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Optimum Design and Energy Management of Hybrid Power Generation Systems, Case Study: AL-Teeb District

A Thesis

Submitted to the Electrical Engineering Department, Faculty of Engineering, Misan University, In Partial The Fulfillment of the Requirements for the Degree of Master of Science in Electrical Engineering

By

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Abstract

To overcome the problems of the conventional electrification of rural border areas from main grid such as long distance, high expensive cost, noneconomic feasibility….etc, the investigation for optimal and best use of alternative energy sources available in this region becomes the lucrative , valuable and, feasible solution of this dilemma. This study focuses on the techno-economic feasibility analysis of an off-grid system that includes photovoltaic panels (PV), wind turbines (WT), and diesel generators (DG) for such regions to achievement the planned goal which is optimum design and energy management of Hybrid Power Generation Systems. The thesis presents a case study of a rural area Al-Teeb District located in the southeastern part of the Iraqi-Iranian border. Five different algorithms based on MATLAB (PSO, Bat Algorithm, Grey Wolf Optimization Algorithm, Dragonfly Optimization Algorithm, and Cuckoo Search Algorithm) are used in this study, along with the HOMER Pro software. When designing a Hybrid Renewable Energy System (HRES), it is crucial to balance five objectives: cost of energy (COE), initial cost (IC), total net present cost (TNPC), reliability (REL), and loss of power supply probability (LPSP). Based on the results from the Bat Algorithm, the ideal values for implementing this system are found to be as follows: (NPV) (1200), (NWT) (47), (NDG) (5), (NBT) (3100), (NCon) (43), COE (0.108 USD/kWh), LPSP (0.0015%), REL (99.848%), initial cost (IC) (4,520,340 USD), and TNPC (8,634,048 USD). The results also indicate that the algorithm successfully reached optimal solutions that contributed to reducing the total costs. Finally, it was concluded that the HRES approach is a suitable way to meet the electricity demands of rural, remote areas in Iraq and other developing countries with similar climates.

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List of Abbreviations

Abbreviation	Definition
HPGS	Hybrid power generator system
COE	Cost of electricity
IC	Initial cost
NPC	Net present cost
NPV	Number of photovoltaics
NWT	Number of wind turbines
NDG	Number of diesel generators
NBB	Number of battery banks
NConv	Number of converters
BB	Battery bank
PV	Photovoltaics
DG	Diesel generator
WT	Wind turbine
Conv	Converters
CRF	Capital recovery factor
DOA	Dragonfly Optimization Algorithm
GWOA	Grey Wolf Optimization Algorithm
PBS	Power Banking Storge

Abbreviation	Definition
O&M	Operating and maintenance costs
M	Million
HS	Hybrid system
HOMER	Hybrid Optimization Multiple Energy Resources
PSO	Particle Swarm Optimization
BA	Bat Algorithm
MPSO -TVIW	Modified PSO or Time Varying Inertia Weight Particle Swarm Optimization
HPSO-TVAC	Self-Organizing Hierarchical PSO with Time-varying Acceleration Coefficients
LPSP	Loss of Power Supply Probability.
CSA	Cuckoo Search Algorithm
MOAs	Metaheuristics Optimization Algorithms
RE	Renewable energy
CRF	Capital recovery factor
TNPC	Total Net Present Cost
REL	Reliability
REP	Renewable Energy Penetration

List of Symbols

Symbol	Definition
Y_{PV}	is the PV rated capacity (kW), meaning its output power
f_{PV}	is the de-rating factor of PV
G_T	is the episode of the solar irradiation on the PV panels in the current time step (kW/m2)
$G_{T,STC}$	is the incident irradiance at standard test conditions (1 kW/m2)
a_P	is the temperature coefficient of power (%/°C).
T_C	is the temperature of PV cell (°C) in the current time step
$T_{C,STC}$	is the temperature of PV cell under standard test conditions (25 °C)
E_L	is the average daily load energy (kWh/day)
AD	is the number of days of battery autonomy
DOD	is battery depth of discharge
η_{inv} and η_{Batt}	represent inverter and battery efficiency respectively
E	is the total energy output (Wh)
V	is the battery voltage (in volts, V)
I	is the battery discharge current (in amperes, A)
f_{PV}	Fraction of energy generated by photovoltaic systems
f_{WT}	Fraction of energy generated by wind turbine systems
f_{DG}	Fraction of energy generated by diesel generator systems
t	is the discharge time (in hours, h)

Symbol	Definition
F_G	Diesel generator is model based on its fuel consumption pattern
$P_{G-rated}$	is the nominal power of the diesel generator
P_{G-out}	is the output power
$A_G \& B_G$	represents the coefficients of the fuel consumption curve as defined by the modeler (l/kWh)
P	is the real or active power output of the diesel generator (in watts, W)
V	is the voltage of the generator (in volts, V)
I	is the current produced by the generator (in amperes, A)
cos a	is the power factor of the generator, which represents its efficiency in converting apparent power to real power, It's a dimensionless value between 0 and 1
$\sqrt{3}$	is a constant factor representing the square root of 3, which is often used in three-phase electrical systems
P_{WT}	output power of the wind turbine (kW)
A	is the swept area of wind turbine (m2)
ρ	is air density (kg/m3)
V	is the wind velocity (m/s)
C_{pmax}	is the wind power coefficient, usually taken as 0.59
P_{load}	is the hourly power consumption
i	is the real interest rate
N	is the system's lifetime
C_{cap}	The total installation capital components cost at the onset of the project

Symbol	Definition
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
C_{rep}	are the replacement cost (US$)
R_{comp}	are the component lifetime (year)
R_{rem}	are the remaining costs of the components (US$)
x_i^{t+1}	The new velocity of particle i at time t+1. This velocity determines how the particle's position will be updated in the next step
v_i^t	The current velocity of particle i at time t. This is the velocity that will be adjusted based on the particle's personal and social influences
pb_i^t	The personal best position of particle i at time t, representing the best position the particle has found so far
x_i^t	The current position of particle i at time t. This is the particle's current location in the search space
gb^t	The global best position at time t, which is the best solution found by any particle in the swarm
$c_1\&c_2$	is called cognitive parameter is called social paramete } both are called acceleration coefficients
$U_1^t\&U_2^t$	are two random numbers varies between 0 to 1
K	is a random number which varies from 0 to 1
Dec-IW	Decrease inertia weight
Inc-IW	Increase inertia weight

Symbol	Definition
w (it)	The inertia weight changes as the iteration count changes
W_{max}	The maximum possible inertia weight is 0.9
W_{min}	The minimum possible inertia weight is 0.4
it	Iteration number
it_{max}	The maximum number of Iteration
K	is a weighting function
f_i	the frequency for bat i
f_{min}	the minimum frequency
f_{max}	the maximum frequency
r	a random number uniformly distributed in the range [0,1]
x_*	is the global best solution found so far
r_i^{t+1}	the pulse rate of bat iii at iteration t+1
r_i^0	the initial pulse rate of bat i
γ	a constant that controls the rate of increase in pulse rate
A_i^{t+1}	the loudness of bat i at iteration t+1
A_i^t	the current loudness of bat i at iteration t
α	a constant typically set between 0 and 1 to reduce loudness over time
x_{best}	is the best − found position.
σ	is a standard deviation.

Symbol	Definition
β	is a parameter that defines the level of randomness in the movement.
ϵ	is a random variable.
D_i	is the distance between the wolf i and the best solution found (alpha wolf)
C	is a coefficient vector that influences the convergence of the algorithm
r_1 and r_2	are random vectors in the range [0, 1]

Chapter (1)
Introduction

1.1. Background

This chapter provides a detailed explanation of the hybrid energy system's components and the software and algorithms used. It also outlines the main objective of this thesis, highlighting the overall approach and methodology adopted in the study.

The world's energy systems have traditionally relied on large-scale hydropower and fossil fuels (coal, oil, and natural gas) to generate electricity. When it comes to serving rural or outlying communities, however, these traditional methods have major limitations. The high expense of producing and transmitting power across great distances is one of the main problems. Power lines, substations, and transformers are all part of the electrical transmission infrastructure, and they can be costly to construct and operate, especially in remote or otherwise difficult-to-access places [1].

Since traditional power generating frequently requires large amounts of fuel and must comply with environmental standards, it tends to be more expensive than other techniques. Further exacerbating these costs are the logistical challenges associated with transporting fuel and maintaining equipment in remote places. Energy providers find it economically unfeasible to invest in infrastructure in border regions and rural areas due to the low population [2].

Alternative solutions for electrifying border and distant locations have been the subject of study in response to these issues. Because of their lower operating costs and relative ease of deployment in remote areas, renewable energy sources like solar, wind, and small-scale hydropower offer great promise as an integrated energy solution. Compared to conventional power generating methods that rely on fossil fuels, these renewable technologies often have less environmental impacts and lower operational costs [3].

Increasing access to electricity in border and rural areas has been the focus of numerous recent studies. For example, microgrids and solar household systems are examples of localized energy systems that can deliver consistent power without investing in costly and expansive transmission infrastructure. A community's unique energy demands can be met by customizing one of these systems. Additionally, batteries and other energy storage innovations have made it more practical to store renewable energy for usage during off-peak hours [1].

A steady and uninterrupted supply of electricity is another concern for governments and organizations, thus they are looking into hybrid systems that integrate renewable and conventional power sources. With the help of these hybrid systems, you may save money and increase reliability by playing to each technology's strengths [2].

Ongoing research and technical breakthroughs offer hopeful solutions to the sub-stantial issues posed by traditional power generation methods in remote and rural places. Improving power availability in underserved locations is achievable through the utilization of renewable energy sources and decentralized systems. This, in turn, can improve quality of life and promote economic development [3].

1.2. Types of Hybrid Power Generation System

A more efficient and dependable power supply can be achieved through the integration of several energy sources in a (HPGS). Solar and wind power, along with more traditional power sources like diesel generators and energy storage devices like battery banks, make up the backbone of HPGS. Energy reliability, operational costs, and environmental effect can all be improved through this integration. In areas that are not connected to the grid, HPGS can offer a reliable and long-term power solution by combining the best features of each component.

1.2.1. Renewable Energy Systems

Using renewable energy sources allows us to tap into naturally occurring resources that can be restored within a human lifetime. Here are the most common kinds:

- **PhotoVoltaic (PV) panels:** are the heart of solar power systems, which harness the sun's rays and turn them into usable electricity. There is a wide range of potential applications for this technology, from modest home installations to massive utility-scale solar farms. The size and efficiency of the installation determine the normal output power of solar panels, which can range from 250 watts to several megawatts. Low operating costs and little environmental impact are two of solar power's main selling points. However, solar power is intermittent because it depends on sunshine availability, which can change depending on the weather and the time of day [4].

- **Wind Power:** Turbines that spin in the wind use its kinetic energy to generate electricity. Both residential and commercial wind turbines, as well as large-scale wind farms, are able to capture wind energy and feed it into the power grid. Small turbines can provide a few kilowatts of power, whereas huge commercial turbines can produce many megawatts. Although wind power is successful in regions with regular wind patterns, it necessitates a large investment in infrastructure and ongoing maintenance [5].

1.2.2. Diesel Generators

Electricity is generated by diesel generators through the combustion of diesel fuel, which powers an engine that is linked to a generator. Important aspects consist of different sizes of diesel generators are available, ranging from small, portable devices for emergency power to massive, industrial-scale machines that run nonstop. Generators can be as little as a few kilowatts or as large as several megawatts, depending on their size and design. Due to their durability and dependability, diesel generators are ideal for use in outlying locations and in the event of an emergency [7].

In places where the power grid is unreliable or not available, diesel generators are commonly employed. When renewable energy sources are unavailable or not enough, they are also used in hybrid systems to generate power. Although they are a reliable backup supply because of the continuous power they produce, their increased operational expenses and fuel consumption and emissions pose environmental problems [8].

Diesel generators have the advantage of being able to run regardless of the weather, making them a dependable and steady power source. Their sustainability is compromised, nevertheless, because to their increased fuel prices and their contribution to greenhouse gas emissions [9].

1.2.3. Power Banking Storge

To generate and store electricity, battery banks use networks of interconnected batteries. Here are the key features:

- Battery banks can contain a variety of types of sophisticated batteries, such as lead-acid, lithium-ion, and others. As an alternative to conventional lead-acid batteries, lithium-ion batteries are gaining popularity because of their superior energy density, increased longevity, and less maintenance requirements [10].
- Battery banks are utilized to store renewable energy excess, which can then be utilized during times of low generation or high demand. In order to provide a steady power supply, balance demand, and lessen reliance on diesel generators, they are essential [11].
- Number of kilowatt-hours (kWh) or megawatt-hours (MWh) that a battery bank can store varies from one system design to another. A battery bank can be anything from a tiny home unit to a massive industrial installation. Large quantities of energy can be stored using advanced storage devices, allowing renewable energy sources that are intermittent to be used more effectively [12].
- Benefits: They allow energy consumption during off-peak hours and provide a buffer against the intermittent nature of renewable sources, which increases the stability and reliability of the energy supply. This contributes to enhancing system efficiency and decreasing operational expenses [13].

1.3. Hybrid Power Generation Systems

To improve the reliability and efficiency of the power supply, (HPGS) integrate multiple energy sources. Important aspects of this system can be explain it briefly in this section:

- **The components of an HPGS:** combines traditional power sources (diesel generators) with renewable power sources (solar, wind, hydropower) and energy storage devices (batteries). The intermittent character of renewable energy sources can be mitigated through this integration, which contributes to a steady and uninterrupted power supply Figure(1.1) [14].
- **Application:** High-performance solar generators are used in places where conventional electricity lines cannot reach, such as in rural or off-grid areas.

They also help grid-connected systems become more efficient and dependable by reducing the effects of renewable energy sources that aren't always available [15].

- **Power:** An HPGS's power output is proportional to the number and size of its integrated components. Because of their scalability, these systems may be tailored to a building's or community's unique energy demands [16].
- **The benefits of HPGS** include increased dependability, reduced costs, and less environmental impact because to the integration of each energy source's best features. As a result, we use less fossil fuel, have cheaper operating costs, and have a more reliable and long-term source of energy [17].

Finally, by integrating many energy sources into a single, robust and efficient system, HPGS provide a flexible answer to the problems associated with power generation. Improved energy reliability, lower prices, and sustainability are all outcomes of this strategy.

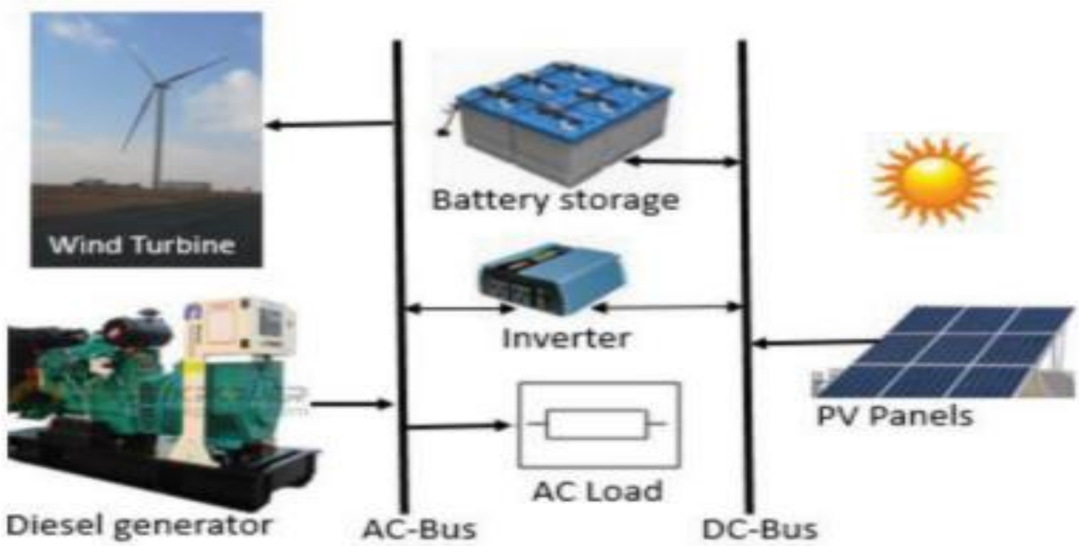


Figure (1.1): WT-PV-DG & BT for HPGS.

1.4. Some of Valuable Optimization Software

The (HPGS) rely heavily on optimization tools for effective design and administration. A dependable and inexpensive energy supply is guaranteed by these systems, which integrate several energy sources like solar, wind, and diesel. These systems' efficiency and performance can be greatly affected by choosing the wrong optimization software. (PSO) and HOMER Pro are two well-known optimization tools utilized in HPGS.

1.4.1. HOMER Pro

Hybrid power systems can be evaluated and optimized with the use of HOMER Pro, an optimization tool that has gained widespread recognition. It gives a complete set of tools to evaluate various energy resource and storage solution combinations. One of HOMER's strongest points is its capacity to simulate intricate power grids that integrate renewables like (WT) and (PV) panels with more traditional components like generators and batteries.

When assessing potential outcomes, the program employs a mix of deterministic and stochastic techniques. In order to find the most sustainable and cost-effective energy mix, HOMER takes into account things like energy prices, environmental implications, and load profiles. You can evaluate the impact of changing input variables on the system's performance using its comprehensive sensitivity analysis features. In both urban and rural areas, HOMER has proven to be an excellent optimization tool for HPGS designs, proving its adaptability and usefulness in many contexts. [177]

1.4.2. Metaheuristics Optimization Algorithms (MOAs)

Metaheuristic algorithms are computational intelligence paradigms especially used for sophisticated solving optimization problems. This theses aims to use some of metaheuristics related issues. The major algorithms selected subcategory are discussed including:

1- Particle Swarm Optimization:
   a- Canonical PSO [18].
   b- MPSO) or TVIW-PSO [19].
   c- HPSO-TVAC [20].
2- BA [21].
3- CSA [22].
4- DOA [23],[24]
5- GWOA [25].

The optimization techniques (a, b, and c) which was mentioned above known as PSO takes its cues from the cooperative actions of fish and birds. Its primary application is the optimization of solutions in spaces that are both complicated and multidimensional. The core of PSO is the initialization of a swarm of particles, which are solutions in search of a problem. Particles learn from one another and their surroundings to fine-tune their positions, eventually settling on the best possible arrangement[26].

The ease and success with which PSO resolves a wide range of optimization issues have earned it widespread acclaim. When more conventional optimization methods fail, it comes in handy. Utilizing PSO within the framework of HPGS allows for the optimization of the dimensions and arrangement of various energy components, including renewable power sources, batteries, and generators. It is a useful tool for optimizing hybrid power systems since it can handle various sorts of problems, such as continuous and discrete optimization.

Bats use echolocation to navigate and locate prey in darkness by emitting sound pulses and analyzing the echoes that bounce back. The fourth Optimization method which was named BA models this behavior to find optimal solutions to complex optimization problems by combining exploration and exploitation of the search space.

This algorithm employs multiple virtual bats, each representing a potential solution to the optimization problem. The positions and velocities of these bats are updated iteratively based on specific equations, with the goal of converging toward an optimal solution [21].

The CSA is an optimization technique inspired by the behavior of cuckoo birds, which lay their eggs in the nests of other birds.

This algorithm was first developed by Yang and Deb in 2009 and has proven effective in solving global optimization problems due to its ability to explore the solution space efficiently[22]. The algorithm is applied in various fields, including hybrid energy systems, where it helps improve the performance and efficiency of these systems.

The DOA is a novel optimization technique inspired by the behavior of dragonflies in nature, which exhibit fascinating behaviors in their search for food and interactions with their environment. This algorithm was introduced by S. A. A.

Y. Al-sharafi in 2016 and has proven effective in a variety of global optimization problems[24]. The DOA is applied in many fields, including hybrid energy systems, where it can enhance performance efficiency and reduce costs.

The GWOA, it is a nature-inspired metaheuristic optimization technique introduced by Mirjalili et al. in 2014. The algorithm mimics the leadership hierarchy and hunting behavior of grey wolves in nature, aiming to find optimal solutions in complex optimization problems. The GWOA is particularly well-suited for solving nonlinear and multidimensional optimization challenges, making it widely applicable across various fields, including engineering, finance, and logistics [25].

Analysis of comparisons although HOMER and five metaheuristic optimization algorithms are excellent HPGS optimization methods, they are not interchangeable and each have their own unique strengths and uses. Offering robust modeling capabilities and sensitivity analysis, HOMER is designed for in-depth optimization and study of energy systems. systems, it really shines when it comes to assessing the environmental and financial impacts of different energy arrangements.

Complex and high-dimensional spaces, however, metaheuristic optimization algorithms a more general-purpose optimization algorithms—trumps the competition. Its primary function in high-performance gas stoker systems is to fine-tune energy component settings and characteristics. When used in conjunction with HOMER, MOA's adaptability to different kinds of optimization problems makes it a valuable tool for hybrid power system design and management.

Finally, optimizing Hybrid Power Generation Systems, both HOMER and MOA's provide substantial benefits. In contrast to MOA's adaptable methods for handling complicated optimization issues, HOMER's thorough framework allows for the evaluation of various energy configurations. Improved HPGS designs are possible thanks to a deeper understanding of the capabilities and uses of these tools.

1.5. Problem Statement

This study focuses on Al-Teeb District, which is known for its substantial challenges when to electrifying rural and border communities. Getting consistent and dependable power to these outlying places is the main problem. Residents are hesitant to move there or use the property for various purposes due to the lack of reliable electrical connection, which contributes to the region's underdevelopment. There is less population density and less room for development when there is unreliable power, which hinders economic activity and impacts people's quality of life generally.

With its abundance of natural resources and promising future for economic development, Al-Teeb District holds great strategic importance. From an oil perspective, the area has huge deposits that, if used wisely, might provide a lot of money for the economy. The region's rich cultural history and picturesque scenery make it an attractive tourist destination. Modern farming practices and industrial operations rely on reliable power, therefore an improvement to the electrical infrastructure will benefit both industries.

One potential solution to the electrification problem is the availability of local energy resources, such as wind and solar power. But efficient optimization and deployment plans are necessary to tap into these resources. Factors such as logistical difficulties, high infrastructure development costs, and the necessity for environmentally conscious yet economically viable solutions all contribute to the difficulty of electrifying Al-Teeb District.

In order to harness the economic potential of Al-Teeb District and improve the quality of life for its citizens, it is vital to improve energy availability to the area. Investing in a strong energy infrastructure will boost the region's appeal as a place to live and work by allowing oil extraction, tourism, agriculture, and industry to flourish.

1.6. The Aim and Objectives

In order to optimize energy systems in rural and border areas (Al-Teeb District), this research primarily aims to address the following issues and opportunities:

1. **Implementation of Hybrid Energy Systems:** one of the primary goals is to investigate and evaluate the possible advantages of hybrid energy systems, which integrate various power sources (both renewable and non-renewable) in off-grid location. This objective aims to minimize costs and environmental effect by designing and optimizing hybrid systems (non-conventional energy source in Iraq) that can efficiently meet the energy demands of the border region and rural areas of the Al-Teeb District.

2. **Optimal Equipment Placement:** The study's overarching goal is to identify the best spots to set up energy-generating machinery including wind turbines, storage facilities, and solar panels. In order to maximize energy production and system efficiency, the study aims to identify the most effective placement strategies. After conducting spatial analysis and considering factors such as resource availability, land use, and environmental impact, District 11 in the Al-Teeb **District** has been chosen as the suitable location.

3. **Using effective methods and Software:** To analyze and understand the outcomes of energy system designs, it is essential to use complex optimization software like HOMER and MOAs. The research is centered around the goal of utilizing cutting-edge software tools for scenario modeling, performance metric evaluation, and sensitivity analysis. Insights about the best system designs and operational methods will be provided by this.

4. **The feasibility study:** this research submit feasible energy system in terms of both economics and the environment is another key objective. Optimal number of PV , WTs , DGs , batteries and converters to make up the system. To make sure the solutions are sustainable and cost-effective, the research will look at things like environmental consequences, savings potential, and cost-benefit ratios.

1.7. Contribution of Study

Firstly, The Al-Teeb District is considered distinct due to the limited research conducted on optimal energy utilization, despite its significant potential and growing importance. Accordingly, this study aims to focus on a specific aspect related to energy resource optimization that has not been thoroughly investigated in previous research.

Secondly, the region is significant because of Al-Teeb District, which is strategically important for more than just its position. Natural resources, economic growth, and environmental impact are all areas where this area has great promise. Improving the area's overall development and sustainability requires a thorough understanding of, and optimization of, energy use.

Thirdly, there is a lack of research on the use of energy resources in Al-Teeb District, in contrast to other areas of Iraq that have received a lot of attention. This void allows for the potential application of cutting-edge analytical techniques to a neglected but rapidly expanding field.

Finally, The expected results of this study have the potential to have a wider impact since they can be used as a template for improving energy efficiency in other understudied areas that are comparable. Politicians and stakeholders engaged in energy development and planning in Iraq, and maybe other areas facing similar problems, might benefit greatly from the method and its findings.

1.8. Outline of Study

The rest of the thiesis is orgnised as following:

Chapter Two reviews how various nations have explored and studied hybrid energy systems. Particularly highlight studies that are akin to what we found in Al-Tayeb region. The outcomes and approaches that have been applied to similar sites are highlighted in this chapter, which discusses the studies' conclusions. For the purpose of enhancing and informing the present study, it gives a thorough review of the literature on hybrid systems.

Chapter three provides a comprehensive analysis of the Al-Tayeb District, including its location, climate, and geography. In this chapter, we take a close look at the local factors that affect power consumption and efficiency. In the sections that follow, the chapter breaks down the planned hybrid energy system for the area, breaking down its key components, their amounts, and their associated prices. Specifically, the HOMER program is utilized to model and assess the practicability of the suggested setup of the system.

Chapter four, the hybrid system in Chapter three is dissected and its parts are applied to seven different optimization algorithms and software, namely the Canonical Particle Swarm Optimization, MPSO or TVIW-PSO, HPSO-TVAC, BA, CSA, DOA, and GWOA. This chapter, seven ways of optimization algorithm will can be used to optimize and modify the design of the energy system. This evaluation of the MOA method's efficacy and efficiency in the Al-Tayeb area includes a comprehensive comparison of metaheuristic optimization algorithms analysis results with HOMER software results.

Chapter five concludes the work. It examines the results obtained using the HOMER program in comparison to those obtained using the metaheuristic optimization algorithms methods. This chapter compares and contrasts several methods for establishing the hybrid energy system in the Al-Teeb District, taking into account factors like total performance, efficiency, and cost-effectiveness. Recommendations for the optimal system configuration round up the chapter, illuminating the next steps toward maximizing the region's energy resources.

Chapter (2)
Literature Review

2.1. Introduction

This chapter aims to review and analyze the literature related to the topic Optimum Design Energy Management of HPGS.The literature review addresses numerous studies and research conducted in this context, to understand various aspects of this significant subject. Energy management in hybrid power generation systems poses a vital challenge in the fields of electrical engineering and energy. Achieving optimal design for these systems requires consideration of various factors and challenges, such as effective component sizing, efficient integration of renewable energy, and ensuring high system reliability.

2.2. Literature Review

Relevant research and studies that highlight energy management techniques in hybrid systems will be discussed. The focus will be on recent developments and technological innovations contributing to improving energy management efficiency and achieving optimal performance in energy production.

Approaches in the literature vary between utilizing algorithms and advanced technologies to achieve optimal energy design and analyzing the performance and reliability of different hybrid systems.

The following researches submit a comprehensive review of available literature of 127 papers from the period 2007 to 2024, providing a thorough and updated overview of the current understanding and developments in the field of energy management design for hybrid power generation systems.

Uwe Deichmann, Craig Meisner, Siobhan Murray, David Wheeler (2007).[27] The study seeks to share research insights and outcomes, emphasizing that the perspectives and conclusions are the authors' own and do not represent the official stance of the World Bank or its associated entities.

Juhari Ab. Razak, Kamaruzzaman Sopian, Yusoff Ali, (2007).[28] The study aims to optimize a hybrid renewable energy system (pico hydro, solar, wind, generator, and battery) by minimizing excess energy and energy costs, using simulations to determine optimal component sizing and configurations for cost-effective, reliable, and efficient energy production.

S.M. Shaahid, I. El-Amin (2008).[29] This research explores the feasibility of a hybrid PV-diesel-battery system to provide cost-effective, sustainable energy for a remote village in Saudi Arabia, aiming to reduce diesel use, lower energy costs, and cut carbon emissions.

José L. Bernal-Agustín, Rodolfo Dufo-López (2009).[30] This study introduces a novel method using the Strength Pareto Evolutionary Algorithm to optimize isolated hybrid energy systems, minimizing lifetime costs and unmet load. It employs evolutionary and genetic algorithms to identify optimal configurations and a new control strategy, demonstrated through a PV-wind-diesel system, providing cost-reliability trade-offs for practical design.

Ajai Gupta, R P Saini, and M P Sharma (2009).[31] This study aims to optimize the sizing and operation of decentralized hybrid energy systems using a mixed integer linear programming model and a C++-based control algorithm, balancing cost-effectiveness and techno-economic performance for components like renewables, battery storage, and fossil fuel generators.

Salwan S. Dihrab, K. Sopian (2010).[32] This study evaluates the feasibility of a hybrid solar-wind energy system in Iraq to address power shortages, identifying Basrah as the optimal location for sustainable energy generation and black-start capabilities.

Shafiqur Rehman, Luai M. Al-Hadhrami (2010).[33] This study explores the feasibility of a PV-diesel-battery hybrid system to reduce diesel use in a village, identifying optimal configurations and showing the hybrid system becomes cost-competitive with diesel-only systems at higher diesel prices.

Shafiqur Rehman and Luai M. Al-Hadhrami (2010).[34] This study evaluates a PV-diesel-battery hybrid system to reduce diesel use in a village, identifying optimal configurations and showing it becomes cost-competitive with diesel-only systems at higher diesel prices.

Shafiqur Rehman, Md. Mahbub Alam, J.P. Meyer, Luai M. Al-Hadhrami (2011).[35] This study explores a wind-PV-diesel hybrid system for a Saudi Arabian village to reduce diesel use, lower energy costs, and cut greenhouse gas emissions, demonstrating its feasibility and environmental benefits.

Nicolas Lopez and Jose F. Espiritu (2011).[36] This research uses software simulations to evaluate hybrid power systems for high renewable energy integration, helping decision-makers optimize micro-grid designs while assessing the software's capabilities and limitations.

Headley Jacobus, Baochuan Lin, David Henry Jimmy, Rashid Ansumana, Anthony P. Malanoski, David Stenger (2011).[37] This research evaluates a PV-diesel hybrid system at Mercy Hospital in Sierra Leone, showing significant cost savings and efficiency improvements compared to diesel-only generation during Wet and Dry Seasons.

D. Yamegueu, Y. Azoumah & X. Py (2011).[38] This research investigates the performance of a PV/diesel hybrid system without storage, highlighting optimal sizing for reliability and cost-efficiency. By comparing diesel-only, PV-only, and hybrid systems, it shows that the hybrid system is the most economical, offering a viable solution for improving electrification in remote off-grid regions.

Sandar Linn, Aung Ze Ya (2012).[39] This research focuses on designing an optimal hybrid energy system (solar, wind, diesel, and battery) for rural electrification, addressing the intermittency of renewables. Using HOMER software, it identifies a feasible system with 64% renewable energy, meeting the village's energy needs and reducing diesel use, highlighting its potential for reliable and sustainable power in rural areas.

YAZDANPANAH JAHROMI M.A., FARAHAT S., BARAKATI S.M. (2012).[40] This study introduces a new method using NSGA-II and match evaluation to optimize off-grid hybrid energy systems, balancing cost, reliability, and sustainability for improved renewable energy design.

K. Kusakana, H.J. Vermaak and B.P. Numbi (2012).[41] This study uses linear programming to optimize the design and cost of hybrid renewable energy systems for off-grid areas, demonstrating its effectiveness through a case study in South Africa.

Svetlana Dumonjic-Milovanovic R., Zdravko Milovanovic N. and Jovan Skundric B. (2013).[42] This study evaluates the economic feasibility of a hybrid PV/Wind/Diesel system through life cycle cost analysis. The results demonstrate the financial viability and justify the implementation of renewable energy systems utilizing solar and wind resources.

Golbarg Rohani, Mutasim Nour (2013).[43] This study designs and optimizes a hybrid renewable energy system (PV, wind, batteries, and diesel) for a remote area in Abu Dhabi using HOMER, achieving a 37% CO_2 reduction and cost-effectiveness for a 500kW load over 25 years.

M.S. Ismail, M. Moghavvemi, T.M.I. Mahlia (2013).[44] This study optimizes a hybrid PV/diesel/battery system for a remote Palestinian community, showing it reduces costs and emissions, making it a sustainable and competitive energy solution.

Ahmad Rouhani, Hossein Kord and Mahdi Mehrabi (2013).[45] This study uses GA and PSO to optimize hybrid energy system sizing, balancing cost and reliability, and validates the model with real weather data from Shiraz.

Mohammad Ali Yazdanpanah-Jahromi, Seyed-Masoud Barakati, Said Farahat (2013).[46] This study proposes a multi-objective optimization method for hybrid energy systems, minimizing costs and maximizing reliability, validated with data from Zabol, Iran, and applicable to other locations.

O. Arikan, E. Isen, A. Durusu, Student Member, IEEE, B. Kekezoglu, A. Bozkurt, A. Erduman (2013).[47] This study presents a solar-wind-battery hybrid system at Yıldız Technical University, highlighting renewable energy's role and outlining future system improvements.

Timothy Oluwaseun Araoye, Evans Chinemezu Ashigwuike, Sadiq Abubakar Umar (2013).[48] This study optimizes a hybrid micro-grid (PV, diesel, biogas, and battery) for Agu-Amede village, showing reduced diesel use and lower costs with increased biogas production, ensuring reliable and sustainable energy supply.

Ali M. Eltamaly, Khaled E. Addoweesh, Umar Bawah and Mohamed A. Mohamed (2013).[49] This study proposes a method to optimize hybrid PV/wind/battery systems, validated with Saudi data, and demonstrates its economic feasibility and reliability using a custom program.

Djohra Saheb-Koussa, Mustapha Koussa, and Nourredine Said (2013).[50] This study assesses a wind-diesel-battery hybrid system in Algeria, proving its cost and environmental advantages over diesel-only systems, and recommends it as a sustainable solution for remote areas.

Anita Gudelj, Maja Krčum (2013).[51] This study optimizes hybrid renewable energy systems using HOGA, showing cost and emission reductions for a location in southern Croatia, despite their dependence on climatic conditions.

M. Martínez-Díaz, R. Villafáfila-Robles, D. Montesinos-Miracle and A. Sudrià-Andreu (2013).[52] This study optimizes a hybrid PV-Wind-Diesel-Battery system for a telecommunication station in Catalonia, balancing economic, technical, and environmental criteria to identify the most sustainable and cost-effective solution.

Subir Ranjan Hazra, Asiful Habib, Engr. Kazi Sakhawat Hossain, Md. Abdullah Al Jubaer (2014).[53] This study designs a hybrid diesel-PV-biogas system for Char Nizam Island, Bangladesh, using HOMER to provide sustainable, affordable electricity and reduce emissions, addressing the country's power crisis and supporting rural development.

S. M. Shaahid, I. El-Amin, S. Rehman, A. Al-Shehri, F. Ahmad,

J. Bakashwain, and Luai M. Al-Hadhrami (2014).[54] This study optimizes a hybrid wind-PV-diesel system for a remote Saudi village, achieving 24% renewable energy use, reducing emissions, and lowering energy costs to $0.118/kWh using HOMER software.

Sabrije F. Osmanaj, Rexhep A. Selimaj (2014).[55] This study aims to use hybrid wind-solar systems combined with traditional power to ensure reliable and efficient energy supply in remote areas, overcoming weather-related limitations.

Zakieh Tolooi, Hadi Zayandehroodi, Alimorad Khajehzadeh (2014).[56] This study aims to design a cost-optimized solar/wind hybrid power system for residential use by applying GSA and PSO algorithms, reducing long-term costs over 20 years and enhancing renewable energy's economic viability.

Makbul A. M. Ramli, Ayong Hiendro and H. R. E. H. Bouchekara (2014).[57] This study evaluates hybrid PV/diesel systems in western Saudi Arabia using HOMER software to optimize energy production, reduce costs, fuel use, and carbon emissions by comparing stand-alone diesel, hybrid PV/diesel, and hybrid PV/diesel with battery storage.

Mutasim Nour, Golbarg Rohani (2014).[58] This study aims to design and evaluate a cost-effective, stand-alone PV-diesel hybrid power system for a rural village in Al Gharbia, UAE, using HOMER software to demonstrate its economic feasibility, reduced CO_2 emissions, and advantages over grid extension.

SANDAR LINN, AUNG ZE YA (2014).[59] This study designs a solar/wind/diesel hybrid system with battery storage for rural Myanmar, using

HOMER software to optimize system size, cost, and renewable energy integration (63%) at $0.453/kWh.

Aditya Hridaya, Chirag Gupt (2015).[60] This study evaluates the economic feasibility of a hybrid PV/wind/battery/diesel system for remote locations using HOMER software, optimizing system design, costs, and reliability based on renewable resource availability.

Hisham El Khashab, Mohammed Al Ghamedi (2015).[61] This study evaluates renewable energy systems (PV, wind, fuel cell) in Yanbu, Saudi Arabia, using HOMER software to compare energy costs and assess feasibility for developing countries.

Omar Hazem Mohammed, Yassine Amirat and Mohamed Benbouzid (2015).[62] This study uses a genetic algorithm to optimize a wind/PV/tidal/battery hybrid system in Brittany, France, focusing on cost reduction and reliable energy supply over 25 years.

George N. Prodromidis, Leonidas Kikareas, Panagiota Stamatopoulou, Grigoris Tsoumanis, Frank A. Coutelieris (2015).[63] This study designs a RES hybrid system, validates its performance experimentally, and develops an ITMS model to accurately predict system operation, addressing discrepancies in HOMER simulations.

Akbar Maleki, Mehran Ameri b, Farshid Keynia (2015).[64] This study optimizes a hybrid PV/wind/battery system using PSO variants, with PSO-CF achieving the lowest costs and best performance based on real-time data from Iran.

S. Rehman1 and I. El-Amin (2015).[65] This study compares hybrid power systems in Saudi Arabia, finding the diesel-only system cheapest (0.037 US$/kWh) and the PV-diesel hybrid system (0.038 US$/kWh) the most economical hybrid option.

Abubakar Bala, Abubakar Abdulsalam, Bello Suleiman Muhammad, Bayero University Kano (2016).[66] This research aims to design an optimal hybrid energy system for the EE department at Bayero University Kano, reducing costs and environmental impact while improving energy reliability.

Monika G. Barade and Anindita Roy (2016).[67] This study aims to optimize a photovoltaic-diesel-battery hybrid system for remote areas, balancing energy sources to minimize costs and reduce diesel dependency through system sizing and sensitivity analysis.

H. Wicaksana, M. M. Muslim, S. F. Hutapea, A. Purwadi, Y. Haroen (2016).[68] This study aims to design an optimal hybrid PV-Diesel-battery system for Sebira Island, showing that a 70% PV fraction reduces energy costs and enhances sustainability compared to the existing diesel-only system.

Vincent Anayochukwu Ani (2016).[69] This study aims to demonstrate the feasibility of a PV/diesel/battery hybrid system for a home in Southern Nigeria, showing lower lifetime costs and improved reliability compared to a diesel/battery system, despite higher initial costs.

Ali M. Eltamaly, Mohamed A. Mohamed (2016).[70] This study aims to develop a computer program for optimizing hybrid renewable energy systems (wind/PV/battery) that outperforms existing software in accuracy, speed, and flexibility to achieve the lowest energy cost and highest reliability.

Bartosz Ceran, Qusay Hassan, Marek Jaszczur and Krzysztof Sroka (2016).[71] This study aims to evaluate a hybrid power generation system (solar, wind, fuel cells, and hydrogen storage) to identify optimal solutions and cost limits, supporting effective system design and analysis.

Abdullah Ajlan, Chee Wei Tan, Abdirahman Mohamed Abdilahi (2016).[72] This study aims to identify an optimal off-grid hybrid system (photovoltaic/wind/diesel) for rural electrification in Yemen, balancing cost, environmental impact, and reliability to support global climate goals.

Sana Charfi, Ahmad Atieh, Maher Chaabene (2016).[73] This study aims to evaluate and compare diesel-only, PV/battery, and hybrid PV/diesel/battery systems for factory power in Tunisia, Jordan, and Saudi Arabia, identifying the hybrid system as optimal for Tunisia and Jordan and diesel-only as best for Saudi Arabia.

Victor O. Okinda, Nicodemus A. Odero (2016).[74] This research aims to optimize a hybrid wind-solar power system, showing that wind and solar can complement each other in specific locations, and identifies an optimal off-grid configuration with competitive energy costs, while revealing that cost-effective solutions may not maximize resource use.

E. Hamatwi, C.N. Nyirenda, I.E. Davidson (2016).[75] This research aims to design and optimize a PV-Diesel hybrid energy system for a remote village in Namibia, demonstrating its economic and environmental advantages over diesel-only systems and offering a model for electrifying similar off-grid areas.

Q Hassan, M Jaszczurand J Abdulateef (2016).[76] This research aims to design and optimize a hybrid solar PV and wind turbine system for a rural area in Iraq, demonstrating that renewable energy can provide a cost-effective and reliable power solution, though wind energy viability depends on local wind resources.

SK.A. Shezan, S. Julai, M.A. Kibria, K.R. Ullah, R. Saidur, W.T. Chong, R.K. Akikur (2016).[77] This research aims to design and evaluate an off-grid PV-wind-diesel-battery hybrid energy system for a remote area in Malaysia, demonstrating its cost-effectiveness, reduced CO2 emissions, and feasibility for regions with similar renewable energy resources.

D.Jagan, M. Vikram Goud, A. Srilatha (2016).[78] This research aims to design and optimize a PV-fuel cell-battery hybrid power system for remote AC loads, using HOMER software to evaluate system performance and sensitivity to fuel cell consumption, which impacts overall costs.

Temitope Adefarati, Ramesh C. Bansal, Jackson John Justo (2017).[79] This research aims to optimize a hybrid power system (PV, wind, diesel, and battery storage) for remote areas, using HOMER software to minimize costs and demonstrate the economic benefits of integrating renewable energy sources.

Ajoya Kumar Pradhan, Mahendra Kumar Mohanty, Sanjeeb Kumar Kar (2017).[80] This study optimizes an off-grid hybrid renewable energy system (solar PV and wind) to lower energy costs and improve reliability using HOMER-Pro, analyzing factors like load patterns, solar irradiance, wind speed, and diesel prices from a village in Odisha, India, with sensitivity analysis on key parameters.

Ali M. Eltamaly, Mohamed A. Mohamed, M. S. Al-Saud & Abdulrahman I.

Alolah (2017).[81] This study optimizes the size of a hybrid renewable energy system (HRES) for remote areas by dividing loads into high- and low-priority parts, reducing system size and energy costs. Using a smart PSO algorithm in MATLAB and validation with HOMER, it shows load division lowers energy costs.

Sarangthem Sanajaoba Singh, Eugene Fernandez (2017).[82] This study optimizes a hybrid energy system (solar, wind, and battery) as a cost-effective alternative to diesel systems, using Cuckoo Search for optimization and comparing it with other algorithms. It analyzes the impact of solar/wind resources and capital costs on energy costs through sensitivity analysis.

Mohammad Masih Sediqi, Masahiro Furukakoi, Mohammed E. Lotfy, Atsushi Yona and Tomonobu Senjyu (2017).[83] This study optimizes a grid-connected hybrid energy system (solar, wind, and batteries) for Afghanistan's North-east region to address winter power shortages. Using a genetic algorithm, it minimizes life cycle costs (LCC) while ensuring reliability through loss of power supply probability (LPSP).

Adrian Mansur (2017).[84] This study optimizes a hybrid energy system for Salemo Island to address solar intermittency, evaluating SPP and battery additions to minimize LCOE, operating costs, and NPC while balancing capital investments.

Zaid BARI, Majid BEN YAKHLEF (2017).[85] This study proposes an optimization model to identify the most economical and reliable RES configuration (Wind Turbine-Battery, PV-Battery, or hybrid) for remote areas, using data from Morocco. Hybrid systems are the most cost-effective, and Wind Turbines are generally better than PVs, except in Zagora.

Hamza Siyoucef, Benameur Afif, Youcef Islam Djilani Kobibi, Samir Ghouali, Boualem Merabet, Saad Motahhir (2017).[86] This study models and optimizes a hybrid PV-Wind energy system for remote Maghreb areas, using MATLAB and HOMER to improve energy access for mobile base stations or smart grids, potentially enhancing rural livelihoods and living standards.

Anand Singh, Prashant Baredar (2017).[87] This study optimizes a hybrid energy system (solar PV, biomass gasifier, fuel cells, and batteries) for an institute in Bhopal, India, using HOMER. It achieves a cost of energy of 15.064 Rs/kWh and optimal sizing of 5 kW biomass, 5 kW solar PV, and 5 kW fuel cell.

Mohamed Dekkiche, Toufik Tahria, Ahmed Bettahar, Bachir Belmadani (2017).[88] This study optimizes a hybrid PV-Diesel-Battery system for an isolated site in Algeria, achieving a COE of 0.224 $/kWh. It reduces emissions, saves fuel, and is more cost-effective than grid connection for distances over 1.35 km.

Ali Saleh Aziz, Mohammad Faridun Naim bin Tajuddin, Mohd. Rafi bin Adzman, Makbul A. M. Ramli (2018).[89] This study assesses a PV/diesel/battery hybrid system for a remote Iraqi village, optimizing it with HOMER. The best configuration costs $162,703, but degradation, load growth, and temperature reduce PV/battery efficiency, increase diesel use, and raise emissions over time.

B. Modu, A. K. Aliyu, A. L. Bukar, M. Abdulkadir, Z. M. Gwoma, M. Mustapha (2018).[90] This study evaluates a hybrid PV/diesel-battery system for five houses in Katsina, Nigeria, using HOMER. The PV-diesel-battery system is the most cost-effective ($0.434/kWh) and reduces CO_2 emissions significantly.

Wemogar Elijah Borweh, Emmanuel Asuming Frimpong and Lena Dzifa Mensah (2018).[91] This study designs a cost-effective, off-grid hybrid energy system (PV-diesel-battery) for rural electrification, optimizing for low costs, reduced emissions, and reliable power using HOMER software.

Miriam Madziga, Abdulla Rahil and Riyadh Mansoor (2018).[92] This study aims to design a reliable and sustainable hybrid energy system (PV-diesel-battery) for Gwakwani, South Africa, optimizing for energy demand, cost, and pollution to identify the best off-grid electrification solution.

Jean-Laurent Duchaud, Gilles Notton, Christophe Darras, Cyril Voyant (2018).[93] This study uses Multi-Objective Particle Swarm Optimization to design a cost-effective and reliable microgrid power plant, minimizing costs and imported energy while adapting to site-specific meteorological conditions for optimal energy autonomy.

Bouthaina Madaci, Rachid Chenni, Kamel Eddine Hemsas (2018).[94] This study designs a fuzzy logic-based energy management system for a rural hybrid energy system (PV, wind, battery, electrolyzer) to ensure reliable power, protect batteries, and manage surplus energy efficiently.

Loiy Al-Ghussain and Onur Taylan (2018).[95] This study develops a PV/wind hybrid system sizing method to maximize renewable energy use, ensure cost-effectiveness, and enhance energy security and environmental benefits, using METU NCC as a case study.

Isiaka Shuaibu, Musefiu Aderinola, Isah Magaji (2019).[96] This study designs an optimized Hybrid Renewable Energy System (HRES) for Bayero University

Kano (BUK) using HOMER 3.4.3, combining solar, wind, diesel, and battery storage to enhance reliability, cost-efficiency, and sustainability while supplementing the existing power supply.

Patryk Palej, Hassan Qusay, Sławosz Kleszcz, Robert Hanus, Marek aszczur (2019).[97] This study optimizes a grid-connected Hybrid Renewable Energy System (HRES) with solar and wind components, balancing economic (cost) and environmental (CO2 emissions) objectives. It shows trade-offs between the two, prioritizing cost efficiency while considering environmental impacts indirectly.

Hla Myo Aung, Moe Sam, Zaw Min Naing (2019).[98] This study evaluates a solar-powered greenhouse dryer for betel nuts, reducing drying time by 10-15 days and improving quality while protecting against environmental factors. With a one-year payback period, it is recommended as a sustainable solution for farmers.

Leonard Kipyegon Rotich, Joseph Kamau, Jared Ndeda, Robert Kinyua (2019).[99] This study designs and optimizes a hybrid power system (solar PV, wind, and grid) for the East African School of Aviation using HOMER software, identifying the optimal configuration (200 kW wind, 120 kW solar PV, and grid) based on economic metrics (NPC and COE).

Kamal Anoune, Mohsine Bouya, Azzeddine Laknizi, Abdellatif Ben Abdellah, Abdelali Astito, Mokhtar Ghazouani (2019).[100] This study optimizes a hybrid solar-wind energy system for cost-effectiveness and reliability, using TRNSYS and Matlab to analyze weather data and load profiles. It identifies the best configuration for specific cities and provides a techno-economic and environmental assessment.

Cherechi Ndukwe, Tariq Iqbal, Xiaodong Liang and Jahangir Khan (2019).[101] This study designs a hybrid power system (solar PV, battery storage, converter, and diesel generator) for Umuokpo Amumara village to provide sustainable electricity, meeting its daily energy demand. Sensitivity analysis evaluates system performance under varying solar irradiation and load conditions.

SK. A. Shezan (2019).[102] This study aims to design an off-grid hybrid energy system (PV, diesel, and batteries) for ecotourism areas in Malaysia, ensuring cost-effectiveness, reliability, and reduced CO_2 emissions.

Htet Wai Yan Soe, Hla Aye Thar, Aung Ze Ya (2019).[103] This study aims to design an off-grid solar-diesel hybrid system to provide sustainable, cost-effective electricity for a rural village in Myanmar, utilizing solar energy potential.

Jijian Lian, Yusheng Zhang, Chao Ma, Yang Yang, Evance Chaima (2019).[104] This study aims to review and optimize the design of hybrid renewable energy systems by analyzing sizing methods, evaluation indicators, and advanced technologies to improve reliability, cost-effectiveness, and sustainability.

A.M. Hemeida, M.H. El-Ahmar, A.M. El-Sayed, Hany M. Hasanien, Salem Alkhalaf, M.F.C. Esmail, T. Senjyu (2019).[105] This study aims to design and assess a hybrid renewable energy system (wind, solar, and battery storage) for Makadi Bay, Egypt, demonstrating its cost-effectiveness and feasibility in meeting energy demands compared to standalone systems.

Ahmed A. Zaki Diab, Sultan I. EL-Ajmi, Hamdy M. Sultan, Yahia B. Hassan (2019).[106] This study aims to optimize the design of a grid-connected hybrid energy system (solar, wind, and fuel cell) using a modified optimization algorithm (MFFA) to ensure cost-effective, reliable, and sustainable energy supply, validated through a real case study in Egypt.

Ayodele Benjamin Esan, Ayoade Felix Agbetuyi, Oghenevogaga Oghorada, Kingsley Ogbeide, Ayokunle. A. Awelewa, A. Esan Afolabi (2019).[107] This study aims to assess the reliability and economic viability of a hybrid energy system (solar, diesel, and batteries) for a rural Nigerian community, highlighting its environmental benefits, cost savings, and reliability through simulation and sensitivity analysis.

JAMIU O. OLADIGBOLU, (Member, IEEE), MAKBUL A. M. RAMLI, AND YUSUF A. AL-TURKI (2020).[108] This research focuses on designing and analyzing a hybrid renewable energy system (hydro, solar, wind, diesel, and batteries) to electrify a remote Nigerian village, ensuring cost-effectiveness, environmental sustainability, and alignment with the Sustainable Development Goal of affordable and clean energy.

Abdullrahman Abdullah Al-Shamma'a, Fahd A. Alturki, Hassan M. H. Farh (2020).[109] This study investigates the optimal design and economic viability of hybrid renewable energy systems (solar, wind, battery, and diesel) for remote areas in Saudi Arabia, demonstrating cost savings and increased renewable energy integration through advanced optimization techniques.

Shafiqur Rehman (2020).[110] This study evaluates hybrid renewable energy systems (e.g., wind, solar PV, and diesel with or without batteries) to determine the most effective configurations for Saudi Arabia. The goal is to diversify the energy mix, reduce reliance on fossil fuels, and address environmental challenges.

Aayush Bista, Nasib Khadka, Ashish Shrestha and Diwakar Bista (2020).[111] This study explores hybrid power systems to sustainably meet Kathmandu University's energy needs, identifying the best energy mix and recommending generators for future demand while maximizing renewable energy use.

Jamiu Omotayo Oladigbolu, Makbul A. M. Ramli and Yusuf A. Al-Turki (2020).[112] This study assesses hybrid solar PV/hydro/diesel/battery systems for off-grid rural electrification in Nigeria, identifying the most cost-effective and environmentally friendly solution. It highlights the system's technical and economic viability while analyzing the impact of variables like solar radiation and interest rates on performance.

Nasser Yimen, Theodore Tchotang, Abraham Kanmogne, Idriss Abdelkhalikh Idriss (2020).[113] This research develops and evaluates a hybrid renewable energy system (solar PV/wind/battery/diesel) for off-grid electrification in rural Nigeria. It demonstrates the system's economic and environmental advantages over traditional grid-extension and diesel generators, highlighting its potential for sustainable energy solutions in sub-Saharan Africa.

Abdullah Al Shereiqi, Amer Al-Hinai, Mohammed Albadi and Rashid Al-Abri (2020).[114] This research introduces a new method to optimize hybrid wind, solar, and battery systems (HWSPS) by reducing wind farm power losses and generation fluctuations. It employs a two-step process—wind farm optimization and sizing of solar PV and storage—without using load demand data. The approach is tested in Thumrait, Oman, emphasizing reliability and cost-effectiveness.

AHMAD AL-SARRAJ, Hussein T. Salloom, Kareem K. Mohammad, Saad

M.Mohammadghareeb (2020).[115] This study simulates and optimizes a hybrid power system (grid, solar PV, wind, and batteries) for urban buildings to promote clean energy and reduce emissions, identifying the sellback system as optimal through a case study in Iraq.

ZAIDOON W. J. AL-SHAMMARI, M. M. AZIZAN, A. S. F. RAHMAN (2021).[116] This research assesses hybrid energy systems (solar, wind, diesel, batteries, and converters) to provide electricity to Zerbattiya, Iraq. It identifies a wind-diesel system as the most cost-effective option, offering a practical solution for rural electrification in remote areas.

Muaz Izzuddeen Sabudin, Mohd Noor Syawal Mustapha, Muhammad Adzim Mohd Rozi and Devaraj Tharuma Rajah (2021).[117] This research focuses on designing a hybrid renewable energy system (solar PV and hydropower) for a rural village in Malaysia to replace diesel-based electricity. It uses HOMER to determine the optimal system, emphasizing cost-effectiveness and sustainability, while analyzing the impact of increasing energy demand.

Majed A. Alotaibi and Ali M. Eltamaly (2021).[118] This research designs a hybrid renewable energy system (wind, solar PV, and pumped hydro storage) for a remote Saudi Arabian location, incorporating a dynamic tariff-based demand response strategy to lower costs and system size. It highlights the economic and environmental advantages of PHES over traditional storage systems and uses a novel optimization algorithm for efficient system design.

Kennedy Muchiri, Joseph Ngugi Kamau, David Wafula Wekesa, Churchill Otieno Saoke, Joseph Ndisya Mutuku, Joseph Kimiri Gathua (2021).[119] This research evaluates energy usage in rural Machakos, Kenya, and proposes a standalone wind/PV hybrid system tailored to the average household's energy needs. Using local solar and wind data, it sizes the system components to ensure reliable and sustainable energy supply for rural areas.

Abdullah Al-Shereiqi, Amer Al-Hinai, Mohammed Albadi and Rashid Al-Abri (2021).[120] This research proposes a method to optimize hybrid wind-solar systems (HWSPS) using advanced algorithms to reduce output fluctuations and enhance grid compatibility. Tested on a site in Oman, it identifies optimal system sizes for wind, solar, and battery storage, offering a cost-effective solution for stable renewable energy integration.

James Morales Lassalle, Dante Figueroa Martínez, Luis Vergara Fernández (2021).[121] This research assesses the viability of hybrid renewable energy systems (HRES) for islands, focusing on cost reduction and environmental benefits. By reviewing 73 cases, it identifies key HRES components, energy demand trends, and data challenges, while proposing solutions to enhance renewable energy planning for isolated regions.

Khalid Almutairi, Seyyed Shahabaddin Hosseini Dehshiri, Seyyed Jalaladdin Hosseini Dehshiri (2021).[122] This research explores the viability of implementing a hybrid renewable energy system (HRES) to supply electricity to buildings in Bostegan village, Iran. It assesses technical, economic, and environmental factors to identify the best system setup, examines the effects of fuel price changes and renewable energy variability, and investigates the possibility of using the system's output for hydrogen production.

Abdullah Al Abri, Abdullah Al Kaaf, Musaab Allouyahi, Ali Al Wahaibi, Razzaqul Ahshan (2022).[123] This study focuses on developing a hybrid renewable energy system for rural electrification in Oman, aiming to minimize reliance on diesel fuel, lower greenhouse gas emissions, and achieve sustainable energy solutions using advanced modeling tools like HOMER and ETAP.

Monyiachi N. Minja and Aviti T. Mushi (2022).[124] This study focuses on developing a hybrid energy system using solar, wind, and backup diesel generation with battery storage to ensure a stable and sustainable power supply for Mwanza International Airport, addressing the challenges of fossil fuel dependency and enhancing energy efficiency.

Karankumar Patel, Dharmik Kiranbhai Kachhadiya, Dhruvkumar Rinkeshbhai Kapatel, Dr M. Tariq Iqbal (2022).[125] This study focuses on developing a hybrid energy system using solar PV, diesel generation, and battery storage to provide reliable and cost-effective electricity to the remote community of Francois, reducing fossil fuel dependency and improving energy sustainability.

Mohamed Kandil, Mohamed Aly, Mohamed Akl, M. Tariq Iqbal (2022).[126] This study explores the development of a hybrid energy system integrating diesel generators and solar PV panels for Grey River, using HOMER Pro for optimization and MATLAB Simulink for dynamic simulations to ensure cost-effectiveness, reliability, and stability under different load scenarios.

Siddhanth Kotian, Afreen Maliat, Abdul Azeez, Dr. Tariq Iqbal (2022).[127] This study aims to design and optimize a hybrid power system (solar PV, wind, battery storage, and diesel) to replace Ramea Island's non-operational wind-diesel system, using tools like RETScreen, REopt, and Homer Pro, and simulating the design in MATLAB/Simulink.

Yasser F. Nassar, Samer Y. Alsadi, Hala J. El-Khozondar, Mohamoud S. Ismail, Maher Al-Maghalseh (2022).[128] This study aims to design a Hybrid Renewable Energy System (solar, wind, and biomass) for Jenin Governorate, Palestine, to fully meet the region's electricity demand at a cost of $0.313/kWh, addressing the ongoing energy crisis.

Ali M. Eltamaly, Khaled E. Addoweesh, Umar Bawa, Mohamed A. Mohamed (2022).[129] This study aims to optimize the economic sizing of hybrid renewable energy systems (wind and solar) for three Saudi Arabian sites, using a methodology to select the best components, analyze energy costs, and develop a computer program for system design.

Ahmad Sakhrieh, Jamil Al Asfar, Nour Abu Shuaib (2022).[130] This study seeks to design and optimize a cost-effective and efficient hybrid energy system for a cow farm in Jordan, utilizing a mix of renewable and conventional energy sources like solar, biogas, diesel, and batteries. Through technical and economic analysis using HOMER software, the goal is to identify the best system configuration that maximizes renewable energy use, minimizes costs, and significantly reduces greenhouse gas emissions.

Hosein Kalantari and Seyed Ali Ghoreishi-Madiseh (2022).[131] This study aims to replace diesel in off-grid mining with a wind-powered system combined with battery, hydrogen, and thermal storage, identifying a hydrogen-powered fleet with hybrid storage as the most cost-effective and sustainable solution for remote open-pit mines.

Harrison Oyibo Idakwo, P. I. Adamu, V. Stephen, I. Bello (2022).[132] This research focuses on developing a hybrid renewable energy system using solar PV and wind turbines with storage to deliver sustainable and reliable electricity to off-grid communities like Sabon Gida in Kaduna State. By integrating these energy sources, the study supports the UN's goal of affordable and clean energy, with the prototype successfully meeting the community's energy needs.

Zakaria Belboul, Belgacem Toual, Abdellah Kouzou, Lakhdar Mokrani, Abderrahman Bensalem (2022).[133] This study optimizes a standalone hybrid renewable energy microgrid using MOSSA to minimize energy costs and power supply losses for residential users in Djelfa, Algeria.

Hussein M. K. Al-Masri, Abed A. Al-Sharqi, Sharaf K. Magableh, Ali Q. Al-Shetwi, Maher G. M. Abdolrasol and Taha Selim Ustun (2022).[134] This study evaluates a hybrid PV-biogas grid-connected energy system in Jordan, utilizing real data and the MOFEPSO algorithm to optimize system design for reliability and cost-efficiency, providing actionable solutions for decision-makers.

Polamarasetty P Kumar, Ramakrishna S. S. Nuvvula, Md. Alamgir Hossain, SK. A. Shezan (2022).[135] This research explores the use of hybrid renewable energy systems with various battery technologies and dispatch strategies to deliver sustainable electricity and freshwater to remote, off-grid villages in Odisha, India, aiming to optimize system performance and minimize costs.

Rovick Tarife, Yosuke Nakanishi, Yining Chen, Yicheng Zhou, Noel Estoperez and Anacita Tahud (2022).[136] This study develops a method to design and optimize a hybrid renewable energy microgrid for rural agricultural areas in the Southern Philippines, balancing reliability, cost, and environmental impact through multi-objective optimization and power management strategies.

Fayza S. Mahmoud, Ashraf M. Abdelhamid, Ameena Al Sumaiti (2022).[137] This study seeks to combine the utility grid with a hybrid system of solar, wind, and fuel cells to ensure reliable power supply and overcome the drawbacks of relying on a single renewable energy source. It emphasizes efficient hydrogen storage management and power exchange to reduce system costs and handle load variability, employing optimization methods (MPA and SOA) to achieve optimal component sizing.

Md. Rasel Ahmed, Md. Rokib Hasan, Suharto Al Hasan, Muhammad Aziz and Md. Emdadul Hoque (2023).[138] This research focuses on tackling power deficits in Bangladesh through a hybrid energy system integrating solar, wind, and diesel with battery storage. By utilizing HOMER Pro software, the study seeks to reduce NPC, COE, and CO_2 emissions while fulfilling energy needs in Rangpur. It analyzes seven grid-connected setups and uses MLR to determine the best system based on economic, technical, and environmental factors.

Ahlem Zegueur, Toufik Sebbagh and Abderrezak Metatla (2023).[139] This study investigates the viability of implementing an eco-friendly hybrid energy system combining solar, wind, diesel, and battery storage to power remote telecommunication stations in Skikda, Algeria. It compares various energy configurations to determine the most economically and environmentally optimal solution, focusing on minimizing costs and reducing greenhouse gas emissions.

Ilunga Kajila Rice, Hanhua Zhu, Cunquan Zhang and Arnauld Robert Tapa (2023).[140] This research explores combining solar PV systems with diesel power plants in Lubumbashi, DR Congo, to improve energy reliability and promote sustainable development through economic and environmental benefits.

FOUAD ZARO, NOOR ABU AYYASH (2023).[141] This study designs a sustainable microgrid for Al-aroub Technical College using solar, biogas, fuel cells, and hydrogen storage, emphasizing its cost-effectiveness, reliability, and environmental benefits over traditional systems.

Yuet Sing Li, Mohammad Bahrami, Mohammad Faraji Nejad, and Mohammad Tariq Iqbal (2023).[142] This study investigates hybrid renewable energy systems in St. Lewis, NL, as a sustainable model for remote communities, aiming to enhance energy security, reduce emissions, and replace diesel generators.

Nikita Yadav, Yashwant Sawle, Baseem Khan, Yini Miro (2023).[143] This research focuses on designing and optimizing a hybrid energy system (PV, wind, and diesel) using HOMER Pro to minimize costs and emissions while meeting electrical demand, demonstrating the feasibility and benefits of renewable energy integration in the chosen location.

Saheed Ayodeji Adetoro, Lanre Olatomiwa, Jacob Tsado, Solomon Musa Dauda (2023).[144] This research evaluates the performance of ABC, GA, and PSO algorithms in optimizing a hybrid renewable energy system for a dairy farm, focusing on cost-effectiveness, reduced diesel dependency, and lower emissions, with PSO proving to be the most efficient approach.

Hartadhi, Kholid Akhmad, Riza (2023).[145] This research focuses on increasing solar PV integration in existing hybrid PV-Diesel systems for off-grid islands, aiming to minimize fossil fuel use, reduce energy costs and emissions, and align with national renewable energy policies through optimized system modeling.

Md. Arif Hossain, Ashik Ahmed, Shafiqur Rahman Tito, Razzaqul Ahshan, Taiyeb Hasan Sakib (2023).[146] This research introduces a hybrid optimization approach (NSGA II + GWO) to optimize the renewable energy mix (wind, solar, and batteries) in microgrids, focusing on cost reduction and reliability improvement, and demonstrating superior performance compared to standalone optimization algorithms.

Taofeek Afolabi and Hooman Farzaneh (2023).[147] This research evaluates the design and operation of an off-grid hybrid renewable energy system in a rural Nigerian community, employing PSO optimization and fuzzy logic control to reduce energy costs and achieve efficient energy management for sustainable power supply.

Meisheng He, Habib Forootan Fard, Khalid Yahya, Mahmoud Mohamed, Ibrahim Alhamrouni (2023).[148] This research seeks to determine the best hybrid renewable energy system configuration (PV, bio generator, diesel, and batteries) for a case study region, balancing cost, emissions, and reliability while addressing land constraints and grid dependency, with sensitivity analyses to ensure adaptability to varying conditions.

Ali M. Jasim, Basil H. Jasim, Florin-Constantin Baiceanu, and Bogdan-Constantin Neagu (2023).[149] This research designs a cost-effective and sustainable hybrid microgrid for Basra, Iraq, combining renewable energy sources and storage, optimized with a hybrid GWCSO algorithm to achieve minimal energy costs, low emissions, and reliable power supply compared to other optimization methods.

Hakan Acaroğlu, Fausto Pedro García Márquez (2024).[150] This research assesses the economic viability of HVDC transmission for wind energy systems in Turkey, proposing a 1,000 km transmission line and analyzing costs, subsidies, and long-term profitability to serve as a model for similar projects in Turkey and developing countries.

J. Lu, F. L. Siaw, T. H. G. Thio, J. J. Wang (2024).[151] This research develops an optimized energy management model for hybrid renewable systems (wind, solar, diesel, and storage) using an enhanced gray wolf optimization algorithm to minimize costs, reduce environmental impact, and improve reliability for sustainable energy solutions.

Table (2-1), basically, it reviews the important issues such as, year of publishing, area of study, type of hybrid energy system, types of load, on or off grid, objective functions, and the methods or software.

Table (2-1) Summary of Literature Review or HPGS

Ref.	year	Study Area	Hybrid Energy System	Load/ Demand	Connectivity Type	Objective functions	Methods/ Sotware
[27]	2007	China / Guangdong	PV–WT-BT	city	Off-grid	LPSP, LCE	HSWSO
[28]	2007	Malaysia	PV-WT-pico hydro-BT-DG	village	Off-grid	NPC, COE	HOMER
[29]	2008	Saudi Arabia / Rafha	PV–BT-DG	city	Off-grid	COE, NPC, CO2 emissions	HOMER
[30]	2009	Spain / Zaragoza	PV–wind–diesel	city	Off-grid	COE, life cycle	Pareto evolutionary algorithm/ HOMER
[31]	2009	India	Biomass-Biogas-PV-BT-DG	village	Off-grid	COE	Algorithm written by C++
[32]	2010	Iraq/Basrah	PV–WT-BT-DG-FC	city	Off-grid	COE, TNPC	MATLAB code
[33]	2010	Saudi Arabia / Rafha	PV-DG-BT	City	Off-grid	COE	HOMER
[34]	2010	Saudi Arabia / north of kingdom	PV-DG-BT	Village	Off-grid	COE	HOMER
[35]	2011	Saudi Arabia/remote rural village	PV-WT-BT-DG	Village	Off-grid	COE, TNPC, AOC, LCE	HOMER
[36]	2011	USA / El Paso	PV–WIND-DIESEL	City	Off/On-grid	TNPC, GWP NOx	HOMER
[37]	2011	Sierra Leone	PV–WT	hospital	Off-grid	efficiency	MATLAB code
[38]	2011	sub-Saharan Africa	PV–WIND-DG	City	Off-grid	LCC	MATLAB code
[39]	2012	Myanmar/remote rural village	PV-WT-BT-DG	Village	Off-grid	COE, NPC, IC	HOMER
[40]	2012	Iran /Zabol	PV–WT	City	Off-grid	IC, CC	NSGA-II algorithm
[41]	2012	South Africa / Kwazulu-Natal	WT-PV-micro-hydro	Village	Off-grid	IC	Linear Programming

Ref.	year	Study Area	Hybrid Energy System	Load/ Demand	Connectivity Type	Objective functions	Methods/ Sotware
[42]	2013	Bosnia / Banjaluka region.	PV-WT-BT-DG	City	Off-grid	CRF, ELC	HOMER
[43]	2013	United Arab Emirates /Ras Musherib	PV-WT-BT-DG	city	Off-grid	COE, NPC, CO2 emissions	HOMER
[44]	2013	Palestine	PV–BT-DG	city	Off-grid	COE	HOMER
[45]	2013	Iran / Shiraz	WT-PV-FC-BT	city	Off-grid	LPSP, LCE, EXC, NPC	HOMER / PSO/GA
[46]	2013	Iran /Zabol	PV-WT-BT-DG	city	Off-grid	IC, ACS, CC	MOPSO and NSGA-II
[47]	2013	Croatia / Zagreb	PV-WT-BT	Yldz Technical /universty	Off-grid	COE, TNPC	HOMER
[48]	2013	Nigeria / Agu-Amede village	PV-DG-Biogas	village	Off-grid	COE, TNPC	HOMER
[49]	2013	Saudi Arabia/ten locations	PV-WT-BT-DG	city	Off-grid	LEC, TNPC, AE, CRF	NPCP
[50]	2013	Algeria / Bouzareah	WT-DG-BT	village	Off-grid	NPC, COE	HOMER
[51]	2013	Croatia / Hvar	PV-DG-WT-BT	city	Off-grid	NPC, COE	HOGA
[52]	2013	Spain /Catalonia.	PV-DG-WT-BT	Telecommunication Centre	Off-grid	NPC	HOMER
[53]	2014	Bangladesh /Char Nizam	PV–BT-DG-Biogas	city	Off-grid	COE, NPC	HOMER
[54]	2014	Saudi Arabia / Rafha	PV-WT-BT-DG	city	Off-grid	COE	HOMER
[55]	2014	Kosovo	PV–WT-BT-DG	building	Off-grid	COE, TNPC	HOMER
[56]	2014	IEEE-30 bus	PV-WT	simulation	Off-grid	total cost	MATLAB 7.1/GA/PSO
[57]	2014	Saudi Arabia / Makkah	PV-DG-BT	city	Off-grid	NPC, COE	HOMER
[58]	2014	UAE / Al Gharbia	PV-DG-BT	city	Off-grid	NPC, COE	HOMER
[59]	2014	Myanmar / Nyaung Myint	PV-DG-WT-BT	village	Off-grid	COE	HOMER
[60]	2015	India / Dist. Bhopal	PV-WT-BT-DG	telephone / ecchange office	Off-grid	TNPC	HOMER
[61]	2015	Saudi Arabia / Yanbu and Dhalm	WT-PV-FC	city	Off-grid	RE cost, CO2 emission	HOMER

Ref.	year	Study Area	Hybrid Energy System	Load/ Demand	Connectivity Type	Objective functions	Methods/Sot ware
[62]	2015	French / Brittany	PV-WT-BT-DG	city	Off-grid	COE, TNPC	MATLAB, NREL, HOMER
[63]	2015	Greece / Agrinio	PV-WT-BT	city	Off-grid	COE	HOMER
[64]	2015	Iran / three cites	PV-WT-BT	city	Off-grid	TAC	PSO-W, PSO-CF, PSO-RF, MPSO, SA, TS, HS
[65]	2015	Saudi Arabia / Arar	PV-DG-WT-BT	city	Off-grid	COE	HOMER
[66]	2016	Nigeria/Electrical Engineering Department of Bayero University, Kano	PV–BT- DG	Education	Off-grid	COE, NPC, GHG	HOMER
[67]	2016	India / Pune	PV–BT- DG	hospital	Off-grid	COE	HOMER
[68]	2016	Indonesia / Sebira Island	PV–BT- DG	city	Off-grid	LCOE	HOMER Pro and PVSyst
[69]	2016	Nigeria / residential home located	PV–BT- DG	home	Off-grid	COE, NPC, IC	HOMER
[70]	2016	Saudi Arabia / Dhahran	PV–WIND-BT	city	Off-grid	IC, EOC	HOMER/ AWE-1 /NPCP
[71]	2016	Poland / Poznań	WT-PV-FC	city	Off/On-grid	COE, NPC, LCOE	MATLAB
[72]	2016	Yemen / Shafar	PV-WT-BT-DG	city	Off-grid	COE, CO2 emissions	HOMER
[73]	2016	Tunisia, Jordan and KSA	PV/BT/DG	city	Off-grid	COE, TNPC	HOMER
[74]	2016	Kenya / far-flung region	PV-WT-BT-DG	city	Off-grid	LPSP, LCOE	HOMER
[75]	2016	Namibia / Oluundje	PV-DG	city	Off-grid	NPC	HOMER
[76]	2016	Iraq /Muqdadiyah	PV-WT-BT-DG	city	Off-grid	NPC, COE	HOMER Pro.
[77]	2016	Malaysia / KLIA Sepang Station	PV-WT-DG-BT	city	Off-grid	NPC, COE	HOMER
[78]	2016	Malaysia	PV-DG-WT-BT	Village	Off-grid	NPC, COE	HOMER
[79]	2017	South Africa / remote area	PV-WT-BT-DG	village	Off-grid	COE, NPC	HOMER

Ref.	year	Study Area	Hybrid Energy System	Load/ Demand	Connectivity Type	Objective functions	Methods/ Sotware
[80]	2017	India / remote village in Khurda	PV-WT-BT-DG	Village	Off-grid	COE	HOMER
[81]	2017	Saudi Arabia	PV-WT-BT-DG-full cell	city	Off-grid	COE, TNPC	HOMER/ PSO
[82]	2017	India / Almora District of Uttarakhand	PV-WT-battery	village	Off-grid	IC, LCOE	HOMER/PSO , GA
[83]	2017	Afghanistan / Northeast part	PV-WT-BT-DG	village	Off/On-grid	LCC, LPSP	GA
[84]	2017	Algeria / Djanet	PV-BT-DG	village	Off-grid	LPSP	MATLAB
[85]	2017	Morocco / Ghajar and Billinton	PV-WT-BT	City	Off-grid	LOEE, LOLE, COE	HOMER
[86]	2017	Australia	PV-WT-DG-BT	City	Off-grid	NPC, COE	HOMER
[87]	2017	India/ Bhopal	PV-Biogasifier-BT-FC	village	Off-grid	NPC, COE	HOMER
[88]	2017	Algeria / Chlef	PV-DG-WT-BT	City	Off-grid	COE	HOMER
[89]	2018	Iraq /remote rural village in Diyala	PV–BT- DG	village	Off-grid	NPC, CO2 emissions	HOMER
[90]	2018	Nigeria / Katsina state	PV–BT- DG	village	Off-grid	COE, NPC, CO2 emissions	HOMER
[91]	2018	Ghana /	PV–BT- DG	city	Off-grid	LCOE, CO2 emissions	HOMER
[92]	2018	South Africa / Gwakwani	PV-WT-BT-DG	city	Off-grid	COE, CO2 emissions	HOMER
[93]	2018	Greece / Tilos and Ajaccio	PV-WT-BT	city	Off-grid	ACS, LPSP	MOPSO
[94]	2018	Algeria / Setif	PV-WT-BT-DG	city	Off-grid	NPC, COE	HOMER
[95]	2018	Cyprus / Guzelyurt	PV-WT-FC	city	Off-grid	LCOE	Meteonorm 7.1
[96]	2019	Nigeria / Kano	PV-WT-BT-DG	Bayero University	Off-grid	COE	HOMER
[97]	2019	Poland	WT-PV	University of Science	Off/On-grid	NPC, CO2 emissions	HOMER
[98]	2019	Myanmar / Na Bu Taw village	PV-BT-DG	village	Off-grid	LCOE	HOMER
[99]	2019	Kenya	PV–WT	commerial applications	Off-grid	COE, TNPC	HOMER
[100]	2019	Morocco, 6 cities	WT-PV-BT	City	Off-grid	COE, CO2 emissions	TRNSYS and Mat lab

Ref.	year	Study Area	Hybrid Energy System	Load/ Demand	Connectivity Type	Objective functions	Methods/ Sotware
[101]	2019	Nigeria / Umuokpo Amumara	PV-WT-BT	City	Off-grid	NPC, COE	HOMER
[102]	2019	Malaysia / village	PV-BT-DG	Village	Off-grid	NPC, COE	PVSYST
[103]	2019	Myanmar / Inn Ma village	PV-DG	Village	Off-grid	COE	HOMER Pro.
[104]	2019	Togo / Lomé	PV-WT-BIO DG-BT	City	Off-grid	TNPC	ILP/HOMER
[105]	2019	Egypt / Makadi Bay	PV-WT-BT	City	Off-grid	COE	TORSCHE optimization
[106]	2019	Egypt / Ataka	PV-WT-FC	City	Off/On-grid	COE	MFFA
[107]	2019	Nigeria	PV-DG-BT	Village	Off-grid	COPT, LOLE, LOLP, ELL	HOMER
[108]	2020	Nigeria/remote rural village	PV-WT-BT-DG	Village	Off-grid	COE, NPC, CO2 emissions	HOMER
[109]	2020	Saudi Arabia / villages near Arar	PV-WT-BT-DG	Village	Off-grid	LPSP, COE, ASC	HOMER
[110]	2020	Saudi Arabia	WT-PV-DSL	commercial applications	Off-grid	average cost	MATLAB code
[111]	2020	Nepal / Dhulikhel	PV-WT-BT-Biomass	Kathmandu University	Off/On-grid	COE, TNPC	HOMER
[112]	2020	Nigeria / Mboke	PV-Micro Hydro-DG-BT	City	Off-grid	NPC, COE, CRF	HOMER
[113]	2020	Nigeria / Fanisau	PV-WT-BT-DG	City	Off-grid	TAC, COE	MATLAB
[114]	2020	Oman / Thumrait	PV-WT-BT	City	Off/On-grid	LPSP, COE	GA-NIA
[115]	2020	Iraq / Baghdad	PV-DG-WT-BT	City	Off/On-grid	NPC, COE	HOMER
[116]	2021	Iraq/Zerbattiya	PV-WT-BT-DG	City	Off-grid	NPV, NWT, NDG, NBT, Nconv, COE, NPC, and IC	HOMER
[117]	2021	Malaysia / village	PV-hydrogrid-BT	Village	Off/On-grid	NPC	HOMER
[118]	2021	Saudi Arabia / Dumah Aljandal	PV–WIND-BTHydrogen storage	city	Off-grid	ESS, TNPC, LCE	GRP-PSO
[119]	2021	Kenya / Machakos	PV–WT	city	Off-grid	COE, TNPC	MATLAB code

Ref.	year	Study Area	Hybrid Energy System	Load/ Demand	Connectivity Type	Objective functions	Methods/ Sotware
[120]	2021	Oman / Thumrait	PV-WT-BT	city	Off-grid	LPSP, COE	Gaussian Savitzky–Golay GA
[121]	2021	Bangladesh / Martin's Island	PV-WT	city	Off-grid	NPC, COE IRR	HOMER
[122]	2021	Iran / Bostegan	PV-DG-WT-BT	city	Off-grid	NPC, LCOE	SWARA–WASPAS
[123]	2022	Oman / Al-Dhafrat Rural Area	PV-WT-BT-DG	Village	Off-grid	COE, NPC, CO2 emissions	HOMER
[124]	2022	Tanzania / Mwanza	PV-WT-BT-DG	Airport	Off-grid	COE, NPC	HOMER
[125]	2022	Canada / Francois	PV–BT- DG	city	Off-grid	COE, NPC, ESS	HOMER /MATLAB/Simulink
[126]	2022	Canada / Grey River in Newfoundland	PV– DG	city	Off/On-grid	NPC	HOMER /MATLAB/Simulink
[127]	2022	Canada / Ramea Island	PV-WT-BT-DG	city	Off-grid	COE	HOMER
[128]	2022	Palestine	PV–WT-Biomass	city	Off-grid	LCOE	HOMER
[129]	2022	Saudi Arabia / Dhahran, Duhlom, Yanbou	PV–WT	city	Off-grid	COE, NPC, IC	HOMER
[130]	2022	Jordan	PV-WT-BT-DG	city	Off-grid	NPC, LCOE	HOMER
[131]	2022	Canada/ Diavik Diamond	WT/ BT, hydrogen, and thermal storage	city	Off-grid	COE, TNPC	HOMER Pro.
[132]	2022	Sabon Gida Community of Kaduna State	PV-WT-BT	city	Off-grid	COE	HOMER
[133]	2022	Algeria / Djelfa	PV-WT-BT-DG	city	Off-grid	LPSP, COE	MOSSA
[134]	2022	Jordan /Al-Ghabawi territory	PV–biogas	city	Off/On-grid	LPSP, COE, IR, ACS	MOFEPSO
[135]	2022	India / Odisha	DG-BT	city	Off-grid	LF, CC	MATLAB
[136]	2022	Philippines / Rogongon	PV-WT-BT-DG	city	Off-grid	LCOE, LPSP, GHG	MOPSO
[137]	2022	Egpt/ Marsa Alam	PV-WT-FC	city	Off/On-grid	NPC, COE, CRF, LPSP	MPA/ SOA
[138]	2023	Bangladesh/Metropolitan Area	PV-WT-BT-DG	Health and Education	Off/On-grid	NPC, COE, CO2 emissions	HOMER

Ref.	year	Study Area	Hybrid Energy System	Load/ Demand	Connectivity Type	Objective functions	Methods/ Sotware
[139]	2023	Algeria /rural telecommunication station in the city of Skikda	PV-WT-BT-DG	telecommunication station	Off-grid	COE, NPC	HOMER
[140]	2023	Congo / Lubumbashi	PV–BT- DG	City	Off-grid	COE, NPC, CO2 emissions	HOMER
[141]	2023	Palestine / Hebron City	PV-Biogas-full cel G-Hydrogen storage unit	City	Off-grid	LCOE, NPC, CO2 emissions	RET screen
[142]	2023	Canada / St. Lewis in Labrador	PV-WT-BT-DG	Street	Off-grid	COE	HOMER
[143]	2023	India	PV-WT-BT-DG	Village	Off-grid	COE, NPC, IC	HOMER
[144]	2023	Nigeria	WT-Biogas-PV- BT-DG	village	Off/On-grid	COE, NPC, LCOE	HOMER / PSO/GA/ABC
[145]	2023	Indonesia	PV-WT-BT-DG	city	Off-grid	COE, TNPC	HOMER
[146]	2023	New Zealand / Auckland	PV-WT-BT	city	Off-grid	LPSP, COE	NSGA II / GWO
[147]	2023	Nigeria / Olooji	PV-WT-BT-DG	city	Off-grid	LPSP, LCOE	PSO, FLC
[148]	2023	Indonesia / Malang	PV, Bio Generator, DG-BT	city	Off/On-grid	TNPC, COE, CO2 emittion	HOMER
[149]	2023	Iraq / Basrah	PV-WT-Biogasifier-BT	city	Off-grid	LCOE	GA/PSO/ALO /GWO/GWCSO
[150]	2024	Turky/Sakarya Karasu district	PV–BT- DG	village	Off-grid	UEC, TNPC, COST	HOMER
[151]	2024	USA / Montague	PV–WT-BT-DG	hospital	Off-grid	WSSD, WSDS	PSO, WOA, GWO, IGWO

2.3. Summary of Literature Review

Some vital notes about the table (2-1) can be shown as follow:

1. Geographical Scope: The studies span various countries, mostly focusing on rural and off-grid areas. Countries include Saudi Arabia, India, Nigeria, Kenya, Myanmar, Egypt, and several others. Many studies focus on specific regions or cities within those countries, aiming to assess the potential of hybrid energy systems for local power generation.

2. Hybrid Energy Systems: The most common hybrid systems include combinations of Photovoltaic (PV), Wind Turbines (WT), Battery Storage (BT), Diesel Generators (DG), Biomass, Biogas, and sometimes Hydrogen Storage or Fuel Cells (FC). These systems are designed to meet local energy demand while addressing factors like sustainability, reliability, and cost-efficiency.

3. Connectivity Type: The majority of the studies focus on **off-grid** systems, indicating the interest in providing energy to areas without reliable access to centralized grid electricity. A few studies consider **off/on-grid** systems, focusing on areas that may transition between grid connection and self-sufficient energy production.

4. Objective Functions: The main objectives vary according to the studies but generally include:

- Cost of Energy (COE): Used to evaluate the cost-effectiveness of energy systems.

- Net Present Cost (NPC): Assesses the total cost of the energy system over its lifetime.

- CO2 Emissions: Evaluating the environmental impact of the energy systems.

- Life Cycle Cost (LCC) and **Life Cycle Emissions (LCE):** Considering the long-term costs and environmental impacts of the system.

- Reliability Indices (e.g., LPSP, LCOE): Related to the reliability and continuity of power supply.

- Other factors such as **Efficiency**, **Fuel Savings**, and **Economic Feasibility** are also considered in some studies.

5. Software and Methods: Many studies use **HOMER** (**Hybrid Optimization of Multiple Energy Resources**) for simulation and optimization, particularly for system cost analysis. Other software tools include **MATLAB**, **MATLAB/Simulink**, **PSO**, **GA** (**Genetic Algorithm**), and more specialized tools like **MOPSO**, **NSGA-II**, and **TRNSYS**. These are used for various optimization techniques, including genetic algorithms, particle swarm optimization, and other heuristic approaches to optimize system design and performance.

6. Focus Areas: There are specific mentions of energy solutions for critical infrastructure like **hospitals**, **telecommunication centers**, **education**, and

research institutions. Many studies focus on rural villages, remote areas, and places with unreliable power access.

7. Technological Advancements: Over time, more advanced energy systems such as hydrogen storage and fuel cells are included in the studies, particularly in the later years of the table (2020-2024).

This table provides a comprehensive view of the trends in hybrid energy systems research, with a focus on off-grid, sustainable solutions for diverse geographic and socioeconomic contexts.

2.4. Background of HPGS Modeling

HPGS combine multiple energy sourcestypi cally renewable (PV), (WT) and non-renewable (DG) to improve reliability, efficiency, and sustainability. Modeling such systems involves analyzing their components, performance, and energy flow to design optimized and cost-effective solutions for specific applications, especially in remote or off-grid areas.

2.4.1. HPGS Modeling

Depending on the available resources in the study area, the HPGS system proposed in this study includes solar PV, Wind Turbine, BB, and a diesel generator, which are modelled mathematically. These components have a big impact on the microgrid system's cost, reliability, and environmental impact. These multiple renewable energy sources improve system efficiency and reduce the need for energy storage. Figure (2.1), This figure was obtained using the HOMER Pro software depicts the HPGS's schematic structure. For simplicity, most components are represented by a certain number of units, with one comparable battery representing the BESS capacity. Because auxiliary equipment (such as inverters and charge controllers) is included in the main equipment's efficiency and capital cost, their size and number are not defined. The units for power and energy are set to kilowatts (kW) and kilowatt-hours (kWh), respectively, and the timestep for the optimization process and analysis is set to one hour.

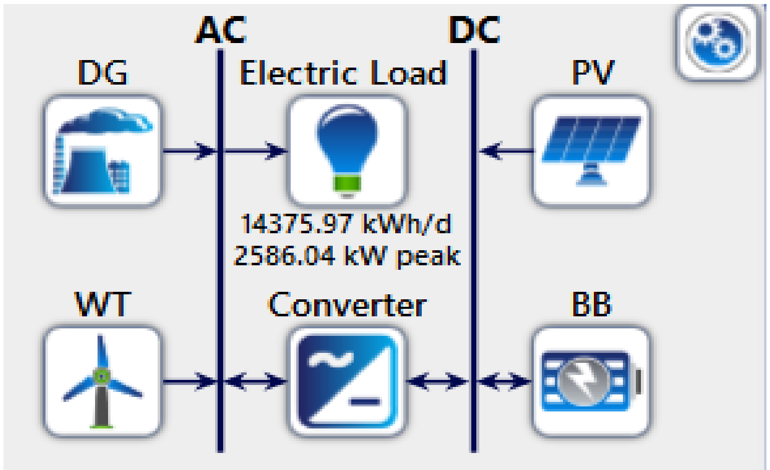


Figure 2.1: HPGS model schematic structure.

2.4.1.1. Solar PV model

Photovoltaic (PV) is a technology that converts sunlight into electricity. It is a method of generating electrical power by using solar cells to capture and convert sunlight into direct current (DC) electricity. These solar cells are typically made from semiconductor materials like silicon.

the Iraqis' geographical position, receives a high amount of sunlight each year, with an average of 12 daylight hours every day. Hence, it would be preferable to incorporate a PV system into the HREM structure. Solar cells, also known as PV cells, are electrical devices that convert solar energy from the sun into electrical energy for use in various applications. In a PV system, the total power created by each PV panel constitutes the power generated by the system as a whole, while the power generated by each panel at each hour is calculated using solar radiation and cell temperature. The following equation gives the output power of a PV system in kilowatts (kW):[152]

$$P_{PV} = Y_{PV} * f_{PV} * \left(\frac{G_T}{G_{T,STC}}\right) * [1 + a_P * \left(T_C - T_{C,STC}\right)] \tag{2.1}$$

2.4.1.1.1 The photovoltaic process works

1. Absorption of Sunlight: Photovoltaic cells are made of semiconductor materials that have special properties. When sunlight (photons) strikes the surface of these cells, it is absorbed by the semiconductor material.

2. Creation of Electron-Hole Pairs: When photons are absorbed, they provide enough energy to the electrons in the semiconductor material to free them from their normal positions. This creates "electron-hole pairs," where electrons are excited and move freely within the material.

3. Generation of Electric Current: The movement of these excited electrons creates an electric current. This current flows through the semiconductor material and can be collected by electrical contacts on the cell.

4. Conversion to Usable Electricity: The electric current generated by individual PV cells is typically in the form of direct current (DC). To make it usable for most household appliances and the electrical grid, it is often converted into alternating current (AC) through an inverter.

5. Utilization: The converted AC electricity can be used to power homes, businesses, or other electrical devices. Excess electricity generated by PV systems can be stored in batteries for use during periods of low sunlight or fed back into the grid.

Photovoltaic systems come in various forms, from small solar panels on rooftops to large solar farms that can generate significant amounts of electricity. They are a clean and renewable energy source, as they do not produce harmful emissions during electricity generation and rely on sunlight, a virtually limitless resource. PV technology plays a crucial role in the transition to sustainable and environmentally friendly energy sources.

Photovoltaic (PV) technology encompasses various types and configurations, each designed for specific applications and efficiency [178].

2.4.1.1.2. Types of PV systems:

1. Crystalline Silicon Solar Cells:

- *Monocrystalline Silicon:* These solar cells are made from single-crystal silicon wafers, offering high efficiency and a sleek black appearance.

- *Polycrystalline Silicon:* These cells use multiple silicon crystals, making them more affordable but slightly less efficient than monocrystalline cells **[179]**.

2. Thin-Film Solar Cells:

- *Amorphous Silicon (a-Si):* These cells are made from non-crystalline silicon, which is deposited as a thin film on a substrate. They are less efficient but can be flexible and lightweight.

- *Cadmium Telluride (CdTe):* CdTe thin-film solar cells are known for their cost-effectiveness and good performance in real-world conditions.

- *Copper Indium Gallium Selenide (CIGS):* CIGS thin-film solar cells offer a good balance between efficiency and flexibility.

3. Organic Solar Cells:

Organic photovoltaics (OPVs) use organic materials, often polymers, to generate electricity. They are lightweight and flexible, suitable for specific applications like flexible solar panels.

4. Concentrated Photovoltaics (CPV):

CPV systems use lenses or mirrors to concentrate sunlight onto small, high-efficiency solar cells. These systems are mainly used in large solar farms and require precise tracking to follow the sun.

5. Bifacial Solar Cells:

Bifacial solar cells can capture sunlight from both sides (front and back), increasing energy production by reflecting light from surfaces beneath the panel.

6. Solar Thermal PV (PVT):

These hybrid systems combine PV panels with solar thermal collectors. They generate electricity while simultaneously capturing heat for various applications like water heating or space heating **[179]**.

7. Building-Integrated Photovoltaics (BIPV):

BIPV systems are integrated into building materials, such as solar roof tiles, solar windows, and solar facades, to provide both electricity generation and architectural functionality.

8. Solar Tracking Systems:

- Solar trackers are mechanisms that tilt or follow the sun's path to optimize the angle of sunlight hitting the PV panels, increasing energy production.

9. Off-Grid and Grid-Tied Systems:

- *Off-grid PV systems* are standalone systems that generate electricity for remote locations or when no grid connection is available.
- *Grid-tied PV systems* are connected to the electrical grid, allowing excess electricity to be fed back into the grid and often incorporating net metering for utility bill savings.

10. Solar Farms:

Large-scale PV installations in the form of solar farms, which can consist of thousands of PV panels, are designed to supply electricity to the grid or specific industrial needs.

The choice of PV technology depends on factors like location, budget, energy requirements, and aesthetic considerations. Advances in PV research and development continue to improve efficiency and reduce costs, making solar energy an increasingly attractive and accessible renewable energy source.

The efficiency of photovoltaic (PV) solar cells and systems can vary widely depending on several factors, including the type of solar cell, its design, environmental conditions, and the quality of components used.

2.4.1.1.3. General efficiency ranges for different types of PV solar cells

1. Crystalline Silicon Solar Cells

- *Monocrystalline Silicon:* Typically has an efficiency range of 15% to 22%. High-quality monocrystalline panels can achieve efficiencies above 20%.

- *Polycrystalline Silicon:* Efficiency ranges from 13% to 16%. Advances in manufacturing have improved efficiency in recent years **[179]**.

2. Thin-Film Solar Cells:

- *Amorphous Silicon (a-Si):* Efficiency ranges from 6% to 10%. a-Si panels are less efficient but can be cost-effective and useful in certain applications.

- *Cadmium Telluride (CdTe):* Efficiency can range from 9% to 15%, with some high-performing CdTe panels achieving efficiencies above 20%.

- *Copper Indium Gallium Selenide (CIGS):* Efficiency varies but can be in the range of 10% to 14%.

3. Organic Solar Cells (OPVs): Efficiency ranges from 5% to 15%, with ongoing research to improve performance.

4. Concentrated Photovoltaics (CPV): CPV systems can achieve very high efficiencies, often above 40% or even 45%. However, they require precise tracking and are typically used in utility-scale installations.

5. Bifacial Solar Cells: Bifacial cells can provide a modest efficiency boost, often increasing energy production by 5% to 30% depending on the reflectivity of the surface below the panels.

It's essential to understand that the reported efficiency of a solar cell is based on ideal laboratory conditions. Real-world efficiency is influenced by various factors, including

- *Location:* Solar panel efficiency is affected by the amount of sunlight a location receives and its angle to the sun.

- *Temperature:* Solar panels become less efficient as they heat up. High temperatures can reduce their output.

- *Dust and Dirt:* Accumulation of dirt and dust on the panels can reduce efficiency. Regular cleaning can help maintain performance.

- *Shading:* Even partial shading of a solar panel can significantly reduce its efficiency.

- *Age and Degradation:* Solar panels degrade over time, with their efficiency declining by about 0.5% to 1% per year.

- *Inverter Efficiency:* The inverter, which converts DC electricity to AC, can affect the overall system efficiency.

- *Quality of Components:* The quality of the solar panels, inverters, wiring, and installation can all impact the overall system efficiency.

Advancements in solar cell technology and manufacturing processes continue to improve the efficiency of PV systems. High-efficiency solar cells, such as monocrystalline PERC (Passivated Emitter Rear Cell) and bifacial modules, are becoming more common in the market, allowing homeowners and businesses to generate more electricity from a given area of solar panels.

When considering a PV system, it's essential to assess the specific conditions of the installation site and the quality of the components to estimate the system's real-world efficiency and expected energy production.

2.4.1.2. Battery bank (Battery Energy Storage System)

A battery bank is a collection of multiple batteries connected to store electrical energy. These banks are commonly used in various applications to provide backup power, store energy generated from renewable sources, or deliver power in off-grid or remote locations.

A BESS is required in a microgrid to prevent power imbalances. The type of power required and the power supplied by the battery energy storage unit determine the type of battery energy storage unit to be used. Lithium-ion batteries were chosen for this study due to their high energy density, long life cycle, and high efficiency. BESS should not be discharged below 20% of its capacity and should not be charged over 90% of its capacity to maximize battery life [180]. The battery

storage capacity is given as:[152]

$$C_{WT} = (E_L * AD) / (\eta_{inv} * \eta_{Batt} * DOD) \tag{2.2}$$

2.3.1.2.1. Some key points about battery banks:

1. Energy Storage: The primary purpose of a battery bank is to store electrical energy. When excess electrical power is generated, such as from a solar panel array or a wind turbine, it can be stored in the battery bank for later use when the energy source is not producing electricity.

2. Backup Power: Battery banks are often used as backup power systems for homes, businesses, and critical infrastructure. In the event of a power outage, the stored energy in the battery bank can be used to provide electricity until regular power is restored.

3. Off-Grid Systems: In off-grid or remote locations where there is no access to a central power grid, battery banks are an essential component of standalone power systems. They store energy generated from renewable sources, like solar or wind, to provide continuous electricity.

4. Voltage and Capacity: Battery banks can be configured to provide specific voltage levels and capacity to meet the requirements of the intended application. The number and type of batteries in the bank determine the overall voltage and capacity.

5. Battery Types: Battery banks can consist of various types of batteries, including lead-acid batteries (flooded, gel, or AGM), lithium-ion batteries, and others. The choice of battery type depends on factors like cost, energy density, and maintenance requirements.

6. Inverters and Charge Controllers: Battery banks are typically connected to inverters and charge controllers. Inverters convert the DC power stored in the batteries into AC power for use in most electrical devices. Charge controllers regulate the charging of the batteries to prevent overcharging and damage.

7. Monitoring and Management: Battery banks often include monitoring and management systems that track the state of charge, voltage, and temperature of the batteries. This data helps optimize battery performance and lifespan.

8. Sizing: Properly sizing a battery bank is crucial to meet the specific energy needs of the application. It involves determining the capacity (in ampere-hours or watt-hours) required and the number of batteries needed to achieve that capacity.

Battery banks are used in a wide range of settings, from small-scale residential systems to large-scale industrial and utility applications. They are a critical component of renewable energy systems, providing a means to store and use electricity generated from intermittent sources like solar and wind, making energy available when it's needed most[180].

2.4.1.2.2. The efficiency of battery

The efficiency of a battery bank refers to its ability to store and later deliver electrical energy while minimizing energy losses. Several factors can influence the efficiency of a battery bank:

1. Charging Efficiency: When charging the batteries in a battery bank, energy can be lost as heat due to the electrical resistance within the batteries and associated charging equipment. The charging efficiency is typically high, often exceeding 90% for many battery types, such as lithium-ion and lead-acid batteries. This means that more than 90% of the energy supplied during charging is effectively stored in the batteries.

2. Discharging Efficiency: When discharging the stored energy from the battery bank to power devices or systems, there can be losses due to internal resistance and voltage drop within the batteries. Discharging efficiency also often exceeds 90% for most battery technologies.

3. Self-Discharge: Over time, batteries can self-discharge, which means they lose a small amount of energy even when not in use. This self-discharge rate varies depending on the type of battery but is generally low.

4. Temperature: Battery efficiency is influenced by temperature. Batteries typically operate most efficiently within a specific temperature range. Extreme temperatures, whether too hot or too cold, can reduce battery efficiency and capacity.

5. Depth of Discharge (DoD): The efficiency of a battery bank can also be affected by the depth to which the batteries are discharged during each cycle. In general, deeper discharges may result in slightly lower efficiency.

6. Battery Chemistry: Different battery chemistries have varying efficiencies. For example, lithium-ion batteries are known for their high round-trip efficiency, often exceeding 90%, while lead-acid batteries can have slightly lower efficiency, particularly if deeply discharged.

7. Inverter Efficiency: When the battery bank is used to power devices or systems that require AC electricity, the efficiency of the inverter (which converts DC battery power to AC) plays a role in overall system efficiency. Inverters typically have efficiencies in the range of 85% to 95%.

8. Cycling Efficiency: The efficiency of a battery bank can change over time with repeated charge and discharge cycles. Some battery chemistries maintain high efficiency even after numerous cycles, while others may experience a gradual decrease.

It's important to note that the efficiency of a battery bank is just one factor to consider when designing an energy storage system. Other factors, such as the cost of the batteries, their lifespan, maintenance requirements, and their ability to meet specific energy storage needs, also play a significant role in system selection.

When evaluating battery banks for specific applications, it's essential to consider the entire energy storage system, including the charging and discharging components, and assess the overall system efficiency to ensure it meets the desired performance and energy management goals.

This equation is straightforward and simply multiplies the voltage and current to calculate the power output of the battery bank in watts. If you are dealing with a battery bank that has multiple batteries connected in series or parallel, the voltage and current should be appropriately calculated based on the configuration.

Keep in mind that this equation provides the instantaneous power output of the battery bank. The actual power delivered over time depends on the discharge duration and the capacity of the batteries. Battery capacity is typically rated in ampere-hours (Ah), and the total energy output (in watt-hours, Wh) can be calculated as follows:

$$E=V * I * t \tag{2.3}$$

This equation takes into account the duration of discharge, and it provides the total energy delivered by the battery bank over that period.

2.4.1.2.3. Replacement Cost of Batteries

The cost of replacing batteries majorly contributes to the overall operating cost of an HRES. Battery replacement depends on the battery usage cycle NT, which in turn is dependent on the depth of discharge (DOD). The operating cost of the battery (CBat) in (USD/kWh).[153]

2.4.1.3. Diesel generator

A diesel generator also known as a diesel genset or diesel-powered generator, is a machine that generates electricity using a diesel engine as its primary source of power. It is commonly used as a backup power source or as a standalone power generation solution in various applications, including residential, commercial, industrial, and remote locations.

Diesel generators are a more traditional form of energy that is utilized as a backup to compensate for power shortages in HPGS. Typically, it serves as the primary mover, compensating for the imbalance between renewable energy sources and load, especially in remote microgrids. The following equation is used to determine the diesel generator's fuel consumption in liters/hour [152]

$$F_G = B_G * P_{G-rated} + A_G * P_{G-out} \tag{2.4}$$

2.4.1.3.1. Operation Cost of the Diesel Generator

In an HPGS, a generator provides the energy needed to power the load at a critical time when renewable energy and battery energy are not enough. A generator needs to be run between 70% and 89% of its rated capacity for optimal efficiency [181].

2.4.1.3.2. A diesel generator typically works

1. Diesel Engine: The core component of a diesel generator is a diesel engine. Diesel engines are internal combustion engines that use diesel fuel as their primary source of energy. They are known for their durability, fuel efficiency, and reliability.

2. Generator Alternator: Connected to the diesel engine is a generator alternator (also known as a generator head or generator winding). The alternator consists of coils of wire that rotate within a magnetic field to generate electrical voltage.

3. Combustion Process: The diesel engine burns diesel fuel in a controlled combustion process. As the fuel burns, it generates high-pressure gases that drive a piston, which, in turn, rotates a crankshaft. This mechanical energy is used to turn the alternator.

4. Electricity Generation: The rotation of the alternator within the magnetic field induces an electrical current in the coils of the alternator. This electrical current is then converted into usable electricity. The voltage and frequency of the generated electricity can be adjusted to match the desired output.

5. Voltage Regulation: Diesel generators typically have voltage regulation systems to ensure a stable output voltage. This is crucial to prevent damage to connected electrical equipment.

6. Control Panel: Diesel generators come equipped with a control panel that allows operators to start, stop, and monitor the generator's performance. They may also have safety features and automatic shutdown mechanisms in case of issues like low oil pressure or high engine temperature.

Diesel generators are favored for their ability to provide reliable and continuous power over extended periods, making them suitable for critical applications where interruptions in power supply are not acceptable. They are commonly used in industries such as healthcare, data centers, telecommunications, construction, and as emergency backup power sources for homes and businesses. Diesel generators are available in various sizes and power capacities to meet different requirements, from small portable generators to large industrial units.

Diesel generators come in various types and configurations to suit different applications and power requirements.

2.4.1.3.3. Types of diesel generators:

1. Portable Diesel Generators: These are small, compact generators designed for portability and ease of use. They are often used for recreational activities, camping, and as backup power for small appliances and tools at home or on job sites.

2. Home Standby Generators: Home standby generators are designed to provide backup power to residences during electrical outages. They are typically permanently installed and connected to the home's electrical system. When a power outage occurs, an automatic transfer switch (ATS) detects the loss of utility power and starts the generator to supply electricity to the home.

3. Commercial Diesel Generators: Commercial generators are used in businesses, offices, and small to medium-sized industrial settings. They are designed to provide backup power during outages or as a primary power source in remote locations. These generators often come in various power ratings to meet the specific needs of the application.

4. Industrial Diesel Generators: Industrial generators are heavy-duty units designed for continuous operation and powering large facilities, factories, data centres, and critical infrastructure. They can range from several kilowatts to megawatts in capacity and are built to withstand heavy loads and extended run times.

5. Trailer-Mounted Generators: These generators are mounted on trailers for easy transportation to different locations. They are commonly used in construction sites, outdoor events, and other temporary power needs.

6. Silent/Soundproof Generators: These generators are equipped with soundproof enclosures to reduce noise levels during operation. They are commonly used in residential areas, hospitals, and places where noise pollution must be minimized.

7. Rental Generators: Rental generators are available for temporary power needs, such as during events, construction projects, or emergency situations. Rental companies provide a variety of generator sizes and types to meet specific requirements.

8. Prime Power Generators: Prime power generators are designed for continuous, long-term operation as the primary source of electricity. They are commonly used in remote locations, off-grid applications, and industries with unreliable utility power.

9. Emergency Backup Generators: These generators are specifically designed to provide backup power during emergencies, such as natural disasters or grid failures. They are crucial for maintaining critical infrastructure, including hospitals, data centres, and emergency response facilities.

10. Hybrid Generators: Hybrid generators combine diesel power with other energy sources, such as solar panels or batteries, to improve efficiency and reduce fuel consumption. They are used in off-grid and environmentally conscious applications.

These are some main types of diesel generators, and each type is designed to meet specific power generation needs and environmental conditions. When choosing a diesel generator, it's essential to consider factors such as power requirements, intended use, fuel efficiency, and noise levels to select the most suitable type for your application.

2.4.1.3.4. The efficiency of diesel

The efficiency of a diesel generator refers to how effectively it converts the chemical energy in diesel fuel into electrical energy. Several factors influence the efficiency of a diesel generator:

1. Engine Efficiency: Diesel engines are known for their high thermal efficiency compared to other internal combustion engines. Modern diesel engines can achieve thermal efficiencies of 30% to 40% or even higher, depending on factors like engine design, size, and load. This means that a significant portion of the energy from the diesel fuel is converted into mechanical energy to drive the generator.

2. Generator Efficiency: The generator alternator, which converts mechanical energy into electrical energy, also has its own efficiency rating. High-quality generators typically have higher electrical conversion efficiencies, which means they waste less mechanical energy as heat during the generation process.

3. Load Matching: Diesel generators are most efficient when they operate close to their rated load capacity. Running a generator at a light load can reduce its efficiency because the engine may not be operating in its optimal efficiency range. Conversely, overloading a generator can lead to decreased efficiency and increased wear and tear.

4. Engine Size and Type: The size and type of the diesel engine used in the generator can impact its efficiency. Smaller engines may be less efficient than larger ones, especially when running at partial loads. Additionally, newer engine technologies, such as common rail fuel injection and turbocharging, can improve efficiency.

5. Maintenance and Tuning: Regular maintenance, tuning, and keeping the engine in good condition can help maintain its efficiency over time. Clean filters, well-maintained fuel injectors, and proper oil levels are all factors that can affect efficiency.

6. Environmental Conditions: Environmental factors, such as temperature and altitude, can affect the efficiency of a diesel generator. Engines may need to be tuned differently to operate optimally in extreme conditions.

7. Fuel Quality: The quality of the diesel fuel used can impact efficiency. Low-quality or contaminated fuel may lead to reduced engine performance and efficiency.

8. Exhaust Aftertreatment: Modern diesel generators may incorporate exhaust aftertreatment systems, such as selective catalytic reduction (SCR) and diesel particulate filters (DPF), to reduce emissions. While these systems are essential for environmental compliance, they can slightly affect overall efficiency.

In general, diesel generators can be highly efficient when properly designed, maintained, and operated. Their efficiency makes them a popular choice for applications where reliability and fuel efficiency are critical, such as backup power systems and remote power generation. However, to achieve and maintain optimal efficiency, it's essential to select the right generator size, perform regular maintenance, and ensure proper load management.

2.4.1.3.5. The power output of a diesel generator

The following equation is used to determine the diesel generator's power output in (w) [154][155].

$$P= \sqrt{3} * V * I * \cos a \qquad (2.5)$$

This equation accounts for the power factor and provides the real power output in kilowatts. In three-phase generator systems, the $\sqrt{3}$ factor is included to calculate power accurately.

2.4.1.4. Wind turbine model

A wind turbine is a device that converts the kinetic energy of wind into mechanical energy, which is then used to generate electricity. Wind turbines are a vital component of the renewable energy industry and are used to harness the power of the wind to produce clean and sustainable electricity. They are commonly found in wind farms, onshore and offshore, as well as in smaller applications like residential or commercial installations.

The power output of a wind turbine is determined by the regional wind speed and wind turbine characteristics. This study uses the following equations to determine the output power of a wind turbine:[152].

$$P_{WT} = \frac{1}{2}\rho A V^3 C_{pmax} \tag{2.6}$$

2.4.1.4.1. A typical wind turbine works

1. Rotor Blades: Wind turbines have a set of rotor blades mounted on a hub. These blades are designed to capture the kinetic energy of the wind as it blows.

2. Wind Energy Conversion: When the wind blows, it exerts force on the rotor blades, causing them to rotate. This rotational motion converts the kinetic energy of the wind into mechanical energy.

3. Generator: The rotating motion of the blades is connected to a generator through a shaft. The generator contains coils of wire and a magnetic field. As the rotor blades turn the shaft, it spins the coils within the magnetic field, inducing an electrical current. This process is based on the principles of electromagnetic induction.

4. Electricity Generation: The electrical current generated by the generator is typically in the form of alternating current (AC). However, some wind turbines generate direct current (DC), which is then converted to AC using an inverter. The electricity generated is then ready for distribution and use.

5. Control Systems: Wind turbines are equipped with control systems that allow them to adjust the angle and orientation of the rotor blades to optimize energy capture and operate efficiently under various wind conditions. These systems also include safety features to shut down the turbine in extreme wind conditions to prevent damage [182].

2.4.1.4.2. Types of wind turbines

Wind turbines come in various sizes and designs, with the most common types being:

1. Horizontal Axis Wind Turbines (HAWT): These turbines have a horizontal rotor shaft and blades and are the most prevalent type of wind turbine. They can range from small residential turbines to massive utility-scale installations.

2. Vertical Axis Wind Turbines (VAWT): VAWTs have a vertical rotor axis and are less common but have advantages in certain applications, such as urban environments and locations with turbulent winds.

3. Offshore Wind Turbines: These are wind turbines installed in bodies of water, typically in the ocean. They are often larger and more powerful than onshore turbines due to the stronger and more consistent wind resources found offshore.

Wind energy is a renewable and environmentally friendly source of electricity, as it produces no greenhouse gas emissions during operation. It has become an essential part of the global effort to transition to cleaner and more sustainable energy sources. Wind turbines can be deployed in various settings, from remote

areas to densely populated regions, making them a versatile and scalable renewable energy solution [183].

2.4.1.4.3. The efficiency of wind turbine

The efficiency of a wind turbine is typically measured as the "capacity factor" or "efficiency factor." It represents the actual energy output of the turbine relative to its maximum potential energy output if it were operating at its rated capacity continuously. The capacity factor is expressed as a percentage. The efficiency of a wind turbine depends on several factors, including its design, location, and wind conditions.

1. Design Efficiency: The design of the wind turbine, including the shape and size of the rotor blades, the type of generator used, and the control systems, plays a significant role in determining its efficiency. Modern wind turbine designs are optimized for better efficiency.

2. Wind Speed: The efficiency of a wind turbine is highly dependent on the wind speed. Wind turbines have a specific range of wind speeds at which they operate most efficiently. They start generating electricity at a certain "cut-in" wind speed, reach peak efficiency at the "rated" wind speed, and then "cut out" or shut down at higher wind speeds to avoid damage. The efficiency is highest at the rated wind speed.

3. Site Location: The location of the wind turbine also impacts its efficiency. Wind turbines located in areas with consistent and strong wind patterns tend to have higher capacity factors. Onshore wind turbines may have lower capacity factors than offshore turbines because offshore locations often have more consistent and stronger winds.

4. Maintenance and Upkeep: Regular maintenance and proper upkeep of the wind turbine are essential to maintain its efficiency over time. Neglecting maintenance can lead to decreased performance.

5. Turbulence and Wake Effects: Turbulence caused by nearby objects, such as buildings or other turbines, can reduce the efficiency of a wind turbine. Turbines in wind farms are often spaced apart to minimize these effects.

6. Technology Advances: Advances in wind turbine technology, including improvements in blade design, materials, and control systems, have led to higher efficiency and energy capture.

7. Seasonal and Daily Variations: Wind conditions can vary throughout the day and across seasons. Wind turbines need to adapt to these variations, which can impact their overall efficiency.

The capacity factor of a wind turbine typically ranges from 20% to 50% or higher, depending on the factors mentioned above. A well-sited and well-maintained wind turbine in an area with consistent wind resources can achieve a higher capacity factor. Wind farm developers carefully assess wind conditions when selecting locations for wind turbines to maximize their efficiency and energy production.

It's important to note that while wind turbines may not operate at their maximum capacity continuously due to variable wind conditions, they still provide a valuable source of renewable energy, especially when integrated into a diverse energy mix alongside other renewables and conventional power sources.

2.4.1.5. Converters

Converters are essential components of hybrid energy systems because they allow for the efficient integration and utilization of energy from several sources. Solar panels, wind turbines, and conventional generators are common components of such systems, as are energy storage devices like batteries. The converters are the parts of the system that control the transformation of energy, making sure everything works together smoothly**.**

2.4.1.5.1. Types of Converters

There are several types of converters commonly used in hybrid energy systems:

1. DC-DC Converters: These converters are used to step up or step down the direct current (DC) voltage from sources like solar panels or batteries to match the required voltage level of the load or another part of the system. They are essential for optimizing the power flow between different DC sources and the load.
2. DC-AC Inverters: Inverters convert direct current (DC) from batteries or solar panels into alternating current (AC), which is the standard form of electricity used in most homes and businesses. In hybrid systems, inverters are critical for integrating renewable energy sources with the grid or for supplying AC loads directly.
3. AC-DC Rectifiers: These converters are used to convert alternating current (AC) from the grid or generators into direct current (DC) to charge batteries or power DC loads. Rectifiers are key components in systems that involve both AC and DC circuits.
4. Bidirectional Converters: Bidirectional converters can operate in both directions, converting DC to AC and AC to DC, depending on the system’s needs. These converters are particularly useful in systems with energy storage, as they allow for both charging (AC to DC) and discharging (DC to AC) of batteries [184].

2.4.1.5.2. Role of Converters in Hybrid Systems

Converters serve several critical functions within a hybrid energy system:

1. Energy Integration: Converters enable the integration of different energy sources, ensuring that power generated from renewable sources like solar or wind can be effectively combined with conventional generators and storage systems.
2. Power Quality Management: Converters help manage and improve power quality by regulating voltage and frequency, ensuring stable and reliable electricity supply to the load. This is especially important in systems where power sources have variable outputs, such as solar or wind energy.
3. Efficiency Optimization: By converting energy to the appropriate form for storage or use, converters help maximize the overall efficiency of the system. For example, DC-DC converters ensure that energy stored in batteries is used efficiently by stepping down or stepping up voltage as needed.
4. Grid Compatibility: In grid-connected hybrid systems, converters ensure that the electricity generated by the system is compatible with the grid's voltage and frequency standards. This is particularly important when exporting excess energy back to the grid or when the system operates in a grid-tied mode.
5. Protection and Safety: Converters also play a role in protecting the system from faults, such as overvoltage, overcurrent, or short circuits. Advanced converters are often equipped with protection mechanisms that can isolate faulty sections of the system to prevent damage [184].

2.4.1.5.3. Challenges and Considerations

While converters are essential for the operation of hybrid energy systems, they also present several challenges:

1. Efficiency Losses: Despite their importance, converters can introduce efficiency losses, particularly during energy conversion processes. Minimizing these losses through the use of high-efficiency converters is a critical design consideration.
2. Complexity and Cost: Hybrid energy systems with multiple converters can be complex to design and operate. Additionally, converters add to the overall

cost of the system, making cost-benefit analysis an important part of the system design process.

3. Reliability: Converters are subject to wear and tear, which can affect the reliability of the overall system. Ensuring that converters are robust and have adequate maintenance protocols is crucial for long-term system stability.

2.5. Different types of PSO

For certain types of situations, Basic PSO may not be the best solution. Many modifications to the basic method have been suggested for PSO's use in various issue categories. Variations in the constants or solution approach have led to the proposal of many variants of PSO.

2.5.1. Canonical Particle Swarm Optimization

In 2002, a new sort of approach was introduced into Particle Swarm Optimization by Maurice Clerc and James Kennedy [18]. The algorithm's convergence qualities are determined by a combination of many factors. They added a "Constriction Factor (X)" to the standard PSO to regulate the particles' convergence characteristics. Once the Constriction Factor (X) is included, the formula for updating velocities becomes:

$$v_i^{t+1} = X(v_i^t + c_1 U_1^t (pb_i^t - x_i^t) + c_2 U_2^t (gb^t - x_i^t)) \qquad (2.7)$$

Where:

$$X = \frac{2k}{(|2 - Q\sqrt{(Q^2 - Q)}|)}$$

$$Q = c_1 + c_2$$

2.5.2. Modified PSO (MPSO) or Time Varying Inertia Weight Particle Swarm Optimization (TVIW-PSO)

As early as 1998, Yuhui Shi and Russell Eberhart [19] 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 is the new rule for velocity updates:

$$v_i^{t+1} = \text{w (t)}. v_i^t + c_1 U_1^t (pb_i^t - x_i^t) + c_2 U_2^t (gb^t - x_i^t) \quad (2.8)$$

From its starting value to its ultimate value, the time-varying inertia weight, w (t), often follows a linear pattern. Parameters $c_1$and c_2 are typically both set to 2 [18]. Two methods exist for changing the inertia weight with respect to time. With time-varying inertia weight, the value of the inertia weight varies between iterations. Yuhui Shi and Russell Eberhart coined the term "Dec-IW" [19] to describe a situation in which its values constantly fall. The term "Inc-IW" was first coined by Zheng et al. [164] and describes a situation where 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, while for Inc-IW, it ranges from 0.4 to 0.9 Figure (2.2). For completeness' sake, both versions are sometimes presented.

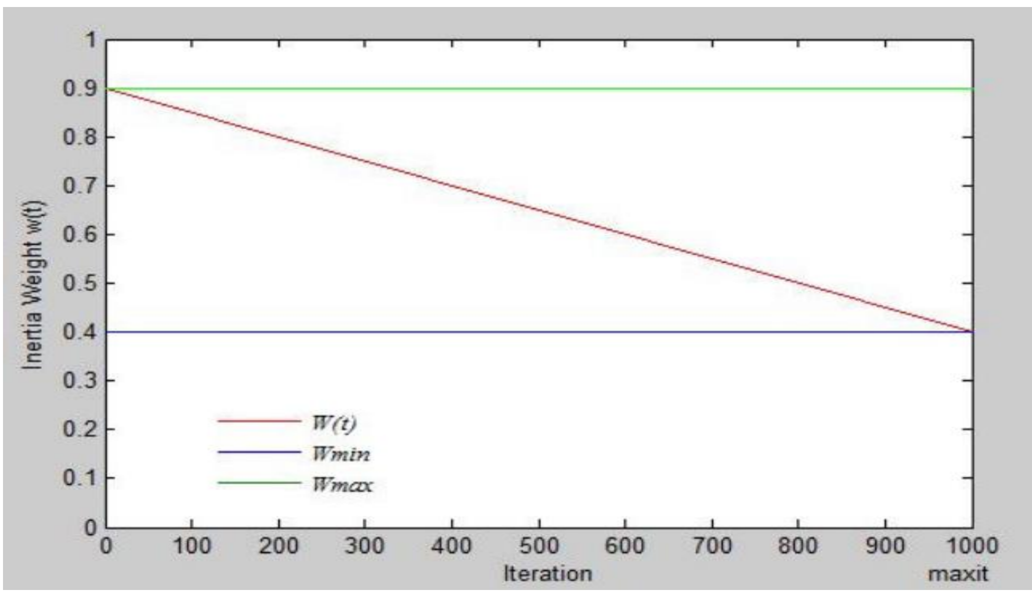


Figure (2.2): Inertia Weight versus Iteration. [165]

Theoretically, it may be expressed as:

For *Dec-IW*,

$$\text{w (it)} = c_1 = W_{max} - \frac{W_{max} - W_{min}}{it_{max}} . it \quad (2.9)$$

For *Inc-IW*,

$$\text{w (it)} = c_1 = W_{max} + \frac{W_{max} - W_{min}}{it_{max}} . it \quad (2.10)$$

2.5.3. Self-Organizing Hierarchical PSO with Time-varying Acceleration Coefficients (HPSO-TVAC)

In their original publication, Ratnaweera et al. [20] presented this method. He removes the velocity component from the time-varying inertia weight equation's right-hand side. Using this method, they suggested a new formula for updating velocity as:

$$v_i^{t+1} = c_1 U_1^t (pb_i^t - x_i^t) + c_2 U_2^t (gb^t - x_i^t\,) \tag{2.11}$$

The acceleration coefficients, however, follow a pattern similar to that of TVAC-PSO; that is, c_1 fluctuates between 2.5 and 0.5, while c_2 fluctuates between 0.5 and 2.5, as shown in the equations. A particle's new velocity is reinitialized to a value corresponding to the maximum permissible velocity Vmax if it reaches 0 in any dimension during the velocity computation. Last but not least, the re-initialization of velocity is likewise reduced linearly from Vmax at start of run to (0.1*Vmax) at finish. You may get a general idea of the PSO optimization method from the preceding explanation. The optimization of the suggested hybrid system, which will be covered in the future chapter, was done using a Stochastic Inertia Weight PSO approach. Table (2.2).

Table (2.2): Input parameters. [167]

Parameters	Unit	Value
PV:		
Initial cost	$/KW	1300
Replacement cost	$/KW	1300
O&M cost	$/unit/year	10
Rated power	Watts	1000
Lifetime	year	25
WT:		
Initial cost	$/KW	18,000
Replacement cost	$/KW	17,000
O&M cost	$/unit/year	130
Rated power	KW	10
Lifetime	year	20
DG:		
Initial cost	$/KW	13,000
Replacement cost	$/KW	13,000
O&M cost	$/unit/year	0.3
Rated power	KW	100
Lifetime	hours	15,000
BB:		
Initial cost	$/KWh	600
Replacement cost	$/KWh	600
O&M cost	$/unit/year	10
Rated power	KWh	1
Lifetime	year	10
Converter:		
Initial cost	$/KW	4500
Replacement cost	$/KW	4500
O&M cost	$/unit/year	10
Rated power	KW	20
Lifetime	year	15
Economic parameters: [165]		
Real interest	%	4
$c_1 = c_2$	-	2
W	-	0.9
N-Ite	-	500
System Lifetime	year	25

2.6. Bat Algorithm

The **(BA)**is a metaheuristic optimization technique developed by Xin-She Yang in 2010, inspired by the echolocation behavior of bats. Bats use echolocation to navigate and locate prey in darkness by emitting sound pulses and analyzing the echoes that bounce back. The Bat Algorithm models this behavior to find optimal solutions to complex optimization problems by combining exploration and exploitation of the search space.

This algorithm employs multiple virtual bats, each representing a potential solution to the optimization problem. The positions and velocities of these bats are updated iteratively based on specific equations, with the goal of converging toward an optimal solution [174][21].

2.6.1. Components of the (BA)

1. *Frequency (f):* Determines how bats adjust their movement range. Each bat has a random frequency, which helps control the step size in the search space.

$$f_i = f_{min} + (f_{max} - f_{min}) \cdot r \qquad (2.12)$$

2. *Velocity (v):* The velocity of each bat is updated based on the difference between the bat's current position and the global best solution found so far.

$$v_i^{t+1} = v_i^t + (x_i^t - x_*) f_i \qquad (2.13)$$

3. *Position (x):* The position of each bat is updated based on its current velocity and frequency, which guides the bat to new regions of the search space.

$$x_i^{t+1} = x_i^t + v_i^{t+1} \qquad (2.14)$$

4. *Pulse Rate (r) and Loudness (Ai):* Pulse rate controls how frequently a bat explores new solutions, while loudness governs how intensely a bat focuses on exploiting the local search space. As the algorithm progresses, loudness decreases,

making bats more focused on refining solutions, while pulse rate increases to encourage local search[174][21].

$$r_i^{t+1} = r_i^{0*\left(1-e^{\{-\gamma t\}}\right)} \tag{2.15}$$

$$A_i^{t+1} = \alpha A_i^t \tag{2.16}$$

This formulation allows the Bat Algorithm to adapt dynamically, making it highly efficient for solving complex optimization problems across a variety of fields such as machine learning, engineering, and energy systems optimization.

2.6.2. Steps of (BA)

1. Start
2. Initialize parameters: Define population (bats), frequencies, velocities, and loudness.
3. Generate initial population: Randomly generate solutions for each bat.
4. Evaluate fitness: Calculate the fitness function for each bat.
5. Generate new solutions:
    - Adjust the frequency for each bat.
    - Update the velocity and position of each bat.
6. Local search (random walk):
    - Generate a local solution around the best bat using a random walk.
7. Evaluate new solutions:
    - If the new solution is better than the previous one and meets the loudness criteria, accept it.
8. Update loudness and pulse rate: Gradually reduce loudness and increase pulse rate as iterations progress.
9. Check stopping criteria:

- If the stopping condition (e.g., maximum iterations or desired fitness) is met, go to step 10.
- Otherwise, return to step 5.

10. Return best solution.
11. End.

2.7. Cuckoo Search Algorithm

The **(CSA)**is an optimization technique inspired by the behavior of cuckoo birds, which lay their eggs in the nests of other birds. This algorithm was first developed by Yang and Deb in 2009 and has proven effective in solving global optimization problems due to its ability to explore the solution space efficiently[22]. The algorithm is applied in various fields, including hybrid energy systems, where it helps improve the performance and efficiency of these systems.

2.7.1. Use of (CSA) in Hybrid Systems

Hybrid systems that combine renewable energy sources (such as solar and wind energy) with fossil fuels (like diesel generators) provide an effective solution to meet increasing energy demands. The Cuckoo Search Algorithm can optimize load distribution, reduce operating costs, and enhance reliability. For instance, the algorithm is used to optimize the scheduling of diesel generators and determine the necessary battery sizes for energy storage.

2.7.2. Components of the (CSA)

The Cuckoo Search Algorithm consists of several key components:

1. Individuals (Solutions): Each cuckoo bird represents a potential solution to the optimization problem.

2. Parameter Ratios: These define how non-ideal birds are replaced with new ones.

3. Fitness Evaluation: This measures the quality of each solution based on the objective function.

2.7.3. Equations of the (CSA)

The algorithm involves several fundamental equations, including:

1. Update Cuckoo Position:

$$x_i^{t+1} = x_i^t + \alpha \cdot (x_{best} - x_i^t) + \sigma.\ \epsilon \tag{2.17}$$

Replacement of Solutions: Poor solutions are replaced with new random ones, enhancing the exploration of the solution space effectively.

2.7.4. Steps of (CSA)

1. Start: The algorithm begins.

2. Initialize Parameters: Set the parameters such as population size, number of iterations, and other relevant settings.

3. Generate Initial Population: Create an initial population of solutions (cuckoo eggs).

4. Evaluate Fitness of Each Solution: Assess the quality of each solution based on the objective function.

5. Is Termination Criterion Met?: Check if the algorithm should stop (e.g., maximum iterations or satisfactory solution found).

   - Yes: Output the best solution found.

   - No: Continue to the next steps.

6. Select Cuckoo Eggs for Replacement: Identify which cuckoo eggs (solutions) will be replaced.

7. Generate New Solutions Using Lévy Flights: Create new solutions using Lévy flight patterns to ensure exploration of the solution space.

8. Evaluate Fitness of New Solutions: Assess the quality of the new solutions.

9. Replace Worst Solutions with New Ones: Replace the least fit solutions in the population with the new solutions.

10. Repeat: Loop back to evaluating the fitness of the solutions.

2.8. Dragonfly Optimization Algorithm

The **(DOA)** is a novel optimization technique inspired by the behavior of dragonflies in nature, which exhibit fascinating behaviors in their search for food and interactions with their environment. This algorithm was introduced by S. A. A. Y. Al-sharafi in 2016 and has proven effective in a variety of global optimization problems [23]. The Dragonfly Optimization Algorithm is applied in many fields, including hybrid energy systems, where it can enhance performance efficiency and reduce costs.

2.8.1. Use of the (DOA) in Hybrid Systems

Hybrid systems that combine renewable energy sources (such as solar and wind energy) with traditional energy sources (like diesel generators) provide an ideal solution to meet increasing energy demands. The Dragonfly Optimization Algorithm aids in optimizing the performance of these systems by determining the best operating strategies, such as scheduling generators and minimizing operational costs. For example, the algorithm can be utilized to optimize the energy distribution among different sources and ensure system sustainability[175] .

2.8.2. Components of the (DOA)

The **(DOA)** consists of several key components, including:

1. Individuals (Solutions): Each dragonfly (or solution) represents a different state of the optimization problem.

2. Movements: These include the flying and clustering behaviors of dragonflies, which are used to explore the solution space.

3. Fitness Evaluation: The quality of each solution is measured based on the objective function.

2.8.3. Equations of the (DOA)

The **(DOA)** involves several fundamental equations, including:

1. Update Dragonfly Position:

$$x_i^{t+1} = x_i^t + \alpha \cdot (x_{best} - x_i^t) + \beta \cdot r \tag{2.18}$$

2. Solution Evaluation: Each solution is evaluated based on the objective function to select the most efficient solutions .

2.8.4. Steps of (DOA)

1. Start: The algorithm begins.

2. Initialize Parameters: Set parameters such as population size, number of iterations, and other relevant settings.

3. Generate Initial Population: Create an initial set of solutions (dragonflies).

4. Evaluate Fitness of Each Solution: Assess the quality of each solution based on the objective function.

5. Termination Criterion Met?: Check if the stopping criterion has been reached (e.g., maximum iterations or a satisfactory solution).

   - Yes: Output the best solution found.

   - No: Proceed to the next steps.

6. Select Dragonflies for Movement: Identify which dragonflies will be moved based on their fitness.

7. Update Positions Using Dragonfly Behavior: Calculate new positions for the selected dragonflies based on their behavioral patterns.

8. Evaluate New Solutions: Assess the quality of the new solutions generated.

9. Replace Less Fit Solutions: Substitute the least fit solutions with the new solutions.

10. Repeat: Return to the fitness evaluation step.

2.9. Grey Wolf Optimization algorithm

The (GWOA) is a nature-inspired metaheuristic optimization technique introduced by Mirjalili et al. in 2014. The algorithm mimics the leadership hierarchy and hunting behavior of grey wolves in nature, aiming to find optimal solutions in complex optimization problems. The (GWOA) algorithm is particularly well-suited for solving nonlinear and multidimensional optimization challenges, making it widely applicable across various fields, including engineering, finance, and logistics [25].

2.9.1. Use of the GWOA in Hybrid Systems

Hybrid systems that integrate multiple energy sources, such as solar, wind, and diesel generators, benefit significantly from optimization algorithms like GWO. By utilizing GWOA, researchers can effectively optimize the operation and management of these systems to enhance efficiency and reduce costs. For instance, GWO has been applied to optimize the scheduling of energy generation in hybrid renewable energy systems, balancing the supply and demand while minimizing operational costs [176].

2.9.2. Components of the (GWOA)

The (GWOA) consists of several key components:

1. Population Initialization: The algorithm starts with a group of solutions (grey wolves) randomly initialized within the search space.

2. Hierarchy: Each grey wolf is assigned a rank based on its fitness, with the best solution referred to as the alpha wolf, followed by beta, delta, and omega wolves.

3. Hunting Mechanism: The wolves update their positions based on the positions of the alpha, beta, and delta wolves, simulating the hunting behavior of grey wolves.

2.9.3. Equations of the (GWOA)

The GWOA involves several fundamental equations that govern the movement of wolves in the search space:

1. Position Update

$$X_i^{t+1} = X_i^t + A \cdot D_i \tag{2.19}$$

2. Distance Calculation:

$$D_i = |C \cdot X_{best} - X_i| \tag{2.20}$$

3. Coefficient Vectors:

- The vectors (A) and (C) are defined as:

$$A = 2a . r_1 - a \tag{2.21}$$

$$C = 2 . r_2 \tag{2.22}$$

2.9.4. Steps of (GWOA)

1. Start: The algorithm begins.

2. Initialize Parameters: Set parameters such as the number of wolves, maximum iterations, and other settings.

3. Generate Initial Population of Wolves: Create a population of wolves randomly distributed in the solution space.

4. Evaluate Fitness of Each Wolf: Assess each wolf's position based on the objective function to determine fitness.

5. Termination Criterion Met?: Check if the stopping criteria have been met (e.g., maximum iterations or a satisfactory solution).

- Yes: If the criteria are met, output the best solution found.
- No: Continue to the next steps.

6. Update Position of Wolves: Identify the wolves that will be moved based on their fitness levels.

7. Calculate Distance to Alpha Wolf: Measure the distance between each wolf and the alpha wolf.

8. Update Positions Based on Alpha, Beta, and Delta: Calculate new positions for wolves using the hunting behavior modeled after grey wolves.

9. Evaluate New Positions: Assess the fitness of the new positions to see if they yield better solutions.

10. Replace Less Fit Wolves: Substitute less fit wolves with newly generated solutions.

11. Repeat: Return to the fitness evaluation step.

Chapter (3)
Modeling of System

3.1. Introduction

This chapter presents a detailed explanation of the software tools and algorithms used, along with their relevant aspects. It also includes the selection of the study location, the demographic data such as population size, the total electrical load, and other required information. Furthermore, it outlines the main components of the hybrid energy system that will be implemented using the mentioned software and algorithms.

This chapter delves into a meticulous study of the vital and economic aspects that form the basis for evaluating the feasibility of the project in the Al-Teeb **District**. The research aims to determine the economic value of the project and its impact on the surrounding area, with a focus on several key indicators.

The chapter begins by elucidating the economic aspects of the project through a detailed analysis of the expected costs and revenues. It sheds light on how the project will affect the local economy and contribute to the growth of the industrial sector in Al-Teeb **District**.

A close examination of the population in the area will be undertaken to understand their needs and consumption patterns. Additionally, the total burden will be calculated by determining the number of households and factories in the area, contributing to a more comprehensive analysis of the economic environment.

Following the introduction, the specific location of the project will be identified, and the environmental elements in the region will be studied. The calculation of solar radiation, wind speed, and temperature will be conducted to assess the impact of these factors on the sustainability and efficiency of the project.

This chapter consolidates all these aspects to provide a comprehensive understanding of the economic feasibility of the project. A thorough understanding of these economic, environmental, and social factors is crucial for making strategic decisions that lead to the success of the project and its benefits for the local community.

Through this review, we anticipate that the chapter will present a comprehensive analysis, establishing the foundations for sustainable and effective decision-making in the field of investment. For the design and analysis of hybrid energy systems, including microgrids, an advanced software package called HOMER Pro is utilized. Through scenario modeling, the tool assists users in determining the best system configuration, taking into account factors such as cost, dependability, and environmental impact. Renewable and hybrid energy projects in off-grid or remote places are commonly planned using HOMER Pro.

3.2. Flowchart of work

The flowchart illustrates the main steps followed in this research. It starts with collecting site data, followed by entering system components and their specifications. HOMER Pro software is then used for analysis, and several optimization algorithms are applied. Finally, results are verified, compared, and the best solution is selected based on performance Figure (3.1).

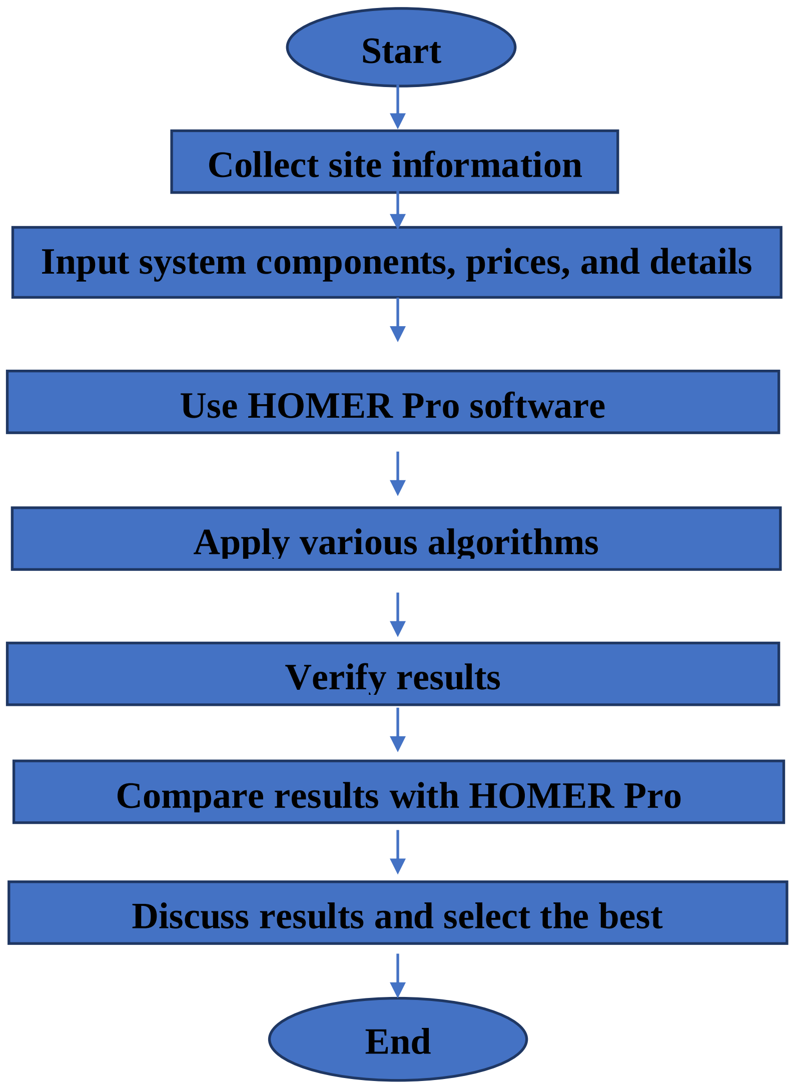


Figure (3.1): Flowchart of the Workflow

3.3. Location and Population

A hybrid power station is scheduled to be constructed in Al-Teeb **District**, located in the city of Amarah, Iraq, at an elevation of 50 meters above sea level. Al-Teeb covers approximately 12.8% of the total area of Amarah, spanning 2070 square meters. This area is isolated from the national electricity grid and is situated in southeastern Iraq along the Iraqi-Iranian border at coordinates 32°25'34" N and 47°10'06" E Figure (3.2). The region includes nine districts Table (3.1) was obtained through the Directorate of Agriculture – Agricultural Lands Department and a field visit to the region, both residential and agricultural. Al-Teeb is characterized by a Type III climate, where both the rainiest and driest months are relatively short, with precipitation occurring during 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. It is one of the most remote rural areas of Amarah City, located approximately 100 km from the city centre. Many rural areas in Iraq, especially in the south, have limited connections to the power grid. Therefore, to help meet the electrical demands of the region, it would be beneficial to utilize more renewable energy sources such as (PV), (WT), (DG), and (BB). Most residents in these remote areas belong to low-income communities lacking connectivity to the main grid. The data used were provided by the National Administration of Statistics in Iraq and the Maysan Governorate's Department of Agriculture, Land Section. The location of Al-Teeb District is illustrated in Figure (3.2) This figure was obtained through the Directorate of Agriculture – Agricultural Lands Department.

3.4. Estimating load

A truly need and biggest challenge that the border rural areas are suffering is difficult chance to connect to electricity grid due to nature of area and distance among population centers. Al-Teeb **District** has five hundred tiny residences, one school, ten stores, and more, as shown in Table (3.2) This table was prepared through a field visit to the region and by calculating the household loads based on actual conditions observed on-site. the city's current population is sourced 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. Since air conditioning is costly and uses a lot of energy, it is not something that these communities think about using. Low-income communities rarely have these kinds of machines. Table (3.3) shows that energy consumption rates in Iraqi houses are 41.292 kWh/d, in schools it is 16.614kWh/d, and in

shopping stores, it is 5.384 kWh/d, According to the field visit to the area and the load calculations. 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, it will be assumed that the electrical supply will meet 1.2 of the current loads throughout that time. Thus, 20,720.882 kWh/d is the estimated average energy usage in the Al-Teeb **District**. Table (3.3), Figure (3.3) and Figure (3.4) were obtained using the HOMER Pro software, Table (3.4) This figure was obtained using the HOMER Pro software Table (3.3), Figure (3.3) shows that after 20 years, the loads will be around (24,865.0584 kWh/d).

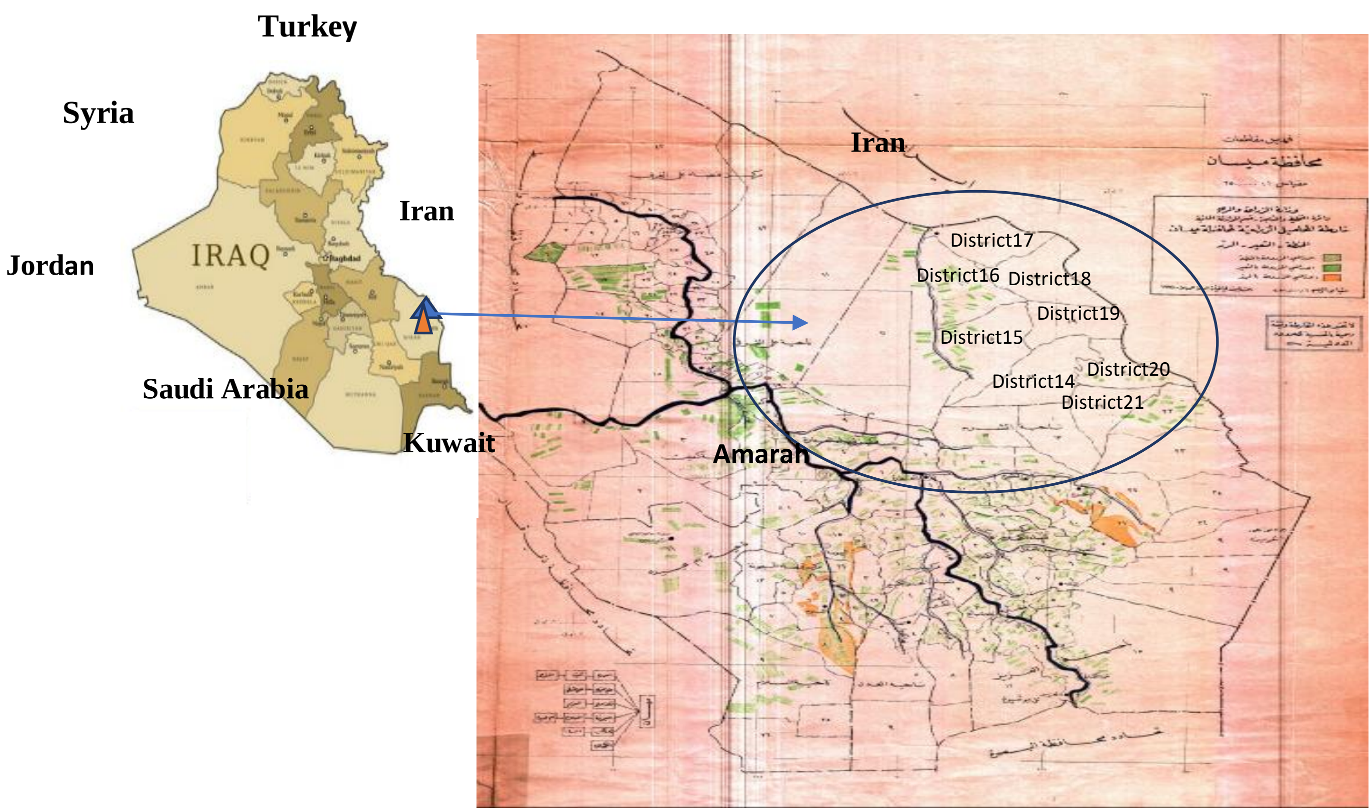


Figure (3.2): Study area- rural agricultural area composed of nine district unelectrified sites in Al-Teeb **District**, Amarah city, Iraq.

Table 3.1: Districts of Al-Teeb.

District Name and Number	No.of Home
District 11 (Said Noor): total homes Al-Shuwaikh: Al-|Rumaila: Said Youssf: Bani Laam:	200 100 20 30 50
District 15 (Teeb Khattita): total homes In Winter: In Summer:	100 70 30-40
District 14 (South Al-Teeb Island, Bazrkan): total homes Al-Sada Labkhat Village: Bani Kaaab Village: Al-Khafaja Area: Al-Dabat Area : Al-Jiyazna Area : Al-Rabieat (Al-Ruwaished) Area:	110 25 20 20-30 10 15 20
District 16 South Al-Teeb Island Al-Zubaidat Area	40
District (17-18-19-20-21) total homes	50
Total	500

Table 3.2: Load of the homes.

Load	Quantity	Usage Hours	Power (Watts)	Total load (KW)	Total load KWh/d
Lights	8	12	15	0.120	1.440
Ceiling fan	4	24	52	0.208	4.992
Washing machine	1	1	350	0.350	0.350
Refrigerator	1	20	220	0.220	4.400
Ventilating fan	2	6	38	0.076	0.456
TV.	1	15	300	0.300	4.500
Water pump electric	1	2	375	0.375	0.750
Electric water heater	1	4	1000	1.000	4.000
Air Condition	2	12	1095	2.190	52.56
Electric iron	1	1	1000	1.000	1.000
Total load for one household				5.839	41.292
Total load for 500 households				2919.5	20,646

Table 3.3: Load demand of Al-Teeb **District**.

load	Quantity	KW	KWh/d	Total load (KW)	Total load (KWh/d)
Homes	500	5.839	41.292	2,919.5	20,646
School	1	3.757	16.614	3.757	16.614
Shopping stores	10	0.302	5.384	3.02	53.84
Total daily energy load				2926.277	20,716.454
After 20 years					24,859.7448

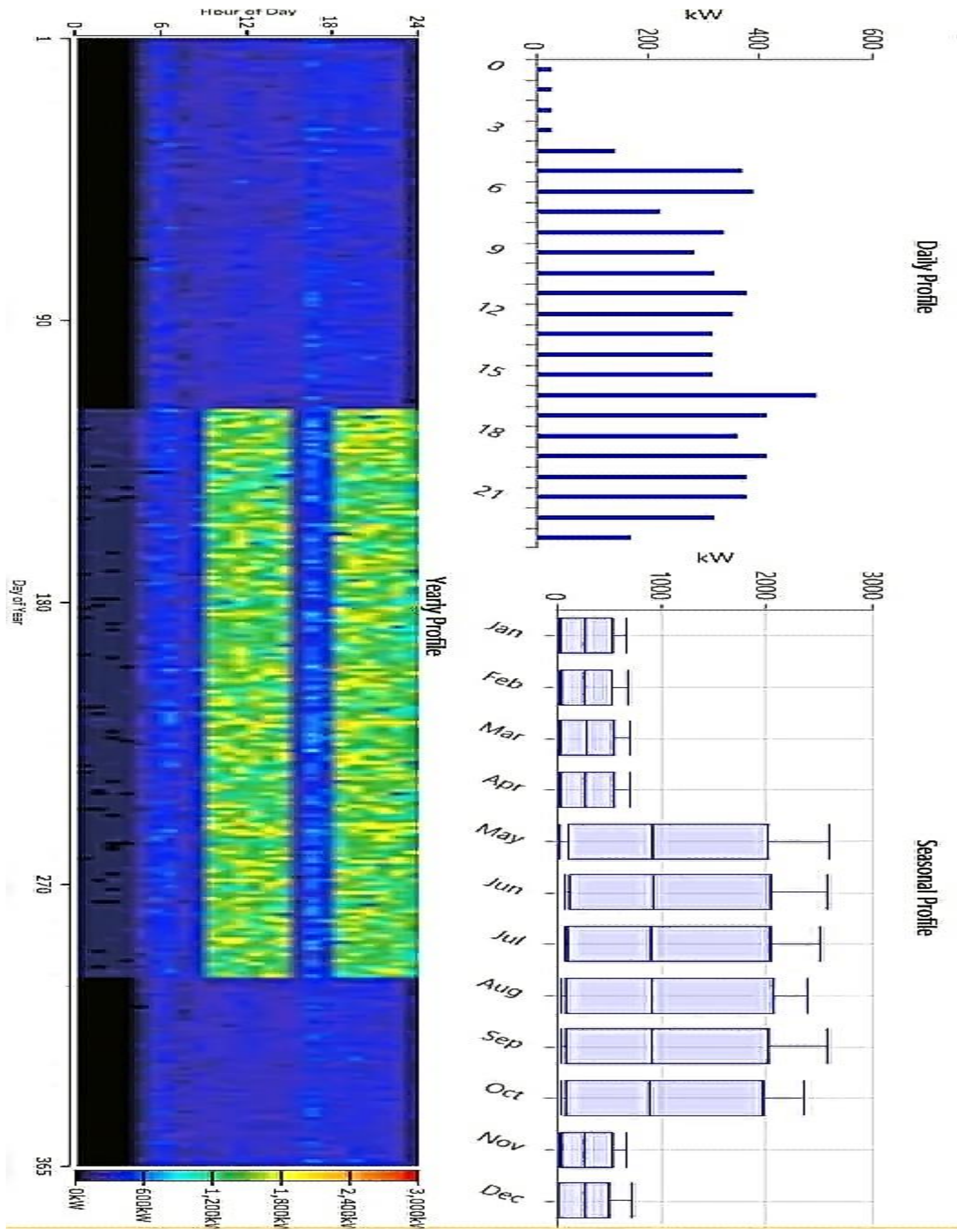


Figure 3.3: Load profile.

Table 3.4: Daily electric load demand per hour of Al-Teeb **District**.

Hour	January	February	March	April	May	June	July	August	September	October	November	December
0	30.000	30.000	30.000	30.000	134.000	112.958	112.958	112.958	112.958	112.958	30.000	30.000
1	30.000	30.000	30.000	30.000	134.000	112.958	112.958	112.958	112.958	112.958	30.000	30.000
2	30.000	30.000	30.000	30.000	134.000	112.958	112.958	112.958	112.958	112.958	30.000	30.000
3	30.000	30.000	30.000	30.000	134.000	112.958	112.958	112.958	112.958	112.958	30.000	30.000
4	140.000	140.000	140.000	140.000	244.000	222.958	222.958	222.958	222.958	222.958	140.000	140.000
5	365.500	365.500	365.500	365.500	469.500	448.458	448.458	448.458	448.458	448.458	365.500	365.500
6	386.542	386.542	386.542	386.542	490.542	469.500	469.500	469.500	469.500	469.500	386.542	386.542
7	222.882	222.882	222.882	222.882	326.882	305.840	305.840	305.840	305.840	305.840	222.882	222.882
8	334.882	334.882	334.882	334.882	438.882	417.840	417.840	417.840	417.840	417.840	334.882	334.882
9	281.042	281.042	281.042	281.042	1,480.042	1,459.000	1,459.000	1,459.000	1,459.000	1,459.000	281.042	281.042
10	319.042	319.042	319.042	319.042	1,518.042	1,497.000	1,497.000	1,497.000	1,497.000	1,497.000	319.042	319.042
11	372.882	372.882	372.882	372.882	1,571.882	1,550.840	1,550.840	1,550.840	1,550.840	1,550.840	372.882	372.882
12	351.840	351.840	351.840	351.840	1,550.840	1,529.798	1,529.798	1,529.798	1,529.798	1,529.798	351.840	351.840
13	313.840	313.840	313.840	313.840	1,512.840	1,491.798	1,491.798	1,491.798	1,491.798	1,491.798	313.840	313.840
14	313.840	313.840	313.840	313.840	1,512.840	1,491.798	1,491.798	1,491.798	1,491.798	1,491.798	313.840	313.840
15	313.840	313.840	313.840	313.840	313.840	292.798	292.798	292.798	292.798	292.798	313.840	313.840
16	501.340	501.340	501.340	501.340	605.340	584.298	584.298	584.298	584.298	584.298	501.340	501.340
17	411.840	411.840	411.840	411.840	515.840	494.798	494.798	494.798	494.798	494.798	411.840	411.840
18	358.000	358.000	358.000	358.000	1,557.000	1,535.958	1,535.958	1,535.958	1,535.958	1,535.958	358.000	358.000
19	411.840	411.840	411.840	411.840	1,610.840	1,589.798	1,589.798	1,589.798	1,589.798	1,589.798	411.840	411.840
20	373.840	373.840	373.840	373.840	1,572.840	1,551.798	1,551.798	1,551.798	1,551.798	1,551.798	373.840	373.840
21	374.840	374.840	374.840	374.840	1,573.840	1,552.798	1,552.798	1,552.798	1,552.798	1,552.798	374.840	374.840
22	320.000	320.000	320.000	320.000	1,519.000	1,497.958	1,497.958	1,497.958	1,497.958	1,497.958	320.000	320.000
23	170.000	170.000	170.000	170.000	1,369.000	1,347.958	1,347.958	1,347.958	1,347.958	1,347.958	170.000	170.000

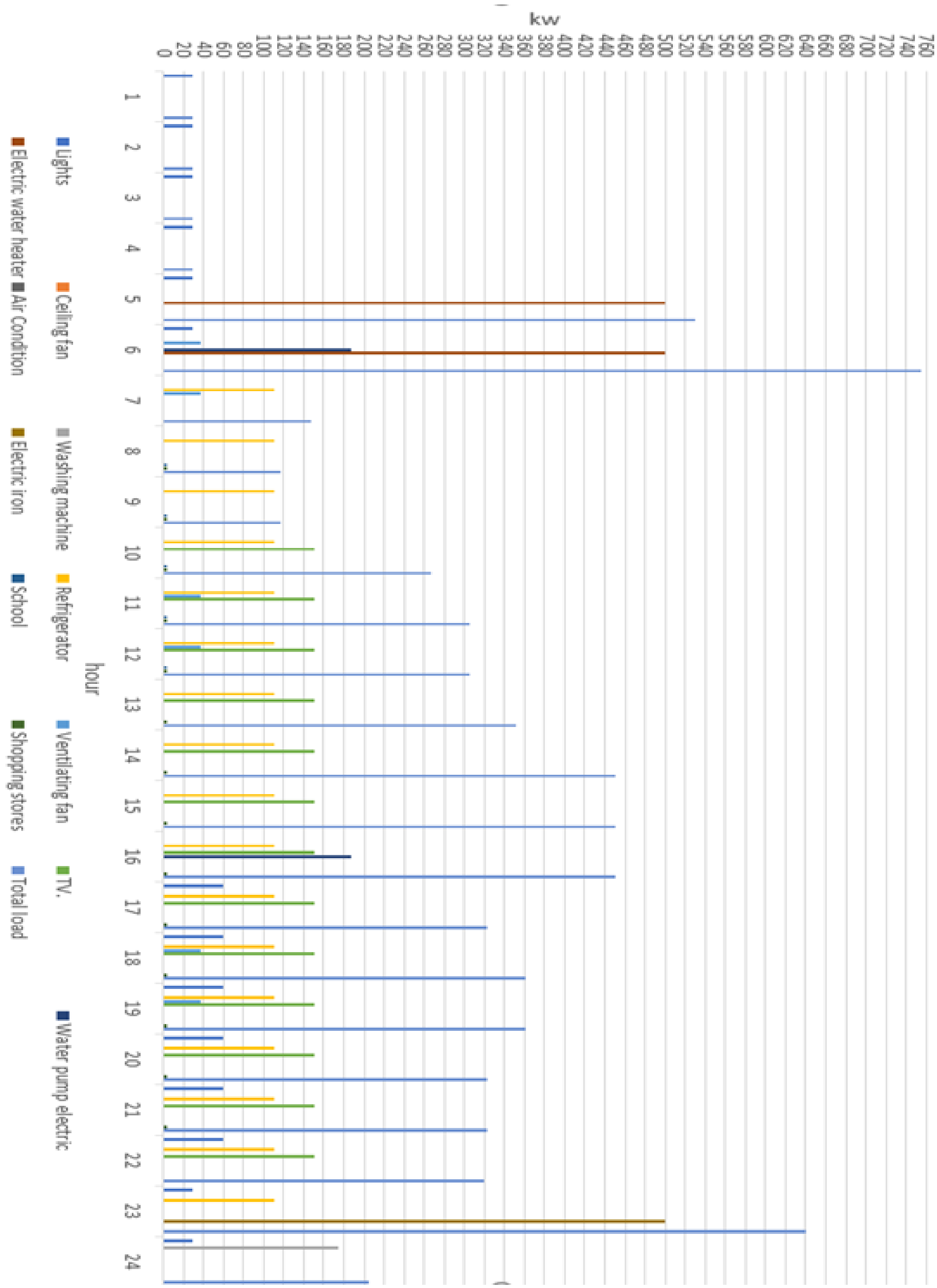


figure 3.4: Demand load of one day in January.

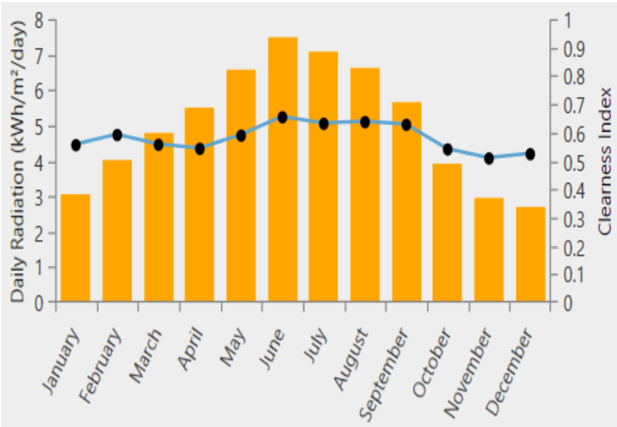
3.5. Main Components

Compiled the list of components using items sold in the Iraqi market, and we contacted several wholesalers and contractors to get their rates. Table (3.5) This table was obtained using the HOMER Pro software, shows that, following consideration of lifetime, basic cost, operating and maintenance costs, and extra expenses, the best options were selected.

3.5.1. Photovoltaic Panel

The term (PV) refers to the technology that turns sunlight into direct current (DC) power *2*. Iraq has access to a plentiful solar energy source because of its geographical position. Table (3.5) shows that the total installation cost was $1300. Operating and maintenance costs were $10 per year per 1,000 W, while the cost of replacement was $1000. PV panels are designed to last for 25

years. Surface meteorology and solar energy data from NASA's database for 2024 were used to get temperature and solar radiation data. Figure (3.5) This figure was obtained using the HOMER Pro software, shows the computed average annual solar radiation, which is 5.03 kWh/m2/d. Figure (3.6) This figure was obtained using the HOMER Pro software, shows that the yearly temperature was 22.42 ºC , Table (3.6). The total area used for this PV (2,187m^2).



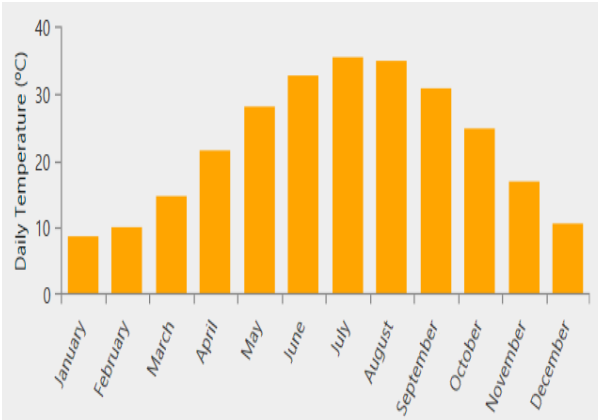


Figure 3.5: Average annual solar radiation.

Figure 3.6: Average annual temperature.

3.5.2. Wind Turbine

The **(WT)** generate power by transforming the mechanical energy of the wind into electrical energy. One way to lessen our impact on the environment is by switching away from fossil fuels, which is why wind turbine farms have emerged as powerful sources of (RE) [157]. Though the manufacturer predicts relatively inexpensive operational and maintenance expenses in the first few years, they predict much greater repair costs starting in year 10 and beyond; therefore, a certain amount of further expenditure has to be expected. There seems to be a strong correlation between the age of the turbine and the operating and maintenance costs. One wind turbine with a 10 kW potential power and an alternating current (AC) voltage output is utilised in this study. As shown in Table (3.5), the price of a turbine starts at $18,000, goes up to $17,000 when replaced, costs $130 per year to run and maintain, and lasts for 20 years. The wind speed statistics for 2024 came from the official NASA database of surface meteorology and solar energy. Figure (3.7) This figure was obtained using the HOMER Pro software, shows that 5.52 m/s , Table (3.6) was the average wind speed for the year. The total area used for this WT (289,100m^2).

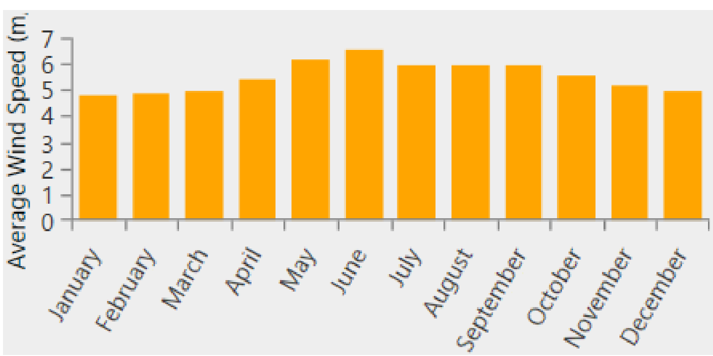


Figure 3.7: Average annual wind speed.

3.5.3. Diesel generator

The often poor dependability of PV-wind hybrid systems is a key factor limiting the expansion of the market for these renewable power sources. (DGs) are thus now thought to be suitable for enhancing system dependability [158]. A (DG) with an estimated 100 kW of power and an engine cooling system that uses liquid were selected. The starting price is $13,000, and the cost to replace it is also $13,000. The cost of operation and maintenance is $15 per hour as well. This generator has a 15,000-hour lifetime, as shown in Table (3.5) [116]. Diesel costs $0.3 per litre in Iraq, according to the country's Ministry of Oil.

3.5.4. Battery bank

The costliest component of (RE) generation systems is usually the battery. Due to the unpredictable nature of solar and wind generation, a PV and WT system must include battery storage to provide a steady output of electricity. So, the battery stores energy and helps even out power fluctuations caused by imbalances in supply and demand. [159]. This uses one kilowatt-hour of battery power. The battery costs $600 upfront, $600 to replace, and $10 per year for operation and maintenance. The selected battery has a lifetime of 10 years, as indicated in Table (3.5) [116].The total area used for this BB ($132m^3$).

3.5.5. Converter

The converter is a crucial part of the system because it takes the direct current (DC) power from the PV modules and turns it into alternating current (AC). It also turns any excess AC power back into DC so that it may be stored in the battery and used when power processing isn't available. The initial investment for this converter is $4500, the cost to replace it is $4500, and the cost to operate and maintain it is $10 per year. Table (3.5) shows that while operating at a 20 kW conversion rate, it has a lifespan of 15 years and an efficiency of 90% [160].

Table 3.5: The components list.

N	Capital cost ($)	Replace cost ($)	O&M Cost	Lifetime	Power	Type
1	1300	1000	$10/y	25 years	1 KW	PV
2	18000	17000	$130/y	20 years	10 KW	WT
3	13000	13000	$0.3/h	15,000 hours	100 KW	DG
4	600	600	$10/y	10 years	1 KWH	BB
5	4500	4500	$10/y	15 years	20 KW	Con

Table 3.6: Long-term monthly average daily meteorological data for Al-Teeb **District**.

Month	Average Wind Speed (m/s)	Month Solar	Average Global	Daily Temperature (ºC)
		Clearness Inex	Daily Radiation (kWh/m^2/day)	
January	4.760	0.555	3.080	8.640
February	4.880	0.591	4.050	10.170
March	4.960	0.557	4.780	14.680
April	5.380	0.543	5.510	21.630
May	6.130	0.589	6.560	27.950
June	6.530	0.654	7.510	32.680
July	5.950	0.631	7.100	35.280
August	5.960	0.637	6.630	34.840
September	5.970	0.627	5.640	30.840
October	5.570	0.540	3.920	24.820
November	5.190	0.508	2.940	16.810
December	4.980	0.523	2.690	10.690
Annual Average	5.52	0.579	5.03	22.42

3.6. System components

Solar and wind power would constitute the backbone of AI-Teeb District's planned hybrid energy infrastructure. In this system, solar panels, wind turbines, battery units, diesel generators, and converters play a significant role. Tables (3.7), (3.8), (3.9), (3.10), and (3.11) show the specs of PV, WT, DG, Con and BB, These details were obtained from the HOMER Pro software, in that order.

Table 3.7: PV inputs details of Monocrystalline Silicon.

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	$ 1300/kW
Cost of replacement	$ 1000/kW
Operating and maintenance cost	$ 10 /kW/year
Lifetime	25 years
Tracking system	Fixed
The dimensions	1.8*1 m^2

Table 3.8: Wind turbine input details.

Input	Data specification
Diameter of rotor	7m
Rated power	10 KW AC
Capital cost	18000
Replacement cost	17000
Operating and maintenance cost	$130/y
Lifetime	20 years
Hub height	24 m
Working Wind Speed	3-30 m/s
Number of Blades	Three blades

Table 3.9 Diesel generator input details.

Input	Model No. GF2-85KVA
Power(50HZ)	100kw
Capital cost ($)	13000
Replacement cost ($)	13000
O&M cost/h ($)	0.3
Lifetime	15000 hours
Minimum load ratio	25%
Fuel used	Diesel
Rated RPM	1500 rpm

Table 3.10: Battery bank inputs details.

Input	Data specification
Nominal voltage	12 V
Nominal capacity	1kwh
Round trip efficiency	80%
Capital cost	600$
Replacement cost	600$
Operating and maintenance cost	$10/y
Lifetime	10 years
Dimensions(L*W*H)	0.4*0.09*0.16 =0.042m^3

Table 3.11: Converter inputs details**.**

Input	Value
size	20kw
Capital cost	4500
Replacement cost	4500
Operating and maintenance cost	$10/y
Lifetime	15years
Efficiency	95%

3.7. Techniques

As mentioned before, the components that are believed to generate electricity include (PV) systems, (WT), and (DG). Hence, the sum of the energy generated by diesel generators (E_{DG}), wind turbines (E_{WT}), and photovoltaic systems (E_{PV}) is equal to the total energy created (E_T). Consequently, the percentage of total energy produced that comes from each source is as follows:

$$f_{pv}=\frac{E_{pv}}{E_T} \tag{3.1}$$

$$f_{WT}=\frac{E_{WT}}{E_T} \tag{3.2}$$

$$f_{DG}=\frac{E_{DG}}{E_T} \tag{3.3}$$

Three main economic indicators, namely (COE), (IC), and (NPC), are considered in this study. Since the value of (NPC) is based on a mathematical idea, it is more dependable than (COE) when considering economic considerations [161], [162]. (COE) refers to the average price per kilowatt-hour (kWh) of the system's usable electrical energy. To determine COE, divide the cost of electricity generation by the total amount of supplied electricity.

3.8. Methodology and constraints

Attaining an objective function that considers several limitations, such as optimum size for each system component, high dependability, and renewable energy penetration, is the emphasis of this chapter's energy cost optimization efforts[169].

3.8.1. Cost of energy

One common and popular metric for evaluating the financial feasibility of HRES is the cost of energy (COE)[170]. Everyone agrees that it's the same as the cost of power or the constant price per unit of energy, and here's how to calculate it:

Cost of energy (COE) (\$/kwh) = $\frac{Total\ Net\ Present\ Cost}{\sum_{H-1}^{H-8760} P_{Load}}$ CRF (3.4)

CRF = $\frac{i(1+i)^N}{(1+i)^N-1}$ (3.5)

The following formula can be used to determine each configuration's total Net Present Cost (NPC):

NPC (\$) = $C_{cap} + C_{Rep} + C_{O\&M} + C_f - C_{Salv}$ (3.6)

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 the remaining life. In addition, instead of the capital cost, the replacement cost is used as the basis, and the value of each part may be shown as follows:

S = $C_{rep}\,\frac{R_{rem}}{R_{comp}}$ (3.7)

After the best component mix for each location is found, the subsequent environmental effect of each system is also computed. The whole carbon footprint was used to evaluate the associated environmental effect. We also calculated the yearly electrical energy generation of each part for the most optimal systems that might be implemented[161], [163].

3.8.2. Reliability analysis

One statistical measure that can indicate the likelihood of power outages due to low renewable energy or technical difficulties in meeting demand is the Loss of Power Supply Probability (LPSP) [171]. Equation (4.13) shows a probabilistic technique to calculating the Loss of Power Supply Probability (LPSP), and Equation (4.14) shows a method for calculating the reliability (REL), which may be represented as:

$$LPSP = \frac{\sum(P_{Load}+P_{PV}+P_{WT}+P_{SOC_{min}}+P_{DG})}{\sum P_{Load}} \quad (3.8)$$

$$REL = (1\text{-}LPSP)*100\% \quad (3.9)$$

3.9. Scenario for HOMER Pro:

This section presents various system configurations simulated using HOMER Pro software to evaluate the techno-economic feasibility of different hybrid power setups. Each scenario combines specific energy sources such as PV, WT, DG, and BB to analyze their performance, cost-effectiveness, and reliability. The following subsections detail the components used in each scenario and present the corresponding simulation results.

3.9.1. Scenario (PV-WT-DG-BB)

The shown components in Figure (3.8) are the photovoltaic (PV), wind turbine (WT), diesel generator (DG), battery (BB), and converter that were part of this scenario. The simulation results are shown in Figure (3.9) This figure was obtained using the HOMER Pro software.

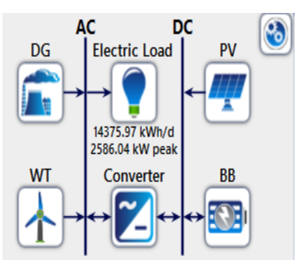


Figure 3.8: System design.

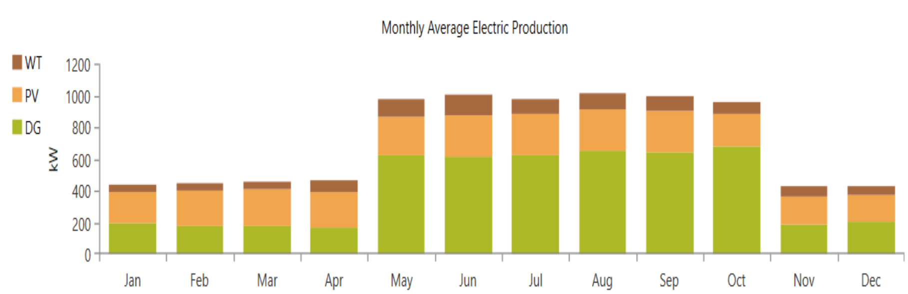
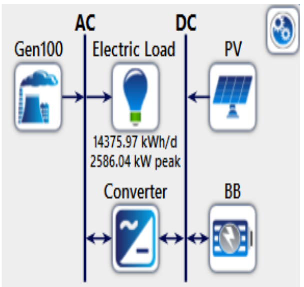


Figure 3.9: Simulation results.

3.9.2. Scenario (PV-DG-BB)

Photovoltaic (PV), diesel generator (DG), battery (BB), and converter were the parts involved in this scenario, as shown in Figure (3.10). Figure (3.11) This figure was obtained using the HOMER Pro software, displays the outcomes of the simulations conducted on these parts.



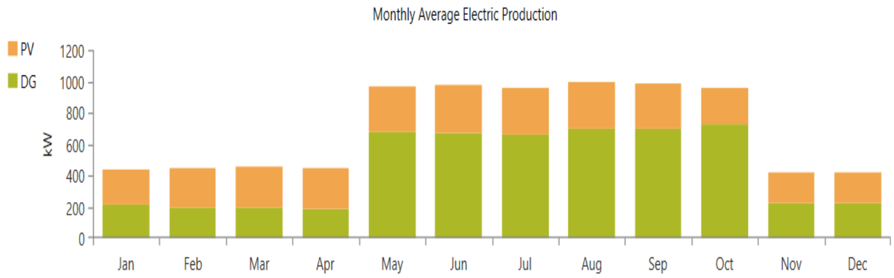
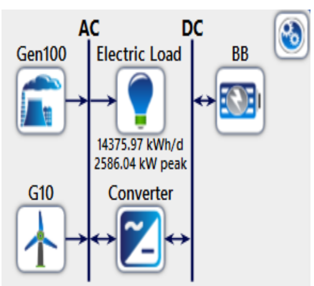


Figure 3.10: System design. Figure 3.11: Simulation results.

3.9.3. Scenario (WT-DG-BB)

Figure (3.12) shows the components that were part of this scenario, which comprised the wind turbine, diesel generator, battery, and converter. Figure (3.13) This figure was obtained using the HOMER Pro software, displays the outcomes of the simulations for these parts.



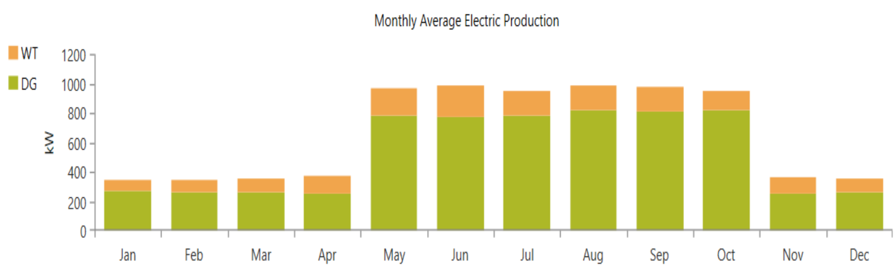


Figure 3.12: System design. Figure 3.13: Simulation results.

3.10. Discussions of the optimal design for Al-Teeb District

According to the details, the most economically feasible design for Al-Teeb **District** is Case 1 (PV-WT-DG-BB), which has the lowest Net Present Cost (NPC), cost of energy (COE), and initial capital cost (IC) value. According to Table 9, the majority of the electrical load in Case 2 (PV-DG) and Case 3 (WT-

DG) is supplied by Renewable Energy (RE), whereas Case 1 achieves the renewable energy objective and offers a more sustainable design. As mentioned earlier.

3.11. Storage system

The system's batteries keep it running and lessen the difficulties with unpredictability that usually occur with renewable energy sources. A storage system's autonomy hours measure how many hours it can provide a constant power supply. Figure (3.14) shows the average charge status for each hour of the year. The monthly state of charge, with the yearly average, lowest (negative), and greatest (positive), are shown in Figure (3.15) This figure was obtained using the HOMER Pro software.

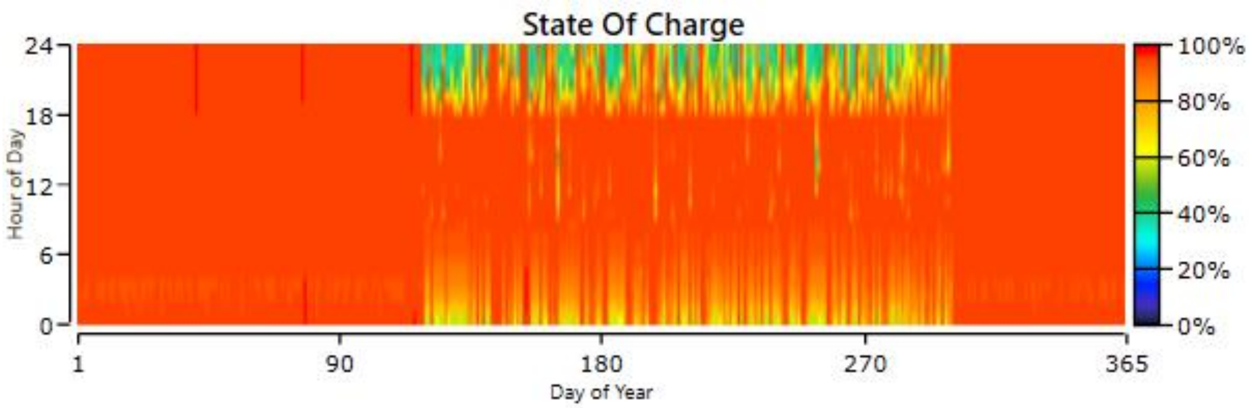


Figure 3.14: State of charge.

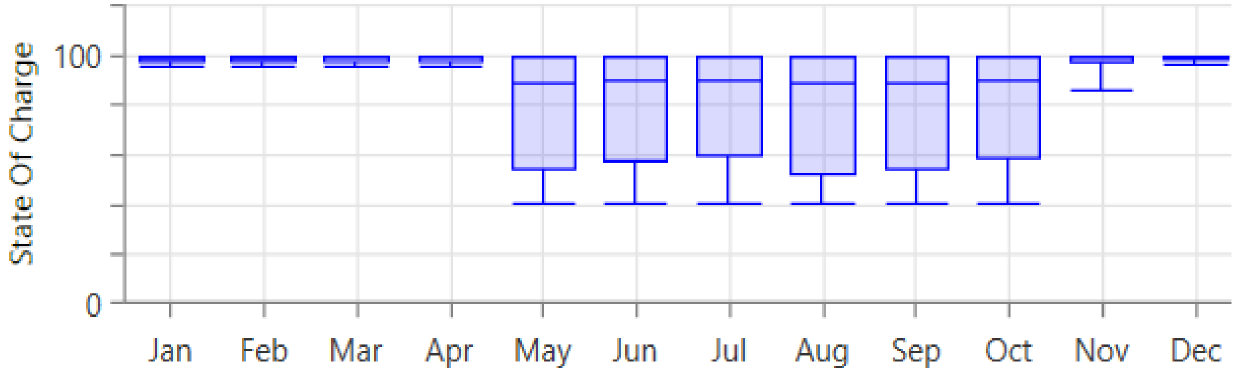


Figure 3.15: State of charge.

3.12. Particle Swarm Optimization (PSO)

One heuristic approach for numerical optimization is particle swarm optimization (PSO), which is based on populations. Inspired by the social behavior of creatures like schooling fish and flocking birds, Kennedy and Eberhart first presented the PSO approach in 1995. Using a population of search points, it generates new possible solutions stochastically using the knowledge extracted from the best ones. It ignores gradient information and needs simple function values. Because of these features, PSO can effectively tackle situations with little knowledge about the objective function. It just takes a few lines of code to implement a paradigm as well. This means that it requires a negligible amount of RAM. The need for basic mathematical operations drastically reduces the time it takes to converge [26].

Particle swarm optimization (PSO) is an iterative search method that uses an objective function (OF) to guide particle movement over a large search region. The motion of each particle is determined by its own past experiences and the experiences of its neighbors.

The idea of PSO may be grasped via the analogy of a school of fish or a flock of birds. The food-seeking criteria are the basis of the approach.

Assume for a moment that a school of fish or a flock of birds is randomly exploring a large region. The searched region has exactly one food item. Not a single fish or bird has pinpointed where the food is. So, people navigate the search space based on their own and their neighbors' experiences. This means that with each iteration, it checks its location relative to the objective and how far away it is in comparison to its past experiences and the optimal position of its nearest neighbor. Then, it adjusts its own pace to locate food most efficiently. Particle Swarm Optimization (PSO) relies on this fundamental notion. "Particles" refers to an individual fish or bird, while "Particles Population" describes the group as a whole. There is an objective worth or fitness for every particle. the result of which is determined by the OF. The velocity vector of a particle, which is affected by both its own actions and external factors, is used to update its location in order to optimize OF. the impact of society.

Within the PSO, the initialization of the particle positions is done at random in accordance with the problem requirements. The initial population, also known as the initial swarm, is the collection of positions of all particles. Our next step is to give every particle a random velocity. Evaluation of the system's cost or objective value is done in accordance with the objective function. For the first state, the optimal location is known as "gbest" (for both the global and personal bests) and "pbest" (for the first state alone). Take into account both individual and group influences while updating the particle locations (xi) and velocities (vi). Updates to velocity in its mathematical form are expressed as:

$$v_i^{t+1} = v_i^t + c_1 U_1^t (pb_i^t - x_i^t) + c_2 U_2^t (gb^t - x_i^t) \qquad (3.10)$$

Furthermore, expression determines position updates:

$$x_i^{t+1} = x_i^t + v_i^{t+1} \qquad (3.11)$$

For the next cycle, we'll utilise the most recent locations and velocities as our starting points. The revised cost is now calculated using these particle locations. When that happens, the particle's new "gbest" location is the one that maximises all costs, and the particle's new "pbest" position is the one that maximises the cost that was assessed independently. The preceding steps are carried out again and again until the stopping condition, which is the maximum iteration limit, is met.

3.12.1. Flow Chart

The flow chart of PSO illustrates the basic workflow of the Particle Swarm Optimization (PSO) algorithm, a computational method inspired by the collective behavior of swarms. The process begins by inputting system parameters such as population size, maximum iterations (max_it), and problem constraints. An initial population of particles with random positions and velocities is generated. The objective function is evaluated for each particle to determine its cost, and the personal best (pbest) and global best (gbest) positions are identified. The particles' velocities and positions are updated using motion equations while ensuring compliance with constraints. If the iteration count (iter) reaches max_it, the optimal solution is outputted; otherwise, the process repeats until convergence Figure (3.16).

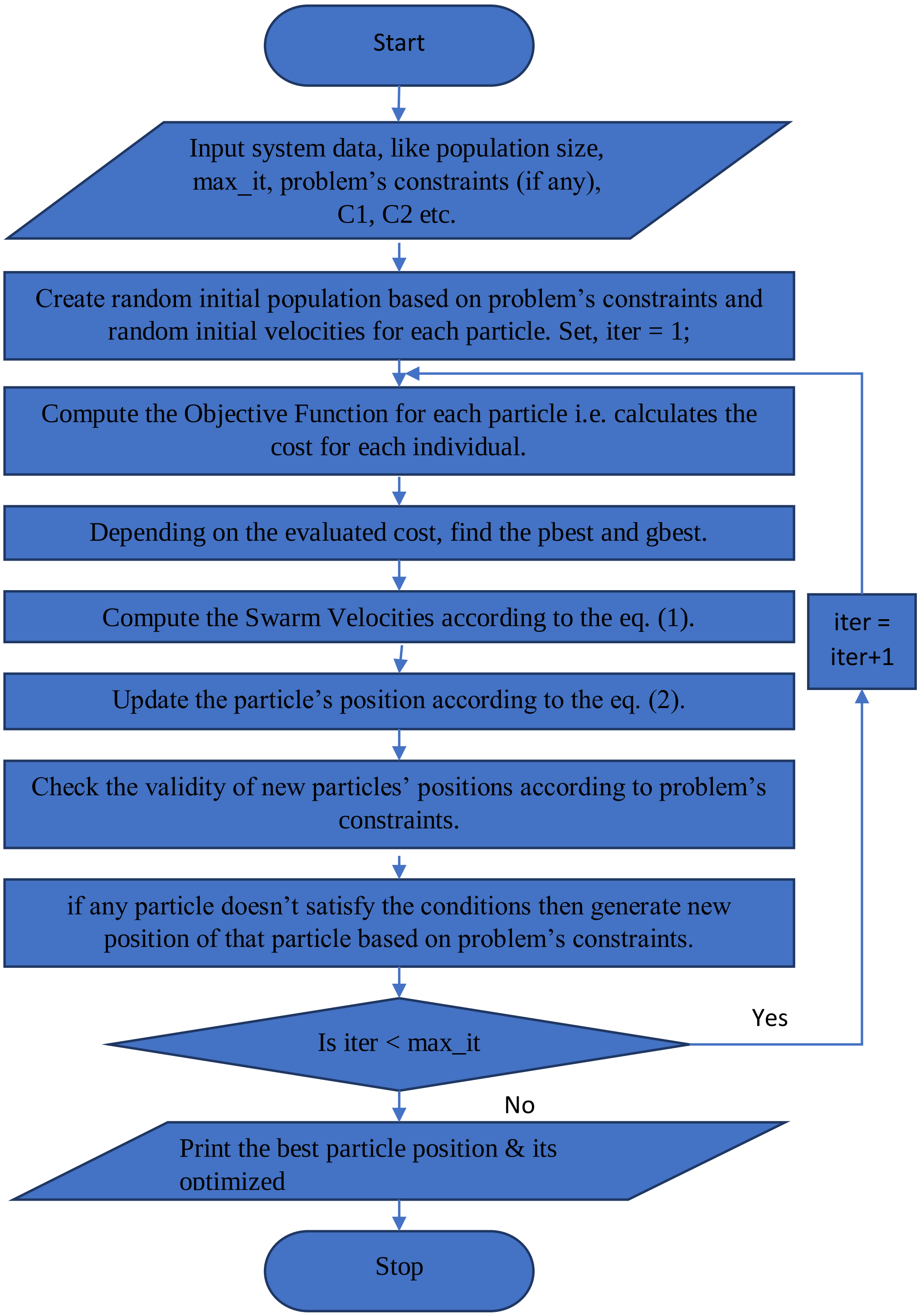


Figure (3.16): Basic PSO algorithm.

3.12.2. PSO optimization algorithm

Many approaches and algorithms are considered artificial intelligence algorithms nowadays. The particle swarm optimization technique is a widely utilized tool. This approach was created by Kennedy and Eberhart in 1995. The approach has been effectively used in computational intelligence, solving challenging global optimization issues across several scientific domains.

Using Particle Swarm Optimization (PSO), particles follow ideal particles in the issue region, promoting population cooperation and competition. Each PSO particle represents a possible solution with two properties, location and velocity. These two variables are adjusted for each particle based on its experience and that of its neighbors. The particles explore the solution region, remembering the goal function value (position). Discovery saves fitness value (P-best). PSO optimizers search the population for additional optimal values. For particles with the best population as topological neighbors, the better value is called the global best (G-best) [172]. Figure (3.17) shows the algorithm technique. In this work, the Particle Swarm Optimization (PSO) approach is used to get optimum outcomes by using particles following the standard formula. This formula aims to find the closest and best particle in a group, considering all particles and following the best one. To accomplish numerous goal functions, this method is used. velocity in its mathematical form is expressed as in equation (2.8), [173]:Furthermore, expression determines position updates as in equation (3.11),

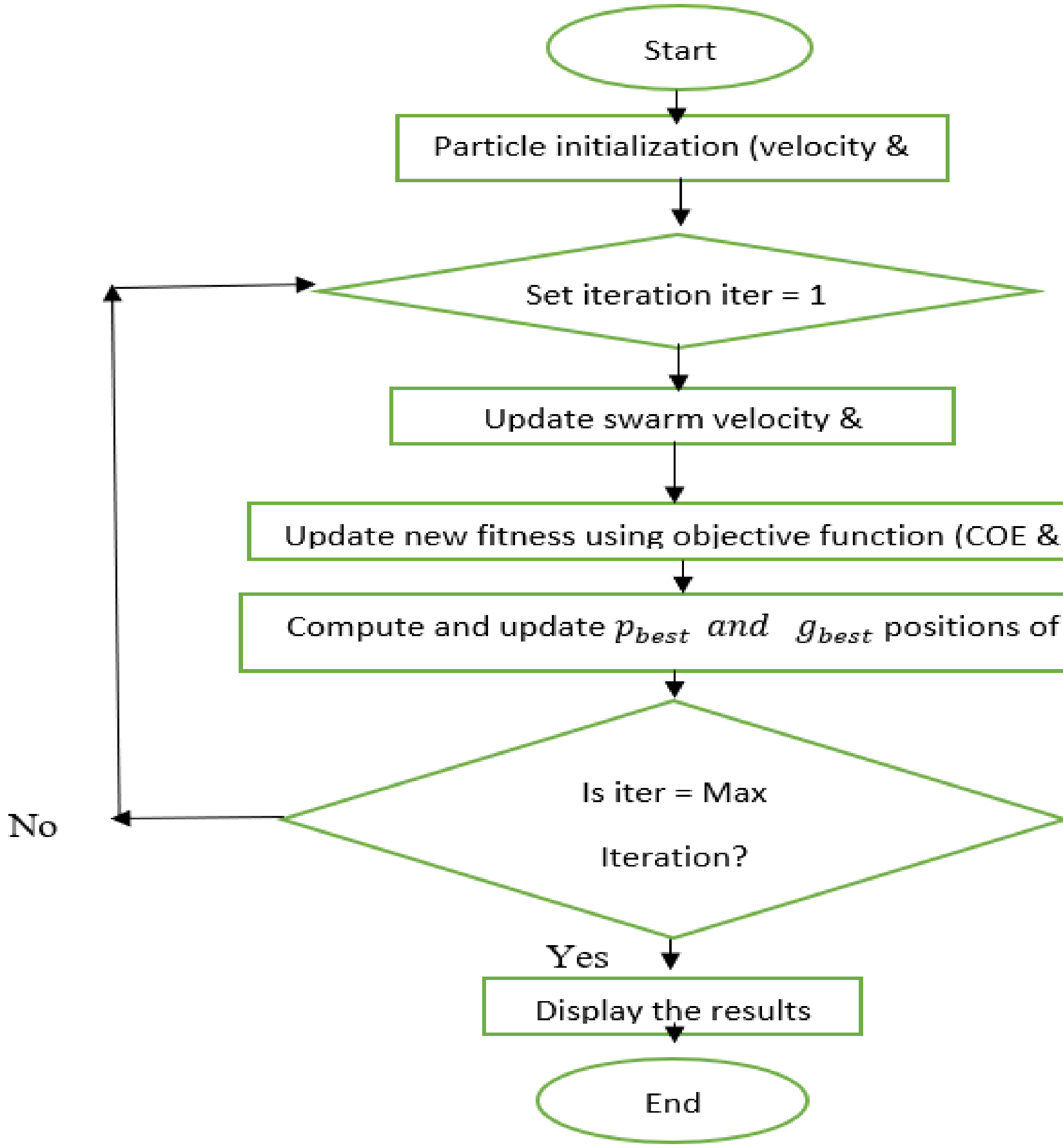


Figure (3.17): Flowchart of the PSO algorithm.

Chapter (4)
Results and Discussions

4.1. Introduction

This chapter presents a detailed discussion of the results obtained from the hybrid energy system, including the outcomes from both the HOMER Pro software and the implemented optimization algorithms. A comparison is made to determine the most optimal result for the hybrid system designed to serve the Al-Teeb district.

The various parts of the test system are laid out and explained in this chapter. At a test site in Misan, Iraq, engineers are conducting a feasibility study on a model system that includes solar photovoltaics, wind turbines, batteries, diesel generators, and converters to convert the DC output from the solar panels and the batteries. The system is being simulated using an advanced meta-heuristic optimization method known as the particle swarm optimization technique (PSO). At the outset, data on social and economic conditions as well as various renewable resources is examined, and the test site is examined. There are a lot of renewable resources in the region. Then, taking into consideration the specific geographical characteristics of that area, the test system is designed and merged to create the hybrid system. In particular, the Al-Teeb District in Iraq will be the focus of the research. The following are a few of the many reasons for choosing this area:

- AL-Teeb **District** is one of the largest rural and remote areas in terms of both area and population in Misan Governorate. Therefore, the demand for energy in this area is also high.
- AL-Teeb **District** features a moderate temperature (22.42 ºC) throughout the year and is characterized by suitable wind speeds (5.52 m/s) for wind turbine generators year-round. Additionally, it exhibits a significant intensity of radiation (5.03 kWh/m^2) suitable for solar cells.

4.2. Energy management and operation strategy

This Study showcased three primary examples of energy management processes for hybrid systems[168].

- The batteries will be charged using the excess energy if the overall energy output of the hybrid system is more than the electrical load.

- Instead of using the diesel generator to make up for the shortfall, the batteries will discharge the load in order to meet the system deficit if the electrical demand surpasses the supply of hybrid power.
- The batteries are empty and the amount of energy produced by renewable sources is insufficient to meet the need. Here, the diesel generator is used to provide the electricity required to fulfill the demand load and to recharge the batteries.

4.3. Results and Discussions for HOMER Pro

In this part, we will go over many potential outcomes regarding the use of various energy sources to power the Al-Teeb **District**. So, for every possible outcome, we calculate the COE and the NPC, or net present cost. 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 diesel generator for operating reliability, and auxiliary tools. They were able to reach this goal by using optimization in the HOMER programme to find the best configuration for the system and to choose components with the right sizes for a renewable hybrid energy system. We entered all the location-related variables and data that pertain to the RES and HS, such as solar radiation, temperature, wind speed, available (PV), (WT), (DG), and (BT) size, project lifetime, location coordinates, and all the price details (capital, replacement, O&M costs, etc.).

Single, double, and triple sources have all been exhausted. To find the optimal design that is also flexible, we looked at the specifics of the operating patterns for each of the suggested combinations and put a number on them to show the pros and cons of each system. Iteratively runs hundreds, if not thousands, of hourly simulations for each scenario to find the optimal system design by ensuring the best possible matching of supply and demand. In every case, the hybrid energy system's output results show that it's superior to the single energy system. The results of these simulations are displayed in Table (4.1).

Table (4.1): lists the situations that were employed.

situations	PV	WT	DG	BB	Converter
1	✓	✓	✓	✓	✓
2	✓	×	✓	✓	✓
3	×	✓	✓	✓	✓

Case 1 takes into account the system's economic feasibility while integrating PV, WT, DG, and battery storage to ensure a steady and dependable power supply. In cases 2 and 3, The PV-DG and WT-DG components of the hybrid system are, respectively. The diesel generator can theoretically generate limitless power (subject to fuel availability), but the system cannot rely solely on them due to financial considerations.

4.4. Results and discussion for PSO

The following location-specific variables and data were entered: solar radiation, temperature, wind speed, available PV size, WT, DG, and BT; project lifetime; project coordinates; price details (including initial cost (IC), replacement cost (RC), O&M), and the number of components of the hybrid power system), etc. The typical yearly energy consumption for a load profile is approximately 20,716.454 kWh/day. Various operation modes were implemented as part of the power management strategy for the Hybrid Micro Grid System (HMGS) to provide a continuous supply of power regardless of the load demand. To find the fastest option for the site, extensive techno-economic study was carried out. Therefore, to examine the proposed systems from an economic perspective, we used the Cost of Energy (COE) indicator. From a technical one, we used the Loss of Power Supply Probability (LPSP) and Reliability (REL) indicators. Finally, from an environmental perspective, we used the Renewable Energy Penetration (REP) indicator. Finding the best solution for optimization problems using the Particle Swarm Optimization technique requires a precise representation of the target function and its restrictions in each particle. Particles in each swarm start with arbitrary location and velocity values according to all limitations (minimum and maximum hybrid components, reliability, etc.) and (PSO) characteristics. One population is used in this study, and each population undergoes 500 rounds of swarm motion. We thought 500 iterations was the upper limit for each population. After that, we updated the location and velocity values every time, kept the best ones, and ignored the bad ones. When the total number of iterations hit the maximum value, the search ended. Reliability and the maximum potential value of renewable energy penetration with minimum expense are the primary goals of the optimal solution configuration of a hybrid renewable energy system (HRES). Based on the probability of power supply loss (LPSP), the reliability (REL) is calculated. The results demonstrated a low cost of energy (COE) of (0.117 US$/KWh), a very strong penetration coverage of renewables of (18 %), and a very high reliability of the hybrid system of (79.35%), all achieved by (PSO) optimization techniques. The most ideal configuration for a Hybrid Renewable Energy System (HRES) was determined to be NPV(1235), NWT(58), NDG(12), NBT (3112) and NC(46) according to the data in Table (4.2) and Figures (4.1), (4.2), (4.3), (4.4). In this investigation, the global optimal point was reached at the iteration number of 465. The development of such systems can be complex and difficult because the optimal combinations are found at distant points with the same fitness value and different configurations in the objective domain. Based on factors including location and availability of energy sources, as well as the system designer's desires, needs, implementation, creation, and expansion of existing systems, the system designer is assigned the ultimate optimal solution.

Table (4.2)**:** Comparison of the results obtained among types of PSO algorithm.

N	**Station**	**MPSO or TVIW-PSO**	**Canonical-PSO**	**HPSO-TVAC**
1	Number of Photovoltaics	1235	1229	1243
2	Number of Wind Turbines	58	56	56
3	Number of Diesel Generators	12	12	12
4	Number of Batteries	3112	3125	3120
5	Number of Converters	46	47	47
6	Cost of Energy($/KWH)	0.117	0.119	0.118
7	Loss Power Supply Probability	0.2065 %	0.2077 %	0.2010 %
8	Number of Global Best	4464	4469	4478
9	Renewable Energy Penetration	18.00 %	18.11 %	17.54 %
10	Reliability	79.35 %	79.23 %	79.88 %
11	Annual energy provided by PV	0.28 %	0.28 %	0.28 %
12	Annual energy provided by WT	29.48 %	29.48 %	29.48 %
13	Annual energy provided by DG	21.91 %	21.91 %	21.91 %
14	Total Net Present Cost (Million $)	9.36	9.47	9.42

A comparison of the number of photovoltaics and batteries using three types of PSO algorithms is presented, showing that HPSO-TVAC resulted in the highest number of photovoltaics (1243), while Canonical-PSO had the lowest (1229). For batteries, Canonical-PSO recorded the highest count (3125), and MPSO had the lowest (3112). These slight variations among the algorithms are illustrated in Figure (4.1).

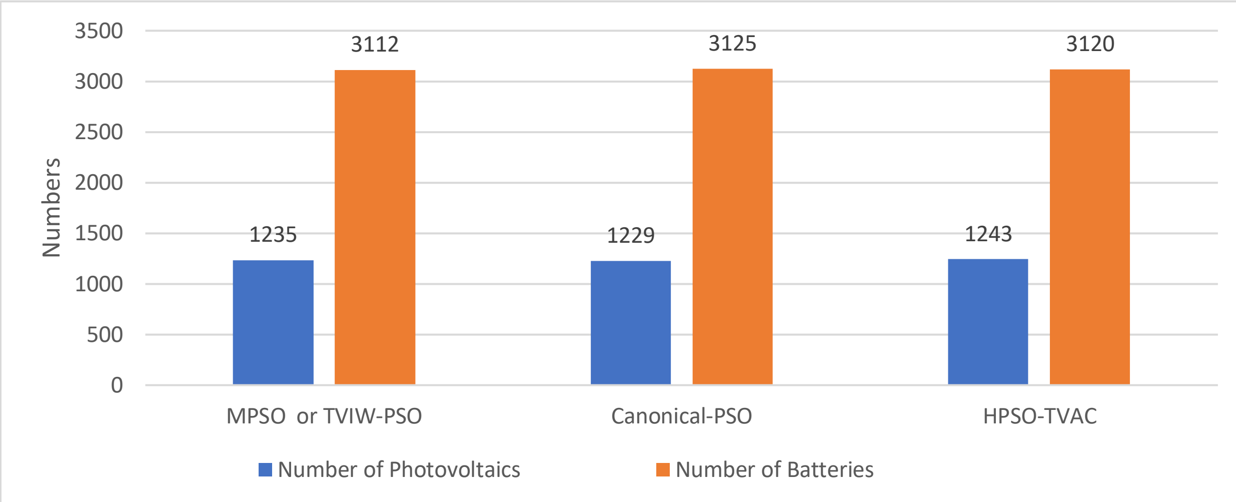


Figure (4.1): Comparison of the numbers of photovoltaics and bank batteries obtained among types of PSO algorithm.

A comparison among PSO algorithms shows that the number of wind turbines slightly varies, with MPSO having the highest (58), while Canonical-PSO and HPSO-TVAC both have 56. All three algorithms resulted in an equal number of diesel generators (12). The number of converters is nearly identical as well, with Canonical-PSO and HPSO-TVAC showing 47 each, and MPSO slightly lower at 46. These values are illustrated in Figure (4.2).

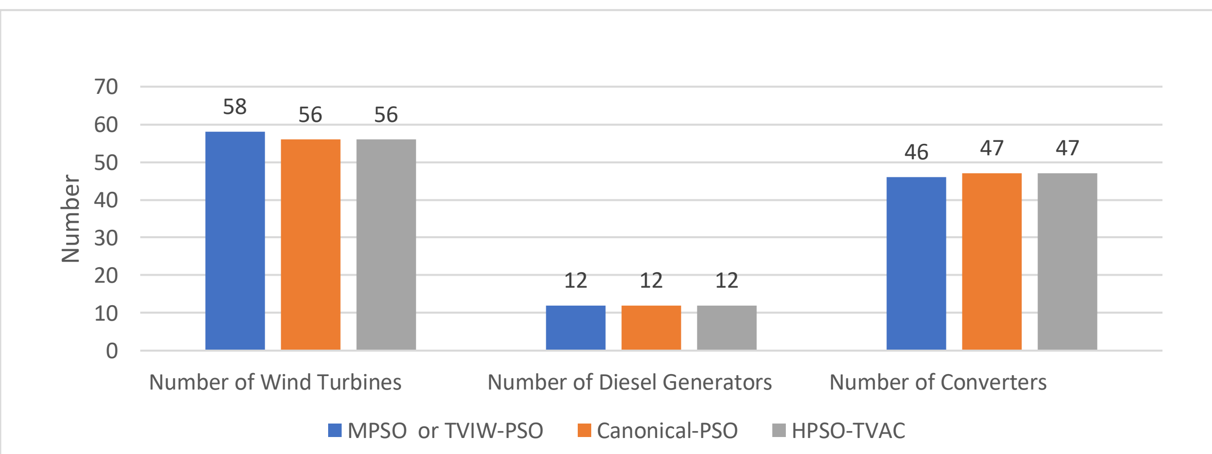


Figure (4.2): Comparison of the numbers of wind turbines, DG and converters obtained among types of PSO algorithm.

The total net present cost varies slightly across the three PSO algorithms. MPSO or TVIW-PSO achieved the lowest cost at 9,360,000, while Canonical-PSO recorded the highest at9,470,000. HPSO-TVAC had a mid-value of $9,420,000. These small differences reflect the cost-effectiveness of each method, as illustrated in Figure (4.3).

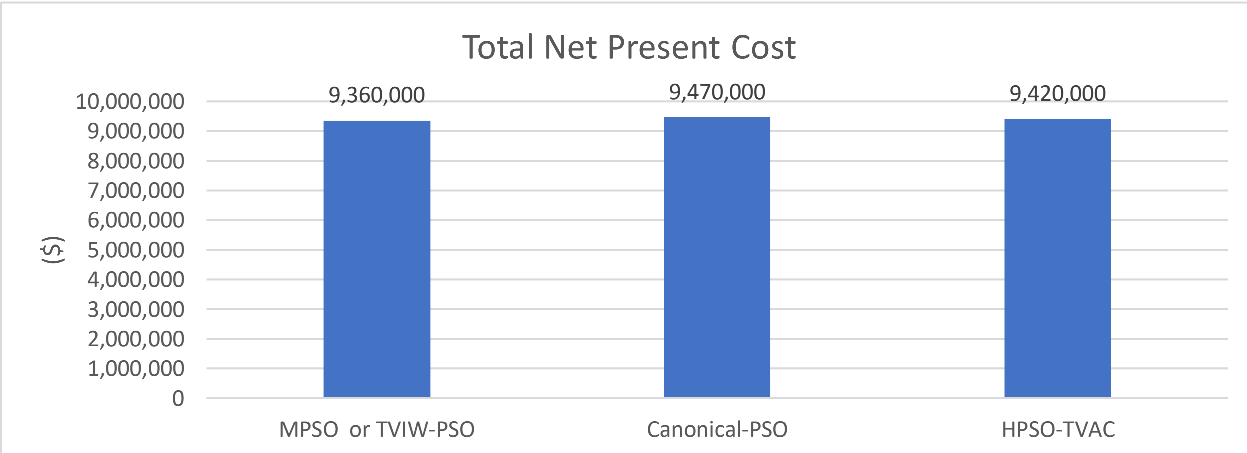


Figure (4.3): Comparison of the total net present cost among types of PSO algorithm.

The comparison reveals minor differences in the cost of energy among the PSO algorithms. MPSO or TVIW-PSO provides the lowest cost at 0.117 /kWh, while Canonical-PSO has the highest at 0.119/kWh. HPSO-TVAC stands between them at 0.118 $/kWh, showing a slight variation in efficiency, as depicted in Figure (4.4).

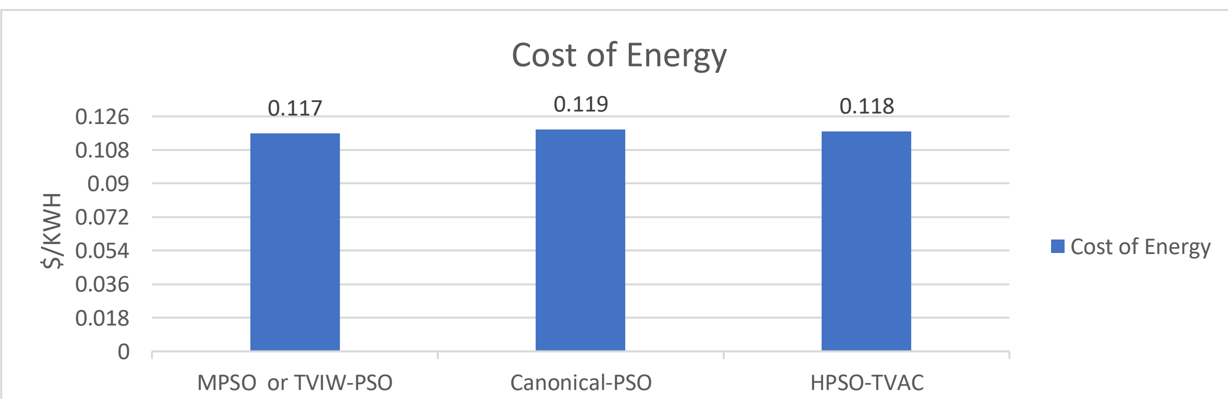


Figure (4.4): Comparison of the cost of energy among types of PSO algorithm.

4.5. Results and discussion for BA

The results derived from the hybrid energy system, which consists of (PV) , WT), (DG), (BT), and (Con), demonstrate its economic and technical viability. This discussion interprets these results and their significance for system performance, cost, and reliability. The system requires 1,200 PV panels, indicating that solar energy plays a primary role in power generation. This reflects the high availability of solar radiation in the region, making it a crucial source for meeting energy demand, particularly during daylight hours. Additionally, the system includes 47 wind turbines, highlighting a strong integration of wind energy as a complementary source. This ensures energy supply during times when solar energy is unavailable or insufficient, such as at night or during cloudy periods. The inclusion of 5 diesel generators serves as backup power sources. The relatively low number of diesel generators indicates an effort to minimize reliance on fossil fuels, thus reducing operational costs and environmental impact. These generators are expected to operate only during prolonged periods of low renewable energy generation. Furthermore, the system utilizes 3,100 batteries for energy storage, which is essential for balancing the intermittent nature of renewable sources. This large storage capacity allows the system to provide power during times of low renewable generation, ensuring continuity and stability in energy supply. The system incorporates 43 converters, which are critical for managing the integration of renewable energy sources with different output characteristics (AC from wind and DC from solar). The number of converters reflects the need for efficient power conversion and transmission to the load. The cost of energy produced by the system is 0.108 $/kWh, which is a competitive rate for hybrid systems. This demonstrates that the system's energy generation is economically feasible, making it a viable option for long-term energy supply. The low cost of energy is attributed to reduced reliance on diesel fuel and the effective use of renewable energy. Additionally, the Loss of Power Supply Probability (LPSP) is 0.0015%, indicating a highly reliable energy supply. This low value represents the probability of failing to meet energy demand, which is negligible, demonstrating that the system can consistently meet load requirements with minimal risk of power shortages. The reliability of the system is 99.848%, which aligns with the low LPSP. This high level of reliability is essential for ensuring a stable energy supply, particularly in remote or off-grid areas where energy security is crucial. The initial cost of the system is $4.520 million. While the upfront capital investment is significant, it is typical for hybrid energy systems that rely on renewable sources. The cost is likely driven by the procurement of renewable energy equipment, batteries, and converters. The total net present cost of the system is $8.634 million table (4.3), accounting for all capital, operational, and maintenance costs over the system's lifetime. This relatively moderate cost reflects the long-term economic benefits of renewable energy integration, with reduced operational costs due to lower fuel consumption and fewer emissions compared to conventional energy systems. Overall, the results indicate that the proposed hybrid energy system provides a robust solution for delivering reliable and cost-effective power. The high number of PV panels and wind turbines emphasizes the system's reliance on renewable energy sources, which reduces operational costs and minimizes environmental impact. The low COE, negligible LPSP, and high reliability demonstrate that the design is capable of consistently meeting energy needs with minimal risk of outages, making it suitable for critical applications in remote communities or off-grid locations.

In summary, this hybrid system not only ensures energy security but also contributes to sustainability goals by reducing dependence on fossil fuels. It offers a highly reliable, cost-effective, and environmentally friendly solution for addressing energy needs in remote areas (Al-Teeb **District**).

Table (4.3)**:** The results of Bat Algorithm.

N	**Station**	**BA**
1	Number of Photovoltaics	1200
2	Number of Wind Turbines	47
3	Number of Diesel Generators	5
4	Number of Batteries	3100
5	Number of Converters	43
6	Cost of Energy($/KWH)	0.108
7	Loss Power Supply Probability	0.0015 %
8	Reliability	99.848 %
9	Initial cost	4.520340
10	Total Net Present Cost (Million $)	8.634048

4.6. Results and discussion for CSA

The analysis of the optimized hybrid energy system, consisting of (PV), (WT), (DG), (BT), and (Con), yields significant insights into its performance, cost-effectiveness, and reliability.

The system incorporates 1,202 PV panels, which underscores the critical role of solar energy in the energy mix. The high number of PV panels reflects the system’s capacity to harness solar power effectively, particularly beneficial given the prevalent solar radiation in the region. This reliance on solar energy aims to meet the energy demand during daylight hours, enhancing the system's sustainability.

In addition to solar energy, the system includes 55 wind turbines. This substantial number indicates a robust integration of wind energy, further diversifying the energy sources available. Wind turbines provide energy during periods when solar generation may be insufficient, particularly at night or during adverse weather conditions, thereby contributing to a more stable and reliable energy supply. The inclusion of 12 diesel generators serves as backup power sources, ensuring energy availability during prolonged periods of low renewable energy generation. While this number is higher than in previous configurations, it highlights a cautious approach to energy security. The system's design aims to minimize reliance on these generators while ensuring that energy demand can still be met effectively. The system utilizes 3,103 batteries, which are critical for energy storage and management. This significant battery capacity allows for the storage of excess energy generated during peak production times for later use, thus balancing supply and demand effectively. The high number of batteries also contributes to enhanced grid stability, reducing the risk of outages. The total of 46 converters facilitates the integration and conversion of the various energy outputs from solar panels and wind turbines. This number of converters is essential for optimizing energy transfer and ensuring compatibility with the electrical grid, highlighting the importance of efficient energy management in the system. The cost of energy (COE) is calculated at $0.115/kWh, which is slightly higher than previous estimates. This cost reflects the economic viability of the system, making it a competitive option in the renewable energy market. The slight increase in COE may be attributed to the higher initial investments in equipment and technology, particularly with the addition of more wind turbines and diesel generators. The Loss of Power Supply Probability (LPSP) is recorded at 0.0023%, indicating a very low probability of failing to meet energy demand. This low percentage signifies that the system is designed to operate reliably, ensuring minimal disruptions in power supply, which is particularly crucial for applications in remote or critical areas. Reliability (REL) stands at 99.774%, which is a commendable figure. This high reliability assures stakeholders that the system will perform consistently, providing a stable energy supply with a minimal risk of outages. The initial cost (IC) of the system is approximately $4.910 million. Although this is a significant upfront investment, it aligns with the typical costs associated with implementing hybrid energy systems that rely heavily on renewable sources. The investment is expected to yield long-term economic benefits through reduced operational costs. The total net present cost (TNPC) amounts to $9.390 million table (4.4). This figure reflects the cumulative capital, operational, and maintenance costs over the lifespan of the system. The moderate TNPC suggests that, despite the initial investment, the long-term savings from operational efficiencies and reduced fuel consumption make the system economically attractive. In conclusion, the results from this hybrid energy system illustrate a well-rounded approach to energy generation that balances renewable resources with reliable backup options. The system's design effectively mitigates risks associated with energy supply while also promoting sustainability. By leveraging both solar and wind energy, alongside strategic use of diesel generators and battery storage, the proposed hybrid system offers a viable and efficient solution for meeting energy needs in a reliable and cost-effective manner for Al-Teeb **District**.

Table (4.4)**:** The results of Cuckoo Search algorithm.

N	**Station**	**CSA**
1	Number of Photovoltaics	1202
2	Number of Wind Turbines	55
3	Number of Diesel Generators	12
4	Number of Batteries	3103
5	Number of Converters	46
6	Cost of Energy($/KWH)	0.115
7	Loss Power Supply Probability	0.0023 %
8	Reliability	99.774 %
9	Initial cost	4.909704
10	Total Net Present Cost (Million $)	9.390168

4.7. Results and discussion for DOA

The results obtained from (DOA) for the hybrid energy system, which consists of (PV), (WT), (DG), (BT), and (Con), provide a clear picture of the system's effectiveness and efficiency in meeting energy demands. The following discussion analyzes the key components of the system and interprets the results.

Firstly, the total number of 1,204 photovoltaic panels indicates a significant reliance on solar energy as the primary source of power generation. This number reflects the system's capability to fully harness the available solar radiation in the region, contributing to long-term cost reduction and enhancing sustainability.

In addition to solar energy, the system incorporates **56 wind turbines**, demonstrating good integration of wind power. This substantial number of turbines is sufficient to meet energy needs during periods when solar energy generation may be inadequate, such as at night or during adverse weather conditions. This diversity in energy sources increases the overall reliability of the system.

The system also includes 11 diesel generators as backup power sources, which is a moderate number. These generators play an essential role in ensuring energy availability during prolonged periods of low renewable energy generation. Although important, the relatively low number of diesel generators helps reduce operational and environmental costs.

Furthermore, the system features 3,119 batteries for energy storage, which is a vital element in energy management. This large battery capacity allows the system to store excess energy generated during peak production times for later use, thus effectively balancing supply and demand. It also contributes to grid stability and reduces the risk of outages.

The results indicate that the system has 47 converters, reflecting the need for effective processing of energy output from the various sources. Converters ensure proper transformation of energy into the required format to feed electrical loads, thereby enhancing system efficiency.

The cost of energy (COE)is approximately $0.11459 per kWh, which is a competitive price in the market. Although the cost has increased slightly compared to previous estimates, it remains within economically acceptable limits, indicating the system's efficiency in generating energy at reasonable prices.

The Loss of Power Supply Probability (LPSP) is recorded at 0.0047%, indicating a very low likelihood of failing to meet energy demand. This low percentage demonstrates the system's strong capability to operate reliably, ensuring minimal disruptions in power supply.

The system's reliability (REL)stands at 99.531%, which is an encouraging figure. This high level of reliability ensures that the system can provide continuous energy supplies, making it a trustworthy option for meeting energy needs in remote or high-demand areas.

Finally, the initial cost (IC) of the system is approximately $4.867 million, which is a reasonable investment considering the system's size and complexity. The Total Net Present Cost (TNPC) is around $9.312 million table(4.5), reflecting capital and operational costs over the system's lifespan. These costs indicate the investments required to achieve long-term operational savings and reduce reliance on fossil fuels. Overall, these results demonstrate the success of the Dragonfly Optimization Algorithm in optimizing the design of the hybrid energy system. The diverse range of energy sources, combined with the use of battery storage and backup diesel generators, provides a comprehensive and reliable solution for meeting energy needs.

Table (4.5)**:** The results of Dragonfly Optimization Algorithm.

N	**Station**	**DOA**
1	Number of Photovoltaics	1204
2	Number of Wind Turbines	56
3	Number of Diesel Generators	11
4	Number of Batteries	3119
5	Number of Converters	47
6	Cost of Energy($/KWH)	0.11459
7	Loss Power Supply Probability	0.0047 %
8	Reliability	99.531 %
9	Initial cost	4.867175
10	Total Net Present Cost (Million $)	9.311824

4.8. Results and discussion for GWOA

The results obtained from (GWOA) for the hybrid energy system, which consists of (PV), (WT), (DG), (BT), and (Con), demonstrate the effectiveness and efficiency of the system in meeting energy demands. The following discussion analyzes the key components of the system and interprets the results.

First, the system includes 1,200 photovoltaic panels, indicating a significant reliance on solar energy as the primary source of power generation. This number reflects the system's ability to effectively harness available solar resources, contributing to long-term cost reductions and enhancing sustainability.

Additionally, the system features 55 wind turbines, demonstrating a good integration of renewable energy sources. This number of turbines is sufficient to meet energy needs during periods when solar energy generation may be inadequate, such as at night or during adverse weather conditions. The diversity in energy sources contributes to the overall reliability of the system.

The system also incorporates 11 diesel generators as backup power sources, which is a reasonable number. These generators play a crucial role in ensuring energy availability during prolonged periods of low renewable energy generation. Although important, the relatively low number of diesel generators helps reduce operational and environmental costs.

Furthermore, the system utilizes 3,100 batteries for energy storage, which is a vital component of energy management. This large battery capacity allows the system to store excess energy generated during peak production times for later use, facilitating the balance between supply and demand and enhancing grid stability.

The results also indicate that the system has 45 converters, reflecting the need for effective processing of energy output from various sources. These converters are essential for ensuring proper transformation of energy into the required format to feed electrical loads, thereby enhancing system efficiency.

The cost of energy (COE) is approximately $0.114 per kWh, which is a competitive price in the market. This cost indicates the system's efficiency in generating energy at reasonable prices, aligning with the costs associated with hybrid systems.

The Loss of Power Supply Probability (LPSP) is recorded at 0.0047%, indicating a very low likelihood of failing to meet energy demand. This low percentage demonstrates the system's strong capability to operate reliably, minimizing the risk of outages.

The system's reliability (REL) stands at 99.530%, which is an encouraging figure. This high level of reliability ensures that the system can provide continuous energy supplies, making it a trustworthy option for meeting energy needs in remote or high-demand areas. Regarding the initial cost (IC) of the system, it amounts to approximately $4,759,310. This investment is reasonable considering the system's size and complexity. Meanwhile, the Total Net Present Cost (TNPC) is around $9.102 million table (4.6), reflecting capital and operational costs over the system's lifespan. These costs indicate the investments required to achieve long-term operational savings and reduce reliance on fossil fuels.

Overall, these results demonstrate the success of the Gray Wolf Optimizer in optimizing the design of the hybrid energy system. By integrating a diverse range of energy sources, along with the use of battery storage and backup diesel generators, the system offers a comprehensive and reliable solution for meeting energy needs.

Table (4.6)**:** The results of Grey Wolf Optimization Algorithm.

N	**Station**	**GWOA**
1	Number of Photovoltaics	1200
2	Number of Wind Turbines	55
3	Number of Diesel Generators	11
4	Number of Batteries	3100
5	Number of Converters	45
6	Cost of Energy($/KWH)	0.114
7	Loss Power Supply Probability	0.0047 %
8	Reliability	99.530 %
9	Initial cost	4.759310
10	Total Net Present Cost (Million $)	9.102831

4.9. Comparison Stat

The results presented in the table (4.7) and figures (4.5), (4.6), (4.7), (4.8), (4.9), (4.10) for the hybrid energy system reveal several performance metrics based on various optimization algorithms, including the (BA), (GWOA), (DOA), (CSA), (PSO), and HOMER Pro program. Key metrics evaluated include (NPV), (NWT), (NDG), (NBT), (NCon), (COE), (IC), (TNPC), (LPSP), and (REL).

The Bat Algorithm exhibits the lowest cost of energy at $0.108 per kWh, making it the most cost-effective option among the algorithms analyzed. In contrast, HOMER Pro presents the highest cost of energy at $0.155 per kWh. The Bat Algorithm also results in the lowest initial cost of approximately $4,520,340, while HOMER Pro again shows the highest initial cost at about $4.91 million.

Regarding the total net present cost, the Bat Algorithm demonstrates the lowest value at $8,634,048, indicating significant economic advantages over the other algorithms. In comparison, the total net present cost for HOMER Pro is around $14.2 million, reflecting a much higher overall expenditure.

The Bat Algorithm also excels in terms of loss of power supply probability, with a rate of only 0.0015%, signifying exceptional reliability. Other algorithms, particularly PSO, show a considerably higher loss of power supply probability at 0.1977%, indicating an increased risk of energy supply interruptions.

Furthermore, the Bat Algorithm achieves a reliability rating of 99.848%, which is the highest among the algorithms, reflecting the system's ability to deliver consistent energy supplies. In contrast, PSO demonstrates a significantly lower reliability of 80.227%, raising concerns about its effectiveness in meeting energy demands.

According to the evaluated performance metrics, the BA stands out as the best optimization method for this hybrid energy system. It not only provides the lowest values for cost of energy, initial cost, and total net present cost, but also ensures minimal loss of power supply probability and high reliability. GWOA ranks next in performance, but its higher costs and lower reliability compared to the BA suggest that it may not be as efficient. Other algorithms, such as the DOA, CSA, and PSO, show relatively poorer results across these critical metrics, underscoring the superior effectiveness of the Bat Algorithm in optimizing the hybrid energy system.

Table (4.7): Comparison of the results obtained among between BA, GWOA, DOA, CSA, PSO and HOMER Pro.

Algorithm	BA	GWOA	DOA	CSA	MPSO	HOMER Pro
NPV	1200	1200	1204	1202	1237	1215
NWT	47	55	56	55	59	59
NDG	5	11	11	12	11	13
NBT	3100	3100	3119	3103	3117	3138
NC	43	45	47	46	47	47
COE($/kwh)	0.108	0.114	0.11459	0.115	0.119	0.155
IC (US$)	4520340	4759310	4867175	4909704	4976785	4.91 M
TNPC (US$)	8634048	9102831	9311824	9390168	9521324	14.2 M
LPSP	0.0015	0.0047	0.00469	0.0023	0.1977	-------
REL	99.848%	99.5304%	99.531%	99.774%	80.227%	-------

This comparison highlights variations in the cost of energy across different algorithms. The BA algorithm achieved the lowest energy cost at 0.108 /kWh, indicating higher efficiency. In contrast, HOMER Pro showed the highest cost at 0.155/kWh. Other algorithms such as GWO, DOA, CSA, and PSO recorded moderate values, ranging from 0.114 to 0.119 $/kWh, as seen in Figure (4.5).

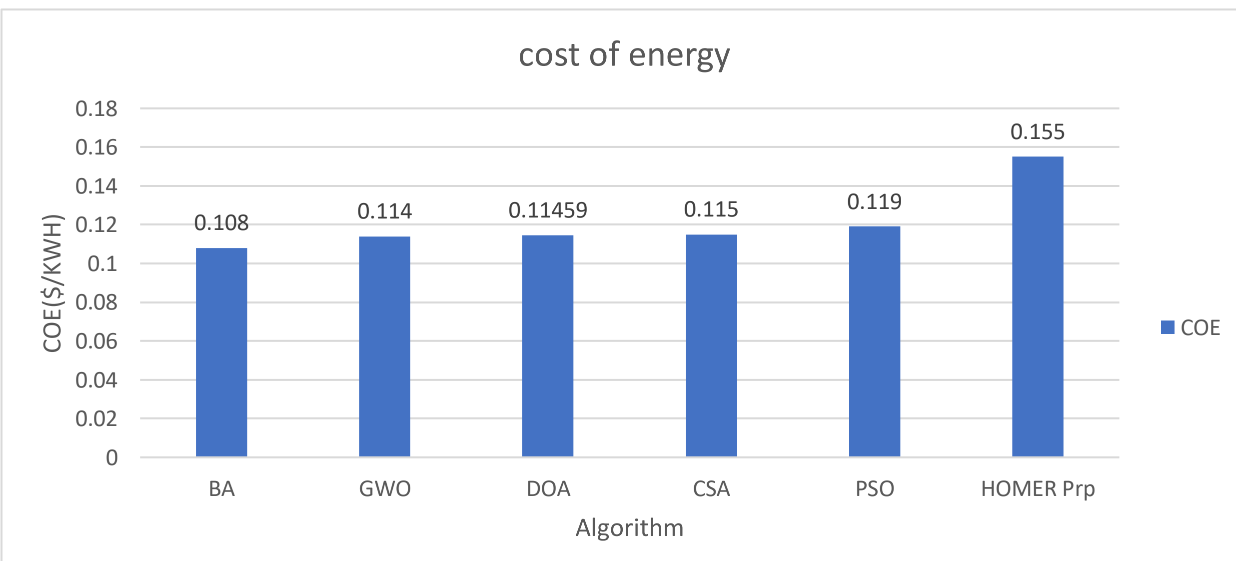


Figure (4.5): Comparison of the cost of energy among types of algorithms.

The total net present cost (TNPC) varies significantly among the algorithms. BA algorithm recorded the lowest cost at 8,634,048, indicating better economic performance. In contrast, HOMER Pro showed the highest TNPC of14,200,000, making it the least cost-effective option. Other algorithms like GWO, DOA, CSA, and PSO fall in between, ranging from 9,102,831 to 9,521,324 as seen in Figure (4.6).

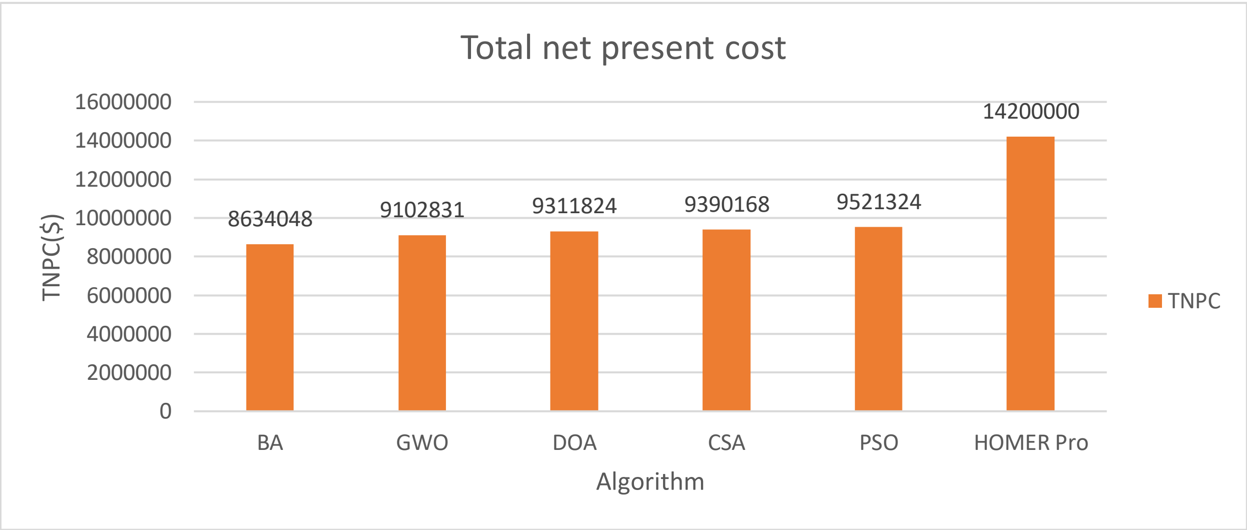


Figure (4.6): Comparison of the total net present cost among types of algorithms.

Initial costs differ among the algorithms, with BA showing the lowest cost at approximately 4,520,340, indicating a more cost-effective start. The PSO algorithm has the highest initial cost, around4,976,785, reflecting greater upfront investment. Other algorithms such as GWO, DOA, CSA, and HOMER Pro fall between these values, showing moderate initial costs. Figure (4.7) illustrates this comparison.

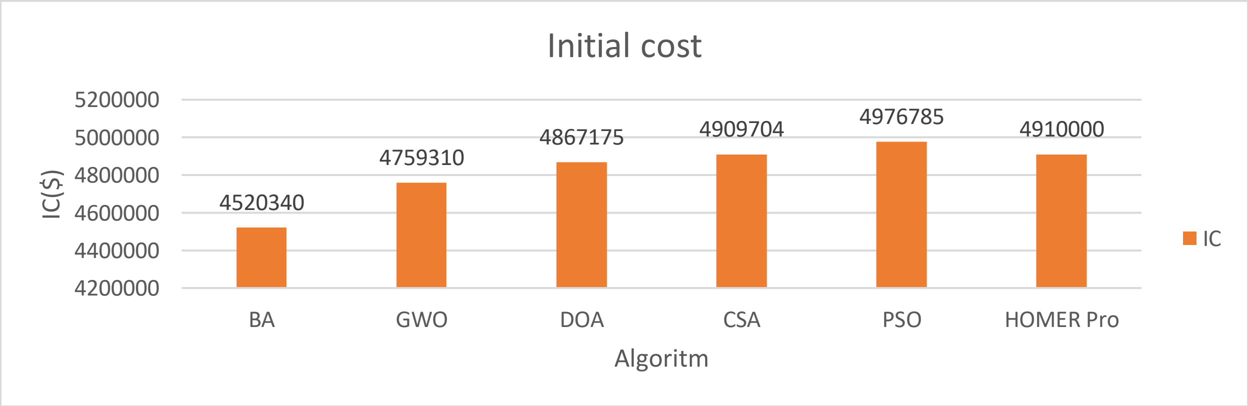


Figure (4.7): Comparison of the initial cost among types of algorithms.

The reliability percentages of the algorithms are generally very high, ranging from about 99.53% to 99.77%, indicating strong performance consistency. PSO shows a notably lower reliability at 80.23%, which suggests less stability compared to the others. The other algorithms BA, GWO, DOA, and CSA perform similarly with minimal differences in reliability. Figure (4.8) presents this comparison.

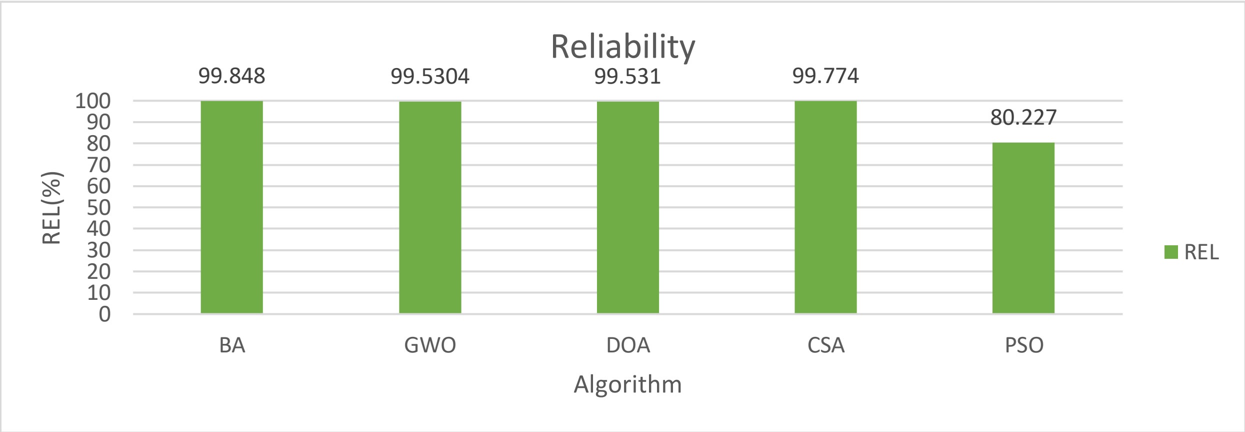


Figure (4.8): Comparison of the reliability among types of algorithms.

The number of photovoltaics (NPV) and bank batteries (NBT) vary slightly across the algorithms. PSO shows the highest number of photovoltaics at 1237, while CSA has the lowest at 1202. Regarding bank batteries, HOMER Pro leads with 3138 units, and GWO and BA have the fewest at 3100. These differences highlight small variations in component allocation. Figure (4.9) illustrates this comparison.

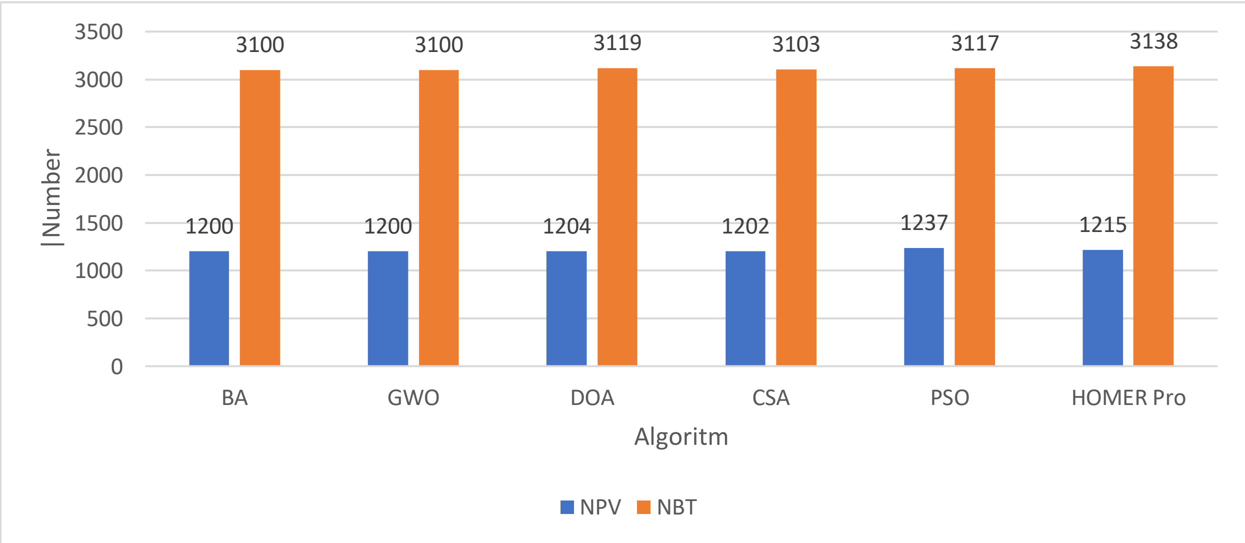


Figure (4.9): Comparison of the numbers of photovoltaics and bank batteries obtained among types of algorithms.

The number of wind turbines (NWT), diesel generators (NDG), and converters (NC) varies across the algorithms. HOMER Pro and PSO have the highest number of wind turbines at 59, while BA has the lowest with 47. Diesel generators are lowest in BA (5) and highest in HOMER Pro (13). Converters show minor variation, ranging from 43 in BA to 47 in DOA, PSO, and HOMER Pro. These variations reflect differences in system design approaches. Figure (4.10) shows this comparison.

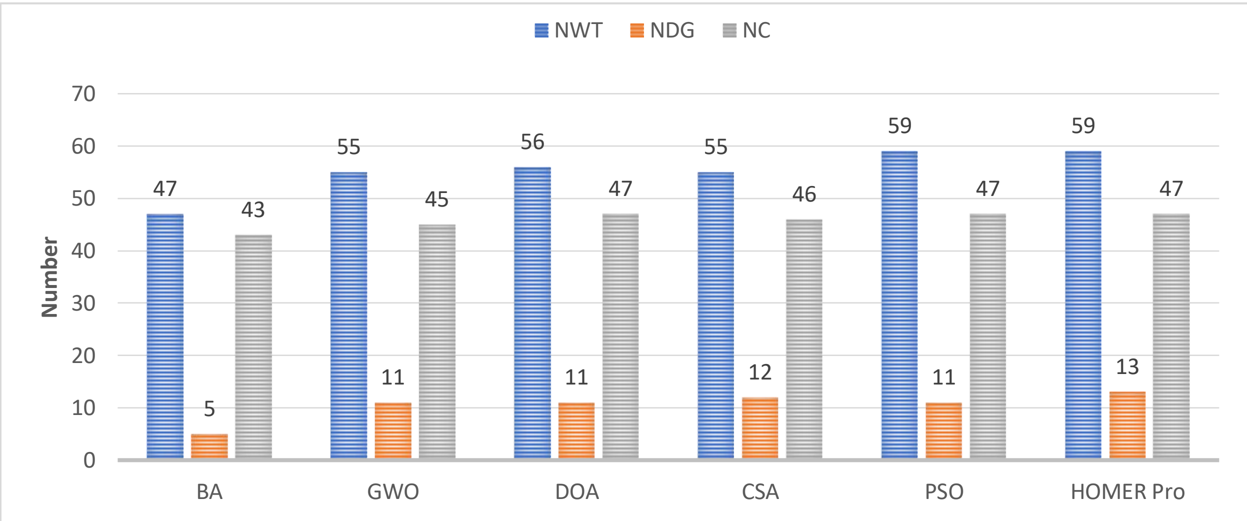


Figure (4.10): Comparison of the numbers of wind turbines, DG and converters obtained among types of algorithms.

4.10. Comparison of My Work with Previous Studies in Ref. [75], [115] &[149]

As shown in the Table (4.8), the current study ("My Work") demonstrates several advantages over the previous studies cited in references [76], [115], and [149]:

- **Load/Demand Coverage**: This work considers a larger and more realistic daily load of 20,716.454 kWh/day for district-level coverage, whereas [76] and [115] cover smaller-scale loads (village or single station), and [149] does not specify the exact value.

- **Hybrid Energy System**: The proposed system integrates PV, WT, DG, and battery storage, offering a well-rounded energy mix. Compared to other studies, this setup ensures higher flexibility and reliability, with [149] adding a biogasifier but lacking detailed demand data.

- **Connectivity Type**: An off-grid system is used, indicating full independence from the main grid, which is essential for remote or rural applications. In contrast, [115] considers both off- and on-grid connections.

- **Objective Functions**: This study optimizes multiple performance metrics, including NPC, COE, IC, LPSP, and system reliability—offering a more holistic evaluation. Other references mainly focus on NPC and COE.

- **Methods and Software**: A variety of modern optimization algorithms (PSO, BA, DOA, CSA, GWO) are applied alongside HOMER Pro, which enhances the robustness of the optimization. In comparison, other studies used limited techniques or relied solely on HOMER.Overall, this study stands out as the most comprehensive and technically advanced among the compared works, offering broader coverage, better optimization, and deeper analysis making it more applicable for real-world renewable energy solutions in Iraq.

Table (4.8): Comparison of My Work with Previous Studies in Ref. [76], [115] &[149].

Ref.	year	Study Area	Hybrid Energy System	Load/ Demand	Connectivity Type	Objective functions	Methods/Sotware
My Work	2025	Iraq/Misan/Al-Teeb	PV-DG-WT-BT	Districts (20,716.454kwh/d)	Off-grid	IC, NPC, COE, LPSP, REL	HOMER Pro, PSO, BA, DOA, CSA, GWOA
[76]	2016	Iraq/Diyala/ Muqdadiyah	PV-DG-WT-BT	Village (92.6kwh/d)	Off-grid	NPC, COE	HOMER Pro.
[115]	2020	Iraq / Baghdad	PV-DG-WT-BT	one station in specific location in the university of nahra (145.5kwh/d)	Off/On-grid	NPC, COE	HOMER
[149]	2023	Iraq / Basrah	PV-WT-Biogasifier-BT	City (.............)	Off-grid	LCOE	GA/PSO/ALO/GWO/GWCSO

Chapter (5)
Conclusion

5.1. Conclusion

This chapter presents a summary of the thesis, highlighting the key aspects that were adopted, the validated results, and the main conclusions. It also provides recommendations for future research and potential improvements in the design and optimization of hybrid energy systems.

The main goal and biggest trend has been seek in this research is submission the optimum design of (**HPGS**) to meet the load demand of isolated, or border, or rural, or remote place and its off grid as case study.

The case study which that elected is AL-Teeb **District**. This region locate in the southeastern republic of Iraq along the Iraqi- Iranian border, it is far from the city of Amara in Misan Government about 100km. Al-Teeb **District** is suffering from difficult chance to connect to national electricity grid due to nature of area and distance among population centers.

Various strategies for modeling of HPGS using different methodologies and software such as famous commercial software namely **HOMER Pro.** Program has been used as firstly attempt, and then it is compared the work with five sophisticated metaheuristics optimization algorithms such as MPSO, GWA, Bat Algorithm, Dragonfly Algorithm, and CSA.

The HOMER Pro tool and the five proposed research methodologies have been clearly indicated to superiority of analysis and an improvement for optimum design of estimated HPGS in AL- Teeb area.

The widespread of goals that have been carefully studied, present a backbone for distinguishing among effective methods to obtain appropriate design and process of HPGS as follow:

- The optimal sizing / configuration of components (number of components)
- Enough capability of system performance such as

1- (minimize the annual **C**ost **O**f **E**nergy,
2- Reliable operation of the system : **REL**iability,
3- Minimize the **T**otal **N**et **P**resent **C**ost,
4- Estimation of **I**nitial **C**ost and
5- Minimize of **L**oss **P**ower **S**upply **P**robability. The values of these parameters.

The proposed methodologies (HOMER Pro. and the five algorithms) best operation and optimum modeling of hybrid power generation system configuration is PV / WT as hybrid renewable energy system with BB unit and DG as a support be capable for electrification the election area in this research as case study regarding the goal that were mentioned in previous paragraph.

According to the evaluated performance metrics, the Bat Algorithm stands out as the best optimization method for this hybrid energy system. It not only provides the lowest values for cost of energy, initial cost, and total net present cost, but also ensures minimal loss of power supply probability and high reliability. The Gray Wolf Optimizer (GWO) ranks next in performance, but its higher costs and lower reliability compared to the Bat Algorithm suggest that it may not be as efficient. Other algorithms, such as the Dragonfly Algorithm, Cuckoo Algorithm, and PSO, show relatively poorer results across these critical metrics, underscoring the superior effectiveness of the Bat Algorithm in optimizing the hybrid energy system.

Finally, the most suitable for implementing this system were as follows, the ideal values analysis of case study for best combination based on Bat algorithm of various energy sources (PV / WT / DG / BB) are NPV(1200), NWT(47), NDG(5), NBB(3100), NC(43), COE(0.108 $/kwh), REL(99.848%), TNPC(8634048 US$), IC(4520340 US$), and LPSP(0.0015%),

5.2. Recommendations for Future work

This thesis used HOMER Pro. Program and five effective optimization methods to design optimum model of hybrid power generation system for case study off- grid electrification. This region namely, AL-Teeb **District** locate along the Iraqi- Iranian border. In spite of the achievements of the objectives, other aspects need to be cover for further improvement. Based on the results achieved and the limitations the following recommendations are made:

1-Using intelligent optimization techniques such as ANN or GA to study the proposed model under this consideration.

2- Recommending making use of the research station of the college of engineering in the AL-Teeb **District** for collecting hourly data of solar radiation, wind speed and ambient temperature of the selected site instead of obtaining it from NASN.

3- Coordinating with another branch of science such as chemistry, geology, or biology to add another kind of energy source, for example biomass, or geothermal energy, ….etc.

4- Design and simulation controller of smart grid based (PV/WT/DG/BB).

5- Recommending the adoption of lithium-ion (Li-ion) batteries as an energy storage solution in future solar power systems due to their high efficiency, long lifespan, excellent storage capacity, and low maintenance requirements, which enhance system reliability and economic viability.

6- Investigate energy storage optimization methods to improve system reliability and cost-effectiveness.

7- Study the environmental impact and carbon footprint reduction potential of the proposed hybrid system.

8- Explore the integration of demand response strategies to better match energy supply and consumption.

9- Conduct sensitivity analysis to evaluate the effects of varying climatic and load conditions on system performance.

10- Develop economic feasibility studies considering future energy price fluctuations and maintenance costs.

11- Implement real-time monitoring and control systems for enhanced

management of hybrid power generation.

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List of Publications

[1] Hussam A. Salim, Jabbar R. Rahesd, “Techno-Economic Feasibility Analysis of Hybrid Renewable Energy System By Using Particle Optimization Technique for the Rural Border Areas in Iraq: Case Study”, *Misan Journal of Engineering Sciences, Vol.3, No.2, Dec.2024, p-p 14-31.* (**See Appendix.A**)

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Appendix A:

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Techno-Economic Feasibility Analysis of Hybrid Renewable Energy System By Using Particle Optimization Technique for the Rural Border Areas in Iraq : Case Study

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Abstract: A truly need and biggest challenge that the border rural areas are suffering is difficult chance to connect to electricity grid due to nature of area and distance among population centers. A case study in this paper, Al-Teeb Area is located in the southeastern of Iraqi-Iranian border. To overcome on this dilemma, a best substitute is Hybrid Energy System (HES). The Techno-Economic Feasibility analysis of grid-tied by photovoltaic(PV) -battery(BT) - wind turbine(WT) - diesel generator (DG) in that region are focus in this research.. This study made use of the MATLAB-based three different types of Particle Swarm Optimization algorithms(PSO),namely,(Modified PSO, Canonical-PSO and Hierarchical PSO with Time-varying Acceleration Coefficients (HPSO-TVAC) When designing a HES, it is important to strike a balance between the three goals of Cost Of Energy (COE), Reliability (REL), and maximizing the value of Renewable Energy Penetration (REP). Based on the results from the first type of PSO algorithm were found to be the most suitable for implementing this system were as follows, the ideal values for Number of Photovoltaic (NPV) (1235), Number of Wind Turbines (NWT) (58), Number of Diesel Generators (NDG) (12), Number of Batteries (NBT) (3112), Number of Converters (NCon)(46), COE (0.117 US$/KWh), loss power supply probability (LPSP) (0.2065%), REL (79.35%), REP (18%) and TNPC (9.36 MUS$). In addition, the results show that the algorithm efficiently and effectively found ideal solutions to lower total costs. Finally, it was determined that HES was a suitable way to fulfill the electrical demands of rural, outlying areas in Iraq and other developing countries with comparable temperatures.

Keywords: Particle Swarm Optimization (PSO), MATLAB, Hybrid System, Economical Cost, Optimization.

1. Introduction

Concerns over the use of non-renewable energy sources have lately grown in response to many worldwide issues brought on by the higher cost of electricity as a consequence of growing electrical power usage. The rise of severe economic and political ramifications on a global scale has been precipitated by environmental degradation, which in turn is caused by unregulated electrical power production, climatic variance, and global warming[1] . Consequently, countries have pushed for renewable energy sources. By making clean, affordable, and environmentally friendly energy more widely available, renewable energy generation may help nations achieve their sustainable energy production targets [2]. Renewable energy offers many advantages, but it isn't without its drawbacks, such as inefficiency and unreliability in generation caused by weather fluctuations, instability, and other irregularities [3]. In [4],the study is conducted in the city of Zerbattiya, Iraq by using MATLAB-PSO, This study addresses rural energy availability in developing countries, focusing on Zerbattiya, Iraq. The paper suggests an HRES with solar panels, wind turbines,

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Appendix B:

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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

الخلاصة

للتغلب على المشاكل الناتجة من توصيل الكهرباء الى المناطق الريفية البعيدة او الحدودية وربطها بالشبكة الوطنية الرئيسية مثل المسافات الطويلة والتكلفة العالية وعدم الجدوى الاقتصادية وغيرها من التحديات الصعبة لكهربة تلك المناطق ، اصبح البحث عن الاستخدام الامثل والافضل لمصادر الطاقة البديلة المتاحة في تلك المناطق كطاقة الرياح ، والطاقة الشمسية، وغيرها من المصادر المتوفرة حلاً مربحًا وقيمًا ومجديا لهذه المشاكل ، لذلك ركزت هذه الدراسة على تحليل الجدوى التقنية والاقتصادية لنظام منفصل عن الشبكة الوطنية لمنطقة ريفية حدودية بعيدة عن خطوط نقل الطاقة الكهربائية الرئيسية لتعمل على تقديم التصميم الامثل لإدارة الطاقة لنظام طاقة هجين متعدد المصادر ، حيث يتضمن هذا النظام الواحا كهروضوئية ، وتوربينات رياح ، ومولدات ديزل ، وبطاريات ،وعاكسات للقدرة.

في هذه الرسالة تم اختيار دراسة حالة لمنطقة الطيب الحدودية في محافظة ميسان بالاضافة لكونها ذات واقع ريفي زراعي و تقع على الشريط الحدودي في الجزء الجنوبي الشرقي من الحدود العراقية-الإيرانية ولا ترتبط بخطوط نقل الطاقة الكهربائية بالرغم من أهميتها الاقتصادية الكبيرة.

بعد تجميع البيانات اللازمة الخاصة بالأحمال الكهربائية من مصادرها المتوفرة والمطلوب تجهيز الكهرباء بصورة مستمرة اليها والحالة الجوية من رياح وطاقة شمسية خلال اشهر السنة وخلال اليوم الواحد تم إدخالها الى برنامج مشهور وهو HOMER Pro وتم الحصول على القيم المثلى المتمثلة بتحقيق التوازن بين خمس اهداف ودلائل وهي اقل تكلفة أولية وأقل تكلفة للطاقة وأقل تكلفة اجمالية وأفضل وثوقيه وانعدام فقدان امدادات الطاقة.

ولغرض المقارنة تم برمجة خمس خوارزميات كفؤة ومشهورة بنتائجها الدقيقة لتطبيقها في برنامج الماتلاب وهي خوارزمية اسراب الطيور PSO بثلاث طرق واختيار افضلها ومن ثم خوارزمية بحث الوقواق Cuckoo Search وخوارزمية امثلية اليعسوب Dragonfly Optimization وخوارزمية الخفاش Bat وخوارزمية الذئب الرمادي Grey Wolf Optimization.

من خلال البحث تبين ان افضل النتائج وأكثرها مثالية كانت باستخدام خوارزمية الخفاش وبالشكل التالي لتجهيز الطاقة الكهربائية في منطقة الطيب وفق المعطيات الموجودة كانت بالشكل التالي : عدد الالواح الكهروضوئية 1200 لوح وعدد توربينات الرياح 47 توربين وعدد مولدات الديزل 5 مولدات وعدد البطاريات 3100 بطارية وعدد عاكسات القدرة 43 عاكس وتكلفة الطاقة 0.108 $/KWh والتكلفة الأولية 4520340$ والتكلفة الصافية الاجمالية 8634048$ والوثوقية 99.848% واحتماليه فقدان امدادات الطاقة 0.0015% .

أخيرا أن البرنامج المستخدم والخوارزميات المختارة تُظهر أيضًا أن الخوارزمية BA تمكّنت من الوصول إلى حلول مثلى ساهمت في تقليل التكاليف الإجمالية ، وتم الاستنتاج أن نهج نظام الطاقة المتجددة الهجين هو طريقة مناسبة لتلبية احتياجات الكهرباء في المناطق الريفية والنائية في العراق والدول النامية الأخرى ذات المناخات المماثلة.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة ميسان

كلية الهندسة

التصميم الامثل وادارة الطاقة لنظام توليد القدرة الهجين: دراسة حالة مقاطعة الطيب

رسالة مقدمة الى مجلس كلية الهندسة في جامعة ميسان كجزء من متطلبات الحصول على شهادة الماجستير في الهندسة الكهربائية

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