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Original Article

Feasibility Study of Off-Grid Rural Electrification in Iraq: A Case Study of the AL-Teeb Area

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Abstract
In developing nations, such as Iraq, supplying power to isolated and rural border areas that are not connected to the grid continues to be a problem. At present, fossil fuels, which are significant causes of pollution, supply around 80% of the world's energy demands. Nonetheless, drastically reducing reliance on fossil fuels has many reasons, including depleting global fossil fuel supplies, increasing costs and growing energy needs. The present study examines the electrical requirements of the Al-Teeb area, a city situated in the eastern region of Iraq, close to the Iranian border. This region has not been researched despite its tourism and oil significance. Despite the unpredictable expansion of many isolated locations in Iraq in recent years, the number of generation stations has not changed. Supplying energy to these places will require considerable time and money. Photovoltaics (PV), wind turbines (WTs), diesel generators (DGs), batteries and converters combined on the basis of their compatibility under three distinct scenarios comprise the system's components. Considering the lowest net present cost (NPC) and cost of energy (COE) of all the examined scenarios, PV, WTs, batteries and DGs are the most economical solutions for the Al-Teeb area. Number of PV (1,215), number of WTs (59), number of DGs (13), number of batteries (3,138), number of converters (47), COE (0.155 US$/kWh), NPC (14.2 million US$) and initial capital cost (4.91 million US$) are revealed by the results. Finally, the results are confirmed using another global optimization method, namely, modified particle swarm optimization.

Keywords
Diesel Generators, Feasibility Study, HOMER Pro, Al-Teeb Area, Photovoltaics, Wind Turbines.

I. Introduction

Growing industrialization and a larger worldwide population are the two major factors that drive up the demand for power [1]. Traditional power plants use fossil fuels, such as coal, oil and gas, to generate electricity. However, the use of these sources contributes to the rise of atmospheric pollutants. Deforestation, biodiversity loss, air and coastal pollution and degradation are some of the negative consequences of burning fossil fuels [2]. All these issues are driving nations to look for new energy sources. Researchers, environmentalists and policymakers worldwide are seeking out renewable energy (RE) sources as alternatives to conventional energy in an effort to decrease emissions [3].Given the extensive damage caused by the 1991 Iraqi uprisings, Iraq is experiencing power outages despite having plenty of fossil fuel resources [4]. The government and the public are oblivious with regard to the importance of RE. Consequently, nonprofit organizations and individual effort are typically responsible for developing these technologies in the country [5]. Many remote rural areas are returning to a primitive and chaotic way of life as a result of the nation's precarious situation. In these areas, people typically use diesel generators (DGs) that are not connected to the main grid. Diesel fuel that leaks from generators not only produce harmful pollutants, but they also increase the levels of naturally occurring underground pollution [5]. Moreover, procuring fuel from far places is not easy. At present, no

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viable alternative to diesel is available other than the adoption of new and clean energy sources [5].

This study aims to provide effective solutions for supplying electricity to the remote areas of Zerbattiya in southeastern Iraq, which face significant challenges in accessing the power grid. Given the current reliance on fossil fuels, which account for 80% of global energy needs, reducing this dependence is crucial. The study finds that combining wind turbines and diesel generators offers the most cost-effective solution in terms of both cost of energy and net present cost, with results indicating the need for 39 wind turbines, 5 diesel generators, 351 batteries, and 88 converters. Renewable energy resources such as solar, hydro, and wind are clean and have the potential for broader application. Integrating these sources with backup units can provide cleaner, more economical, and reliable power compared to single-source systems. This study investigates the feasibility of using an integrated energy system to supply electricity to a remote school in southern Iraq. The HOMER software is used for technical, economic, and environmental assessments, with detailed analyses of optimal energy systems to identify the most viable off-grid solution. The system is then compared with options for grid extension and diesel generator systems. Considerable challenges are associated with RE sources, such as wind and solar power, because they are highly dependent on climatic and weather-related factors [6]. Considering this case, meeting the load demand by using only wind or solar power is only feasible at extremely high solar radiation or strong wind speeds. An energy storage device or backup power source is frequently required when RE sources are employed [7]. When switching to a renewable power source and when energy sources, such as solar radiation, or cut-in speed are limited, a backup energy source or storage can be utilised to meet the load requirement. In addition, DG power is constant and unaffected by the weather. The simultaneous use of many energy sources brings attention to the limitations of traditional and alternative power systems. Compared with energy systems that rely on a single source, multisource hybrid RE systems that are well-designed, scalable and controlled are more likely to achieve improved quality and reliability [7]. Comprehensive research on RE technologies in Iraq and their applications and functions is lacking.

In place of grid expansion, the authors of [5] assessed a decentralised diesel/photovoltaic (PV) hybrid power system in Iraq. To electrify the selected location, the authors recommended integrating energy systems. The authors of [8] evaluated the efficiency of a hydro/diesel energy system in providing power to a rural location in Iraq. Compared with off-grid DGs, hybrid energy systems reduce electric power costs per kWh whilst simultaneously reducing noise and air pollution. In [9], a hybrid power-producing system that combined PV and fuel cells was evaluated for its ability to provide electricity to remote rural parts of Iraq. The results showed that a PV/fuel cell combination might provide a satisfactory outcome with the right components and the recommended control methods. The current study aims to use mathematical modelling and simulation to determine if a pollution-free hybrid PV/wind/battery power generation system can supply energy to a city in far southeast Iraq, called the Al-Teeb area, which is close to the Iranian border. Important variables, including ambient temperature, load variations and interest rate, are considered in this study. Fig. 1 shows the schematic of the proposed hybrid power generation system (HPGS).

Despite the importance of this region for its oil and tourism, it is considered unattractive to residents due to the lack of electricity. Therefore, this work aims to supply it with renewable energy lines to attract residents. In previous research, hybrid systems have been discussed in the following ways: either through the HOMER software or through algorithms, each separately. However, in this paper, the hybrid system is discussed and compared using both the HOMER software and the MPSO algorithm simultaneously. The differences in the system components between the HOMER software and the MPSO algorithm are observed and analyzed.

The outlines of this study can be summarize by some importance point as follow:

1- Provide a comprehensive analysis of the AL-Teeb area (location, climate, geography).

2- Take close look at local factor that affect power consumption and efficiency.

3- Utilizing the HOME Pro program to breaks down the planned HES for this region.

4- Comparison the finding of study with another optimization method.

5- Establishing optimal configuration of hybrid energy system for AL-Teeb area

II. Contribution of Study

There is a lack of research on the use of energy resources in this region despite its growing importance . Secondly, this area is strategically important for more than its position because it contain natural resources, economic growth, and environmental. Finally, its hope that the results of this study will be presented a wider impact since they can be used as a template for improving energy efficiency in other understanding areas that are comparable.

III. Traits of The Selected Nural Region

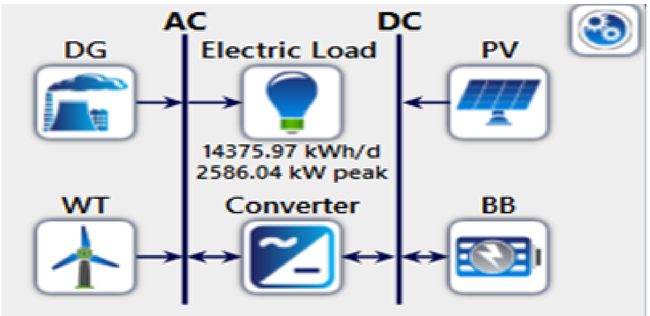

Fig. 1. Schematic structure of the proposed HPGS model

A. Location and population

A hybrid power station is scheduled to be constructed in the Al-Teeb area, located in the city of Amarah, Iraq, at an elevation of 50 m above sea level. Al-Teeb covers approximately 12.8% of the total area of Amarah, spanning 2070m^2

This area is isolated from the national electricity grid and situated in southeastern Iraq along the Iraqi–Iranian border at coordinates 32°25′34″ N and 47°10′06″ E Fig. 2. The region includes nine districts, both residential and agricultural. Al-Teeb is characterised by a Type III climate, precipitation occurring in December, January, February and March, and dry conditions prevailing in June, July and August.

The remaining months experience moderate climatic conditions, making the area suitable for agriculture and residential purposes. Al-Teeb is one of the most remote rural areas in Amarah City, located approximately 100 km from the city centre. Many rural areas in Iraq, particularly in the south, have limited connections to the power grid. Therefore, utilising RE sources, such as PV, wind turbines (WTs), DGs and battery banks (BBs) will be beneficial for meeting the electrical demands of the region. Most residents in these remote areas belong to low-income communities that lack connectivity to the main grid. The data used were provided by the National Administration of Statistics in Iraq and Maysan Governorate's Department of Agriculture, Land Section [10]. The location of the Al-Teeb area is illustrated in Fig. 2.

B. Estimating load

No power from the national grid reaches the Al-Teeb area. The Al-Teeb area has 500 small residences, 1 school and 10 stores, amongst others, with data provided by the Iraqi Ministry of Planning. The number of electricity and energy consumers in this city is derived from as stated in Table I, These data were obtained by the Municipality of Maysan Governorate in Iraq, Agricultural Land Department, through a field visit to the Al-Teeb Area. According to Table I, whilst the city's current population is obtained from the National Statistics Administration database. The agricultural sector is the economic backbone of the town. Consequently, most people who work throughout the day are not at home. Air conditioning is costly and consumes considerable energy, and thus, it is not used in these communities.

TABLE I.
LOAD DEMAND OF THE AL-TEEB AREA.

load	Quantity	Load kWh/day	Total load (kWh/day)
Homes	500	41.292	20,646
School	1	16.614	16.614
Stores	10	5.384	53.84
Total			20,716.454
After 20 years			24,859.7448

Low-income communities rarely have access to these types of appliances. The energy consumption rates of Iraqi houses, schools and stores are 41.292, 16.614 and 53.84 kWh/day, respectively, according to figures provided by the Iraqi Ministry of Electricity [11]. The demand for power in Iraq increases about 1% annually, according to statistics from the Ministry of Power. In addition, the suggested system is expected to last for an average of 20 years.

Therefore, the electrical supply is assumed to meet 1.2 of the current loads throughout that period. The estimated average energy usage in the Al-Teeb area is 20,716.454 kWh/day, as indicated in Table I. Fig. 3 shows that the loads will be around 24,859.7448 kWh/day after 20 years. Fig. 3 show in details the daily, seasonaly and yearly profiles of energy in this region. This profile has taken from HOMER program.

IV. MAIN COMPONENTS

The list of components by using items sold in the Iraqi market and then contacted several wholesalers and contractors to obtain their rates. The next sections present the best options selected after considering lifetime, basic cost, operating and maintenance (O&M) costs and additional expenses.

A. PV (Photovoltaic)

PV refers to the technology that transforms sunlight into direct current (DC) power [11]. Iraq has access to abundant solar energy source because of its geographical position. The installation cost is US$1,300. O&M costs comprise US$10 per year per 1,000 W, whilst replacement cost is US$1,000. PV panels are designed to last for 25 years.

Surface meteorology and solar energy data from the 2024 database of the the National Aeronautics and Space Administration (NASA) provide temperature and solar radiation data.

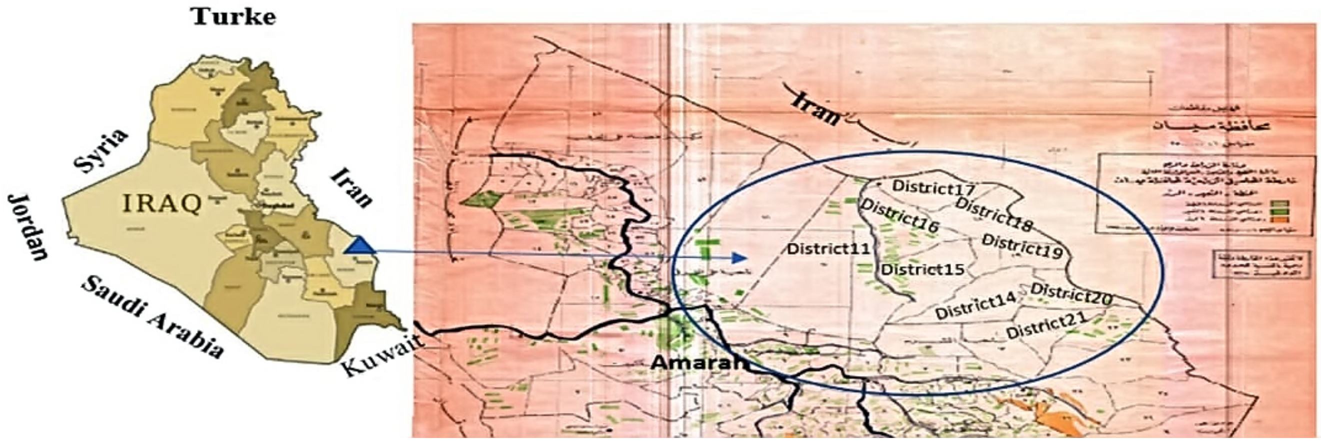

Fig. 2. Study area: a rural agricultural area composed of nine districts with unelectrified positions in the Al-Teeb Area, Amarah City, Iraq l

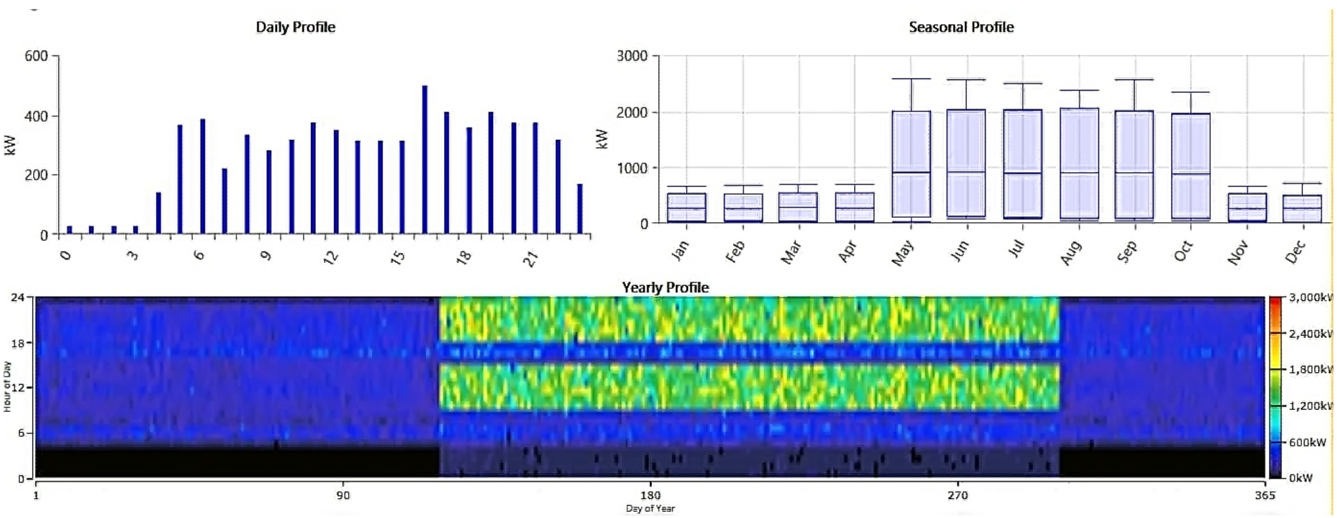

Fig. 3. Load profile

Fig. 4 shows the computed average annual solar radiation, i.e. 5.03 kWh/m2/day. Fig. 5 [12] indicates that the yearly temperature is 22.42°C. The total area used for PV is $2,187\,\mathrm{m}^2$.

B. WTs (Wind Turbines)

WTs generate power by transforming the mechanical energy of the wind into electrical energy. One way to lessen effect on the environment is by shifting away from fossil fuels; hence, WT farms have emerged as powerful sources of RE [13]. Although the manufacturer predicts relatively inexpensive O&M expenses in the first few years, they foresee considerably greater repair costs starting in year 10 and beyond; therefore, a certain amount of additional expenditure must be expected. A strong correlation apparently exists between the age of the turbine and O&M costs. A wind turbine with a 10 kW potential power and an alternating current (AC) voltage output is utilised in this study. The price of a turbine starts at US$18,000, goes down to US$17,000 when replaced and costs US$130 per year to run and maintain. A turbine can lasts for 20 years. The wind speed statistics for 2024 come from the official NASA database of surface meteorology and solar energy. Fig. 6 [12] shows that the average wind speed for the year is 5.52 m/s. The total area used for this WT is $289,100m^2$.

C. DGs (Diesel Generators)

The frequently poor dependability of PV–wind hybrid systems is a key factor that limits the expansion of the market for these renewable power sources. DGs are currently believed to be suitable for enhancing system dependability [14]. A

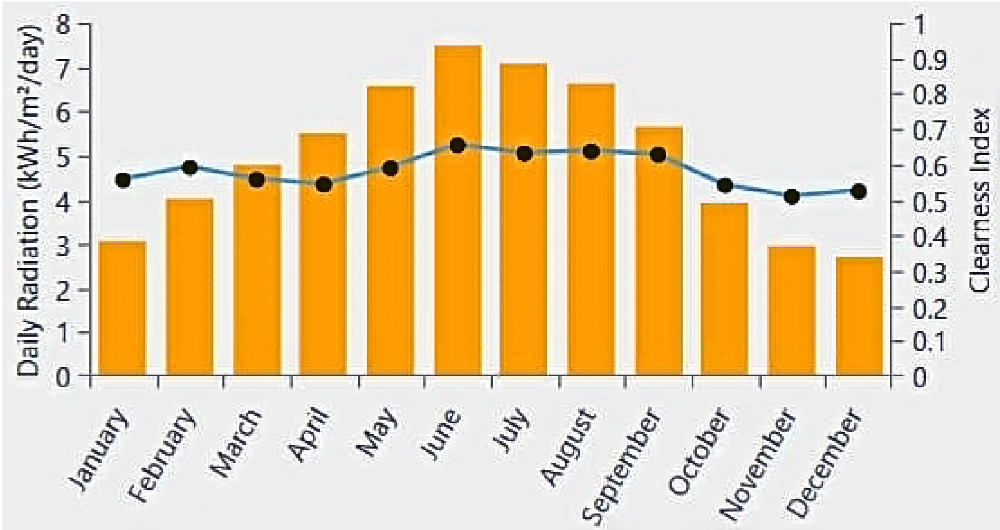

Fig. 4. Average annual solar radiation

Fig. 5. Average annual temperature

Fig. 6. Average annual wind speed

DG with an estimated 100 kW of power and an engine cooling system that uses liquid are selected. The starting price is US$13,000, and the cost of replacement is also US$13,000. The O&M costs are US$15/h. This generator has a 15,000 h lifetime [10]. Diesel costs US$0.3 per litre in Iraq, according to the country's Ministry of Oil [15].

D. BBs (Battery Banks)

The costliest component of RE generation systems is typically the battery. Given the unpredictable nature of solar and wind power generation, PV and WT systems must include battery storage to provide a steady output of electricity. The battery stores energy and helps even out power fluctuations caused by imbalances in supply and demand [16]. The current study uses1 kWh of battery power. The battery costs US$600 initially, US$600 for replacement and US$10 per year for O&M.

The selected battery has a lifetime of 10 years [10]. The total area used for this BB is $132m^3$.

E. Converter

The converter is a crucial part of the system because it receives direct current (DC) power from the PV modules and transforms it into alternating current (AC). It also transforms excess AC power back into DC, such that it may be stored in the battery and used when power processing is not available. The initial investment for this converter is US$4,500, replacement cost is US$4,500 and O&M costs comprise US$10 per year. As a result that whilst operating at a 20 kW conversion rate, the converter has a lifespan of 15 years and an efficiency of 90% [10].

V. System Components Description

Solar and wind power will constitute the backbone of AI-Teeb area's planned hybrid energy infrastructure. In this system, PV, WTs, battery units, DGs and converters will play significant roles. Table II, Table III,Table IV, Table V and Table VI provide the specifications of PV, WTs, DGs, converter and batteries, respectively. The specifications for the components' input can be found in various references [4, 15, 17, 18]. Those prices for those components were obtained through HOMER Pro software due to its direct connection with the global market.

TABLE II.
PV Input Details

Input	Data specifications
Derating factor	90%
Nominal operating cell temperature	47 °C
Temperature coefficient	$-0.48\%/^oC$
Efficiency under standard test condition	13%
Ground reflectance	20%
Cost of capital	US$1,300/kW
Cost of replacement	US$1,000/kW
O&M cost	US$10/kW/year
Lifetime	25 years
Tracking system	Fixed
Dimensions	1.8×1 m2

TABLE III.
WT Input Details

Input	Data specifications
Diameter of rotor	7 m
Rated power	10 kW AC
Capital cost	US$18,000
Replacement cost	US$17,000
O&M cost	US$130/year
Lifetime	20 years
Hub height	24 m
Working wind speed	3–30 m/s
Number of blades	3

TABLE IV.
DG Input Details

Input	Model no. GF285KVA
Power (50 HZ)	100 Kw
Capital cost	US$13,000
Replacement cost	US$13,000
O&M cost	US$0.3/h
Lifetime	15,000 h
Minimum load ratio	25%
Fuel used	Diesel
Rated revolution per minute (rpm)	1500 rpm

TABLE V.
BB Input Details

Input	Data specifications
Nominal voltage	12 V
Nominal capacity	1 kWh
Round trip efficiency	80%
Capital cost	US$600
Replacement cost	US$600
O&M cost	US$10/year
Lifetime	10 years
Dimensions (L×W×H)	0.4×0.09×0.16 = 0.042 m^3

VI. Techniques

As mentioned earlier, the components that are believed to generate electricity include PV systems, WTs and DGs. Hence, the sum of the energy generated by PVs (E_PV), WTs (E_WT) and DG systems (E_DG) is equal to the total energy created (E_T). Consequently, the percentage of total energy produced that originates from each source (f_pv,f_WT,f_DG) is as follows:

$$f_{pv} = \frac{E_{pv}}{E_T} \tag{1}$$

$$f_{WT} = \frac{E_{WT}}{E_T} \tag{2}$$

$$f_{DG} = \frac{E_{DG}}{E_T} \tag{3}$$

TABLE VI.
BB INPUT DETAILS

Input	value
Size	20 kW
Capital cost	US$4,500
Replacement cost	US$4,500
O&M cost	US$10/year
Lifetime	15 years
Efficiency	95%

Three major economic indicators, namely, the total cost of energy (COE), the initial capital cost (IC) and the net present cost (NPC), are considered in this study. The value of NPC is based on a mathematical concept. It is more dependable than COE with regard to economic considerations [17, 18]. COE refers to the average price per kWh of the system's usable electrical energy. To determine COE, the cost of electricity generation is divided by the total amount of supplied electricity. COE can be expressed as follows:

$$\mathrm{COE}\left(\frac{\$}{\mathrm{kWh}}\right)=\frac{\text{Total Net Present Cost}}{\sum_{h=1}^{8760} P_{\text{load}}}\times \mathrm{CRF} \tag{4}$$

where P-Load (h) is the hourly power consumption, CRF is the capital recovery factor and total NPC (TNPC) is the sum of all component costs. The following represents the CRF equation:

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

where N is the system's lifetime or (amortisation term), and i is the real interest rate [10].
The following formula can be used to determine each configuration's TNPC:

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

where C_cap is the total installation capital components cost at the onset of the project, C_Rep is the total replacement cost for all the components, $C_(O\&M)$ is the total O&M cost for all the components of the system, C_f is the total fuel cost and C_Salv is the salvage value of the system.
The phrase 'salvage value' is used to define the end-of-project value of a power system component. This value is expected to decrease at a linear rate, which is directly proportional to remaining life. In addition, instead of capital cost, replacement cost is used as the basis, and the value of each part may be shown as follows:

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

where C_rep is the replacement cost (US$), R_comp is the component lifetime (year) and R_rem is the remaining costs of the components (US$). After the best component mix for each location is determined, the subsequent environmental effect of each system is also computed. The whole carbon footprint is used to evaluate the associated environmental effect. We also calculate the yearly electrical energy generation of each part for the most optimal systems that may be implemented [17, 19].

VII. SCENARIOS, RESULTS AND DISCUSSIONS

In this section, we present many potential outcomes regarding the use of various energy sources to power the Al-Teeb area. For every possible outcome, we calculate COE and NPC. However, the simulation does not account for rent, taxes or any other expenses. To address power outages, this study examines the practical sizing of a PV–WT hybrid system. This system includes a battery unit for power storage, a DG for operating reliability and auxiliary tools. This goal is achieved by using optimisation in the HOMER programme to find the best configuration for the system and choose components with the right sizes for a renewable hybrid energy system. We enter all the location-related variables and data that pertain to RES and HS, such as solar radiation, temperature, wind speed, available PV, WTs, DGs, battery size, project lifetime, location coordinates and all the price details (i.e. capital, replacement and O&M costs).

Single, double and triple sources are exhausted. To find the optimal design that is also flexible, we examine the specifics of the operating patterns for each of the suggested combinations and assign a number to them to present the pros and cons of each system. To find the optimal system design by ensuring the best possible matching of supply and demand, hourly simulations for each scenario are run iteratively hundreds, if not thousands, of times. In every case, the output results of the hybrid energy system indicate that it is superior to the single energy system. The results of these simulations are presented in Table VII.

Case 1 considers the system's economic feasibility whilst integrating PV, WT, DG and battery storage to ensure a steady and dependable power supply. In Cases 2 and 3, the components of the hybrid system are PV–DG-BB and WT–DG-BB respectively. DG can theoretically generate limitless power (subject to fuel availability), but the system cannot rely solely on DG due to financial considerations.

TABLE VII.
LIST OF EMPLOYED SITUATIONS

Situations	PV	WT	DG	BB	Converter
1	✓	✓	✓	✓	✓
2	✓	X	✓	✓	✓
3	X	✓	✓	✓	✓

A. Scenario PV–WT–DG–BB

The components shown in Fig. 7 are PV, WT, DG, BB and converter, which are parts of this scenario. The simulation results of amount of energy which that comes from each type of sources are presented in Fig. 8.

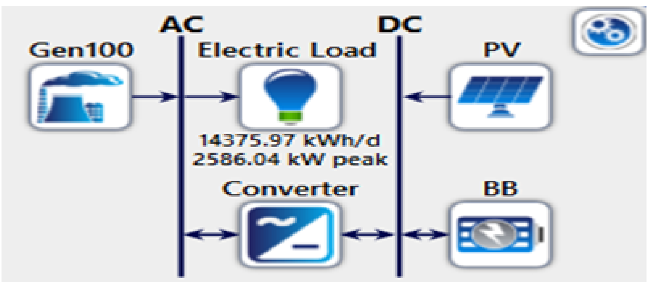

Fig. 7. System design

B. Scenario PV–DG–BB

PV, DG, BB and converter are the parts involved in this scenario, as shown in Fig. 9. Fig. 10 displays the outcomes of energy sources which that comes from each type of sources and simulations conducted on these parts.

C. Scenario WT–DG–BB

Fig. 11 shows the components that are parts of this scenario, namely, WT, DG, BB and converter. Fig. 12 presents the outcomes of the simulations for these parts and explain the amount of energy from each source.

D. Results of Scenarios

For the neighbourhood under study, Table VIII provides the designs for each scenario. The total annual electrical energy production of each of the three sources of generation, i.e. DGs, WTs and PV, is calculated. The goal of HOMER is finding the most economical solution that can manage electrical loads and operational reserves. To avoid capacity shortage, any expenditure will be compensated by HOMER because fulfilling load demand and preserving operating reserves are critical duties. However.
If the proposed combinations of the dispatchable sources can meet the load requirements just as effectively, then HOMER will choose the one with the lowest cost. Evidently, certain scenarios may meet their electrical demands completely through the use of RE. Thus, a comprehensive economic analysis is required to determine the best-case scenario for the site. We utilise the system's IC in US dollars, its NPC in US dollars and its COE in US dollars per kWh to economically examine the proposed solutions. The Al-Teeb area is located in south-eastern Iraq, not far from the Iranian border, and this research investigates potential methods for producing RE in this area. Finally, the results of the HOMER under the rule Right of Way prove beyond doubt the total cost (NPC) AND (COE) in Scenario PV–WT–DG–BB are minim to obtain best results compared with another scenarios.

TABLE VIII.
LIST OF EMPLOYED SITUATIONS

Station	1	2	3
NPV	1215	1416	—
NWT	59	—	99
NDG	13	13	13
NBT	3138	3529	3798
NConv	47	125	383
COE (US$/kWh)	0.155	0.160	0.189
NPC US$M	14.2	14.6	17.2
IC US$M	4.91	4.37	4.46

In accordance with the details, the most economically feasible design for Al-Teeb is Case 1 (PV–WT–DG–BB), which has the lowest NPC, COE and IC values. From Table 9, the majority of the electrical load in Case 2 (PV–DG) and Case 3 (WT–DG) is supplied by RE. Meanwhile, Case 1 achieves the RE objective and offers a more sustainable design as mentioned earlier.

E. Modified Particle Swarm Optimization (PSO) Algorithm

Many approaches and algorithms are considered artificial intelligence algorithms at present. The PSO technique is a widely utilised tool. This approach was presented by Kennedy and Eberhart in 1995. It has been effectively used in computational intelligence, solving challenging global optimisation issues across several scientific domains [20]. As early as 1998, Shi and Eberhart [21] suggested incorporating a method into PSO. To manage the original PSO's diversification–intensification behaviour, they added a 'time-varying inertia weight, w(t)' to the fundamental PSO. This new rule is for velocity updates:

$$v_i^{t+1} = v_i^t + c_1 U_1^t (p\_b_i^t - x_i^t) + c_2 U_2^t (g\_b^t - x_i^t) \tag{8}$$

$$v_i^{t+1} = w(t) \cdot v_i^t + c_1 \cdot U_1^t \cdot \left(p_{b,i}^t - x_i^t\right) + c_2 \cdot U_2^t \cdot \left(g_b^t - x_i^t\right) \tag{9}$$

U_1^t and $U_2^t$are two random numbers that vary between 0 and 1. From its starting value to its ultimate value, the

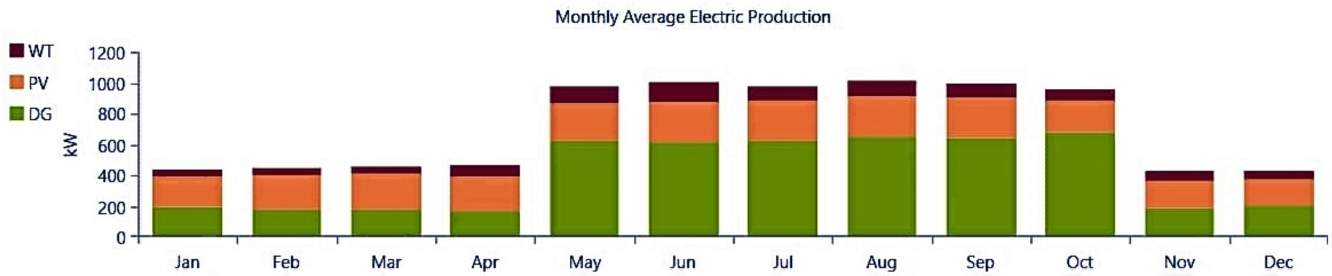

Fig. 8. Simulation results

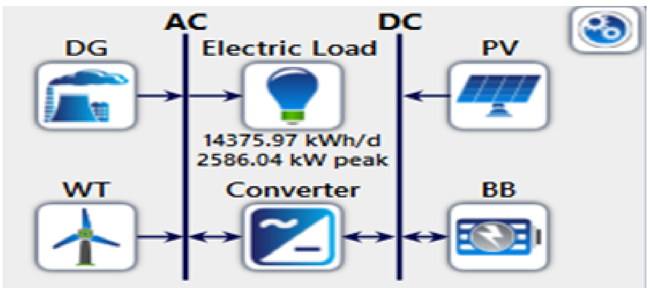

Fig. 9. System design

time-varying inertia weight, w(t), frequently follows a linear pattern. Parameters $c_1$and c_2 are typically both set to 2 [18]. Two methods are available for changing the inertia weight with respect to time. With time-varying inertia weight, the value of the inertia weight varies between iterations. Shi and Eberhart coined the term 'Dec-IW' [21] to describe a situation wherein its values constantly fall. The term 'Inc-IW' was first coined by Zheng et al. [20], and it describes a situation wherein the value of w(t) is continually increasing. For Dec-IW, the inertia weight is typically set to 0.9, with a final value of 0.4, For Inc-IW, it ranges from 0.4 to 0.9. For the sake of completeness, both versions are sometimes presented. Theoretically, it may be expressed as For Dec-IW

$$w(it) = W_{\max} - \frac{W_{\max} - W_{\min}}{it_{\max}} \cdot it \tag{10}$$

For Inc-IW

$$w(it) = W_{\max} + \frac{W_{\max} - W_{\min}}{it_{\max}} \cdot it \tag{11}$$

w (it) is the inertia weight changes as iteration count changes, W_{max} is the maximum possible inertia weight (0.9), W_{min} is the minimum possible inertia weight (0.4), it is the iteration number and t_{max} is the maximum number of iterations. Furthermore, the following expression determines position updates [20]:

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{12}$$

F. Results of The Modified PSO (MPSO) Algorithm

The following location-specific variables and data are entered: solar radiation, temperature, wind speed, available PV size, WT, DG, BB, project lifetime, project coordinates, price details (i.e. IC, replacement cost RC and O&M cost) and the number of components of the hybrid power system. The typical yearly energy consumption for a load profile is approximately 20,716.454 kWh/day. Various operation modes are implemented as part of the power management strategy for the hybrid microgrid system to provide a continuous supply of power regardless of the load demand. To determine the fastest option for the site, extensive techno-economic study is conducted. To examine the proposed systems from an economic perspective, the COE indicator and TNPC are used along with the minimum number of all components, such as PV–WT–DG–BB. Finding the best solution for optimisation problems by using the PSO technique requires a precise representation of the target function and its restrictions in each particle. Particles in each swarm start with an arbitrary location and velocity values in accordance with all the limitations (e.g. minimum and maximum hybrid components, reliability) and PSO characteristics. One population is used in this study, and each population undergoes 500 rounds of swarm motion. We believe that 500 iterations is the upper limit for each population. Thereafter, we update the location and velocity values each time, keep the best values and disregard the bad ones. The search ends when the total number of iterations reaches the maximum value.

The results demonstrate a low COE of 0.117 US$/kWh and a low TNPC of 14.2 M US$. The most ideal configuration for a hybrid renewable energy system is determined to be NPV (1,235), NWT (58), NDG (12), NBB (3112) and NConv (46) in accordance with the data in Table X. In this investigation, the global optimal point is reached at an iteration number of 4464. Table IX provides the percentage of energy generated each year by PV, WTs and DGs. The development of such

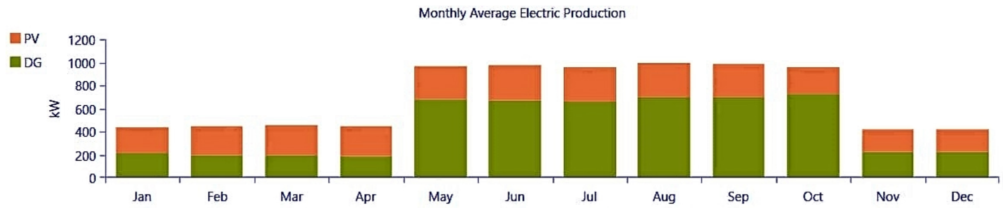

Fig. 10. Simulation results

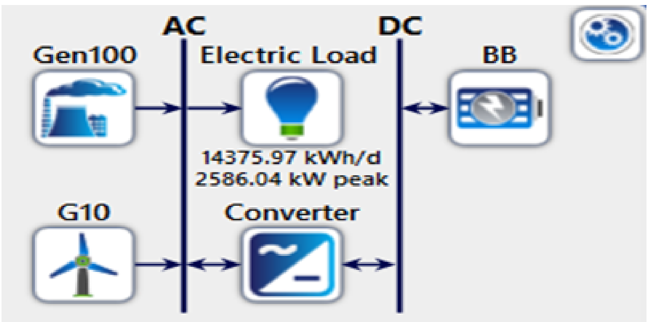

Fig. 11. System design

TABLE IX.
SIMULATION RESULTS OF THE MPSO ALGORITHM

N	Station	MPSO
1	Number of PV (NPV)	1235
2	Number of WTs (NWT)	58
3	Number of DGs(NDG	12
4	Number of Batteries(NBT)	3112
5	Number of Converters(NConv)	46
6	Cost of Energy ($/kWh)(COE)	0.117
7	Loss Power Supply Probability(LPSP)	0.2065 %
8	Number of Global Best(NGB)	4465
9	Renewable Energy Penetration(REP)	18.00 %
10	Reliability(REL)	79.35 %
11	Annual Energy Provided by PV	0.28 %
12	Annual Energy Provided by WTs	29.48 %
13	Annual energy provided by DGs	21.91 %
14	Total NPC (million US$)(TNPC)	14.2

systems can be complex and difficult because the optimal combinations are at distant points with the same fitness value and different configurations in the objective domain. The system designer is assigned the ultimate optimal solution on the basis of certain factors, including the location and availability of energy sources, the desires of the designer and the needs, implementation, creation and expansion of existing systems.

G. Comparison Between Results and Discussion

Table X clearly compares between the two active and valuable methods, the HOMER programme and the MPSO algorithm to obtain optimal and global solutions for the size optimisation, economics, energy management and expansion plans of many hybrid energy systems in selected regions in this study. A slight difference between the two methods is attributed to the numerous parameters in the HOMER programme, whilst the MPSO algorithm is developed in MATLAB with defined objective functions in the code of MPSO.

TABLE X.
COMPARISON BETWEEN THE RESULTS OBTAINED USING HOMER PRO AND THE MPSO ALGORITHM.

Station	HOMER Pro	MPSO
NPV	1,215	1,235
NWT	59	58
NDG	13	12
NBT	3,138	3,112
NCon	47	46
COE (US$/kWh)	0.155	0.135
NPC (US$M)	14.2	14.2
IC (US$ M)	4.91	4.9

Some common limitations in research studies that other researchers might address:

1. Sample Size: A small sample size can limit the generalizability of the results. Future research could use a larger, more diverse sample.
2. Sampling Bias: If the sample is not representative of the population, the findings may not be widely applicable. Researchers could use more rigorous random sampling methods.
3. Study Design: Limitations in the study design (e.g., observational vs. experimental) can affect the ability to infer causation. Future studies could employ more robust experimental designs.
4. Measurement Tools: If the tools or instruments used to measure variables are not reliable or valid, the results may be questionable. Researchers could use or develop more precise measurement tools.

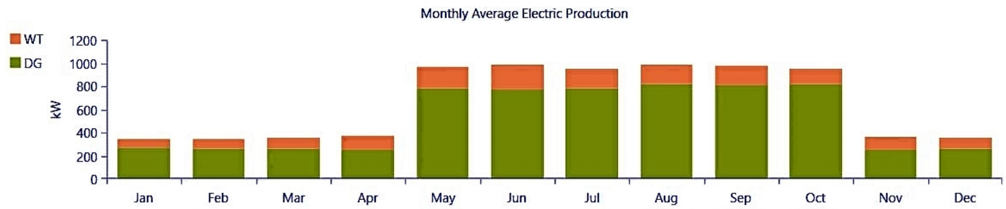

Fig. 12. Simulation results

5. Confounding Variables: Uncontrolled confounding variables can impact the study's findings. Future research could control for or account for these variables more effectively.
6. Temporal Limitations: Studies conducted over a short period may not capture long-term effects. Longitudinal studies could address this limitation.
7. Geographic and Cultural Limitations: Results from one geographic or cultural context may not be applicable to others. Future research could include multiple sites or diverse cultural settings.
8. Self-Report Bias: If the study relies on self-reported data, responses may be biased. Using objective measures or multiple data sources could mitigate this issue.
9. Ethical Constraints: Certain ethical considerations may limit the scope of a study. Future research could find ethically appropriate ways to address these limitations.
10. Technological Limitations: The technology or methods used might be outdated or less effective. Researchers could use more advanced or appropriate technology.

VIII. Storage System

The batteries of the system keep it running and reduce the difficulties with unpredictability that typically occur with RE sources. A storage system's autonomy hours measure the number of hours that it can provide a constant power supply. Fig. 13 shows the average charge status for each hour of the year, this figure Ilustre the contribution of battery banks to proved energy to the load, in first months of year, the state of charge about 95% to 100% because the another sources are sufficient to supply Demond. In summer season and increase of the loads, the state of charge is reduced to 40% because the battery backs will be became as source of energy. The monthly state of charge, with the yearly average, lowest (negative) and highest (positive), is shown in Fig. 14. Where every colour is represented state of charge, for example below, the percentage state of charge 0% t0 20%, yellow 60%, as so on.

IX. Conclusions

This study offers a comprehensive and methodical evaluation of different off-grid options for isolated, rural border areas in Iraq. Different configurations of PV, WT and DG units were included in seven scenarios that were presented and assessed. COE, NPC and IC were determined as economic metrics. Amongst all the examples that were analysed,

Case 1 (PV–WT–DG–BB) had the lowest NPC and COE values with 58% RE penetration and was found to be a workable system, making it the most economical option for the Al-Teeb area. The surplus energy produced in the first case could be beneficial if both population and energy demand increase, leading to more vibrant economic activities in the city. In addition, generating energy with WTs is more economically profitable than using PV panels.

The three cases were discussed in detail through their outcomes, and it was observed that all of them integrate the main components of the system. The first case, which combines all the system components (PV-WT-DG-BB and Con), was identified as the ideal case to supply the Al-Teeb Area with a complete electrical load and ensure load stability from that generation. The primary criteria for selecting the preferred case were the Cost of Energy (COE) and Total Net Present Cost (TNPC) as mentioned above. The costs of the main system components in the first case were applied using the PSO algorithm, and the results were found to be close to those from the HOMER Pro software. Therefore, it became clear that the first case is the best for implementing this system. NPC and COE are US$14.2 million and US$0.155/kWh, respectively. Number of PV (1,215), number of WTs (59), number of DGs (13), number of batteries (3,138), number of converters (47). In accordance with the findings, a relatively small carbon footprint

associated with the DG–RE combination exists. The suggested hybrid power system can lower the amount of greenhouse gas (e.g. CO2) emissions in the city's local atmosphere. Throughout the hybrid plant's lifetime, a complete reduction of greenhouse gas emissions in the city's local atmosphere will be achieved, guaranteeing improved health conditions for the populace and significant financial savings on medical expenses. The greatest possibilities are hybrid designs and

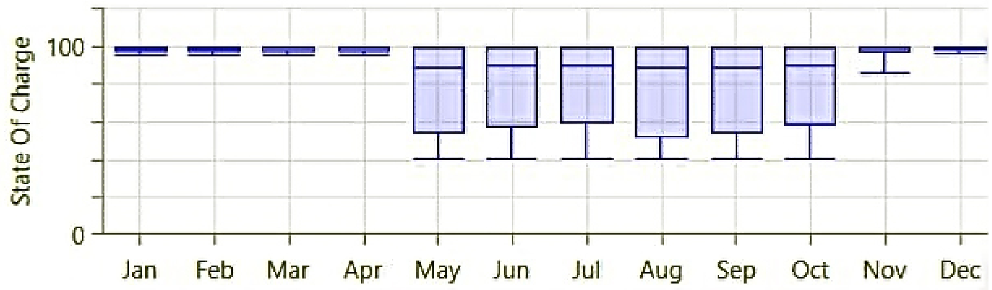

Fig. 13. State of charge

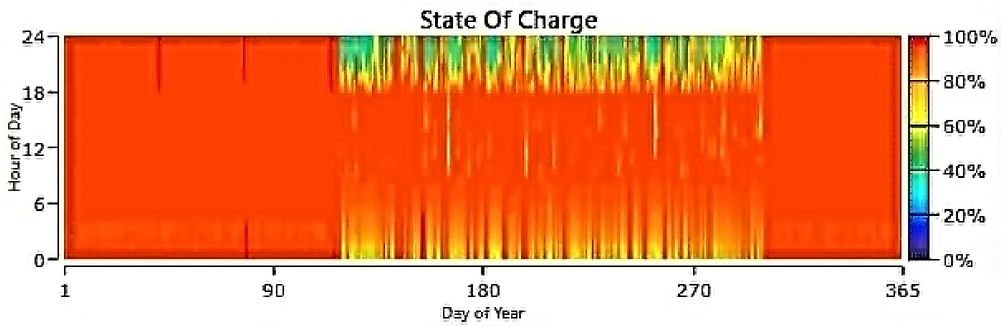

Fig. 14. State of charge

fully RE systems. However, two major obstacles remain: the relatively high O&M costs and the substantial start-up capital expenditure are beyond the resources of low-income rural communities in Iraq. The Iraqi government should actively encourage the use of hybrid RE-based designs for electrification in rural areas as a potential option. By using the simulation results, other researchers can examine and develop future RE generation systems for various regions.

Conflict of Interest

The authors have no conflict of relevant interest to this article.

Author Contributions

For this article, the contributions of authors can be summarize as follows: Conceptualization, Jabbar R. Rashed; methodology, Jabbar R. Rashed; software, Husam A. Salim; validation, Jabbar R. Rashed; formal analysis, Husam A. Salim; investigation, Jabbar R. Rashed; resources, Jabbar R. Rashed and Husam A. Salim; data curation, Husam A. Salim; writing—original draft preparation, Husam A. Salim; writing—review and editing, Jabbar R. Rashed; visualization, Jabbar R. Rashed; supervision, Jabbar R. Rashed; project administration, Jabbar R. Rashed; funding acquisition, Husam A. Salim.

Nomenclatures	
I	Real interest rate
N	Lifetime for the system
Abbreviations	
BB	Battery bank
COE	Cost of electricity
CRF	Capital recovery factor
DG	Diesel generator
HPGS	Hybrid power generator system
IC	Initial cost
NBB	Number of battery banks
NConv	Number of converters
NPC	Net present cost
NPV	Number of photovoltaics
NWT	Number of wind turbines
NDG	Number of diesel generators
O&M	Operating and maintenance costs
PV	Photovoltaics
RE	Renewable energy
WT	Wind turbine
M	Million
HS	Hybrid system
GHG	Greenhouse gas

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