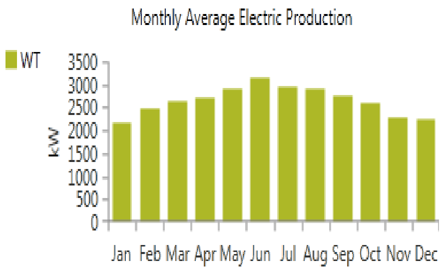

Fig. 11. Simulation results (case 3).

5.4. Scenario 4

Photovoltaic (PV), Wind Turbine (WT), Battery (BT), and converter were the components included in this scenario, as shown in Fig. 12, and their simulation results is shown in Fig. 13.

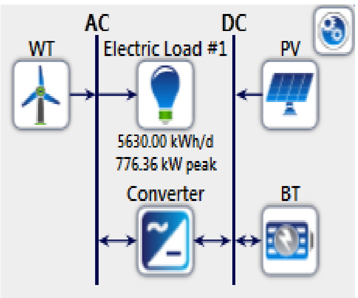

Fig. 12. System design (case 4).

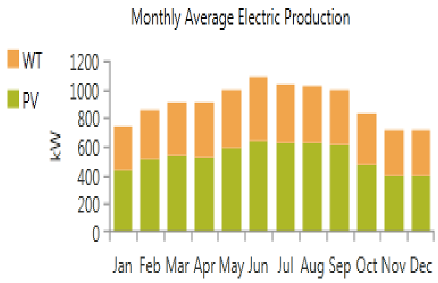

Fig. 13. Simulation results (case 4).

5.5. Scenario 5

Photovoltaic (PV), Diesel Generator (DG), Battery (BT), and converter were the components included in this scenario, as shown in Fig. 14, and their simulation results is shown in Fig. 15.

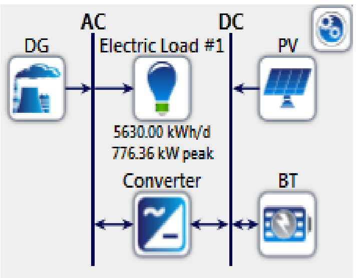

Fig. 14. System design (case 5).

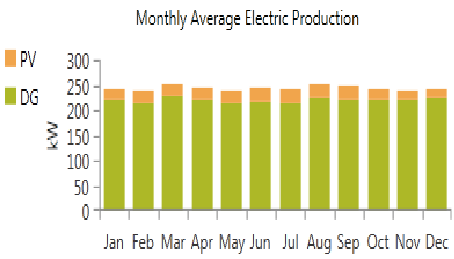

Fig. 15. Simulation results (case 5).

5.6. Scenario 6

Wind Turbine (WT), Diesel Generator (DG), Battery (BT), and converter were the components included in this scenario, as shown in Fig. 16, and their simulation results is shown in Fig. 17.

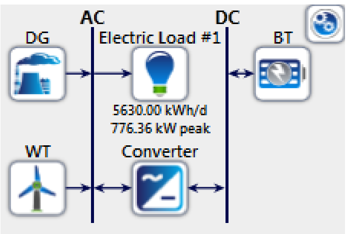

Fig. 16. System design (case 6).

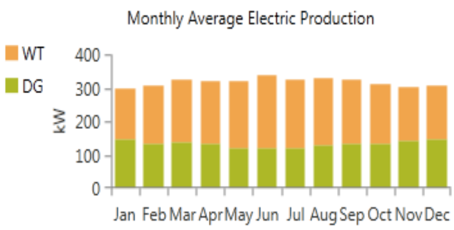

Fig. 17. Simulation results (case 6).

5.7. Scenario 7

Photovoltaic (PV), Wind Turbine (WT), Diesel Generator (DG), Battery (BT), and converter were the components included in this scenario, as shown in Fig. 18, and their simulation results is shown in Fig. 19.

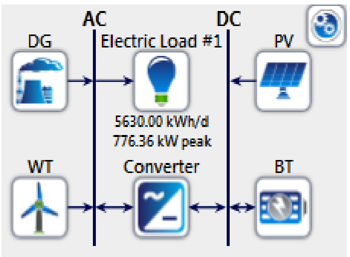

Fig. 18. System design (case 7).

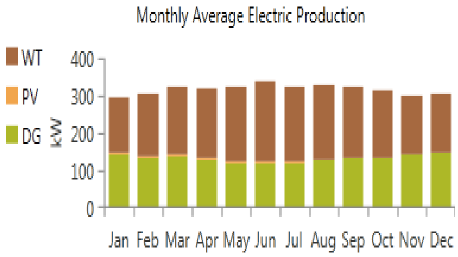

Fig. 19. Simulation results (case 7).

5.8. Results of scenarios

The designs for all cases for this community under study are shown in Table 4. The general annual electrical energy generated by individual generation types Photovoltaic (PV), Wind Turbine (WT) and Diesel Generator (DG) are computed. HOMER searches for the best solution which can cover electrical loads as well as the operating reserve at the lowest cost. Satisfying the loads' demand and operating reserve is regarded as critical roles for HOMER, meaning that any cost will be accepted to avoid capacity shortage. On the other hand, if the proposed combinations of the dispatchable sources can equally supply the loads demand, then HOMER will choose the lowest cost combination. It is also noticeable that cases have the capability to provide the electrical load demanded through 100% Renewable Energy (RE). Therefore, deep economic analysis is required for determining the most economically expedient scenario for the location. Hence, three indicators were used to explore the suggested systems economically, mainly Initial Capital cost (IC) for the system in (US$), Net Present Cost (NPC) in (US$M) and Cost of Energy (COE) in (US$/kWh). The aim of this study was to investigate renewable energy production systems for the Zerbattiya city, located in South-eastern Iraq near the Iranian border.

Table 4. Simulation results.

N	NDG	NPV	NWT	NBT	NConv	COE (US$/kWh)	NPC (US$M)	IC (US$)
1	7	-	-	-	-	0.143	3.40	87,500
2	-	6,265	-	11,835	902	0.813	19.3	14.2 M
3	-	-	565	15,775	1,800	1.09	25.9	18.4 M
4	-	2,811	79	6,623	712	0.485	11.5	8.52 M
5	6	126	-	226	89	0.143	3.40	389,154
6	5	-	39	351	88	0.123	2.92	944,655
7	5	14	39	346	88	0.123	2.93	959,790

5.9. Discussions on the optimal design for Zerbattiya

As detailed, Case 6 (WT-DG) emerges with the lowest Net Present Cost (NPC) value, showing the most economically feasible design for Zerbattiya. It is also noticeable that Case 2 (PV-based system), and Case 3 (WT-based system) have the capability to provide the electrical load demanded through 100% Renewable Energy (RE), but Case 3 (WT-based system) shows the poorest system design in terms of economic viability because of the high cost of wind turbines and large number of storage batteries. Table 4 for Case 6 (WT-DG), and Case 7 (PV-WT-DG) the main share of electrical load is provided by Renewable Energy (RE), whereas Case 6 offers the more sustainable configuration between the two and attains the renewable energy target. As indicated above, even though the Case 6 (WT-DG) configuration is the best long-term option for Zerbattiya, the relatively cheaper short-term option, Case 1 (DG-based system). Should initial start-up outlay be the only criterion considered, among the various suggested configurations, the DG-based system would be the preferred choice. The monthly electricity generated adequately meets the monthly electricity consumed, whereas a difference in the average power generated can be noted because of the sporadic nature of renewable energy resources.

5.10. Storage system

The system batteries support its performance and minimize the unpredictability issues that characteristically affect renewable energy systems. Hours of autonomy, refer to the highest number of hours that the storage system can provide uninterrupted supply of power.

The average state of charge of each hour during the year, as shown in Fig. 20. While the maximum (positive), minimum (negative), and average monthly state of charge during the year, as shown in Fig. 21.

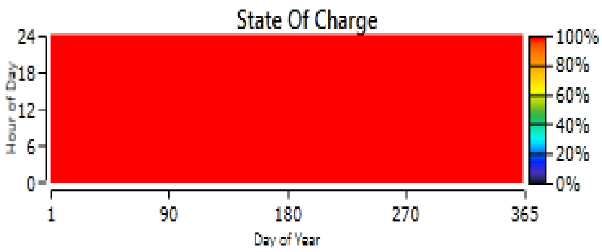

Fig. 20. State of charge.

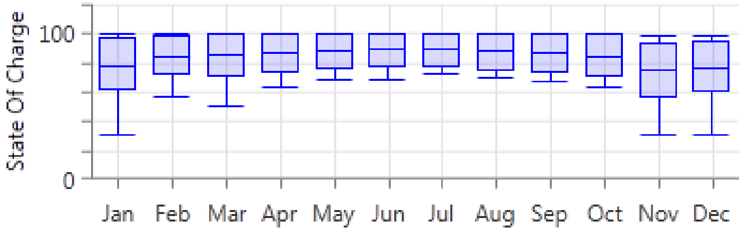

Fig. 21. State of charge.

6. Conclusions

This study provides a systematic and comprehensive assessment of various off-grid designs for small remote communities in Iraq. Seven scenarios were offered and evaluated, comprising different configurations of Photovoltaic (PV), Wind Turbine

(WT), and Diesel Generator (DG) units. The Cost of Energy (COE), Net Present Cost (NPC), and Initial Capital cost (IC) were established as economic indicators. Case 6 wind and diesel (WT-DG) have the lowest Cost of Energy (COE), and Net Present Cost (NPC) values among all studied cases with 58% renewable energy penetration is identified as a feasible system and is thus the most cost-effective design for Zerbattiya. Excess energy generated in (Case 6) would prove useful should the population and resulting energy demand increase, which would entail enhanced economic activities within the city. Also, energy generation via wind turbines offers better economic profitability compared with the use of PV panels.

As indicated above, even though the wind-diesel-battery (WT-DG-BT) configuration is the best long-term option for Zerbattiya, the relatively cheaper short-term option, DG-based system. Should initial start-up outlay be the only criterion considered, among the various suggested configurations, the DG-based system would be the preferred choice. The Cost of Energy (COE), and Net Present Cost (NPC) are US$0.123/kWh, and US$ 2.92 M which is approximately 86% from the (DG) based system US$ 0.143/kWh, and US$ 3.40 M. The results indicated that the combination of Diesel Generator-Renewable Energy (DG–RE) configurations had a very low carbon footprint. The proposed hybrid power system can reduce the additional of greenhouse gas (CO_2 gas emissions) in the local atmosphere of the city, over the life of the hybrid plant, a total reduction of GHG emissions in the local atmosphere of the city will be realized, thereby ensuring improved health conditions for the inhabitants and considerable savings in medical bills. Moreover, although the diesel system is economically most attractive for the short term, the long-term preference is the wind turbine system configuration. However, besides the higher carbon footprint, having to transport fuel to a remote location is a disadvantage. Ideally and hypothetically, as well as for reasons of environmental safety, the total renewable energy and hybrid designs are the best options. However, two significant obstacles stand in the way; the high initial capital outlay for start-up and the relatively high operations and maintenance expenses are beyond the means of low-income communities in the rural communities of Iraq.

A possible solution is for the Iraqi government to actively facilitate the application of the hybrid renewable energy-based designs for electrification in remote locations. Other researchers can benefit by referring to the simulation results in examining and creating future renewable energy generation systems for other areas.

Nomenclatures

i	Real interest rate
N	Lifetime for the system

Abbreviations

BT	Battery
COE	Cost of Electricity
CRF	Capital recovery factor
DG	Diesel Generator
HRES	Hybrid Renewable Energy System
HES	Hybrid Energy System
HS	Hybrid System

IC	Initial Cost
NBT	Number of Battery
Nconv	Number of Converter
NPC	Net Present Cost
NPV	Number of Photovoltaic
NWT	Number of Wind Turbine
O&M	Operating and Maintenance cost
PV	Photovoltaic
RE	Renewable Energy
WT	Wind Turbine

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