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Energy Management Strategy and Nature-Inspired Methods for Integrating Renewable Energy System Considering Cost and Renewability

MASTER’S THESIS

PREPARED BY
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ÖZET

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MALİYET VE YENİLENEBİLİRLİK GÖZ ÖNÜNDE BULUNDURULARAK YENİLENEBİLİR ENERJİ SİSTEMİNİN ENTEGRASYONU İÇİN ENERJİ YÖNETİM STRATEJİSİ VE DOĞADAN ESİNLENEN YÖNTEMLER

Dünyanın yenilenebilir enerji kaynaklarına daha fazla bağımlı hale gelmesiyle birlikte enerji yönetimi kritik bir zorluk haline geliyor. Güvenilir, dayanıklı ve sürdürülebilir güç kaynağı sağlarken yenilenebilir enerji sistemlerinin entegrasyonunu optimize etmek için etkili stratejilere ihtiyaç vardır. Doğadan ilham alan yöntemler bu zorluğun üstesinden gelme konusunda umut vaat ediyor. Sürü zekası, evrimsel algoritmalar ve biyomimikri gibi teknikler karmaşık enerji sistemlerinin modellenmesine, üretim ve dağıtımın optimize edilmesine ve dinamik koşullara uyum sağlanmasına yardımcı olabilir. Örneğin, WOA dağıtılmış enerji kaynaklarını planlamak için kullanılabilirken, insan beyninden ilham alan sinir ağları yenilenebilir enerji üretimindeki dalgalanmaları tahmin edebilir. Doğadan ilham alan yaklaşımları enerji yönetimi stratejilerine dahil ederek yenilenebilir enerji sistemleri, kesinti, belirsizlik ve yenilenebilirlik ihtiyacı gibi faktörleri hesaba katarak daha iyi entegre edilebilir. Bu, yenilenebilir kaynakların doğal avantajlarından yararlanan daha verimli, güvenilir ve sürdürülebilir enerji ağlarına yol açabilir. Bu alandaki daha fazla araştırma ve geliştirme, yenilenebilir enerji geleceğine geçişi hızlandırma potansiyeline sahiptir.

Anahtar Kelimeler: Enerji Yönetimi, Yenilenebilir Enerji, Doğadan İlham Alan, Güvenilir, Balina Optimizasyon Algoritması, Parçacık Sürüsü Optimizasyonu

ABSTRACT

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ENERGY MANAGEMENT STRATEGY AND NATURE-INSPIRED METHODS FOR INTEGRATING RENEWABLE ENERGY SYSTEM CONSIDERING COST AND RENEWABILITY

Energy management is a critical challenge as the world transitions to greater reliance on renewable energy sources. Effective strategies are needed to optimize the integration of renewable energy systems while ensuring reliable, resilient, and sustainable power supply. Nature-inspired methods have shown promise in addressing this challenge. Techniques such as swarm intelligence, evolutionary algorithms, and biomimicry can help model complex energy systems, optimize generation and distribution, and adapt to dynamic conditions. For example, WOA can be used to schedule distributed energy resources, while neural networks inspired by the human brain can predict fluctuations in renewable energy generation. By incorporating WOA approaches into rule-based energy management strategies, renewable energy systems can be better integrated while accounting for factors like intermittency, uncertainty, and the need for renewability. This can lead to more efficient, reliable, and sustainable power networks that leverage the inherent advantages of renewable sources which results in reduction in COE (0.0836) and increasing of REF by 50%. Further research and development in this area has the potential to accelerate the transition to a renewable energy future.

Keywords: Energy Management, Renewable Energy, Nature-inspired, Reliable, WOA, PSO.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

AC	:	Alternating Current
BT	:	Battery
COE	:	Cost of Energy
DC	:	Direct Current
EMS	:	Energy Management Strategy
ESB	:	Energy Storage Battery
FC	:	Fuel Cell
RB	:	Rule-Based
RESs	:	Renewable Energy Sources
REF	:	Renewable Energy Fraction
LB	:	Learning-Based
MATLAB	:	Math Laboratory
OB	:	Optimization-Based
SoC	:	State-of-Charge
WOA	:	Whale Optimization Algorithm
WT	:	Wind Turbine

1. INTRODUCTION

Sources of energy from renewable sources are the solution to the power and environmental problems as an innovation to the traditional power sources [1]. They can feed the devices and meet the demand with clean energy [2]. However, Renewable Energy Sources (RES) face some of the limitation such as sizing and meeting the demand. A system that integrates RESs with the traditional network to create a hybrid scheme is denoted as an on-grid or grid-connected system [3]. A Microgrid (MG) could be employed of improving a connected to the grid structure to get around traditional power limits, which is a significant distinction between MG and a grid-connected system [4]. Consequently, there is no consensus among academics about the exact description of a microgrid. According to every known source of literature, a collection of loads may alternatively be termed a system with a microgrid [5]. Microgrid sources can also function as a programmable system that offers power, heat, or both [4]. Both grid-isolated and grid-connected systems fall under the same classification category when it comes to hybrid systems [6].

Thus, a microgrid system is beneficial because of the advantages it offers, which include adaptability and productivity [7]. Students over the world are using alternative energy sources because of growing environmental concerns and rising consumer demand for electricity. In contrast to the conventional network, the hybrid system can also handle source and load issues [8]. Furthermore, Green House Gas (GHG) emission can be decreased by integrating RESs into urban or remoted region. The most employed RESs includes the solar and the wind energy because to the economical, reliable, and greener energy offered [9].

Numerous studies on the use of EMS in combination with natural methods which have been separated into multiple categories and summarized below have been undertaken:

1. Nature-inspired Energy Generation:
    - Studies have explored the use of photosynthetic principles in developing advanced photovoltaic materials and devices. For example, research has focused on mimicking the light-harvesting structures and energy transfer mechanisms found in plant leaves [9].

    - Researchers have also investigated wind turbine designs inspired by the aerodynamic features of humpback whale fins, leading to improved efficiency and reduced noise.
    - Geothermal energy systems have been studied that emulate the heat transfer and storage mechanisms observed in termite mounds and other natural structures.
2. Nature-inspired Energy Storage:
    - Scholars have investigated energy storage alternatives that draw inspiration from the functional and structural properties of organic materials like wood, bones, and seashells [7].
    - Studies have examined the use of nature-inspired structures and hierarchical designs to develop high-performance batteries and supercapacitors.
    - Using the phase-change characteristics and temperature regulating processes present in living things, biomimetic techniques have also been used to build thermal energy storage devices.
3. Nature-inspired Energy Distribution and Management:
    - The application of optimisation methods and algorithms inspired by nature for the effective distribution and management of energy in power grids and other energy systems has been studied [10].
    - Researchers have developed innovative solutions for energy dispatch and load management by taking inspiration from biological neural networks, WOA, and swarm intelligence.
    - The study of natural self-organization and decentralized decision-making processes has informed the development of distributed energy management platforms and microgrid control systems [10, 11].
4. Integrated Energy Management and nature-inspiration
    - The combination of nature-inspired techniques and energy management concepts has been thoroughly investigated in order to develop more comprehensive and sustainable energy systems [12].
    - These studies have examined the synergies between energy auditing, energy efficiency measures, and the incorporation of nature-inspired components and optimization techniques.

    - Studies have also looked into how energy infrastructure, including buildings, transit systems, and urban energy systems, might be planned and managed using concepts of nature-inspired design.

5. Interdisciplinary Collaborations and Case Studies:
    - Various case research papers and interdisciplinary collaborations have been documented, showcasing the successful integration of energy management and nature-inspired methods [12].
    - These involve the design of structures that are energy-efficient and that are modelled after termite mounds, the development of nature-inspired smart networks, and the development of biomimetic energy strategy technologies [13].
    - Such collaborative efforts have involved researchers from diverse fields, including biology, engineering, computer science, and energy studies.

These works demonstrate the growing quantity of research and practical applications that explore the intersection of EMS and nature-inspired methodologies, underscoring the possibility for enhanced sustainability and efficiency in energy systems.

1.1 Background and Motivation

The beneficial environmental impacts of sources from sources of sustainable energy, such as solar and wind, hydroelectric, and geothermal power, as well as the decreasing expenses of these technologies, have made them becoming increasingly prevalent in recent years [14]. However, the unpredictable and variable characteristics of energy produced from renewable sources poses challenges for grid integration and maintaining a steady and continuous supply of power. The microgrid is composed of multiple interconnected sources and systems, some of which take into account Fuel cells (FC), Wind turbine (WT), and solar power (PV) technologies. It is thought that the first two sources listed will lessen emissions, lessen their influence on the grid, lessen their reliance on it, and meet load demands [15]. Furthermore, the disadvantages associated with the usage of a single energy source can be offset by the integration of many energy sources [15].

The management of energy Strategy encompasses supervisory control optimisation strategies for rules and regulations the implementation process's impact [16]. There are three main categories for supervisory control utilized in various researchers includes Rule-Based (RB), Optimization-Based (OB), and Learning-Based are determined in the research as the EMS [17, 18]. The viability of resources, expenses, damages, and renewability are contingent upon EMS in this context. The microgrid system has to create and construct a model system as one of its challenges. Additionally, there are a number of interesting methods that could facilitate the production process. Power flow in the systems is regulated by a number of optimization methods developed recently [19].

1.2 Background on Energy Management and Nature-Inspired Methods

The suggested scheme of energy monitoring system is given in Figure 1 with the integration of the presented components PV, BT, integrated into the main utility grid to run home appliance that forms the load. Further explanation for the terms of energy management strategy along with the nature-inspired metaheuristic are presented below [20].

1.2.1 Energy Management

- Energy management indicates the practice of observing, controlling, and enhancing the use of energy in a system [14].
- It includes methods and approaches to the usage of energy, increase energy productivity, and move energy use alternative sources.
- Energy management has been practiced for decades, with the concentration on improving the performance and. Sustainability. of buildings, industrial developments, transportation, and power grids.
- Key energy management practices include energy audits, load management, energy-efficient technologies, and the integration of RES.

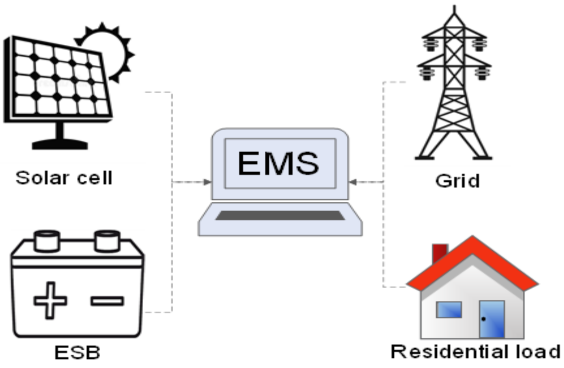


Figure 1. Energy Management Strategy for the system [10].

1.2.2 Nature-Inspired Methods:

- Nature-inspired methods, also known as biomimicry or bioinspiration, involve the study and emulation of natural systems, processes, and strategies to solve human problems [14].
- Biomimicry has been exploited across multiple disciplines, which includes engineering, materials science and technology, architecture, including energy systems [21]..
- The underlying principle is that nature has evolved highly efficient and sustainable solutions to complex challenges over billions of years of evolutionary adaptation.
- Examples of nature-inspired energy solutions include photovoltaic systems inspired by plant leaves, wind turbines inspired by whale fins, and energy storage inspired by the structure of seashells [14].

1.2.3 Convergence of Energy Management and Nature-Inspired Methods:

- The integration of nature-inspired techniques with energy management has been receiving more and more interest in the past few decades as an alternative way of tackling electricity-related issues [22].
- Nature-inspired methods can provide innovative solutions and optimization techniques for energy generation, storage, distribution, and consumption.
- Conversely, energy management principles and practices are applicable to increase the effectiveness and sustainability of nature-inspired energy systems.
- This convergence has directed to the improvement of concepts like biomimetic energy systems, nature-inspired power grids, and nature-inspired energy optimization algorithms.

1.2.4 Interdisciplinary Collaboration:

- Enhancing the combination of energy management and biomimetic approaches necessitates interdisciplinary collaboration among biology, engineering, computer science, materials science, and energy research [14].
- Interdisciplinary teams can leverage their diverse expertise to identify natural analogues, develop nature-inspired technologies, and implement energy management strategies effectively [23].

- Recent developments that integrate elements from biology, engineering, and energy systems have emerged as a result of this partnership, including bioelectronics, bioenergy, and biomimetic robotics [24].

The background and evolution of this convergence highlight the growing recognition of the potential for nature-inspired methods to complement and enhance energy management practices, ultimately driving regarding more green and efficient energy systems. Conventional energy management strategies often rely on centralized control and optimization techniques. This might not be adequate to manage the difficulties of integrating renewable energy on a broad scale [19]. Nature-inspired methods such as swarm intelligence, evolutionary algorithms, and biomimicry, have shown promise in addressing these challenges by providing decentralized, adaptive, and self-organizing approaches to energy management [20].

1.2.5 Motivation

Energy management and nature-inspired methods are increasingly being explored and adopted for a few key reasons:

1.2.5.1 Sustainability and Efficiency

- Conventional energy systems frequently depend on limited, non-renewable resources such as fuels that are fossilised, which exert considerable impact on the planet.
- Nature-inspired methods and energy management techniques aim to optimize energy use, reduce waste, and leverage renewable, sustainable sources of energy.
- This could help in alleviating the impact of climate change, reduce environmental degradation, and support more sustainable development.

1.2.5.2 Resilience and Adaptability

- Natural systems are resilient and can adapt over time to changing environmental conditions.
- Applying nature-inspired design principles and energy management strategies can help create energy systems that are more resilient to disruptions and able to adapt to evolving needs [24].

- This is particularly important as power grids and infrastructure face increasing stress from factors like extreme weather events, aging infrastructure, and rapidly changing energy demand.

1.2.5.3 Optimization and Efficiency:

- Nature has evolved highly efficient processes and systems over billions of years.
- More efficient energy production, storage, distribution, and consumption can result from researching and imitating optimization strategies inspired by nature, for example the kinds observed throughout biological structures [14].
- Energy management methods that leverage real-time data, machine learning, and optimization algorithms can also improve efficiency and reduce energy waste [14].

1.2.5.4 Innovation and New Opportunities

- The integration of management of energy with nature-inspired methodologies inspires innovations within the electric power industry and related businesses.
- Developing novel energy technologies, materials, and systems inspired by natural analogues can create new business opportunities and drive technological progress.
- Interdisciplinary collaboration between fields like biology, engineering, computer science, and energy research can accelerate these advancements

The motivation for using energy management and nature-inspired methods stems from the requirement for more robust, sustainable, and cost-effective of energy techniques that can meet evolving societal and environmental needs. Humans can set up new opportunities for the development of a greener energy future by imitating and learning from natural processes.

1.3 The problem formulation

Although, the RESs are the promising solution to the environmental and power issues. But they are facing storge, sizing, climatology changes limitations. The aforementioned limitation could be addressed by the coupling energy management strategy with nature-inspired algorithm.

Due to fears regarding changes in the climate and increasing global temperatures, in addition to the continued decrease and depletion of resources from fossil fuels, there has been significant worry regarding conventional energy systems. To replace the inefficient conventional systems, a variety of configurations known as the growing popularity of the utilization of energy from natural sources is an innovation in comparison with conventional energy systems, which are essentially fossil-based systems. RESs are more environmentally friendly and more viable than conventional systems. The employing of EMS along with suitable size for guaranteeing minimal investment expenses for the overall system has become essential.

The RESs have been getting greater public interest as a consequence of. the rising global energy. demand and the need to mitigate climate change. Environmental resources of energy involving solar and wind generation are sporadic, which makes grid integration and dependable electricity supply difficult. This proposal describes an energy management approach that takes long-term renewability into account and enhances the implementation of green power sources by utilizing nature-inspired methodologies.

1.4 Scope of the study

The main considering scope of the study will be limited to the main components (PV, BT, Grid, Load) connected via DC-AC converter. The investigation is conducted purely by conducting computer software (MATLAB R2021a); no physical hardware is involved. It is making use of load demand from homes.

1.5 The main objective

- To support the home system by RES and building strategies to spread the power among the system components smoothly based on proposed EMS considering long-term renewability.
- To size the system components considering recent nature-inspired algorithm.
- To assess the efficacy and scalability of the strategized EMS in terms of energy efficiency, grid stability, and cost-effectiveness MDP.
- To benchmark the obtained result

1.6 System components

The main connected components in the system are listed below with briefly explanation [25].

1.6.1 Solar panels

The primary power source in this system is the solar panels, known as photovoltaic (PV) panels. It converts. sunlight into electrical energy that powers electronics and gadgets in the house [25].

1.6.2 Deep cycle battery

Solar energy produced by the panels is stored in the deep cycle battery. Due to this, power can be produced by the system even in the absence of sunlight. Repeated discharges and recharges of deep cycle batteries are intended to occur without noticeably reducing their performance.

1.6.3 Utility grid

The primary electrical grid provided by the nearby power provider is referred to as the utility grid. Though it can be utilized as a backup or supplemental power source, when necessary, the electrical network will not be utilised as the primary generator of energy in an off-grid solar system.

1.6.4 Load (home appliances)

The appliances and electrical equipment in the house that use the power produced by the solar energy systems and stored them in the battery are referred to as the load in this system. Lights, refrigerators, PCs, and other home devices fall under this category.

1.6.5 DC/AC Inverter

The DC electricity generated by the solar panels. is transformed into. AC electricity by the DC/AC inverter., which is an essential component. AC power is necessary for the majority of home appliances and devices to operate.

1.7 Research Methodology

This part provides a brief summary of both the proposed method and the techniques employed to accomplish the study objectives that are detailed in the subsections. Chapter 3 presents more information on the methodology. The approach used is broken down into multiple primary activities to accomplish the research objectives, as shown in Figure 2.

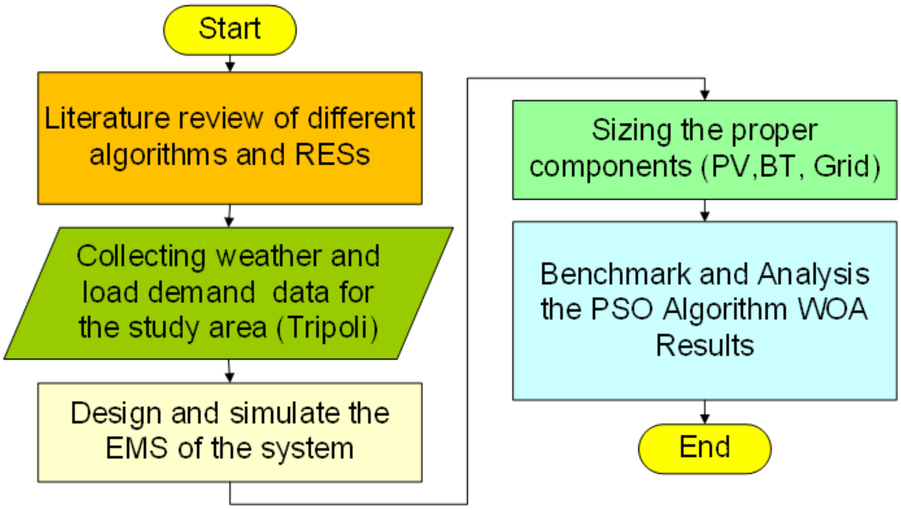


Figure 2. Research strategy.

1.7.1 Literature review of algortihms

This work is considering in providing a comprehensive literature review on Nature-inspired algorithms [26], and EMS. The fundamental objective of the review of the literature is to draw attention to both the positive and negative aspects of numerous methodologies used in the academic studies that have already been done on the subjects mentioned previously.

The database provides evidence highly clear that there will be an abundance of articles in the literature found. Consequently, publications published at conferences, journals having an impact factor, journals indexed in Scopus, and journals in the quartile are given priority. The optimization and EMS for a stand-alone microgrid must also be covered in the study. Each of the publications has been carefully examined in light of the amount of research that has already been done, and a brief compilation of the particularly significant ones was created [27].

1.7.2 Data collection

To assess the power produced of the system that has been suggested, certain significant climatology data from the case study (Tripoli, Libya) have been gathered, considering the system's unique features. The primary climatology data gathered are the ambient temperature and solar irradiation.

1.7.3 Design and simulation

The battery's State-of-Charge. (SoC) capacity, PV generated power, and utility grid integration are all quantitatively counted for every source based on the formula given in chapter three. Strategy EMS for the designed system for smoothly flow the. power based on IF-THEN statements.

1.7.4 Sizing

Nature-inspired metaheuristic algorithm is implemented to size the system components using mathematical equation considering MATLAB coding. Combining a nature-inspired algorithm with a planned EMS to create a system that is inexpensive.

1.8 Findings of the research in Chapter 1

Using (Tripoli -Libya) as an investigation research area, the initial chapter is a summary of the historical context and justification of the utilisation of clean energy resources in contemporary cities with the goal of achieving a system that is both affordable and environmentally friendly.

This study illustrated the capability of Tripoli-Libya (case study) to produce a clean energy under different climatology conditions that using a backup to the electricity system and minimize reliance on the power grid. The climatic data (solar radiation and the surrounding temperature) that have been gathered from the core of. the previously indicated procedure.

The integrated system is a type of hybrid system using PV, BT, Grid, integrated into the residential electrical load to fulfil the electrical load demand. The proposed electrical system has been management though the supervised management control that defined as Rule-Based EMS couple with nature-inspired algorithm to reach a cost-effective system and renewable.

1.9 Organizing chapters

The thesis consists of five main chapters presents the table and figure along with some of the important knowledge as shown in Figure 3.

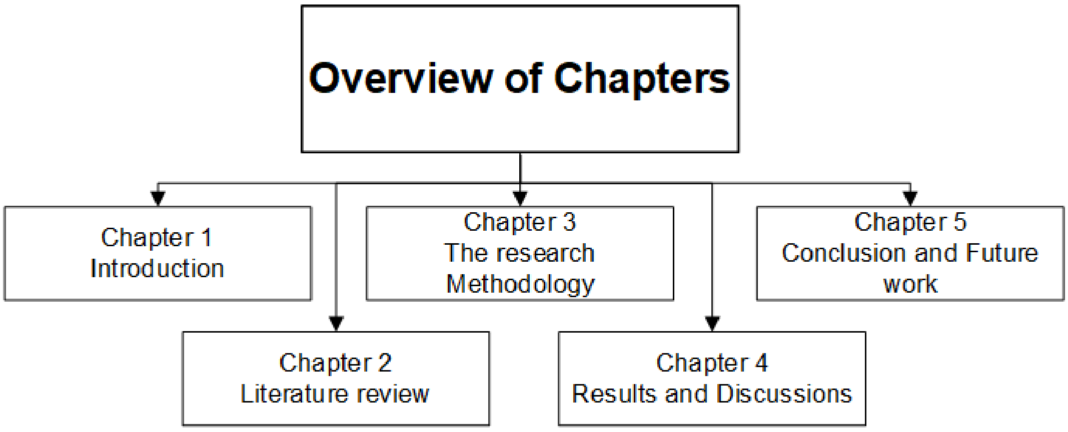


Figure 3. Overview of thesis chapters.

Chapter one considering general introduction on the integrated system and components of RES system and problem statement. The scope is taken a place in chapter one to present the considered limitation of the structure components of the system and types of software along with form of connected system considering software based. Besides, the ending with the thesis organization.

Chapter two presenting the conducted studies in the literature of the microgrid with their classification. Besides, the classification of energy sources that discussing the renewable and non-renewable energy sources. The supervisory control methods that refer to energy management strategies along with their merits and demerits and objectives are presented. In addition, classification of various number of nature-inspired optimization algorithms are tabulated with different types of methods. The supervisory control algorithms a classification is presented and explained. The chapter has closed with chapter summary that summarizing the conducted studies on the literature for and the gap of knowledge

The third chapter outlines A methodical approach that was taken in consideration towards achieving the stated objectives. Additionally, the collected data for the case study is presented and will be utilized to provide the estimated the electricity produced from the coupled suppliers. The recommended diagram presented with main connected components. In addition, the utilized nature-inspired optimization algorithms (PSO and WOA) along with their advantage and disadvantages are presented. Continuously, the energy management strategies are taken a place in this chapter with their merits and demerits. The main mathematical equation for the integrated components is shown in this chapter. The main objectives for reducing the cost and increasing the renewability are considered in this chapter. Eventually, closing the chapter with summarizing the main discussed topics in the chapter.

Chapter four presenting and discussing obtained results. The compared output among all the integrated sources. Furthermore, the produced power acquired from the PV is considered for one-year annual data. Besides, all the proposed strategies have been met and plotted and deeply discussed. The battery represents as one of the integrated sources that has been used for its SoC, and its charging and discharging performance is demonstrated. Eventually, the breakdown of the obtained comparison coupled result for the utilized nature-inspired metaheuristic method and energy management strategy are tabulated followed by the analysis section for the output results using MDP are figured out.

Chapter five presenting the summary of the conclusion and future recommendations. Closing with the recent cited reference.

2. LİTERATURE REVİEW

2.1 Introduction

In the previously mentioned chapter, the general background and problem formulation of renewable energy sources integration with the nature-inspired algorithm with the energy management strategies were presented. The increasing global demand for energy and the need to address. Due to the climate change that has sparked a growing interest in renewable energy sources, energy generation seasonally is not stable. However, grid integration and a consistent energy supply are hampered due to the unstable nature of energy obtained from resources that are sustainable, including the power of the sun and wind. These issues can be resolved by combining energy supervisory control with an algorithm inspired by nature. This literature review explores the current research on energy management strategies and nature-inspired methods for integrating renewable energy systems while considering long-term renewability.

Considerable study has been done on energy management systems due to the rising demand for global energy and the urgent necessity to mitigate warming temperatures. Optimizing energy consumption and integrating renewable energy sources are crucial aspects of this domain. Nature-Inspired Algorithms (NIAs), with along the capacity to handle complicated optimization issues, have emerged as powerful tools for enhancing energy management strategies. This literature review explores the synergy between NIAs and energy management, highlighting key applications, benefits, and challenges [14].

2.2 Concept of Microgrid systems

The general terminology of a microgrid is capable of being expressed as a collection of dispersed energy resources like energy storage system, affordable forms of energy and traditional grid that assembled in a cluster for the specific purpose of meeting local energy demands as shown in Figure 4 [28].

2.2.1 Microgrid classification

The microgrid is able to be grouped into two classifications, grid-connected and standalone. The grid connected refers to the hybrid integrated system. While the standalone can be stands for the isolated system.

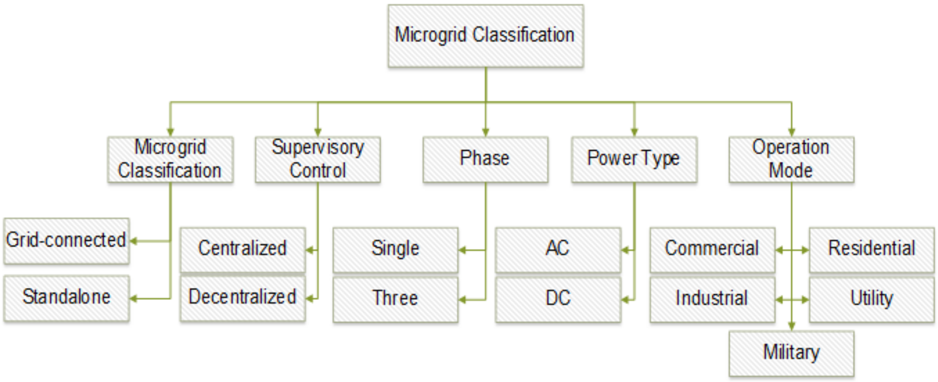


Figure 4. Microgrid classification [22].

Table 1 Main classification of microgrid modes [5].

Classifications	Advantages	Disadvantages	Description
Grid-Connected Microgrids	• Access to the extensive grid for auxiliary electricity. • A surplus of electrical energy can be resold to the national power grid. • More stable and reliable due to grid support.	• Reliance on the primary electrical grid. • Potential for grid disturbances to affect the microgrid.	• These MCs are linked to the primary electrical grid. • It able to run in both "grid-connected" and "islanded" methods.
Standalone Microgrids	• Energy independence. • Enhanced resilience during grid outages. • Applicable in rural regions lacking grid connectivity.	• More complex to manage and control. • Requires robust energy storage solutions. • Limited power capacity compared to grid-connected systems.	• These microgrids function autonomously from the primary electricity grid. • They heavily depend only on local power sources, including wind, solar energy, and the batteries.
Hybrid Microgrids	• Flexibility and adaptability. • Enhanced reliability and resilience. • Can leverage both grid and local resources.	• More complex to design and implement. • Requires sophisticated control systems.	• It combines elements of island and grid-connected systems. • Can connect to the grid when available also operate independently during grid outages.

2.2.2 Supervisory control

The centralized and decentralized are the main two types of supervisory control in microgrid systems [24]. These terms describe how the microgrid's resources are managed and coordinated.

Table 2 Control methods [29].

Controls	Features	Advantages	Disadvantages
Centralized Control	• A single central controller manages all aspects of the microgrid • including generation, storage, load management, and grid synchronization.	• Easier to implement and manage. • could enhance the microgrid's effectiveness in general. • Provides a single point of control for decision-making.	• One singular source of failure Every component of the microgrid may be affected if the central controller failures. • Limited scalability as the microgrid grows, the central controller may become overwhelmed. • Potential for communication bottlenecks All data must pass through the central controller.
Decentralized Control	• Each component (e.g., generator, battery, load) in the microgrid has its own local controller. • These controllers communicate with each other to coordinate actions and ensure overall system stability.	• Increased resilience: the breakdown of a single controller does not impact on the overall system. • Better scalability: Can handle larger and more complex microgrids. • Reduced communication bottlenecks: Data is processed locally.	• More complicated to plan and achieve. • Needs advanced techniques for communication. • It could be more challenging to maximize the microgrid's overall performance.

In addition, the two categories of power flow can be illustrated in Figure 5 as bidirectional and unidirectional , while unidirectional is further subclassified into uncontrolled and controlled power flow followed by the extended classification of controlled into centralized and decentralized [21].

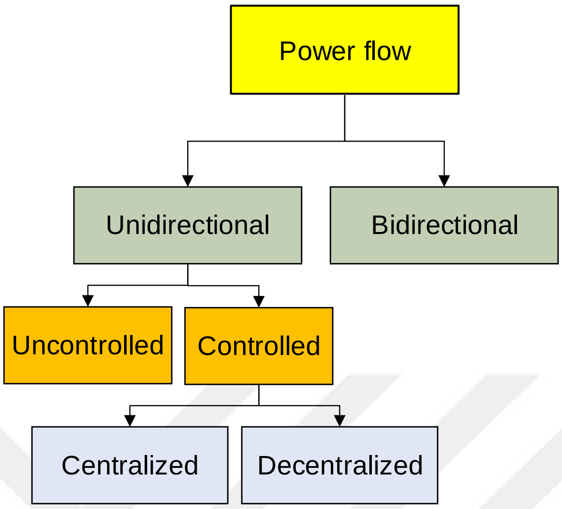


Figure 5. Classification of power flow [20].

There are a few factors between the two regulated types that allow consumers to choose the best option for their action. Decentralized versus centralized control selection is based on a number of variables.

- **Microgrid size and complexity:** Larger and more complex microgrids often benefit from decentralized control.
- **Reliability requirements:** Decentralized control provides greater resilience to failures.
- **Cost and complexity:** The implementation of centralized control is generally less costly, but decentralized control offers greater flexibility and scalability.
- **Communication infrastructure**: Decentralized control requires robust communication networks.

2.2.3 Phases

The classification of presented phases can be further explained as Single-phase, and three-phase refer to the types of AC power systems used within the microgrid, not the connection type.

- **Single-phase:** Typically used for residential and smaller commercial applications.
- **Three-phase:** Its greater power capacity makes it suitable for larger applications in both business and industry.

2.2.4 Power types

The AC and DC are two types of power as demonstrated in Figure 6 [21]. Additionally, both types are important as can be defined:

- **Direct Current (DC):** is crucial for powering sensitive electronics and devices that require constant voltage.
- **Alternative Current (AC):** is essential for delivering power to homes and businesses, as it allows for efficient transmission over long distances.

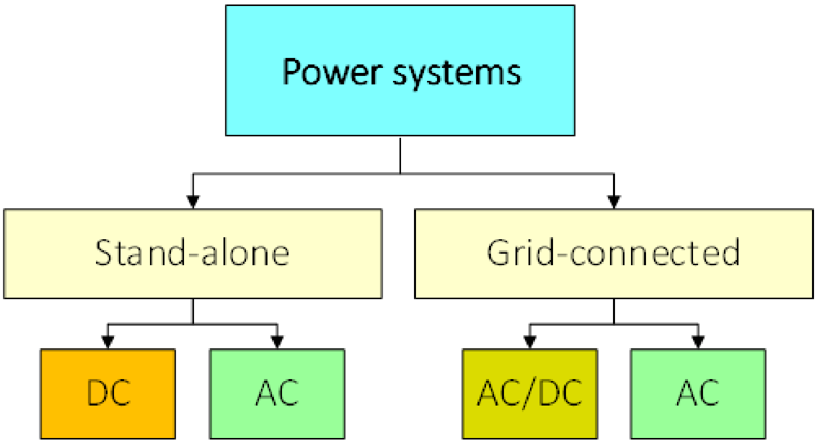


Figure 6. Power system classification [21].

Table 3 Comparison of AC and DC [21].

	Flows	Sources	Characteristics	Applications
AC	• Electrons flow back • Fourth in a cyclical pattern.	• Power plants • Generators.	• Voltage and current fluctuate over time. • More effectively than DC when delivered across farther distances. • simply changed to a different voltage level.	• Household wiring • industrial equipment • Most appliances.
DC	• Electrons are limited to movement in a	• Batteries • Solar panels	• Constant voltage and current.	• Electronics, • Rechargeable batteries

	single direction.	• DC power supplies.	• Easier to control and regulate. • Less prone to interference.	• Some motors.

2.2.5 Operation mode

Numerous kinds of operation modes are present can be implemented for microgrid system such as commercial, residential, utility, and military. the specific operation modes implemented in a microgrid often depend on its intended application [30]. The breakdown of common operation modes for different types of microgrids are tabulated in Table 4.

Table 4 Classification of mode operation and classification [31].

Operation modes	Common Modes	Focus
Commercial Microgrids	• Grid-connected • Hybrid • Peak shaving.	• Reducing energy costs by utilizing local generation and storage. • Improving energy efficiency and sustainability in building PVs. • Enhancing reliability and resilience against grid outages.
Residential Microgrids	• Grid-connected • Hybrid • Islanded (in some cases).	• Increasing energy independence and self-sufficiency. • Reducing reliance on the grid and associated costs. • Improving energy security during power outages at home with solar panels, battery storage, and a backup generator.
Utility Microgrids	• Grid-connected • Hybrid • Islanded.	• Enhancing grid reliability and resilience and providing power to critical infrastructure during grid outages. • Integrating distributed RESs for supporting grid stability and frequency regulation. • A microgrid serving a hospital or data center, with a mix of renewable generation, storage, and grid connection.
Military Microgrids	• Islanded • Hybrid • grid-connected (depending on location).	• Ensuring energy security and independence in remote or hostile environments. • Supplying dependable electricity to critical military activities using a mix of diesel, wind, and solar generators that may run off the grid. • Enhancing resilience against attacks or natural disasters.

The main Key Considerations of the presented mode operation can be listed as presented below:

- **Location and Grid Availability:** Microgrids in remote areas or with unreliable grid access may favor islanded or hybrid modes.
- **Security and Resilience:** Military microgrids prioritize security and resilience, often employing robust backup systems and hardened infrastructure.
- **Cost and Complexity**: Commercial and residential microgrids often prioritize cost-effectiveness and ease of implementation, while utility and military microgrids may focus on reliability and performance.

2.2.6 Energy sources classification

The sources of energy could potentially be classified into both renewable and non-renewable types, as depicted in Figure 7. Renewable energy sources are categorized into many types, similar to non-renewable sources. [32].

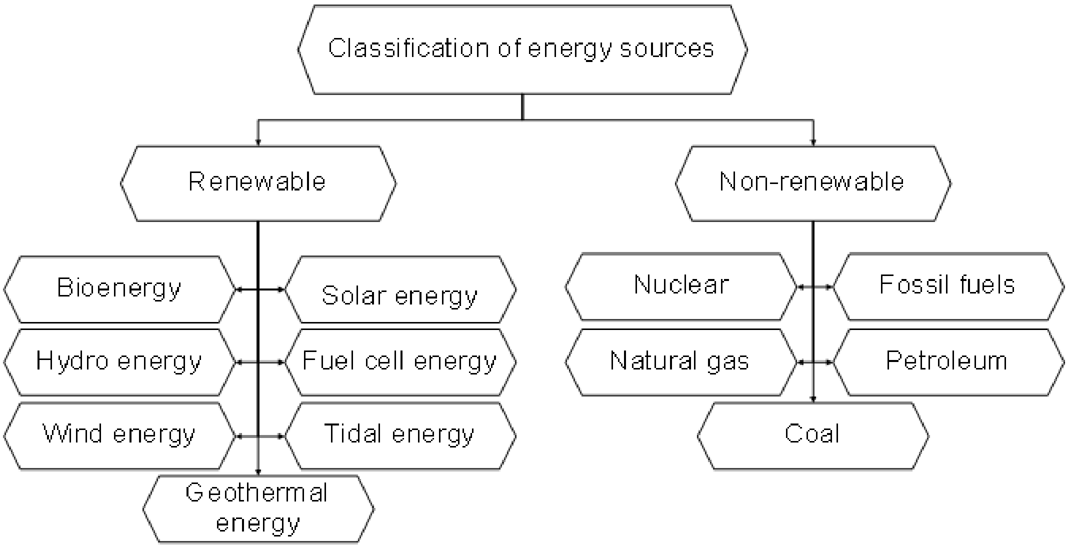


Figure 7. Classification of energy sources [25].

2.2.7 Renewable energy sources

The sources of renewable energies are a crucial component of a sustainable future, offering a clean and reliable alternative to fossil fuels. They harness naturally replenishing resources, minimizing environmental impact and promoting energy independence [25]. Renewable energy sources provide a renewable and environmentally friendly approach to a cleaner energy future. Utilizing natural resources enables us to diminish our dependence on fossils. fuel and establish a additional robust and natural energy framework. The classification of the foremost sustainable forms of energy as follows in Table 2.5.

The Opportunities of Natural sources of energy are quickly developing, propelled by technology innovations, governmental regulations, and increasing consciousness of climate change. With advancements in technology and decreasing costs, renewable energy is set to assume a crucial role in fulfilling global energy requirements while reducing environmental repercussions [24].

Table 5 Renewable Energy Sources classification with the advantages and disadvantages [27, 33]**.**

Renewable sources	Advantages	Disadvantages	Types	Features
Solar Energy	• Abundant, clean, and can be implemented on various scales (from rooftop panels to large-scale solar farms). • Solar energy utilizes photovoltaic cells to convert sunlight directly into electricity.	• Intermittent (sunlight availability varies) • Requires significant space • Manufacturing solar panels can have environmental impacts.	Photovoltaic (PV) Solar	Most common type, using solar panels to generate electricity.
			Concentrated Solar Power (CSP)	Utilizes mirrors to focus direct sunlight, heating a fluid to produce vapor for energy generation.
Wind Energy	• Clean, abundant, and can be implemented on a large scale. • Wind turbines transform the motion energy from the winds into electrical energy.	• Intermittent (wind availability varies), potential impact on wildlife (birds and bats). • Visual impact on landscapes.	Onshore Wind	Wind turbines located on land.
			Offshore Wind	Wind turbines situated in aquatic environments frequently provide more robust and stable wind conditions.

Hydropower	• Reliable, efficient, and can provide flood control and irrigation benefits.	• Significant environmental impact on river ecosystems • Potential for displacement of communities • limited availability in some regions.	Run-of-River Hydropower	Utilizes the natural flow of rivers, with minimal water storage.
			Waterpower	Hydropower exploits the power of water that moves to produce energy.
			Reservoir Hydropower	Dams create reservoirs, storing water and releasing it to drive turbines.
Geothermal Energy	• Clean, reliable, and can provide baseload power.	• Limited availability in specific geographical locations, potential for environmental impacts (e.g., emissions of greenhouse gases), and high initial investment costs.	Geothermal Power Plants	Utilize steam from underground reservoirs to drive turbines.
			• Direct Use Geothermal	• Heat from the Earth is used directly for heating buildings, greenhouses, and other applications.
Biomass Energy	• Renewables can be locally sourced, and can reduce waste.	• Can contribute to air pollution and deforestation if not managed sustainably	Gasification	Converting biomass into a gas fuel for electricity production.

	• Biomass energy employs organic stuff (wood, crops, garbage) to produce heat or power.	• The energy content of biomass is relatively low.	Combustion	Burning biomass directly for heat or electricity generation.
Ocean Energy	• Clean and renewable • Can provide baseload power.	• Currently in preliminary development phases, incurring substantial expenses. • Potential environmental impacts on marine ecosystems.	Tidal Energy	Utilizes the ebb and flow of tides to generate electricity.
			Wave Energy	Captures the energy of ocean waves to generate electricity.
			Ocean Thermal Energy Conversion (OTEC)	Utilizes the thermal differences between warm water on the surface and cold deep water to generate electricity.

2.2.8 Non-renewable energy sources: A Finite Resource with Lasting Impacts

Fossil energy sources are finite resources that take thousands of years for formation, providing them unsustainable in the long term. Although they have traditionally been the primary source of electricity, their utilization entails considerable both social and environmental impact. Petroleum and other petroleum-based sources of electricity have played a significant role in powering our world, but their unsustainable nature and environmental impacts necessitate a shift towards renewable energy. The future of energy lies in harnessing clean and sustainable resources that can meet our energy needs without compromising the health of our planet and future generations [34]. A breakdown of the most prominent non-renewable energy sources.

The Foundation for the Development of Modernism Energy Petroleum-based products (coal, oil, natural gas) are generated from the remnants of prehistoric species over the course of many thousands of years. They are burned to generate heat and electricity.

Table 6 Classification of fossil fuels [35].

Main sources	Classifications	Features
Fossil Fuels	Coal	• Solid-state of energy fuel • Primarily utilized for the generation of energy.
	Oil	• Liquid fossil fuel, used for transportation fuels, plastics, and other products.
	Natural Gas	Gases fossil fuel utilised for heating, thus energy production, and industrial applications
Nuclear Energy	Harnessing Atomic Power	• Nuclear energy utilizes nuclear fission • Atoms splitting in order to produce heat and electricity
	Nuclear Power Plants	Utilize nuclear fission for power generation.
Uranium	Fuel for Nuclear Power	Uranium is a radioactive element used as fuel in nuclear power plants.

Table 7 The Challenges of Non-Renewable Energy [23]**.**

Challenges	Remarks
Social Impacts	• Production and distribution of hydrocarbons can lead to environmental damage • Displacement of communities, and social conflicts.
Environmental Impacts	• Fossil fuel combustion is a major contributor to climate change, air pollution, and water contamination. • Nuclear energy poses risks of accidents and radioactive waste.
Depletion	• Fossil-fueled energy sources are limited, and they are extracted, and consumption are depleting these resources at an unsustainable rate.

Table 8 Advantages and disadvantages of non-renewable energy sources [21].

Sources	Advantages	Disadvantages
Fossil Fuels	• Abundant • relatively inexpensive • well-established infrastructure.	• Major contributor to air pollution, • Climate change • Acid rain. • Extraction and transportation can lead to environmental damage and social conflicts.
Nuclear Energy	• Minimal emissions of greenhouse gases • Elevated density of energy • Dependable baseload energy.	• Risk of accidents and radioactive waste disposal • Potential for weapons proliferation • High initial investment costs.
Uranium	• High energy density • Relatively low greenhouse gas emissions.	• Radioactive waste disposal • Potential for weapons proliferation • Environmental concerns related to mining and processing

To accomplish the shift to sources of clean energy which defined as the transition to RESs is crucial to meet the difficulties presented by energy that is not renewable [23]. By investing in renewable energy technologies and implementing sustainable policies, we can reduce our reliance on finite resources and develop an environment-friendly and more economical energy future.

2.3 Energy Management Strategies for Renewable Energy Integration

Conventional energy management strategies often rely on centralized control and optimization techniques, this may prove insufficient for managing the complexities of large-scale renewable energy integration [36]. Scholars have suggested multiple strategies to tackle these difficulties.:

1. Rule-based Energy Management Strategy

Rule-based. strategies involve setting fixed rules or guidelines for energy use, for instance, deactivating lights while a room is not being utilized. These strategies are simple to implement and can be effective in certain situations [24].

2. Optimization-Based Energy Management Strategy

Optimization-based strategies involve exploiting mathematics. models and algorithms to identify the most efficient use of energy resources. These strategies often involve making trade-offs between different objectives, such as cost and environmental impact [31].

3. Learning-Based Energy Management Strategy

Learning-based strategies involve using machine learning algorithms to analyze patterns in energy use and make predictions about future energy demand. These strategies can be used to optimize energy utilization in real-time, considering variables such as meteorological conditions and population levels.

Table 9 Advantages and Disadvantages of EMS [37, 38, 39].

Approaches	Advantages	Drawbacks
Rule-based	• It doesn't require a complicated mathematical formula. • There is no need for future information. • quicker judgement. • Minimal time for computation. • It needs a little storage. • Provide a precise answer.	• To implement, more technical knowledge is needed. • It is not the most effective prediction technique.
Optimization-based	• Suitable for challenging optimization issues. • It requires fewer technical skills to be applied. • Implemented for real-time application.	• Equations from mathematics are necessary. • Extended calculation the duration • Substantial storage capacity is necessary.

Learning-based	• Adaptive and learning capability • Model-free control	• Time-consuming It is difficult to use

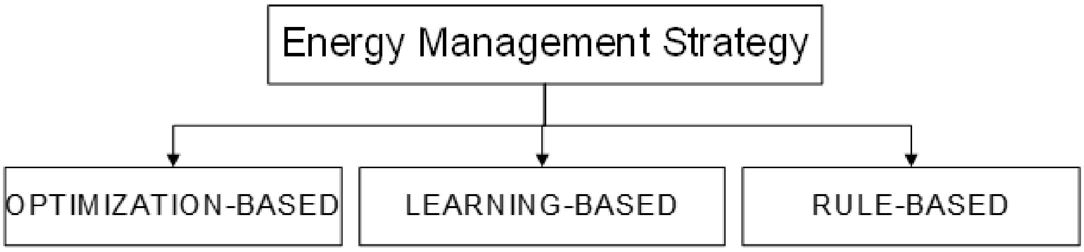


Figure 8. Energy management classification [39].

Table 10 The objective of energy management strategy [24].

EMS objectives	Goal	How can be achieved?
Improve Drivability and Comfort	Ensure a smooth and enjoyable driving experience even with energy-efficient driving techniques or while using hybrid/electric powertrains.	• Optimizing power delivery from the engine and/or electric motor(s). • Smart regenerative brake systems that capture energy during deceleration without compromising brake feel. • Advanced climate control systems minimize energy use while maintaining passenger comfort.
Satisfy Constraints	Operate within the limitations of the vehicle's energy storage and power delivery systems.	• Sophisticated algorithms that monitor SoC of battery, temperature, and overall vehicle energy demand to prevent overloading components. • Predictive control strategies that anticipate driving conditions and adjust energy usage accordingly.
Use Energy Storage System Efficiently	Maximize the usable capacity and lifespan of batteries in hybrid and electric vehicles.	• Controlling charging and discharging rates to minimize battery degradation. • Thermal management systems to keep batteries within optimal temperature ranges.
Reduce Emissions	Minimize the environmental impact of vehicles by lowering greenhouse gas emissions and air pollutants.	• Optimizing engine efficiency to reduce fuel consumption and emissions in combustion engine vehicles. • Promoting the use of electric vehicles that produce zero tailpipe emissions. • Utilizing renewable energy sources for charging electric vehicles.

Improve Fuel Economy	Maximize the distance traveled per unit of fuel or energy consumed.	• Engine downsizing and optimization. • Implementing hybrid powertrains that combine combustion engines with electric motors. • Reducing vehicle weight and aerodynamic drag.

The specific EMS objectives are illustrated in Figure 9 Improve drivability and comfort, satisfy contractions, use energy storge system efficiency, reduce emission, and improve fuel economy. Those are key objectives, particularly in the context of vehicle energy management strategies. Let's break down how each objective contributes to a more efficient and sustainable transportation system: EMSs in vehicles are multi-faceted, aiming to create a balance between performance, efficiency, sustainability, and driver satisfaction. By focusing on these objectives, we pave the way seeking more efficient and ecological transportation alternatives.

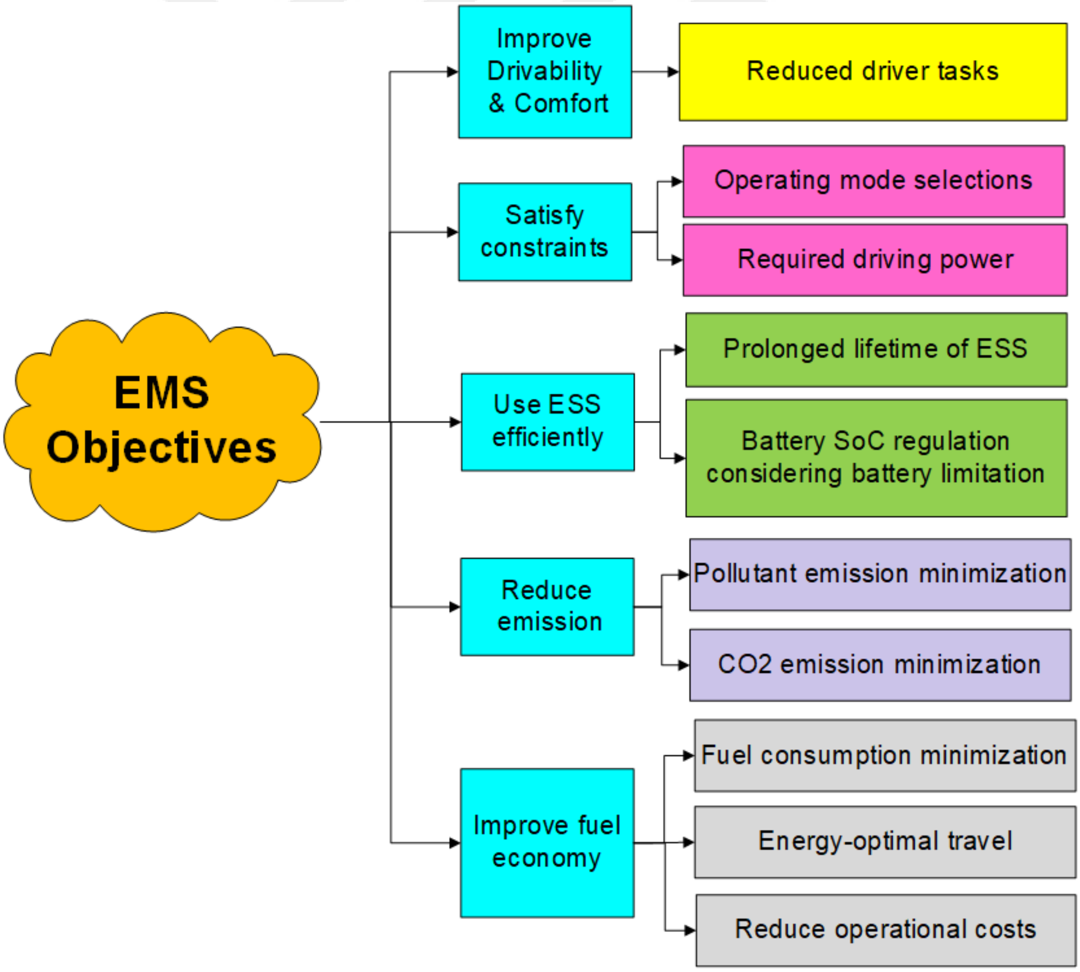


Figure 9. Energy management objectives [24].

2.4 Nature-Inspired Methods for Renewable Energy Integration

Nature-inspired methods, such as swarm intelligence, evolutionary algorithms, and Nature-inspired, have shown promise in addressing the challenges of renewable energy integration [40]. These approaches leverage the principles of self-organization, adaptation, and optimization observed in natural systems.

Based on the classification of the presented algorithms in Figure 10, the three optimization methods are defined as follows. The deterministic algorithms are Simulated Annealing (SA). AM. Linear Programming (LP). Cuckoo Search (CS).

While the stochastic algorithms are refers to an algorithms dealing with uncertainties such as Particle Swarm Optimization (PSO) [41]. Antlion Optimization (ALO) [42]. Genetic Algorithm (GA). Artificial Bee colony (ABC) [43].

Eventually, hybrid algorithms involve the combination of two or more algorithms to provide a distinct functional method, such as Discrete Harmony Search-Simulated Annealing (DHS-SA), Simulated Annealing-Cuckoo Search (SA-CS), and Simulated Annealing-Harmony method (SA-HA). Flower Pollination Algorithm-Simulated Annealing (FPA-SA) [44]. Hybrid big bang-big crunch (HBBS-BC) [45].

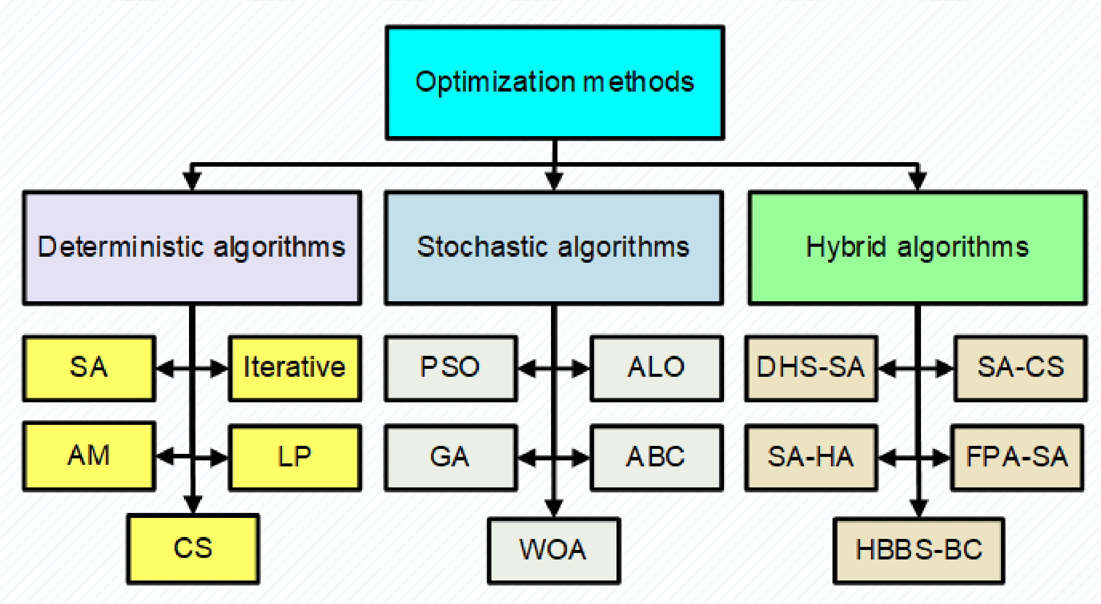


Figure 10. Optimization methods [45, 46].

There are various number of nature-inspired methos, each one has its own characteristics and tasks. As presented in Figure 11 below. The sizing methods manual methods, numerical methods, graphical, probabilistic, software methods, and others.

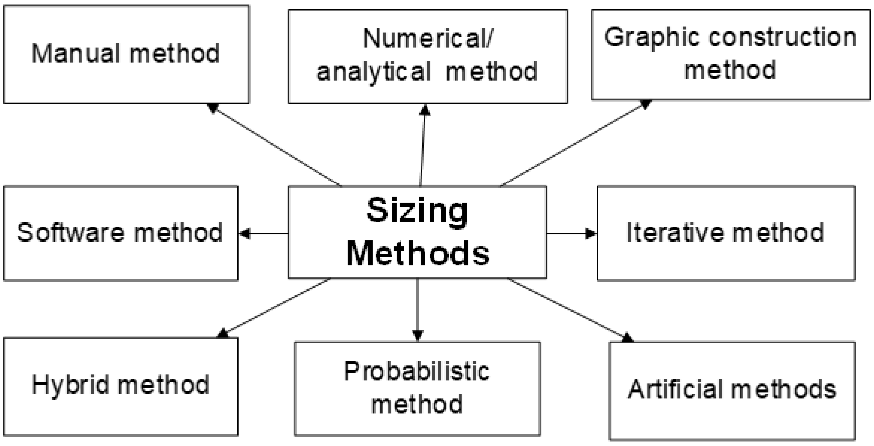


Figure 11. Sizing methods [39]

Table 11 Sizing method [39].

Methods	Advantages	Disadvantages
Manual Method	• No need for technology • Good for understanding fundamental principles.	• Time-consuming • prone to human error.
Software Method	• Increases efficiency, accuracy • Has the ability to handle complex problems.	Requires access to software and may involve a learning curve.
Hybrid Method	Flexibility and improved results by integrating various methods.	Can be complex to implement and manage.
Probabilistic Method	Provides insights into variability and risk.	Results can be less deterministic Require careful interpretation.
Artificial Intelligence methods	Can handle vast amounts of data and uncover patterns not easily visible to humans.	Requires expertise in AI and can be resource intensive.
Iterative Method	Often leads to convergence on a solution and can improve accuracy.	Require many iterations, leading to high computational costs.
Graphic Construction Method	Intuitive and can provide clear insights	Limited by the accuracy of the graphical representation.
Numerical/Analytical Method	• Analytical methods provide precise solutions • Numerical methods can handle complex problems.	Analytical methods can be limited to simpler problems, while numerical methods may introduce approximation errors

2.5 Whale Optimization Algorithm (WOA)

In 2016, Seyedali and Andrew presented the Whale Optimization Algorithm (WOA), a metaheuristic optimization methods stimulated by nature [47]. It resembles the sociable behavior and predatory strategies of whales like humpbacks, especially their bubble-net feeding method.

How WOA Works

Inspiration:

Bubble-Net Feeding: Humpback whales create bubble nets to encircle and trap their prey. This performance is statistically displayed in WOA to perform optimization tasks

Applications of WOA

The WOA is utilized to overcome a number of optimization concerns such as the one mentioned in Table 12. Besides, the merits and demerits of WOA are presented in Table 13.

Table 12 The applications of WOA [48].

WOA applications	Details
Engineering Design Problems	Solving complex design optimization tasks in engineering.
Photovoltaic System Optimization	Monitoring the highest power point in solar energy systems.
Breast Cancer Diagnosis	Enhancing diagnostic accuracy using metaheuristic optimization
Supply Chain Management	Optimizing vehicle routing with limited capacity.

Table 13 Advantages and disadvantages of WOA

	Categories	Explanations
Advantages	Flexibility	It is applicable to a broad spectrum of optimization challenges without needing the gradient of the objective function
	Simplicity	WOA is straightforward to apply and requirements minimum options.
Disadvantages	Convergence Issues	WOA may suffer from slow convergence and susceptibility to local optima.
	Parameter Sensitivity	The efficacy of WOA may be conditional upon the selection of variables. requiring careful tuning.

2.5.1 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is a metaheuristic method for optimization, derived from the social habits observed by creatures like bird flocks and fish schools. The original suggestion of the method was presented by Kennedy and Eberhart in 1995 [49]. The key main principles of the PSO algorithm are delineated in Table 14. The positive and negative characteristics of PSO are represented in Table 15.

Table 14 Basic Concept [13].

Concepts	Explanation
Particles and Swarm	PSO employs an estimated number of candidate solutions, referred to as particles, which traverse the search space to identify the most suitable option.
Movement and Influence	The motion of every single particle is influenced by its individual ideal location and the ideal places determined by other particles in the swarm. This dual influence helps guide the swarm towards the best solutions.
Objective Function	Unlike traditional optimization methods, PSO does not require the gradient of the problem being optimized Contrary to conventional optimization techniques, PSO cannot necessitate the solution of the optimum issue. It requires purely the objective function, providing it applicable to a diverse array of optimization situations.

Table 15 Advantages and disadvantages of PSO [50].

Advantages	Explanations	Disadvantages	Explanations
Simplicity	PSO is straightforward to set up and needs little variables changes.	No Guarantee of Optimal Solution	Similar to other metaheuristic algorithms, PSO fails to guarantee the discovery of the global optimum solution.
Flexibility	It related to a broad spectrum of optimization issues without necessitating the precise gradient of the target function.	Potential for Premature Convergence	The swarm may converge prematurely to a suboptimal solution if not properly managed.

Besides to the presented advantages and disadvantage that tabulated in Table 15, there are numerus number of application of PSO as presented below [49, 51, 52, 53]. While the mechanisme scheme of Particle Swarm Optimization is presented in Figure 12.

- Network
- Optimal shape and sizing design
- Data Clustering
- Function optimization
- Electronics and electromagnetics
- Processing of signals, images, and videos
- Neural networks
- Communication networks
- Reactive power and voltage control
- Ingredient mix
- System identification in biochemistry
- Process biochemistry

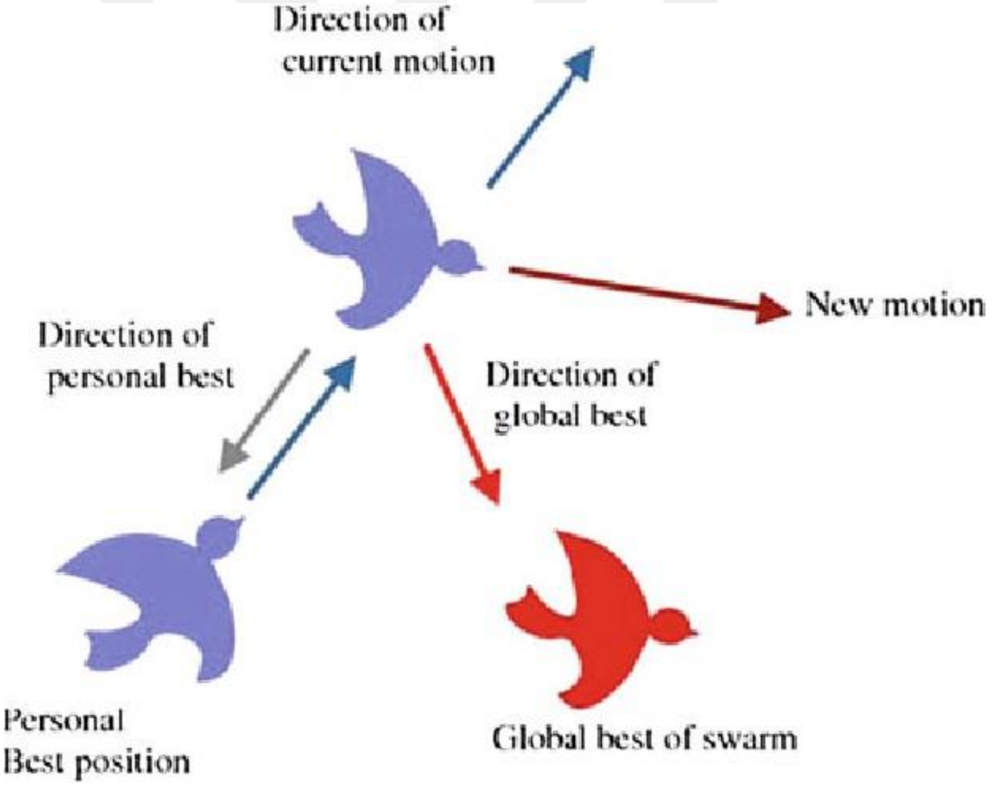


Figure 12. Scheme of Particle Swarm Optimization.

2.6 Objective

2.6.1 The Cost of Energy (COE)

It refers to the total amount of money that a consumer pays for the electricity they use. This cost is made up of several components, considering the expense of the electricity itself, the cost of transmission and distribution, and any taxes or fees associated with the electricity [54].

2.6.2 The Renewable Energy Fraction (REF)

is a measure of the proportion of a country's or region's energy that is generated from renewable sources [55]. This is determined by breaking the total energy produced by energies derived from sources that are renewable that involve the wind, solar energy, hydroelectric, and geothermal electricity, and bioenergy) by the total amount of energy generated from all sources (renewable and non-renewable) and expressing the result as a percentage [56].

3 METHODOLOGY AND MATERIALS

The current chapter discussed the connected studied in the field of integration of green Energy with the methods and Energy Management Strategy (EMS) [37]. Eventually, it closes with the analysis section considering Markov Decision Process (MDP).

3.1 Research methodology scheme

The main followed methodology is demonstrated in Figure 13 with five steps. Step one is denoted for collecting the climatology data, load profile data, and deep cycle battery data. Step two utilizing the mathematical models for the system components. Step three is considered for the EMSs. Step four sizing the components considering the nature-inspired metaheuristic algorithm. Step five presented the results and discussion of the thesis by presenting the obtained compared results of the EMSs and the sizing optimization results.

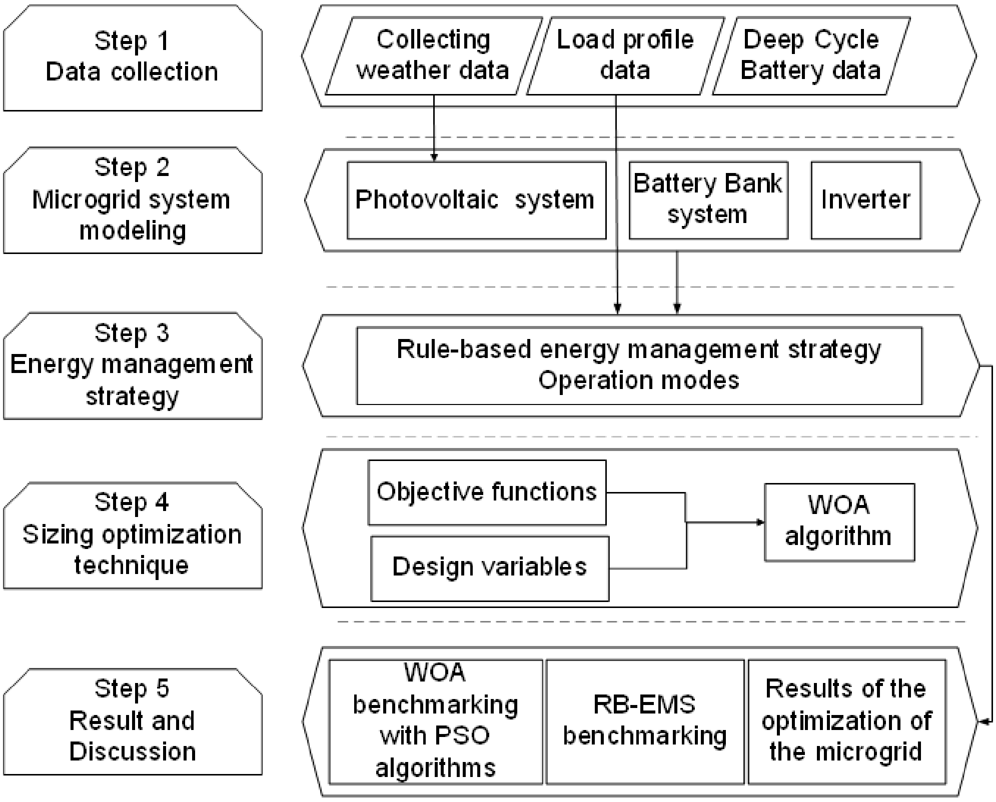


Figure 13. Research methodology flowchart.

3.2 Case study

Libya is a country located in the Mediterranean Sea with almost 2000 km costal region with six borders (Chad, Negar, Sudan, Tunisia, Algeria, and Egypt) as demonastrated in

Figure 14. The site of the study has been situated in the northern section of Libya (Tripoli) which observes four distinct climatic conditions as illustrated in Figure 15 [57].

Figure 14. Libyan map [58].

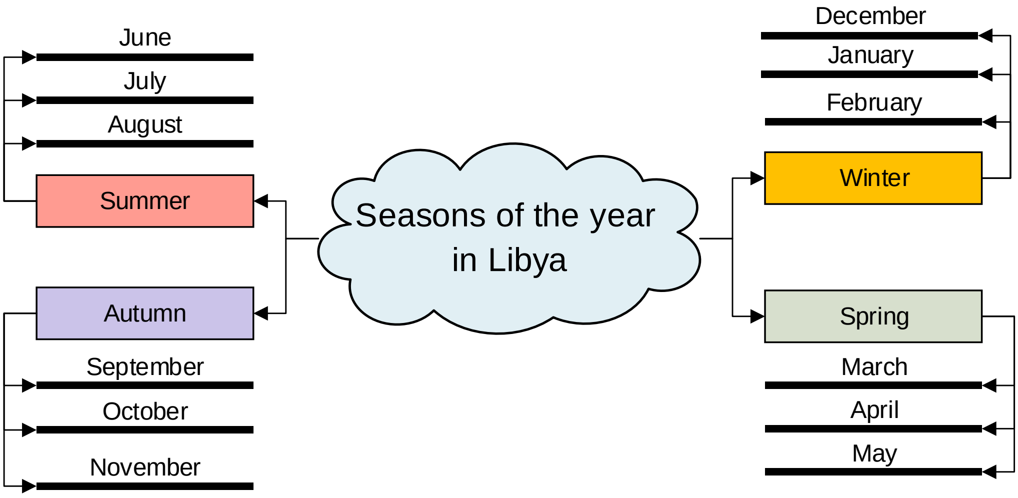


Figure 15 Seasons of the year in the case study.

Figure 16 displays the population of electrified individuals in the case study from 2017 to 2021. While the incremental changes of the load demand in GW is shown in in Figure 17 along with the prediction rises in TW in the period of 2018 – 2035 due to the increasing in the population is presented in Figure 18 [59].

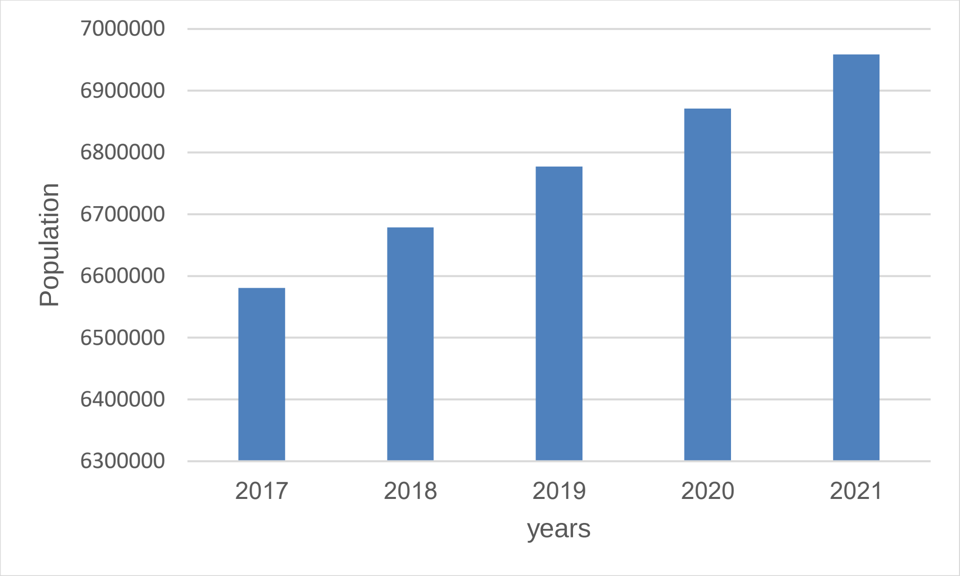


Figure 16. The case study Population [59].

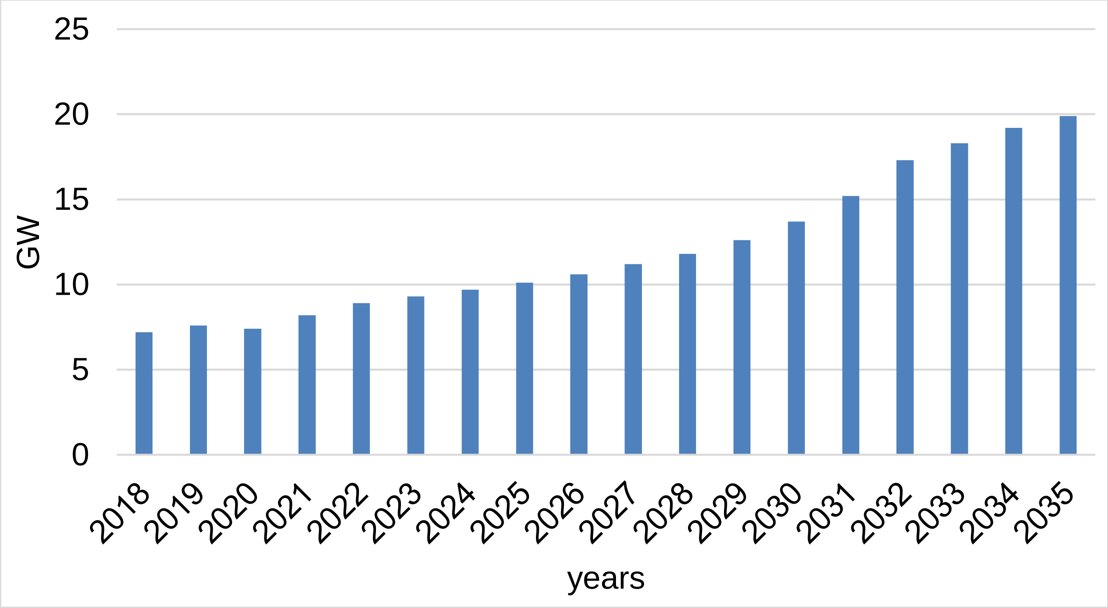


Figure 17. Increasing load (GW) [59].

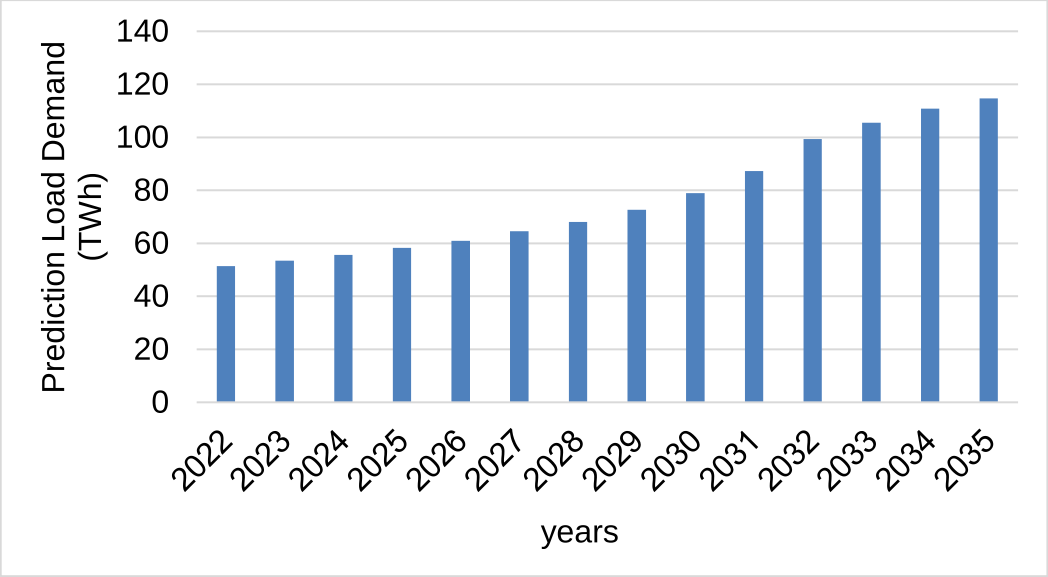


Figure 18. Prediction Load Demand (TWh) [59].

Based on the national strategy, in terms of investment in the same strategy proposed to produce 1750MW in the period of 2023-2025 that costs 1.809 Millar Dolar as that illustrated in Figure 19. Additionally, to the incremental load demand in the 2026-2030 with 850 MW with cost 1.23 M$. Besides the aforementioned planning strategy to achieve 1400MW in 2031-2035 with costs 1.914 M$. The Libyan electricity consumption data is presented in chart in Figure 20

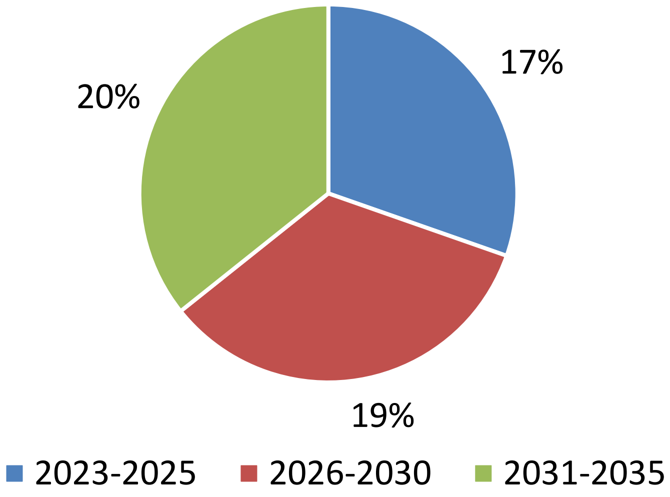


Figure 19. National strategy for energy generation from renewables [59].

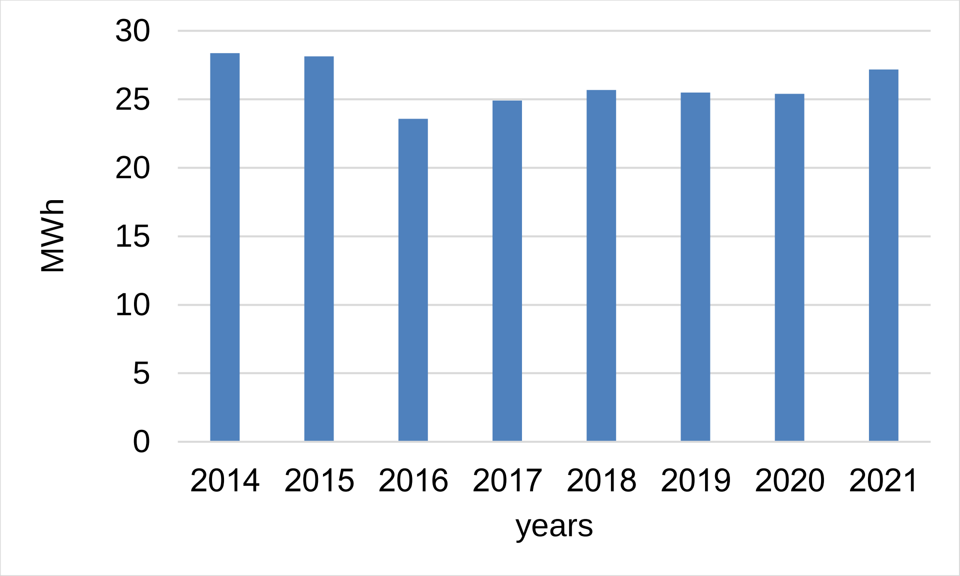


Figure 20. Libyan electricity consumption data chart [60].

The collected climatology data (ambient temperature, solar irradiance, wind speed, and sky clear irradiance) for the case study that have collected from the NASA is illustrated in Figures 21 to 23 [59].

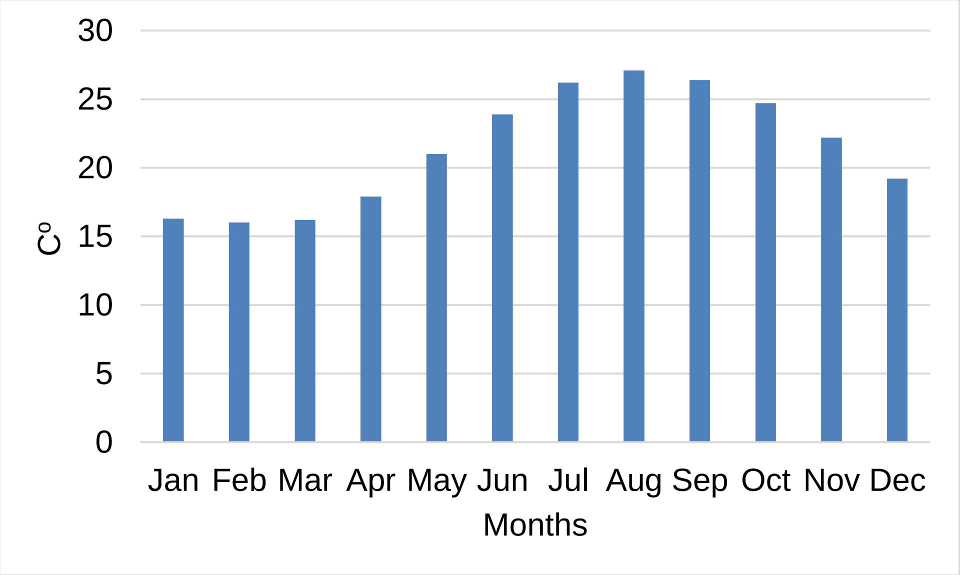


Figure 21. Ambient Temperatures data of the case study [61].

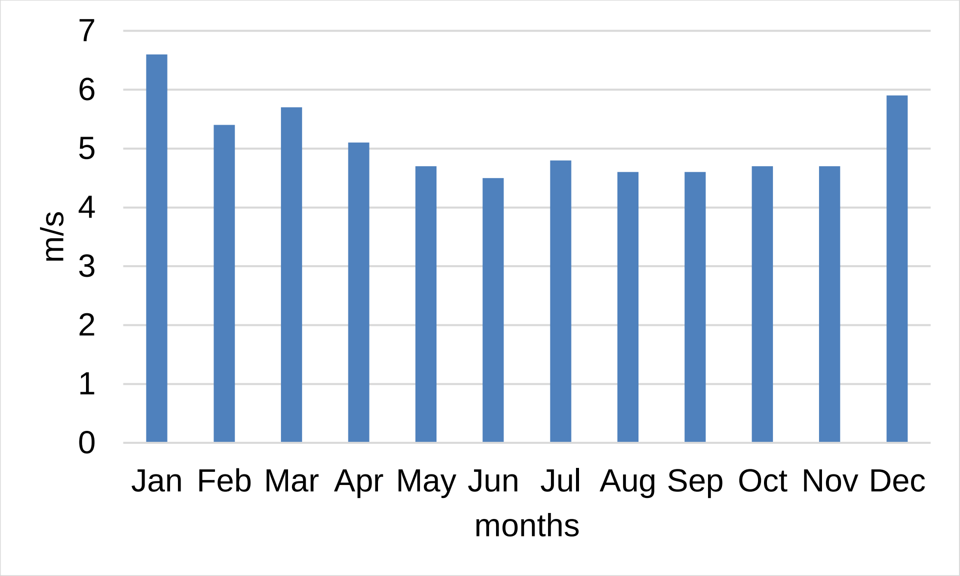


Figure 22. Wind speed data [61].

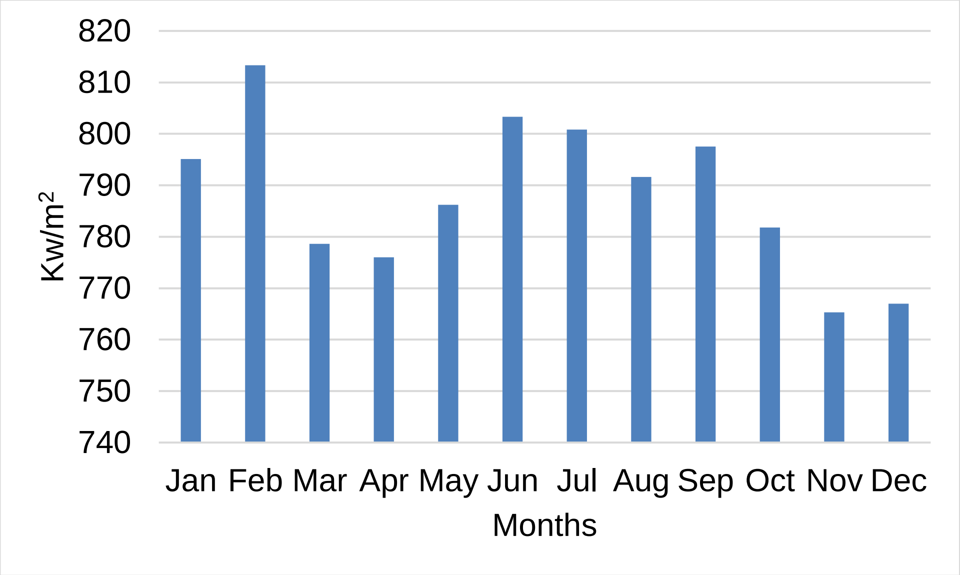


Figure 23. Clear Sky Solar Irradiance [61].

The Distribution of Development Financial Institutions' energy investments by region and sector in (%) in the period of 2013-2022 is demonstrated in Figure 24.

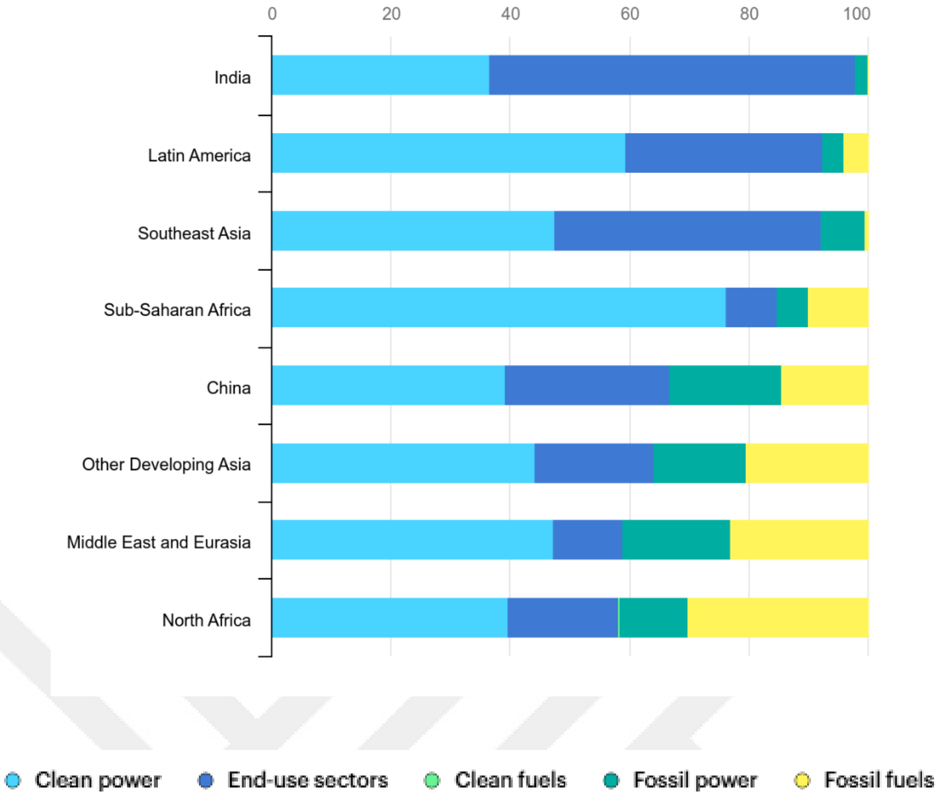


Figure 24. Distribution of Development Financial Institutions' energy investments by region and sector in (%) in the period of 2013-2022 [62].

3.3 Proposed microgrid system

The suggested system consists of PV, ESU, inverter, integrated into the main grid to run home appliances as presented in Figure 25.

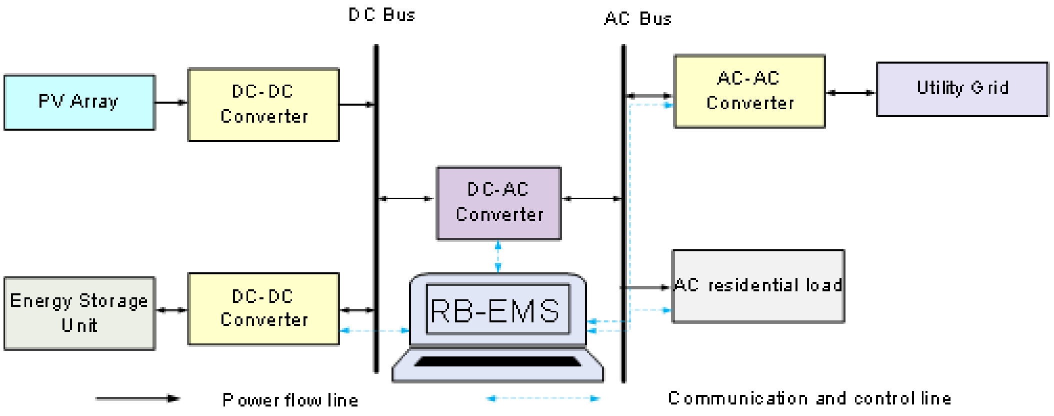


Figure 25. Proposed diagram

3.4 Optimization and strategies

The integrated Whale Optimization Algorithm and management of energy strategy for the aforementioned system is presented the various strategies in Figure 26.

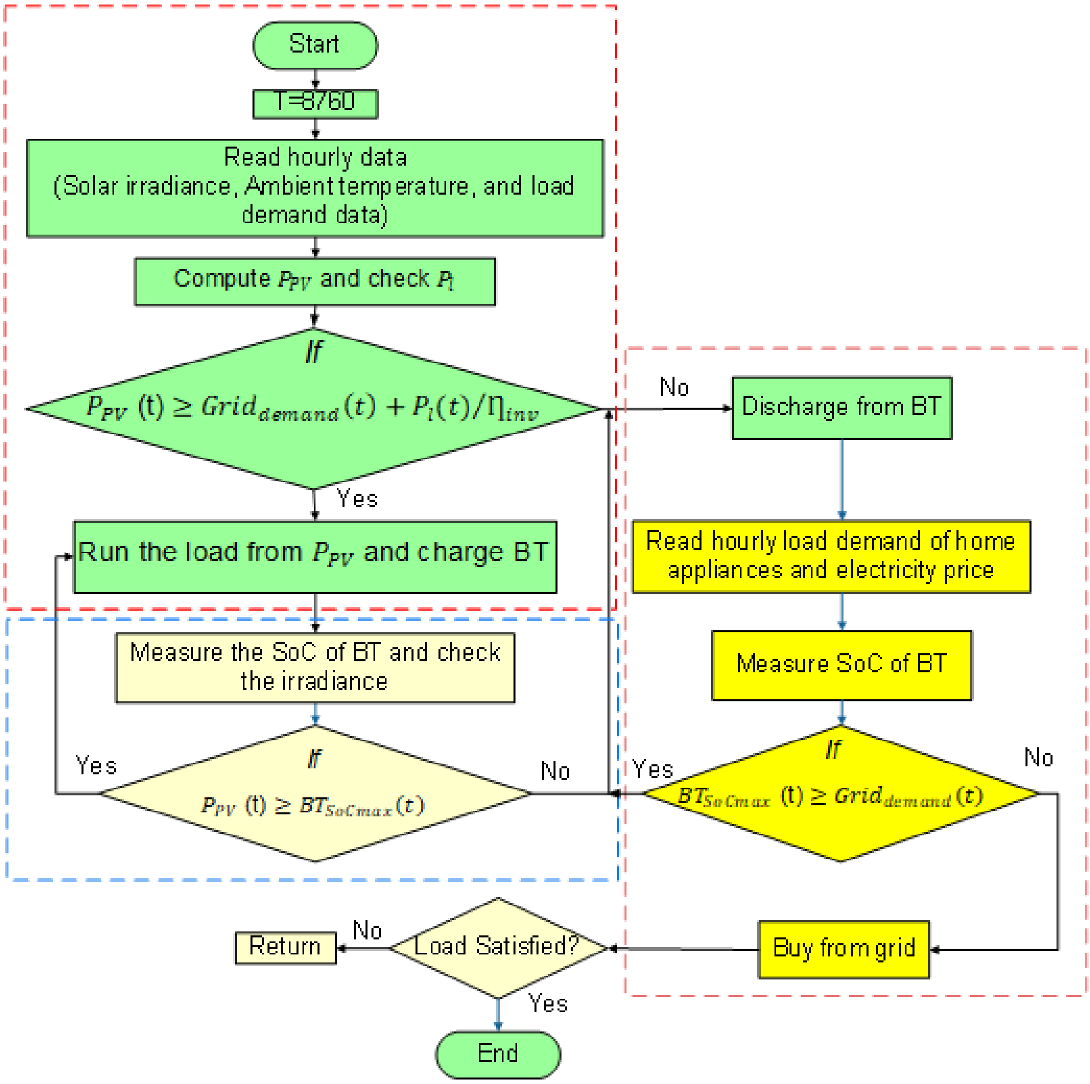


Figure 26. Energy Management Strategy plan.

3.5.1 The proposed nature-inspired algorithm

PSO and WOA are the implemented methods in the proposed system in order to size integrated components and benchmark the acquired results, respectively.

3.4.1.1 Whale Optimization Algorithm (WOA)

The WOA is familiarized by Mirjalili in 2015 in to address optimization algorithm difficulty and mimic the sociable behavior of whales like humpbacks is influenced by the bubble-net shooting technique [63]. Additionally, the operation mechanism is listed below along with their mathematical equations that started from Eq. (1) to Eq. (10) [64]. The WOA is implemented in various applications in different fields in the literature and proposed in the ongoing work to size the components in the considered system [65].

1. Inspiration

Whales are fancy creatures and it interesting things are intelligent and emotional animals. They are considered as the biggest mammals in the worlds and differing form each other as can be classified into 7 types such as killer, Minke, humpback, Sei, right, blue and finback. An adult whale has the ability to get bigger up to 180 t and 30m long. The interesting hunting behavior makes whale a special animal to be inspired in order to address virous form of problems as the foraging behavior illustrated in Figure 27 the bubble-net feeding method.

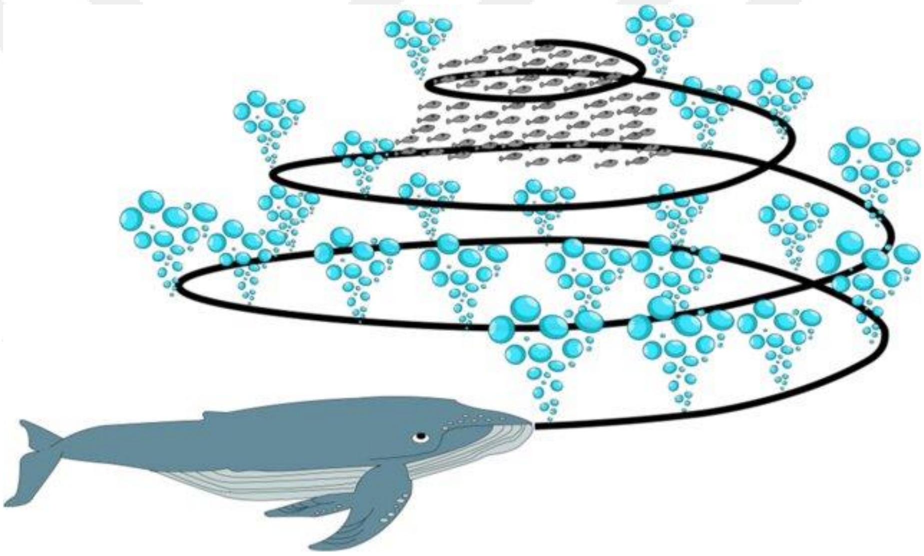


Figure 27. Bubble-net feeding behavior of humpback whales **[64]**

2. Encircling prey

Humpback whales demonstrate mental capacity to ascertain the location of preying and surrounding them. The aforementioned operation can be mathematically done in the subsequent equations Eq. (1) to Eq. (4).

$$\vec{D} = \left|\vec{C}.\overrightarrow{X} * (t) - \vec{X}(t)\right| \tag{1}$$

$$\vec{X}(t+1) = \vec{X}^{*}(t) - \vec{A}.\vec{D} \tag{2}$$

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a} \tag{3}$$

$$\vec{C} = 2.\vec{r} \tag{4}$$

where $\vec{X}$ denotes the orientation of the direction (vector), $\overrightarrow{D}$ is the behavior of the whale for determine the best candidate, the| |is the absolute value, $\vec{A}$ and $\vec{C}$ denotes the value of the coefficient values that can be computed in Equations (3) and (4) as previously stated. Besides, $\vec{X}$* represents the location vector of the optimal solution, $\vec{a}$ is decreased linearly from 2-0, $\vec{r}$ constitutes a stochastic vector [0,1], and t refers to the current iteration.

3. Bubble-net attacking method (exploitation phase)

The listed methods are implemented to apply bubble-net behavior.

- shrinking encircling mechanism

The shrinking encircling process is mathematically presented in Eq. (5)

- Spiral updating position

The spiral updating position is scientifically expressed in Eq. (5) with the help of Eq. (7).

$$\vec{X}(t+1) = \overrightarrow{D'}.e^{bl}.\cos(2\pi I) + \vec{X}*(t) \tag{5}$$

$$\vec{X}(t+1) = \begin{cases} \vec{X}*(t) - \vec{A}.\overrightarrow{D}\vec{X}*(t) - \vec{A}.\overrightarrow{D} & if\ p < 0.5 \\ \overrightarrow{D}.e^{bl}.\cos(2\pi I) + \vec{X}*(t) & if\ p \geq 0.5 \end{cases} \tag{6}$$

The value of $\overrightarrow{D} = \left|\vec{X}*(t) - \vec{X}(t)\right|$ It indicates the distance that exists of ith whale to the prey, p indicates randomness numeral [-1,1], the exponential of (e^{bl}) refers to the number l of [-1, 1], b is frequently present used to define the configuration of an exponential spiral shape. The main mechanism of the WOA is illustrated in the flowchart in Figure 28.

4. Exploration phase (Search for prey)

The random position ($\vec{X}_{rand}$) is mathematically expressed in Eq. (7) and Eq. (8).

$$\overrightarrow{D} = \left|\overrightarrow{\vec{C}.X}_{rand} - \vec{X}\right| \tag{7}$$

$$\vec{X}(t+1) = \overrightarrow{.X}_{rand} - \vec{A}.\overrightarrow{D} \tag{8}$$

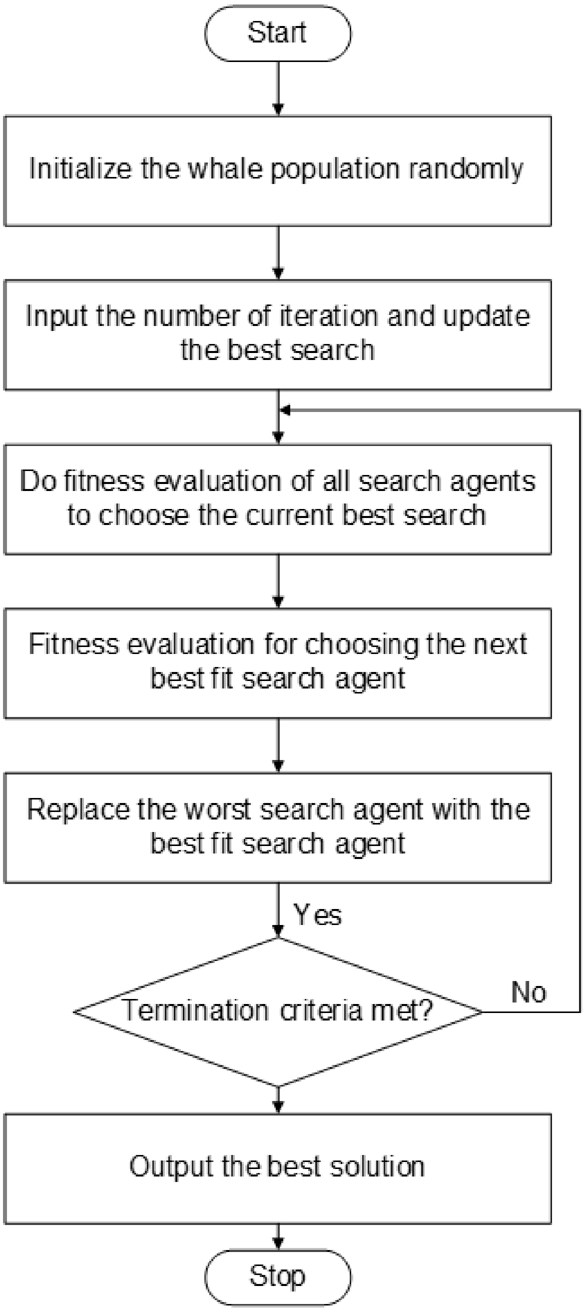


Figure 28. Flowchart of WOA [63].

3.4.1.2 Particle swarm optimization (PSO)

The PSO as a very well-known algorithm was initially introduced by the scientific researchers Kennedy and Eberhart in 1995 which has been implemented in different scientific fields [66]. described the procedure mechanism of the PSO algorithm which start at the initial step (x_t^i), and then proceed to the new position [53]. It simulates the social behaviors of animals, including fish schooling and bird swarming, as documented in the literature in Figure 29, and further shows the flowchart in Figure 30 [66 , 67]. The utilization of PSO is in a vast area of research such as network applications, size design, optimal shape, communication networks, and others as reported in the literature [49, 53].

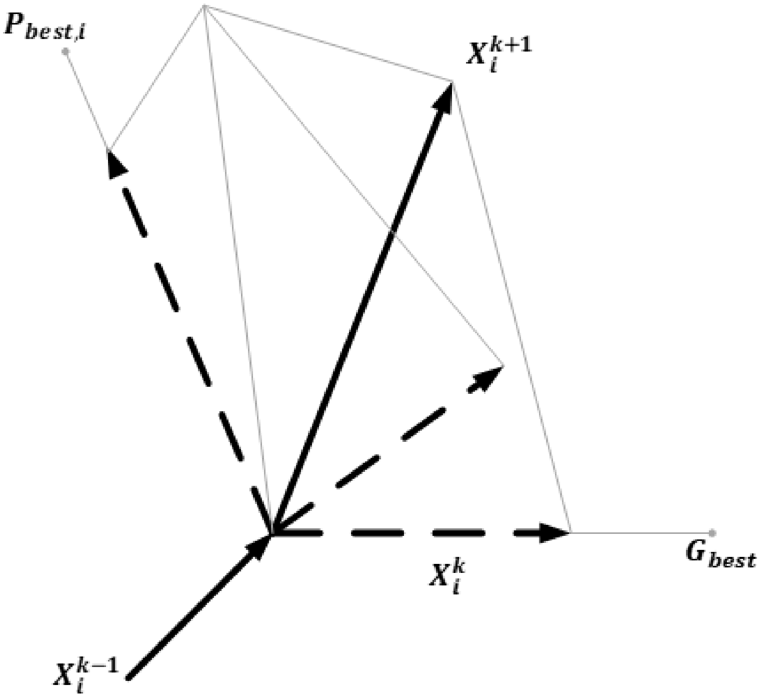


Figure 29. Particle Swarm Optimization algorithm mechanism [53].

PSO has been widely used due to its good quality solution that provided for local search strategy, not for global search strategy. The PSO algorithm mechanism is mathematically presented in Eq. (9) and Eq. (10). Table 16 is tabulating the movement process of PSO for its advantages and disadvantages.

$$x_{k+1}^i = x_k^i + v_{k+1}^i \tag{3.91}$$

$$v_{k+1}^i = wv_k^i + c_1 r_1 \{P_{besti} - x_k^i\} + c_2 r_2 \{G_{best} - x_k^i\} \tag{3.10}$$

Where x in Eq. (9) denotes the location of the particle and v is the particle velocity in the iteration k. Where Eq. (10) presents the w which is the inertia weight damping ratio, c_1 and c_2 are learning coefficient or acceleration factors for P_{besti} and G_{best} , respectively. While $r_1$and r_2 are random integers between 0-1.

The PSO is a stochastic-based algorithm based on swarms that study the animal's social behavior where swarms are made up of a group of individuals known as particles. Each generation made an iteration of procedures of many particles. Every update in the algorithm is recorded for the global optimal best (p_t^g) and current velocity (v_t^i) by replacing the current position to fulfill the ending condition. The positive and negative aspects of the PSO are introduced in Table 16.

Table 16 PSO advantages and disadvantages.

Advantages	Disadvantages
• Easy and simple programming. • Considering large references. • Strength to manage parameters. • Mathematical efficiency is achieved by the generation of excellent products with reduced computing time and consistent convergence. • Maintain fewer parameters for setup. • Decreased programming (computational) difficulty • Rapid convergence rate. • Free derived algorithms are applicable for resolving any category of optimization challenges.	• Comparatively worse performance in determining the global optimum concerning genetic algorithms. • Inappropriate for difficult issues with numerous variables. • Defining the first design criteria might be challenging. • It may converge quickly and get stuck at a local minimum, particularly in complicated issues.

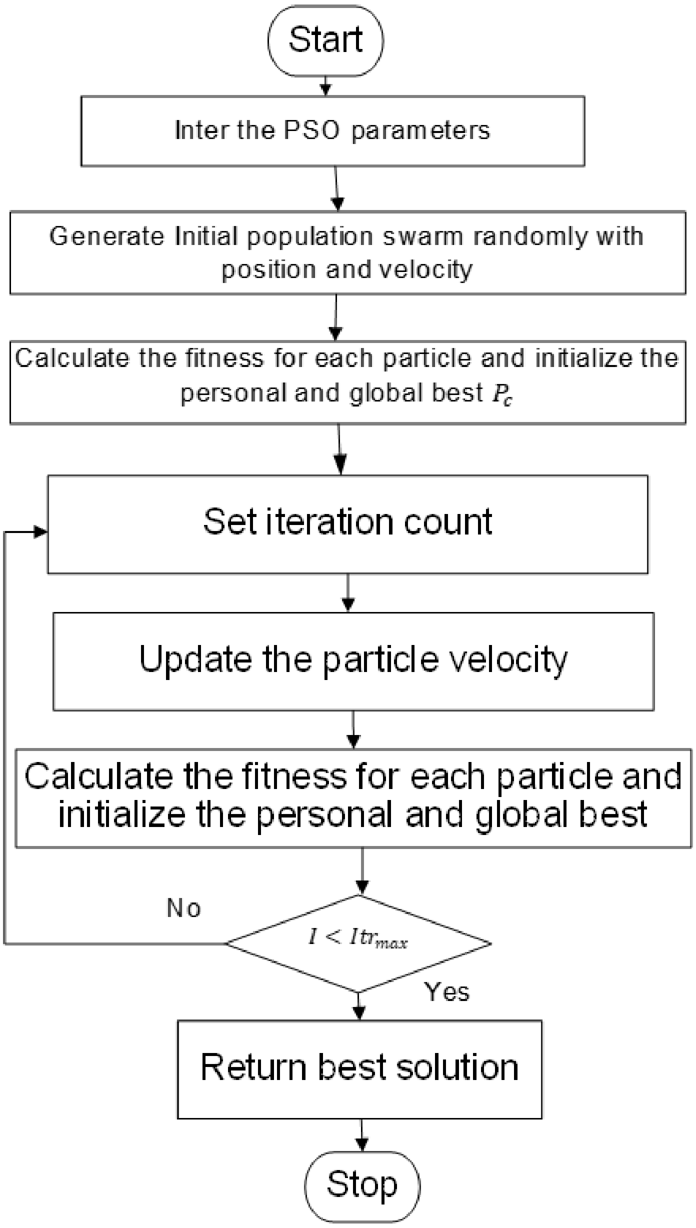


Figure 30. Flowchart of PSO **[67].**

The suggested methodology will encompass the subsequent essential steps:

1. Renewable Energy System Modeling:

Develop detailed models of various energy from sustainable sources, including solar power plants, turbines for wind power, and devices for storing energy, considering their unique characteristics and operational constraints.

2. Nature-Inspired Energy Management Strategy:

Investigate the application of nature-inspired methods, such as swarm intelligence and evolutionary algorithms, to design a decentralized and adaptive energy management strategy. This may include:

- Swarm-based optimization techniques for distributed energy resource allocation and load balancing.
- Evolutionary algorithms for the best configuration and location of alternative power sources and storage devices.
- Biomimicry-inspired approaches for self-organizing and self-healing energy networks.

Based on the above-mentioned methos, swarm based algorithms such as WOA and PSO have been implemented in this study.

3. Long-term Renewability Considerations:

Incorporate mechanisms to guarantee sustainability considering renewability of the energy system, such as:

- Optimizing the use of sustainable sources of energy to minimize depletion and ecological impact.
- Designing adaptive and resilient energy networks that can adapt to changes in resource availability and demand.
- Investigating the integration of energy storage devices with demand-side management methods to enhance reliability as well as the sustainability of the energy system.

4. Simulation and Prototype Development:

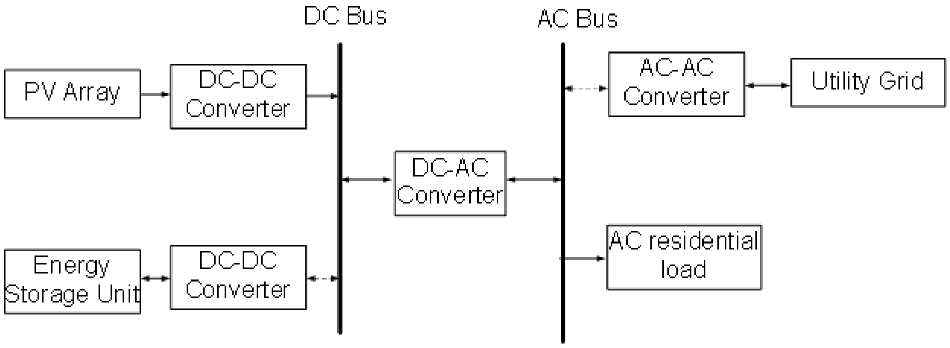
Develop a comprehensive simulation framework to assess the efficacy of the recommended management of energy plan under various scenarios, including different renewable energy mixes, load profiles, and grid conditions. Implement a prototype concerning the energy system of management to validate the proposed approach and assess its feasibility for real-world deployment.

5. Performance Evaluation:

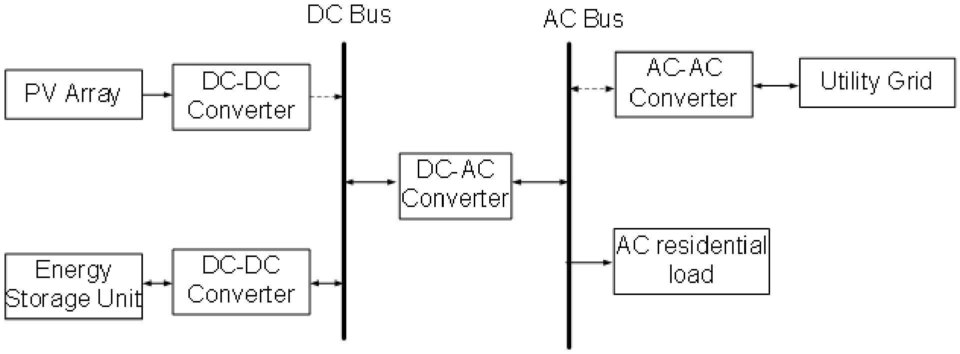
Evaluate the efficacy of the suggested energy management strategy with respect to energy productivity, grid stability, cost-effectiveness, and long-term renewability. Compare the results with conventional energy management approaches and benchmark the system's scalability and adaptability to different energy system configurations.

3.4.2 Proposed Energy Management Strategy

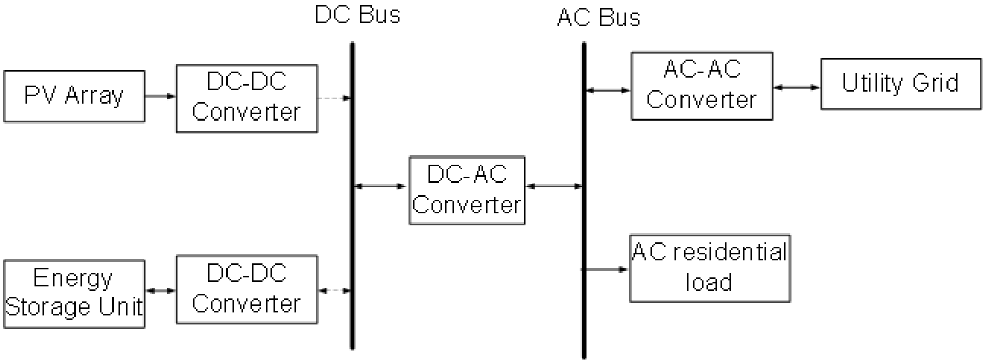
The primary classifications of EMS are Learning-Based (LB-EMS), Rule-Based (RB-EMS), and Optimization-Based (OB-EMS). The Rule-based (RB) systems typically have a small storage requirement because they are dependent on a predetermined framework of rules and conditions for making actions. These rules are usually stored in a small database or a simple data structure, rather than in a large neural network. Additionally, rule-based systems do not require the use of large amounts of data for training, which also helps to keep storage requirements low. The three proposed strategies are presented in Figure 31. Simontinously, the same startgyies have been futher elobrated in Table 17.



(a) PV to load



(b) BT to load



(c) Grid to load

Figure 31. Proposed energy management strategies.

Table 17 Supervisory control strategies.

Rule no	Mode types	IF	THEN
1	PV	$\left(P_{pv}(t)\right) > P_l(t)$	$P_{pv}(t)\ to\ P_l(t)$
2	BT	$P_{BT}(t) > P_l(t) - P_{PV}(t) * \eta_{inv}$	$P_{BT}(t)\ to\ P_l(t) - P_{PV}(t) * \eta_{inv}$
3	Grid	$E_{grid} > P_l(t) - P_{PV}(t) * \eta_{inv}$	$E_{grid}\ to\ P_l(t) - P_{PV}(t) * \eta_{inv}$

3.5 Mathematical models for system components

The formulas for math for the integrated elements are deeply discussed in next subsections [68]. All the mentioned parameters will be presented in Table 18 along with their values.

3.5.1 Photovoltaic (PV)

The most utilized RES in generating clean energy is PV that is easily convert the sunlight into electricity through the solar panels [69]. The estimated energy produced from the PV can be statistically stated in Eq. (11) with the help of Eq. (12).

$$P_{pv_{out}}(t) = P_{(PV_{rated})} \times \frac{G_{(t)}}{1000} * \left[1 + \alpha_t \left(T_{amb} + \left(\left(\frac{NOCT - 20}{800}\right) \times G_{(t)}\right)\right) - T_{C_{STC}}\right] \tag{11}$$

$$T_{C(STC)} = T_{amb} + G_{(t)} * 0.0256 \tag{12}$$

3.5.2 Battery (BT)

The back up storage system that could provide energy to the system as chemical device. The storage capacity of a battery can be computationally computed as represented by Eq. (13). To satisfy the need, it is essential to determine how well the battery is state-of-charge as given in Eq. (14). Most of the necessary information that needs to be known is the amount of charging capacity of the battery using Eq. (15). On the contrary, the quantity of energy discharged from the storage device can be mathematically stated by Eq. (16).

$$C_{BT} = \frac{E_L \times AD}{DOD \times \eta_{inv} \times \eta_{BT}} \tag{13}$$

$$SoC_{Min} = (20\%) \le SoC_t(\%) \le SoC_{Max} \text{ =(100\%)} \tag{14}$$

$$SoC(t) = SoC(t-1).(1-\sigma) + \left(\left(P_{pv}(t)\right) - \frac{P_l(t)}{\eta_{inv}}\right) * \eta_b \tag{15}$$

$$SoC(t) = SoC(t-1).(1-\sigma) + \left(\frac{P_l(t)}{\eta_{inv}} - (P_{pv}(t))\right) * \eta_b \tag{16}$$

- DC/AC Converter

The transferring operation from DC to AC can be done through the DV/AC as integrating different sources that could produce different energy forms which utilize Eq. (17) to calculate the inverter rate (P_{inv}) at time (t).

$$P_{inv}(t) = \frac{P_l^m(t)}{\eta_{inv}} \tag{17}$$

3.5.3 The utility grid

The utility grid as ultimate source. The purchasing and selling operation can be tracked by the two presented equations (18) and (19), respectively.

$$R_{grid} = \sum_{t=1}^{8760} rate_{feed-in} * E_{grid(selling)} \tag{18}$$

$$C_{grid} = C_p * \sum_{t=1}^{8760} E_{grid(purchased)} \tag{19}$$

Where R_{grid} trprwsents the revenue of the selling operatopn based on the utilty grid, the amount of purshasing cost of the bought energy can be denoted as (C_{grid}) , and C_p refers to the cost of buying 1 kW energy from the utiolity grid that equals to (0.04 $/kWh) in the case study [70].

Table 18 Data of integrated parameters with economic parameters.

Main components	Parameters	Value (units)
PV (Maleki et al., 2017)	PV panel reference efficiency	15.8 (%)
	PV system lifetime	20 (years)
	Temperature coefficient (α_t)	-3.7×10^{-3}(°C)
	Nominal operating cell temperature	45 ± 2 ()
	Lifetime	20 (Years)
	Solar panels output power	7.1(kWh)
	Rate Power at STC	325 (W)
BT (Aziz et al., 2020b)	Nominal voltage	12 (V)
	Nominal capacity	2.63 (kWh)
	Round trip efficiency	85 (%)
	Throughput	2285.1 (kWh)
	Capital cost	538 ($)
	Cost of replacement	500 ($)
	Operation and Maintenance (O&M) Cost	8 ($/Year)
	SoC Max	100 (%)
	SoC Min	20 (%)
Grid (Alsharif, Tan, et al., 2023)	Power price (sell)	0.05 ($MWh)
	Power price (purchase)	0.04 ($MWh)
Inverter (Alsharif, Tan, et al., 2023)	Lifetime	20 (YEARS)
	Efficiency (η_{inv})	92(%)
	Rate power	115(kW)
Economic parameters	Annual Interest rate (i)	3(%)
	Project life	25(years)

3.6 Research objectives

The proposed objectives within this investigation are considered to gain a cost-effect that refers to decremental of the COE system and increasing the renewability associated with mathematical models

3.6.1 Cost of Energy (COE)

Where the COE refers to the Cost of Energy (COE) and means the per capita of electricity [54]. Additionally, The Cost of Energy (CoE) is the overall expense involved in generating and supplying energy, usually shown as a cost per unit (like dollars per megawatt-hour, or $/MWh). This cost takes into account several factors, such as (The money invested in infrastructure and equipment, Ongoing operation and maintenance costs, Fuel expenses, Financing costs, Costs associated with meeting environmental regulations).

From an economic perspective, the Cost of Energy (COE) can be characterized on the per capita expense on the energy, functioning as an objective function [55]. Which is known as an infinite source that provides electricity to a system that applies to run electric appliances [14]. The COE can be computed by Eq. (20) [71]. To calculate the COE, the Cost of Energy (COE) is determined using the Discounted Cash Flow (DCF) analysis method, initially introduced by Irving Fisher [72]. Where DCF is employed to estimate or assess the value of capital investment funds [14]. The term DCF is a modern economic term and presents the summary that reflects the present value of money (cost) of the project lifetime. Where it is designed to calculate the payback period which means all capital costs (O&M, replacement cost, and present cost) during the lifetime of the system.

$$COE = \frac{(CRF * \sum_x NPC_x) + \ C_{grid-}\ R_{grid}}{E_{served} + E_{grid-selling}} \qquad (20)$$

The COE specified in Eq. (20) can be derived utilizing the Capital Recovery Factor (CRF), which is employed for estimating the present value of money, as articulated in Eq. (21) [70]. Furthermore, the Capital Recovery Factor (CRF) is a formula that calculates how much you need to pay each year to fully recover your initial investment in a project over a set period of time, considering a certain interest rate i. The Net Present Cost (NPC) expressed in dollars encompasses the expenses (operational and maintenance, replacement, and present costs) over x years [71]. Additionally, the NPC can be denifed as the total value of all costs related to a project over its lifetime, brought back to a specific point in time which includes (the initial investment costs and ongoing operational and maintenance expenses. The NPC is useful for comparing the economic efficiency of different projects or energy alternatives by accounting for the time value of money [14]. While the $E_{grid-selling}$ indicates to the selling energy, E_{served} is the principal load delivered (kWh/year) [14].

$$CRF = \frac{i(1 + i)^n}{(1 + i)^n - 1} \qquad (21)$$

where i indicates the actual interest rate, and n denotes the amortization term, or system lifespan, which corresponds to the duration of the solar panels' effectiveness (20 years) [73]. The NPC ($) is computed by Eq. (22), where the TAC refers to Total Annualized System Cost ($) [14]. Additionally, if the NPC>0 is the project accepted with a positive value. On the contrary, the NPC<0, the project is rejected due to the negative value.

$$NPC(\$) = \frac{TAC}{CRF} \tag{22}$$

Calculating the cost of each component in order to obtain the Annualized System Cost (ASC) as presented in the equations from Eq. (23)-Eq. (27).

$$C_{SOL} = C_{SOL}^{INST} + C_{SOL}^{REP-C} + C_{SOL}^{O\&M} \tag{23}$$

$$C_{BATT} = C_{BATT}^{INST} + C_{BT}^{REP-C} + C_{BATT}^{O\&M} \tag{24}$$

$$C_{INV} = C_{INV}^{INST} + C_{INV}^{REP-C} + C_{INV}^{O\&M} \tag{25}$$

where C_{INV}^{INST}, C_{SOL}^{INST}, C_{BT}^{INST}, and C_{WT}^{INST} are the installation cost of the inverter (per kW), solar panels (per kW), and battery (per unit), respectively. While the $C_{INV}^{O\&M}, C_{SOL}^{O\&M}$, and $C_{BT}^{O\&M}$ are the yearly operational maintenance and operating expenses of the inverter, solar panels, battery, and wind turbine, respectively. The C_{INV}^{REP-C}, C_{SOL}^{REP-C}, and C_{BT}^{REP-C} are the replacement cost of the inverter, solar panels, battery, and wind turbine, respectively [74].

$$ASC = F(N_{SOL}C_{SOL} + N_{BT}C_{BT} + P_{INV}C_{INV}) \tag{26}$$

where the C_{INV} is the expense associated with the inverter (per kW), C_{SOL} is the expense of solar panels (per kW), C_{BT} is the price of the energy storage battery (per unit), and the C_{WT} is the cost of a wind turbine (per kW), and the P_{INV} is the rating power of the inverter. F is the obtained value of CRF. Where the value of NPC of the grid as its replacement cost is Zero.

3.6.2 Renewability (REF)

The final aim function pertinent to this investigation is to optimize renewability through the utilization of the Renewable Energy Fraction (REF) approach [75]. The REF is quantified as the amount of energy delivered to the demand from alternative sources of energy that decreases the carbon dioxide (CO_2) emissions and net present cost (NPC), calculable by Equation (27) [76].

$$REF(\%) = \frac{\sum_{1}^{8760}(P_{PV}) * \Delta t}{\sum_{1}^{8760}(P_{PV} + P_{grid\_purchased}) * \Delta t} \tag{27}$$

where the $P_{grid\_purchased}$ is the amount of purchasing electricity from the grid for one year [14]. The three main presented objective functions have a trade-off. When the LPSP is minimized, the REF is maximized, and the overall system cost rises that increasing the COE. As a result, the designer has to compromise the three objective functions to achieve the optimal result.

3.7 System analysis using Markov decision process (MDP)

Markov Decision Processes (MDPs) constitute a calculated structure for simulating sequence making decisions for difficulties that characterized by unpredictability for microgrid integration systems with optimization algorithms and EMSs [18, 76]. In the context of microgrid integration systems, MDPs may be implemented to simulate the procedure for making decision of the microgrid operator, who needs to make decisions about energy generation, storage, distribution and delivery to satisfy the electricity need of the local community while optimizing various objectives such as cost, reliability, and environmental impact [78]. The main components of an MDP model for a microgrid integration system are included in Table 19.

Table 19 Key components of Markov Decision Processes [79].

Key components	Explanation
States	The states in the MDP represent the different configurations of the microgrid, such as the levels of energy generation, storage, and demand, as well as the grid connection status and other relevant factors.
Actions	The actions in the MDP identify decisions available to the microgrid operator, including modifying the outcome of distributed energy resources, managing the charging and releasing of stored energy systems and the regulation of the exchange regarding the energy the exchange across the microgrid and the main grid.

Transition Probabilities	The transition probabilities in the MDP model the uncertainty in the system, such as the variability in renewables, fluctuations in energy demand, and the reliability of grid connections.
Rewards	The rewards in the MDP represent the objectives the microgrid operator wants to optimize, such as minimizing energy costs, maximizing reliability, or reducing carbon emissions.

The aforementioned key components that are tabulated in Table 19. To find solutions to the MDP and establish the appropriate EMS, researchers and practitioners often use various optimization algorithms, such as dynamic programming, reinforcement learning, or evolutionary algorithms [79]. These algorithms aim to find the policy (i.e., the sequence of actions) that maximizes the expected long-term reward, considering the uncertain and dynamic nature of the microgrid system [79]..

The energy management strategy derived from the MDP model can then be used to control and optimize the operation of the microgrid, including decisions such as [80]:

- When and how much renewable energy to generate
- When and how much energy to store or discharge from energy storage systems
- When and how much energy to buy from or sell to the main grid
- How to coordinate the various distributed energy resources and loads in the microgrid

By using MDPs and optimization algorithms, microgrid operators can develop robust and efficient energy management strategies which are flexible to evolving circumstances and uncertainties, while meeting the needs of energy in the local community in a cost-effective and sustainable manner.

4. RESULTS AND DISCUSSION

4.1 Introduction

The previous chapter presented the following research methodology in this research along with the objectives and sizing method with the utilized supervisory control method. This chapter illustrates the output obtained result from the utilized software for the integrated components. The findings were acquired using MATLAB R2021a and Microsoft Excel, operated on an Intel (R) Core (TM) i5-8250U CPU @ 1.60 GHz. The research is expected to deliver the following key outcomes:

1. An energy management strategy that effectively integrates renewable energy sources while considering long-term renewability, using nature-inspired methods.
2. A simulation framework and prototype implementation to validate the proposed approach and assess its feasibility for real-world deployment.
3. Examination of the efficacy, scalability, and economic capability of the suggested power management technique in relation to traditional methods.
4. Guidelines and recommendations for the practical implementation of nature-inspired and energy management strategies in real-world energy systems.

4.2 Results and Discussion

This section is denoted for discussing and presenting the obtained results from the proposed microgrid photovoltaic system utilized to meet home energy requirements load demand for the houses in the case study. Three primary methodologies were analyzed to evaluate the effectiveness of the system (presented in Chapter 3) in terms of economic and renewable. Additionally, the WOA method for sizing the quantity of components included is taken into account along with the proposed objective function. Furthermore, a sensitivity study has been accomplished on several critical boundaries inside the interrelated framework by employing the Markov Decision Process (MDP), because of its capabilities to address uncertainty.

The main comparison of output power of (Load demand, Battery output, Grid purchase, and Output power from Solar panels) are combined and illustrated for the first 160 hours of the year in grouped plot that presented in Figure 32. In terms of seasonal results, the end of winter as demonstrated in Figure 32 with almost 5.8 kWh from solar panels which is satisfied the load demand as proposed strategies. It is clear that from the presented periods, the discharge energy from BT, the purchased energy from the general grid, and load demand.

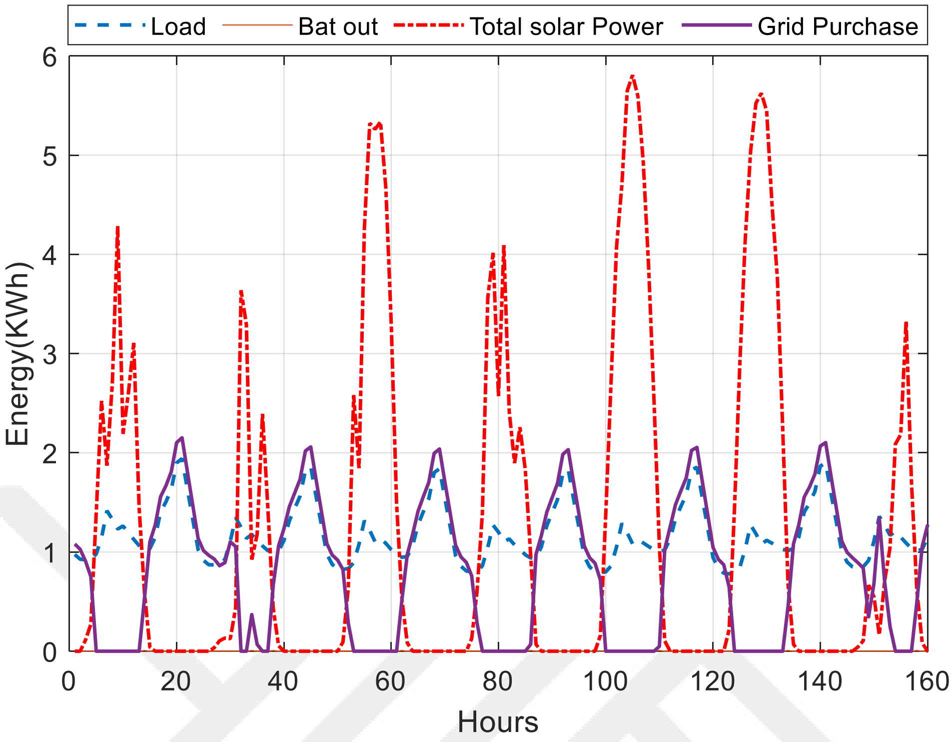


Figure 32. Compered performance of integrated sources.

As shown in Figure 32, x-axis represents to time (hours) while y-axis represents the output power (kWh), most of the time the value of output power generated from the PV is hugher than the load demand during the 160 hours.

As the main integrated sources, it has been considered to be presented separately and show behavior along the year with the different climatology action in the total radiation as well as temperature in Figure 33. According to the suggested objectives, the total amount of generated energy from energy generated from renewable sources exceeds 4 kW. This graph depicts the output power from a photovoltaic (PV) system, measured in kilowatts (kW), over time in hours. The output power fluctuates between 0.5 kW and 4 kW, with peaks and troughs indicating variations in energy production. The x-axis represents the houres of one year.

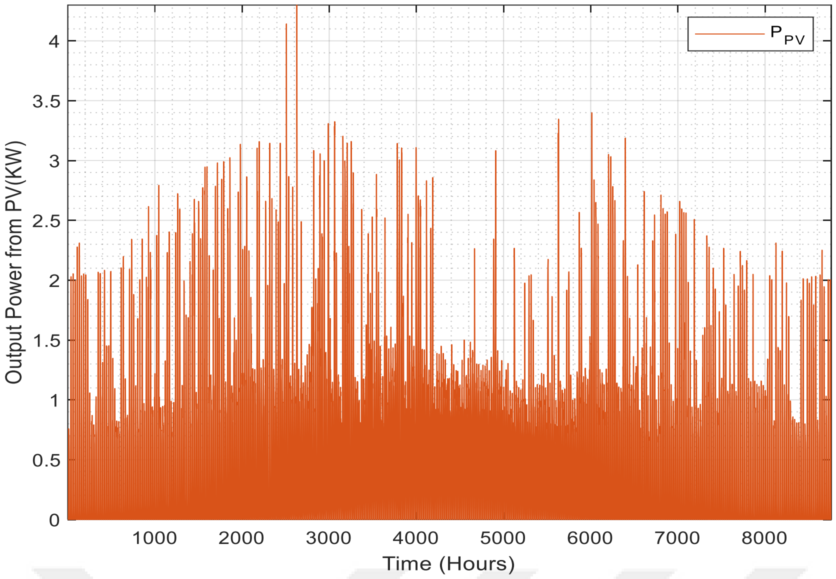


Figure 33. Photovoltaic Output.

The three proposed strategies (PV-to-load, BT-to-Load, and Grid-to-load) are met throughout the year. The next subsection is to consider the aforementioned strategies along with their own separated output.

4.2.1 Strategy one

In the initial technique illustrated in Figure 34, the photovoltaic power produced is adequate to satisfy the demand. This graph illustrates the relationship between energy (measured in K/W) and time (measured in hours). The energy values increase steadily over time, showing a consistent upward trend. The x-axis represents time in hours, while the y-axis represents energy in K/W. The graph suggests a linear or near-linear increase in energy consumption or production over the given time period. This could be useful for analyzing energy usage patterns or performance over time.

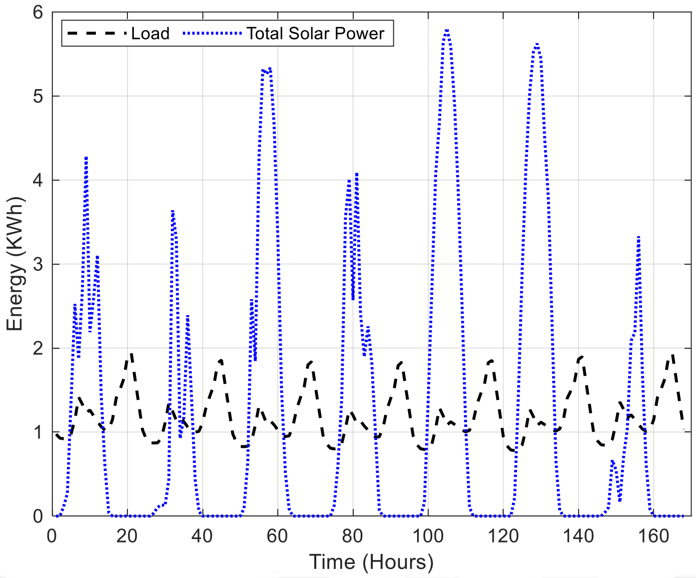


Figure 34. Strategy one (PV to load).

4.2.2 Strategy two

As shown in Figure 35, the battery is regarded as an energy store where the amount of energy in the battery is more than the other integrated sources to meet the demand, the battery in (Bat in) and battery out (Bat out) are shown in Figure 35 and forming the aforementioned operation. The spacing time between the charging and discharging time that equals to (0 kWh) is feeding the end-user from other sources. Where the positive side refers to the electrical charging format, while in the other side presents the discharging mode. While the SoC of the battery as the (SoC_{Max}=100%) maximum and minimum ($SoC_{Min} = 20\%$) are presented in Figure 36.

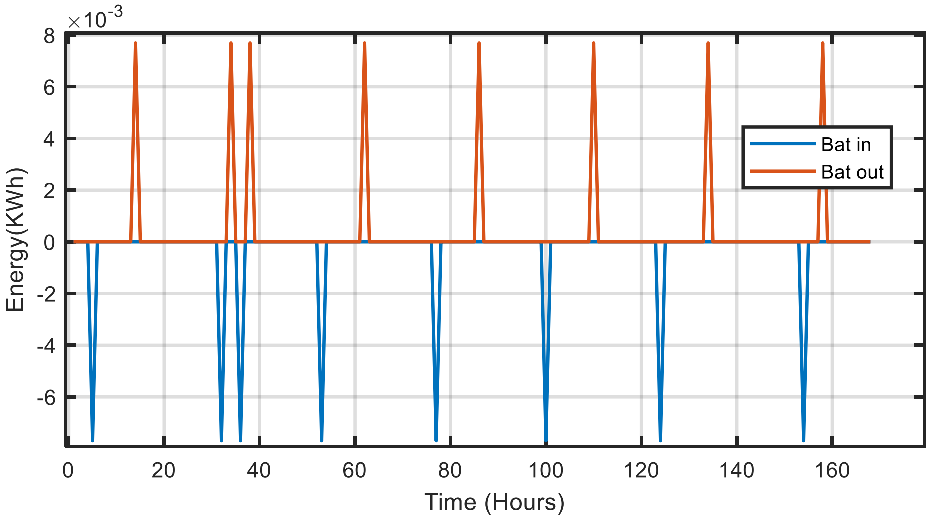


Figure 35. Strategy two (BT to load)

The "Bat in" and "Bat out" labels suggest a comparison between energy entering and exiting from the batteries, which is useful for analyzing efficiency and performance. The graph provides a visual representation of how energy is managed and transferred from batteries over time.

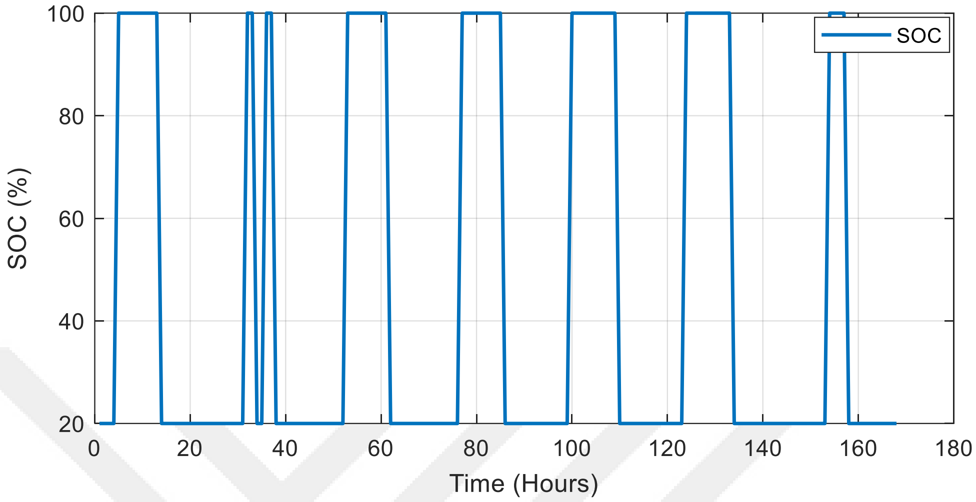


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Figure 36. State-of-Charge (SoC) of deep cycle battery.

This graph represents the State-of-Charge (SoC) of a deep cycle battery over time, measured in hours. The SoC indicates the remaining charge level in the battery, expressed as a percentage. The graph shows how the battery's charge level fluctuates over time, reflecting periods of charging and discharging. This type of data is crucial for understanding the battery's performance, capacity, and efficiency, especially in renewable energy systems.The graph helps in monitoring the battery's health and optimizing its usage.

4.2.3 Strategy three

The general utility grid that utilizes fossil fuels to produce electricity is always the available source, unless in the cases of interruption which refers to instability or need to transfer to the green energy instead. As shown in Figure 37, the system that was established satisfies strategy three. The two dots that are displayed, black and blue, stand for the power that is taken in and taken out from the distribution system for utilities, correspondingly. The first 160 hours show the two operations to selling and buying operation, while the peak of imported energy is (-4 kWh).

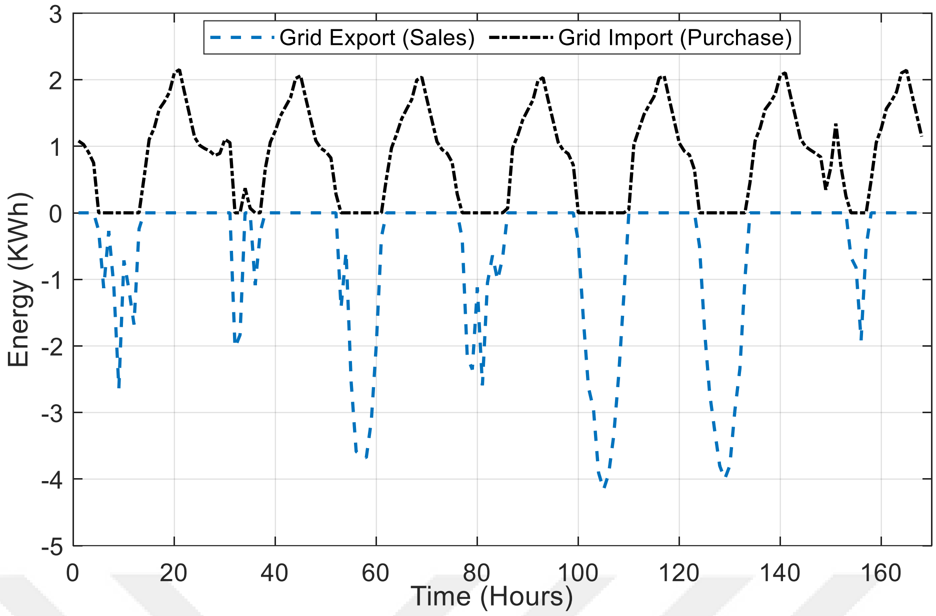

Figure 37. Strategy three (Grid to load).

This graph illustrates the interaction between grid export (sales) and grid import (purchase) over time, as part of Strategy Three (Grid to Load). The graph shows the balance between energy sold back to the grid and energy purchased from the grid, highlighting the dynamics of energy exchange. This strategy is used in energy management systems to optimize energy usage and costs by balancing consumption and production. The graph provides insights into how effectively the system manages energy flow, which is crucial for optimizing grid interactions and reducing energy expenses. The comparative performance outcome of the suggested nature-inspired metaheuristic methods and EMS is presented in Table 20. The list of numbers serves to demonstrate the comparison of COE (0.0836 $/kWh), REF (50%), N-PV (95 units), AD (3 days), and battery capacity. The output performance of the utilized algorithms is presented in Figure 38. The WOA demonstrates superior performance compared to PSO regarding cost efficiency ($/MWh for electricity). The renewavle energy fraction for the first 24 hours is demonastrated in Figure 39. Futhermore, due to the climatology changes in the country, the solar irridance has effected on the outcomes of the renewability. Due to the aforemenioned statemnet, the presented bars in Figure 39 has been acquired. The residincal load (electrical appliances) draws half of its power from the integrated renewable sources.

Table 20 The comparison of results from the proposed algorithms.

	COE ($/kWh)	REF (%)	NPV (units)	AD (Days)	Battery Capacity (kWh)
RB-EMS-WOA	0.0836	50	95	3	45.2
RB-EMS-PSO	0.0962	40	100	2	45.2

This graph shows the convergence of two optimization algorithms, WOA (Whale Optimization Algorithm) and PSO (Particle Swarm Optimization), in terms of Cost of Energy (COE) measured in 8VF (a specific unit or metric). The x-axis represents the number of iterations, ranging from 100 to 1000, while the y-axis shows the COE values, which decrease over iterations. Both algorithms aim to minimize the COE, with WOA and PSO showing different convergence rates and final COE values. This graph is useful for comparing the performance and efficiency of these optimization techniques in reducing energy costs over iterative processes.

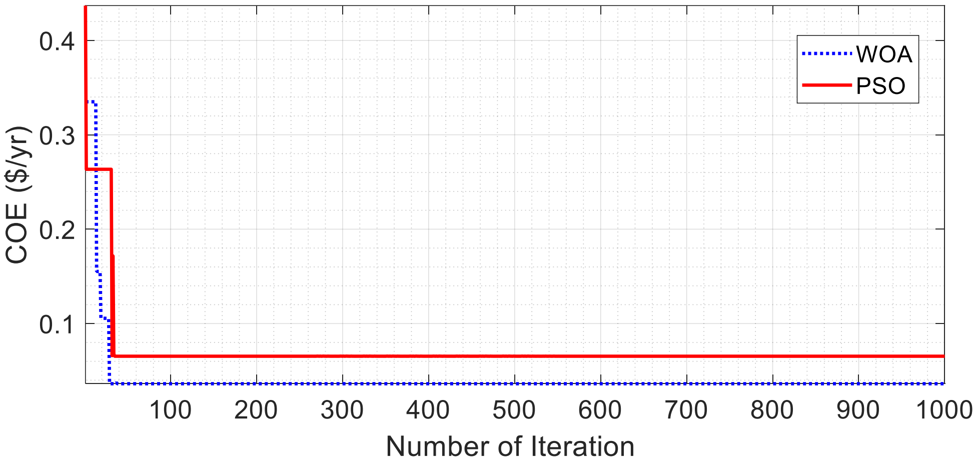

Figure 38 Convergence.

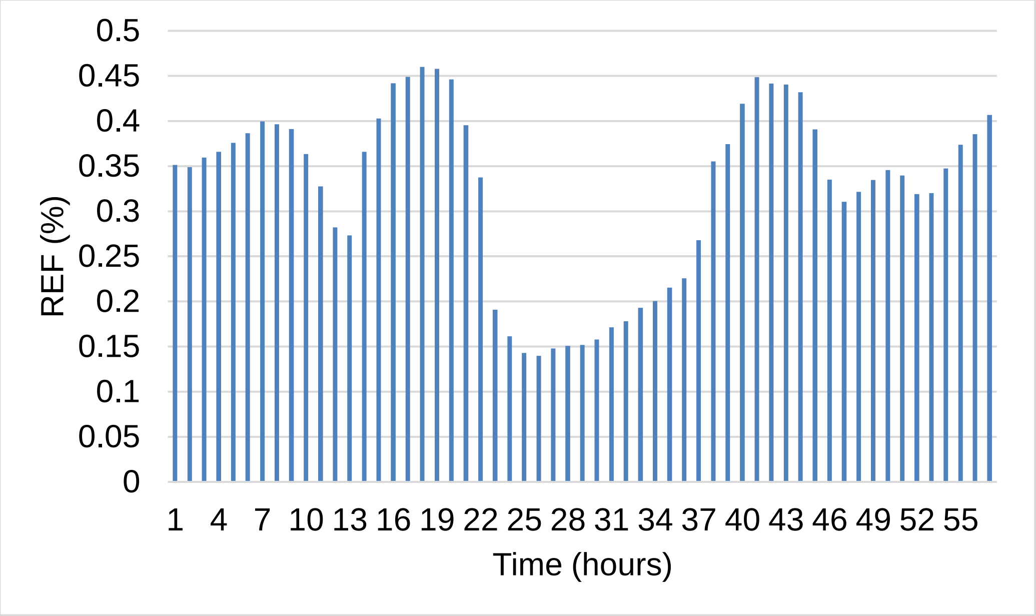

Figure 39. Renewable Energy Fraction

4.3 Sensitivity analysis

The Markov decision process is an analytical tool employed to address uncertainties, such as the amount of power generated from energy produced from renewable sources like photovoltaic systems. Figure 40 presents bar charts utilized for the analysis of the maximum and mean values of photovoltaic electricity produced.

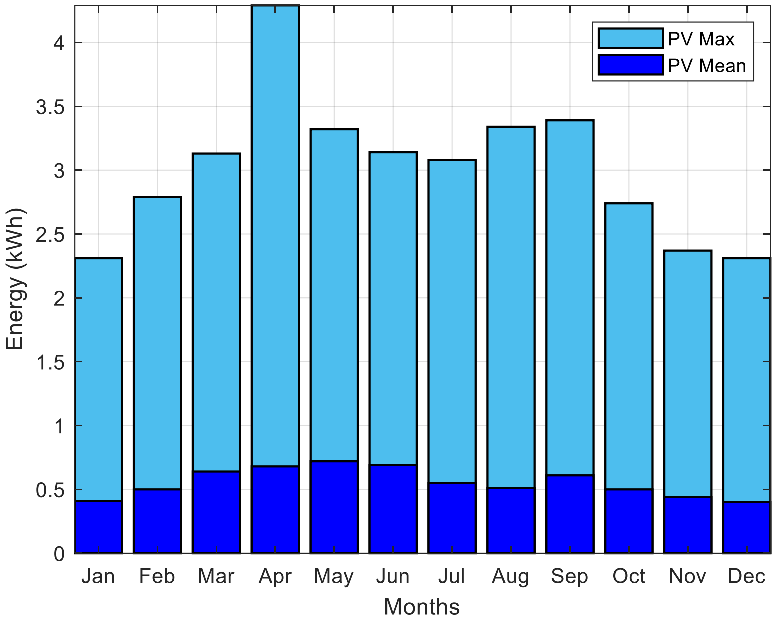

Figure 40. Output Power Max and mean.

An extensive evaluation of the energy produced from the interconnected sources with one another is provided in Figure 41. Additionally, the behaviour of the utility grid for selling and buying is shown in Figure 42.

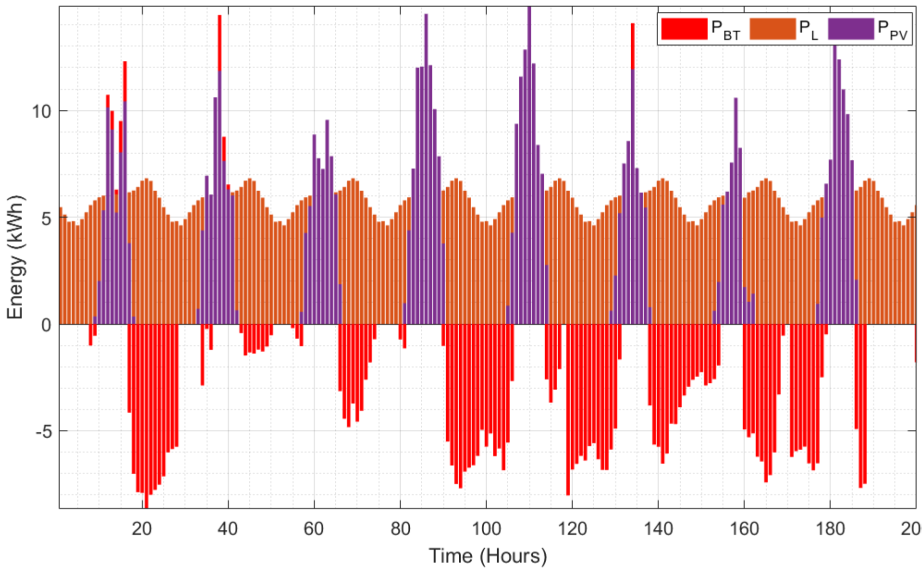

Figure 41. Analysis of outpower from.

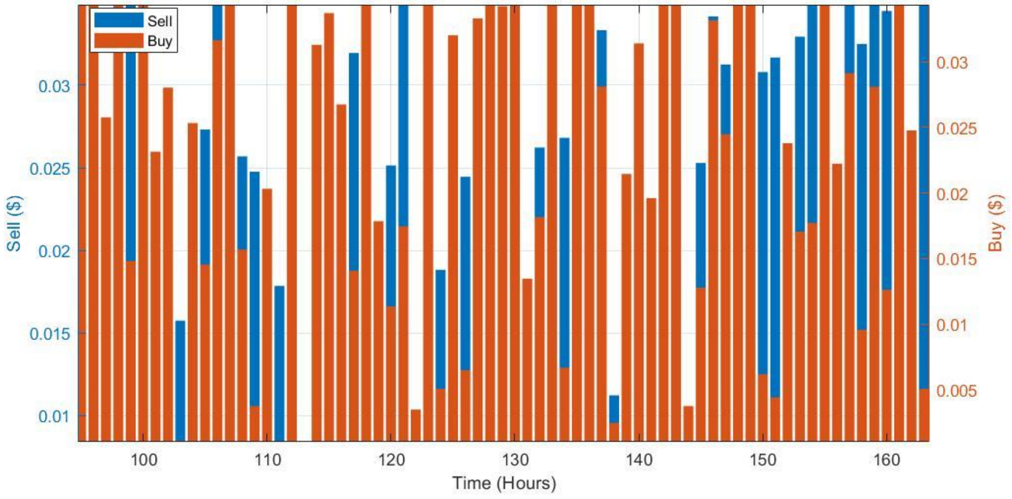

Figure 42. The sell and buy energy from the utility grid.

5. CONCLUSION AND RECOMMENDATIONS

This thesis presents an innovative approach to energy management that leverages nature-inspired methods to boost the integration of renewable energy systems while considering long-term renewability. The most essential aim of this thesis is to enhance the switch operation to a more environmental and robust energy future by tackling the challenges of integrating energy from renewable sources and formulating a robust and adaptable energy management strategy.

5.1 Conclusion

This study prsented the conducted studies and highlights the evolving research on energy management strategies and nature-inspired methods for integrating renewable energy systems while considering long-term renewability. The studies discussed demonstrate the potential of decentralized, adaptive, and self-organizing approaches to overcome the challenges of alternative energy integration and ensure the sustainability of the energy framework. Nevertheless, Further investigation is required for development of comprehensive, scalable, and practical solutions that can be accomplished in practical applications energy systems. Finally, the obtained results of the energy have been presented and analyzed by the Markov Decision Processes due to their intermittences.

5.2 Recommendations

To extend an effective energy management strategy for the integration of renewable energy sources, it's critical to look into the application of algorithms and optimization techniques inspired by nature. Here are a few particular suggestions:

1. Investigate the application of swarm intelligence algorithms like Particle Swarm Optimization (PSO) or Whale Optimization Algorithm (WOA), to optimally size and schedule the various components of the renewable energy system to optimize the use of energy from renewable sources and reduce total expenses.
2. Explore the use of evolutionary algorithms, like Genetic Algorithms (GA), to optimize the design and control parameters to enhance the effectiveness and dependability of the system of renewable energy sources under multiple environmental circumstances.
3. Incorporate biologically inspired concepts, such as self-organization, adaptation, and distributed decision-making, into the energy management strategy to enhance the

system's resilience and ability to react to variations in both energy supply and demand.

4. Develop a multi-objective optimization framework that considers not only economic factors, but also environmental and social impacts, to ensure a more holistic and sustainable approach to renewable energy integration.
5. Examine the incorporation of techniques used in machine learning, which includes artificial neural networks or reinforcement teaching, to allow the energy management system to learn from historical data and adaptively optimize its operations over time.

5.3 Future work

The following recommendations and future work for Nature-Inspired Methods for Integrating Renewable Energy Systems Considering Renewability and an Energy Management Strategy are discussed and recommended:

1. Using simulation models or experimental testbeds, implement and validate the suggested nature-inspired energy management solutions to evaluate their scalability and performance.
2. Examine the several energy sources derived from renewables and the associated storage methods affect the efficacy of nature-inspired techniques and investigate strategies for maximizing their integration.
3. Examine how demand-side management functions and how energy-efficient technologies like building automation and smart appliances are included into the overall energy management plan.
4. To attain greater degrees of renewable energy penetration and system-wide optimization, create a thorough framework for coordinating the energy management of several renewable energy systems (for example, at the community or regional level).
5. Examine how nature-inspired techniques and other cutting-edge technologies, such edge computing or blockchain, might work simultaneously to improve the autonomous and decentralized management of sustainable energy systems.
6. Implementing different stochastic techniques to analyze the obtained results rather than Markov Decision Processes.

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APPENDIX 1. THESIS PREPARATION CHECKLIST

Before the theses are finalized, reproduced, and delivered to the Directorate of the Institution, the checks in the list below are made. The Thesis Proposal Preparation Checklist is prepared according to the example below, signed by the author of the thesis, and submitted to the Directorate of the Institution during the thesis submission. This list is for control purposes only and is not included in the thesis at the copying stage.

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- The approval page was prepared and signed following the thesis writing guide.
- The front pages until the introduction page are numbered with “Roman numerals” as iii, iv, v.
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- Acknowledgments did not exceed one page.
- Both abstract texts did not exceed one page.
- Font, font size, and line spacing were made under the thesis writing guide.
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- Ethics committee approval (if necessary) was added to the thesis.
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- Visual images were used by paying attention to ethical rules.
- Appendices were given as specified in the guide.
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APPENDIX 2. MATLAB CODE

The MATLAB is a powerful programming environment widely used for mathematical modeling, simulation, and algorithm development. It is particularly effective in implementing nature-inspired optimization techniques, such as Whale Optimization Algorithm (WOA) and Particle Swarm Optimization (PSO). These algorithms are often coupled with rule-based energy management strategies to address objectives like renewable energy cost reduction and enhancing energy sustainability.

```
clear all; close all; clc
% Whale Optimization Algorithm (WOA) in MATLAB
% Define the objective function
objectiveFunction = @(x) sum(x.^2); % Example: Sphere
function

% Parameters
numWhales = 30; % Number of whales
maxIterations = 1000; % Maximum number of iterations
dim = 5; % Number of dimensions
lb = -10; % Lower bound
ub = 10; % Upper bound

% Initialize the whales' positions
positions = lb + (ub - lb) * rand(numWhales, dim);

% Initialize the leader (best solution)
leaderPosition = positions(1, :);
leaderScore = objectiveFunction(leaderPosition);

% Main loop
for t = 1:maxIterations
    for i = 1:numWhales
        % Update the position of each whale
        a = 2 - t * (2 / maxIterations); % Decrease
linearly from 2 to 0
        r = rand(); % Random number in [0,1]
        A = 2 * a * r - a; % Compute A
        C = 2 * r; % Compute C

        if rand() < 0.5
            % Shrinking encircling mechanism
```

```
            D = abs(C * leaderPosition - positions(i,
:));
            positions(i, :) = leaderPosition - A * D;
        else
            % Spiral updating position
            b = 1; % Constant
            l = -1 + 2 * rand(); % Random number in [-
1,1]
            D = abs(leaderPosition - positions(i, :));
            positions(i, :) = D * exp(b * l) .* cos(2 *
pi * l) + leaderPosition;
        end

        % Boundary check
        positions(i, :) = max(min(positions(i, :), ub),
lb);

        % Evaluate the new position
        score = objectiveFunction(positions(i, :));

        % Update the leader if a better solution is
found
        if score < leaderScore
            leaderPosition = positions(i, :);
            leaderScore = score;
        end
    end

    % Display the iteration and the best score
    disp(['Iteration ' num2str(t) ': Best Score = '
num2str(leaderScore)]);
end

% Display the final best solution
disp('Best Solution:');
disp(leaderPosition);
disp(['Best Score: ' num2str(leaderScore)]);

%% solar
solar=xlsread('g.xlsx',1,'E19:E8778')';         %% solar
irradiance data W/m^2
temp=xlsread('g.xlsx',1,'F19:F8778')';           %%
temperature data 0C
Tam=temp;                                        %%
ambient temperature 0C
%% % -------------Plotting of PV_out--------------------
---------%%%%%
```

```
Gref=1000;                %% reference solar radiation
(W/m^2)
NOCT=45;                  %% Nominal cell operating
temperature
kt=-3.7e-3;               %% Temperature coefFicient
Tref=25;                  %% Temperature at reference
condition
Tc=Tam+((NOCT-20)/800).*solar; % cell temperature
pv_eff=7.3;               %%  solar panels efficency
(rated power under reference condition)
G=solar;
PV_out=(pv_eff.*(G/Gref)).*(1+kt.*(Tc-Tref));
%PV output power
pp=PV_out;
outputpower=93.*pp;

figure; plot(pp);axis tight;box on;grid on;xlabel('Time
(hours)');ylabel('PV output power (kW)')
title('Output power generated from PV')
figure
plot(Tam,'DisplayName','T_a_m');hold on
plot(solar,'DisplayName','Solar Irr (G)');hold on
plot(wind,'DisplayName','Wind speed');hold off
legend show;grid on;grid minor; box on;axis tight;xlabel
('Time (Hours)')

% %% objective function
figure
REAL_INTREST=3;
ir=REAL_INTREST/100;
CRF=ir.*(1+ir)^20/(1+ir)^20-1; %% capital recovery
factor
NPC=ASC/CRF;
plot(NPC);axis tight;grid on;xlabel ('Renewable
electricty fraction'); ylabel ('NPC ($)')
title ('Total NPC')
display(['The value of NPC is : ', num2str(NPC)])

%% Objective function (1)
Grid_sale=0.015;
Grid_p=0.023;
grid_cost=sum(Grid_p)*.023-sum(Grid_sale)*.015
Grid_purchased=sum(Grid_p)
Grid_sale=sum(Grid_sale)

Cgrid=0.0425.*Grid_p; %%% 0.023 is the buying price
Cgrid is the cost of buying electrcity
```

```
display(['The value of Cgrid is : ', num2str(Cgrid)])

REF=sum(pp)./sum(pp+Grid_purchased); %%%
0.980932456190068
GCF=1-REF;
display(['The value of REF is : ', num2str(REF)])
ob=min (GCF);
%% objective function (2)
Egrid_s=zeros(1,8760);
R_grid=sum(0.02).*Egrid_s; %%=0.0003
display(['The value of R_grid is : ', num2str(R_grid)])

COE=((CRF.*sum(NPC))+grid_cost-R_grid./load1+Grid_sale);
%% COE IN $KWH
% display(['The value of COE is : ', num2str(COE)])



  function
[Anual_cost,Wind_cost,grid_cost,Battery_cost,Inverter_C,
Bin,Bout]=plot_statistics(x)

x %% indexing for number of solar, battery
global ASC

% prompt = 'What battery efficiency? ';
n_bat =0.85;% Battery efficiency.
load Data Ppv Pw_u convert;  %% load the data Ppv,LOad
demand
grids=xlsread('Book1.xlsx',3)'; %% Generated electricity
from grid
%assignin('base','ASC(3)',[ASC,42])
NS=0;
Kms=40; % daily travel of vehicle
consumption_km=Kms*(18/100); % total energy consumption
at the rate of 18KWh per 100 Km.
%% Solar
Nsol=x(2); % no. of batteries that are slelected by PSO
Ps=Ppv.*Nsol;
%% battery
%######inputs############inputs####################in
puts##
Nbat=x(3);    % no. of batteries that are slelected by
PSO
uinv=0.95;
dod=0.8;% battery depth of discharge. it indicates how
much %charge can be drawn from battery.
```

```
AD=3;
EL=convert;
Vs=48;
Bcap=AD*EL/uinv*n_bat*dod*Vs;

SOCmin=xlsread('SOCmin.xlsx',1,'A1:A180')';
SOCmax=xlsread('SOCmax.xlsx',1,'B1:B180')';

% Battery bank
Ebmax=Nbat*40;%3.7*2.6 Nbat*kWh %battery capacity
Ebmin=Ebmax*(1-dod);%  maximum battery discharge.
Eb=zeros(1,8760);
Egrid_p=zeros(1,8760);
Egrid_s=zeros(1,8760);
Edch=zeros(1,8760);
Ech=zeros(1,8760);
Eb(1,1)=1*Ebmax;%state of charge for starting time

% figure;plot (Ebmax);hold on; plot (Ebmin); hold off; grid
on; grid minor; title('Ebmax & Ebmin')
figure;plot (Egrid_p);hold on; plot (Egrid_s); hold off; grid
on; grid minor; title('Egrid_P & Egrid_S')

%^^^^^^^^^^^^^^START^^^^^^^^^^^^^^^^^^^^^^^^^
Pl=convert; % load demand in KW
univ=0.95;    % inverter efficiency
%^^^^^^^^^^Out put power calculation^^^^^^^^^
%% objective function
figure
REAL_INTREST=3;
ir=REAL_INTREST/100;
CRF=ir.*(1+ir)^20/(1+ir)^20-1; %% capital recovery
factor
NPC=ASC/CRF;
plot(NPC);axis tight;grid on;xlabel ('Renewable
Electricty Fraction'); ylabel ('NPC ($)')
title ('Total NPC')
display(['The value of NPC is : ', num2str(NPC)])

%% Objective function (1)
Grid_sale=0.015;
Grid_p=0.023;
grid_cost=sum(Grid_p)*.023-sum(Grid_sale)*.015;
Grid_purchased=sum(Grid_p);
Grid_sale=sum(Grid_sale);

Cgrid=0.0425.*Grid_p; %%% 0.023 is the buying price
Cgrid is the cost of buying electrcity
```

```
display(['The value of Cgrid is : ', num2str(Cgrid)])

REF=sum(Ps)./sum(Ps+Grid_purchased); %%% 0.98093245619
ref=REF*100;
GCF=1-REF;
display(['The value of REF is : ', num2str(REF)])
display(['The value of GCF is : ', num2str(GCF)])
ob=min (GCF);
%% objective function (2)
Egrid_s=zeros(1,8760);
R_grid=sum(0.02).*Egrid_s; %%=0.0003
display(['The value of R_grid is : ', num2str(R_grid)])

COE=((CRF.*sum(NPC))+grid_cost-
R_grid./convert+Grid_sale); %% COE IN $KWH
% display(['The value of COE is : ', num2str(COE)])

figure
ef=[0.8 .85 .9 .95 1 ];
lcoe_value=[0.2351 0.2212 0.2089 0.1980 0.1881];
plot(ef,lcoe_value,'DisplayName','SOC','Marker','*','Col
or',[1 0 1])
ylabel('LCOE($/KWh)');xlabel('Round trip
efficiency');grid on;grid minor;axis tight;legend show
```

charging

```
function [Eb,Edch,Ech,Egrid_p] =
discharge(Pw,Ps,Eb,Ebmax,Pl,t,Ebmin,Edch,Ech,Egrid_p)
 %^^^^^^^^^^^^^^DISCHARGE^^^^^^^^^^^^^^^^^^^
  uconv=0.95;   % CONVERTER efficiency
  uinv=0.95;     % inverter efficiency
    Pdch(t)=(Pl(t)/uinv)-(Ps(t))*uconv);
    Edch(t)=Pdch(t)*1; %one hour iteration time
    Ech(t)=0;
    Egrid_p(t)=0;
    D_Rate=7.2;%7.4; %battery discharge rate
    temp1=0;

      if (Ev(t-1)<(btmax*.2) && (bt(t)==1))
      end

    if(Eb(t-1)-Ebmin)>=(Edch(t)/uconv)
        Eb(t)=Eb(t-1)-(Edch(t)/uconv);
        Egrid_p(t)=0;  % no energy taken from grid
    else
```

```
        if (((bt(t-1)-(Edch(t)-Eb(t-
1)+Ebmin))>btmax*.2)&&(car_av(t)==1)&&((D_Rate)+Eb(t-1)-
Ebmin>=Edch(t)))
            Eb(t)=Ebmin;
            Ev(t)=Ev(t-1)-(Edch(t)-Eb(t-1)+Ebmin);
            Edch(t)=Eb(t-1)-Ebmin;
        else
%            temp=Eb(t-1)-Ebmin;
            Eb(t)=Eb(t-1);
            Egrid_p(t)=Edch(t);
            Edch(t)=0;
        end
    end
end
```

discharge

```
function [Eb,Edch,Ech,Egrid_p] =
discharge(Ps,Eb,Ebmax,Pl,t,Ebmin,Edch,Ech,Egrid_p)
 %^^^^^^^^^^^^^^DISCHARGE^^^^^^^^^^^^^^^^^^^
  uconv=0.95;   % CONVERTER efficiency
  uinv=0.95;     % inverter efficiency
    Pdch(t)=(Pl(t)/uinv)-((Ps(t))*uconv);
    Edch(t)=Pdch(t)*1; %one hour iteration time
    Ech(t)=0;
    Egrid_p(t)=0;
    D_Rate=7.2;%7.4; %battery discharge rate
    temp1=0;

      if (bt(t-1)<(btmax*.2) && (bt==1))
            [bt,Egrid_p]=charge_bt(bt,Egrid_p,t);
      end

    if(Eb(t-1)-Ebmin)>=(Edch(t)/uconv)
        Eb(t)=Eb(t-1)-(Edch(t)/uconv);
        Egrid_p(t)=0;  % no energy taken from grid
        bt(t)=bt(t-1);  %% no energy taken from bt
    else
        if (((Ev(t-1)-(Edch(t)-Eb(t-
1)+Ebmin))>btmax*.2)==1)&&((D_Rate)+Eb(t-1)-
Ebmin>=Edch(t)))
            Eb(t)=Ebmin;
            Edch(t)=Eb(t-1)-Ebmin;
        else
%            temp=Eb(t-1)-Ebmin;
            Eb(t)=Eb(t-1);
            Egrid_p(t)=Edch(t);
```

```
            Edch(t)=0;
        end
    end
end
```

the economic cost calculation

```
function
[Anual_cost,Wind_cost,Solar_cost,grid_cost,Battery_cost,
Inverter_Tcost] =
economic_cost(Nbat,Nsol,Nw,Grid_p,Grid_sale )

%wind cost
Cw = 2300; % cost of wind plant per KW
WC_r=1500; %%% rated capacity of wind
W_sal=2500; %%% replacment cost ($)
W_OM=2; % operation and maintenance cost of wind

%Solar cost
% solar cost
Cs = 1200;   % =capital cost of solar
S_OM=4;      % operation and maintenance cost
S_sal=0;     % replacment cost ($)
%battery cost
BAT_C=40; % batery unit cost  =capital cost
BAT_C_r=67;   % rated capacity of battery
Bat_sal=0;    % replacment cost ($)
Bat_OM=1.67;  %operation and maintenance cost of battery
 % inverter cost per kw
INV_C=127;    % inverter cost per kw
INV_Cr=127;   % rated capacity of inverter
INV_sal=0;    % replacment cost ($)
INV_OM=1;     % operation and maintenance cost of
inverter ($)

%economic index
REAL_INTREST=3;
%life time
PRJ_LF=20;
Bate_L=5; % battery life
ir=REAL_INTREST/100; %%annual real interest rate (%)
% % CRF
% Battery anualized cost
Battery_cost
=Nbat*[Bat_OM+(BAT_C+(BAT_C_r))*(ir*(1+ir).^(PRJ_LF))/((
(1+ir).^PRJ_LF)-1)];
```

```
display(['The value of Battery_cost  is : ',
num2str(Battery_cost )])
% inverter cost calcuation
Inverter_Tcost=100*[INV_OM+(INV_C)*(ir*(1+ir).^(20))/(((
1+ir).^20)-1)];
display(['The value of Inverter_Tcost is : ',
num2str(Inverter_Tcost)])
%Solar annualized cost
Solar_cost=Nsol*[(Cs)*((ir*(1+ir).^(PRJ_LF))/(((1+ir).^P
RJ_LF)-1))+S_OM];
display(['The value of Solar_cost is : ',
num2str(Solar_cost)])
grid_cost=sum(Grid_p)*.023-sum(Grid_sale)*.015
Grid_purchased=sum(Grid_p)
Grid_sale=sum(Grid_sale)

Anual_cost=grid_cost+Inverter_Tcost+Wind_cost+Battery_co
st+Solar_cost;
display(['The value of Anual_cost is : ',
num2str(Anual_cost)])

end
```