TECHNICAL AND ECONOMIC FEASIBILITY STUDY FOR SUPPLYING A REMOTE VILLAGE IN IRAQ WITH DIFFERENT ENERGY SOURCES

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Prepared as
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May 2023

I certify that in my opinion the thesis submitted by Imad Abbas Kadhim ALMASOODI titled “TECHNICAL AND ECONOMIC FEASIBILITY STUDY FOR SUPPLYING A REMOTE VILLAGE IN IRAQ WITH DIFFERENT ENERGY SOURCES” is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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Imad Abbas Kadhim ALMASOODI

ABSTRACT

M. Sc. Thesis

TECHNICAL AND ECONOMIC FEASIBILITY STUDY FOR SUPPLYING A REMOTE VILLAGE IN IRAQ WITH DIFFERENT ENERGY SOURCES

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May 2023, 68 pages

Three scenarios for providing a rural town in Iraq with power were compared in terms of their technical, economic, and environmental merits. These scenarios are: supplying the community with national electricity; using diesel generators; and using photovoltaic panels. Photovoltaic panels are the greatest option for lowering carbon emissions; and have little or no running costs. Due to their economic viability, PV solar cells may be used to meet energy needs when there is no electrical grid or when they are located far from residential areas. They can thus be constructed to meet the electrical needs of rural areas or for signaling reasons. The results obtained from the HOMER software of the three scenarios show that the total cost of supplying from the PV system scenario has a lower cost when compared with the two scenarios mentioned above with proposing the life span is about 25 years.

Key Words : Economic-Technical Aspects, Environmental Aspects, Renewable Energy Resources, Diesel Generator, Grid Electricity, Net present value, Capital cost, Fixed Cost, and Variable Cost.

Science Code : 90544

ÖZET

Yüksek Lisans Tezi

IRAK'TA UZAK BİR KÖYÜN FARKLI ENERJİ KAYNAKLARI İLE TEMİN EDİLMESİ İÇİN TEKNİK VE EKONOMİK FİZİBİLİTE ÇALIŞMASI

Imad Abbas Kadhim ALMSSOODI

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Tez Danışmanı:
Dr. Öğr. Üyesi Tarik Adnan ALMOHAMAD
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Irak'taki bir kırsal kasabaya enerji sağlama konusunda üç senaryo, teknik, ekonomik ve çevresel yönleriyle karşılaştırıldı. Bu senaryolar şunlardır: topluluğun milli elektrikle beslenmesi; dizel jeneratörlerin kullanımı; ve fotovoltaik panellerin kullanımı. Fotovoltaik paneller, karbon emisyonlarını azaltmak için en büyük seçenektir ve çalıştırma maliyetleri yok veya çok azdır. Ekonomik uygunlukları nedeniyle, PV güneş hücreleri, elektrik şebekesi olmadığında veya yerleşim alanlarından uzakta olduklarında enerji ihtiyaçlarını karşılamak için kullanılabilir. Bu nedenle, kırsal alanların veya sinyalizasyon nedenleri için elektrik ihtiyaçlarını karşılamak için inşa edilebilirler. HOMER yazılımından elde edilen sonuçlar, PV sistemi senaryosundan kaynaklanan toplam maliyetin, yukarıda bahsedilen diğer iki senaryoya göre daha düşük bir maliyeti olduğunu ve önerilen ömrün yaklaşık 25 yıl olduğunu göstermektedir.

Anahtar Kelimeleri : Ekonomik-Teknik Yönler, Çevresel Yönler, Yenilenebilir Enerji Kaynakları, Dizel Jeneratör, Şebeke Elektriği, Net Bugünkü Değer, Sermaye Maliyeti, Sabit Maliyet ve Değişken Maliyet.

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SYMBOLS AND ABBREVIATIONS INDEX

F_c : Fuel Consumption

N_p : No of PV panels in parallel

N_s : No of PV panels in series

P_{DG} : Power of the diesel generators

$A\&B$: Constants

C : Capacitance of the boost

D : Duty Cycle

I_{PV} : PV system current

Ib : Battery Current

L : Inductance of the boost

N : Total number of panels

P_{PV} : PV system power

Q : Battery Capacity

V_{PV} : PV system voltage

Vb : Battery Voltage

Vin : Input voltage of the boost

$Vout$: Output voltage of the boost

f : Frequency

i : Interest rate

ABBREVIATIONS

RES : Renewable Energy Source

PV : Photovoltaic

MATLAB : MATrix LABoratory

HOMER : Hybrid Optimization of Multiple Energy Resources

MW : MigaWatt

CO2 : Carbon Dioxide

DC : Direct Current
AC : Alternative Current
MPPT : Maximum Power Point Tracking
P&O : Perturb and Observe
USD : United State Dollar
MS : Micro-Soft
NPC : Net Present Cost
HRES : Hybrid Renewable Energy Resource
KVA : Kilo Volt Ampere
Wh : Watt-hour
CRF : Capital Recovery Factor
TAC : Total Annualized Cost
COE : Cost of Energy
GHG : Greenhouse Gas
HOMER : Hybrid Optimization Model for Energy Resource
LCOE : Levelized Cost Of Energy
HRES : Hybrid Renewable Energy System
MPC : Model Predictive Control
PID : Proportional Integral Derivative
HOMER : Hybrid Optimization Model for Energy Resource
NPC : Neutral Point Clamped
PWM : Pulse Width Modulation
PSO : Particle Swarm Optimization
PFC : Power Flow Control
FLC : Fuzzy Logic Control
NPC : Net Present Cost
CRF : Capital Recovery Factor

PART 1

INTRODUCTION

1.1. INSPIRATION

The alarming increase in pollution caused by conventional power generation units that rely on fossil fuels and nuclear energy is a major concern for the environment. As a result, several countries have revised their electricity production policies by decreasing their reliance on traditional generating units and instead focusing on the adoption of sustainable and eco-friendly methods of generating electricity. Renewable Energy Sources (RES) such as Photovoltaic (PV), wind turbines, and biomass are being increasingly favored due to their accessibility, lack of fuel costs, and environmental sustainability [1].

The utilization of fossil fuels has detrimental effects on the environment, such as contributing to global warming through carbon emissions. Moreover, fossil fuels account for approximately 75% of total energy production worldwide and are rapidly depleting. As a result, the need for alternative, sustainable energy sources have become increasingly vital. RES have emerged as a promising solution, providing clean energy to meet growing demand while addressing the environmental concerns associated with fossil fuels [2]. The integration and implementation of RES have received significant international attention, with countries such as India and Brazil emphasizing renewable energy development and implementation [1], [2].However, despite this progress, over 500,000 European inhabitants still lack access to the national grid, and over 45% of the population in Sub-Saharan Africa, East, South, and Central Asia, South America, and the Middle East continue to live in darkness [3].

In recent years, there has been a growing interest in clean energy sources, particularly in PV energy. As depicted in Figure 1.1, the use of PV has seen a significant increase between 2020 and 2022 in comparison to other RES [4]. While RES systems are designed to operate under specific operating conditions, they may experience disturbances that can alter their performance and behavior. These disturbances can vary in duration, intensity, and effect [1].

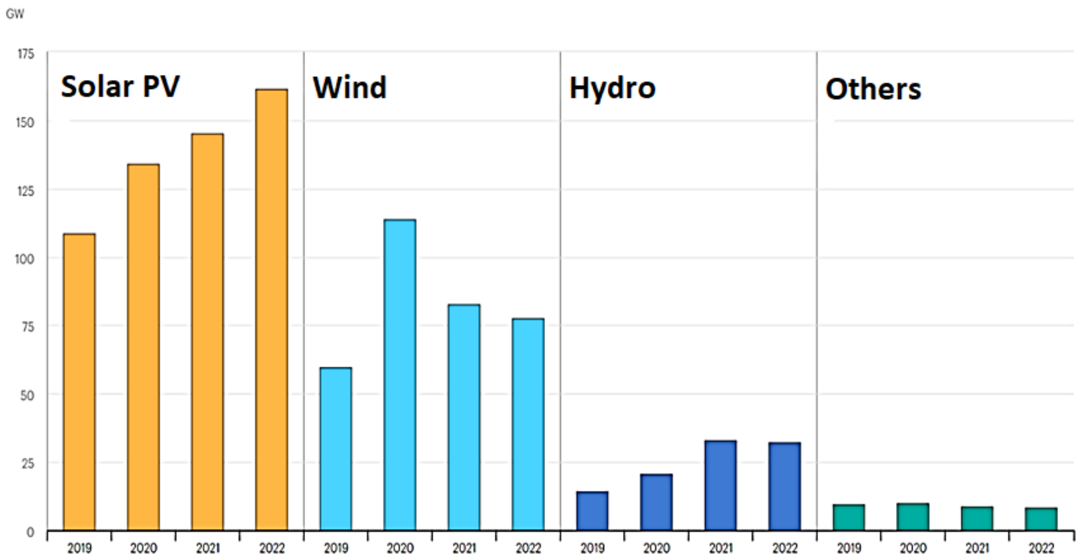

Figure 1.1. Net renewable capacity additions by technology, 2020-2022 [5].

Solar photovoltaic systems are becoming an increasingly popular choice for power generation in Iraq due to their cost-effectiveness and ability to provide electricity to low-voltage loads where grid connectivity is not feasible. The implementation of solar PV systems in remote locations and in conjunction with diesel-based generators and communication transmitters has been proposed in the Iraq Master Plan [6] for electrification purposes. The decreasing trend in the cost of solar energy and the recognition of the necessity for solar power development have also led to the construction of solar power plants in the country. The huge solar energy potential in Iraq can be harnessed by implementing grid-connected solar PV power systems of various sizes based on demand and affordability, while also providing an acceptable return on investment.

To assess the technical and economic feasibility of supplying electric power to a remote village in Iraq, this study will analyze three different scenarios using MATLAB, PVsyst, and HOMER programs. These programs are commonly used in the solar energy industry for modeling, simulation, and optimization of solar PV systems. By utilizing these tools, the study will evaluate the performance and economic viability of the proposed solar PV systems in the remote village, considering factors such as solar irradiation, system sizing, battery storage, and economic indicators. The implementation of solar PV systems in Iraq has the potential to provide electricity to remote areas and contribute to the country's energy security. The use of advanced modeling and simulation tools; MATLAB, PVsyst, and HOMER, can facilitate the planning and design of efficient and cost-effective solar PV systems.

1.2. PROBLEM STATEMENT

The power system in Iraq is composed of three main sections: generating, transmission, and distribution. The generating section produces electricity at voltages below 20 kV, which is then transmitted through the transmission section. Step-up transformers are used to increase the voltage levels to 132 kV and 400 kV. Autotransformers are then used to link the 132 kV high voltage transmission with the 400 kV extra high voltage transmission. The distribution section then takes the electricity and utilizes step-down transformers to reduce the voltage levels to 33 kV and/or 11 kV [7].

The big challenges in Iraq are:

- The problem of villages, the large number of villages that are isolated from the electricity grid in Iraq.
- The inability of the national grid to supply because of the problem of supply and demand. There is a huge difference and a big challenge in this because of various influencing factors (Will mentioned the various factors in the last of this section).

Table 1.1 and Figure 1.2 provide an overview of the installed capacity and available generation in megawatts (MW) for the power system in Iraq. These values are critical in understanding the capacity of the Iraqi electricity system and its ability to meet the country's energy demands. The installed capacity of the system is constantly being updated and expanded to keep up with the increasing demand for electricity in the country.

Table 1.1. The installed and available generation of Iraqi power system /2022 [5].

Type of generation units	Installed capacity MW	Available capacity MW
Thermal generation units	7305	4748
Gas generation units	16385	9192
Hydro generation units	1864	789
Diesel generation units	2327	821
Mobile generation unit	308	0
Total MW	28189	15550

Supply reliability is a significant concern in power system operation and planning, as the power provider utility is responsible for supplying electricity of good quality under various operating and load growth conditions, while also considering the economic impact. Ensuring the reliability of the power system is critical to maintaining the continuous supply of electricity to customers, which is essential for the economic development of the country.

To achieve this goal, power system planners and operators need to consider a range of factors, including load forecasting, system design, equipment maintenance, and contingency planning. These factors are critical in ensuring the power system can withstand unexpected events, such as equipment failures or extreme weather conditions, and still provide a continuous and reliable supply of electricity.

Overall, the reliable operation of the power system is essential to meet the energy demands of the population, drive economic growth, and improve the quality of life in the country. As such, it is crucial for the power provider utility to continually invest in the development and maintenance of the power system to ensure a reliable supply of electricity to customers [6], [7].

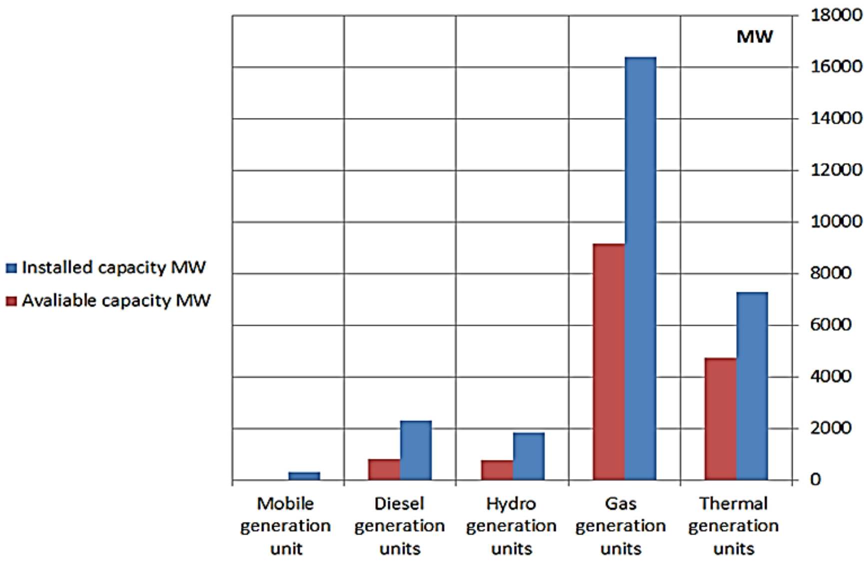

Figure 1.2. The installed and available generation in Iraq [5].

Figure 1.3 provides important information on the percentage of each power generation category in Iraq. This data is critical in understanding the current energy mix of the country and the sources of electricity that are being utilized to meet the energy demands of the population.

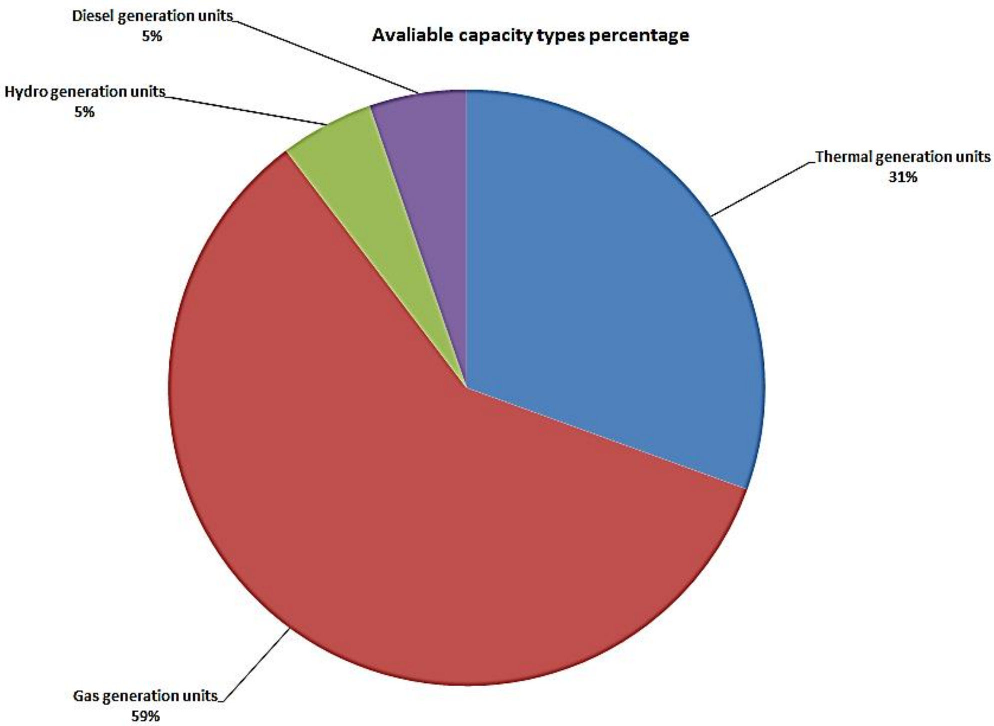

Figure 1.3. The percentage of generation categories in Iraq [5].

Table 1.2 provides crucial information on the average available import power to the Iraqi power system. This information is essential in understanding the capacity of the system to meet the energy demands of the population. The average available import power represents the amount of electricity that can be imported into the Iraqi power system from neighboring countries, which is critical in ensuring a reliable supply of electricity to customers. The data provided in Table 1.2 enables power system planners and operators to make informed decisions regarding the capacity of the system and the need for additional investment to meet growing energy demands. The availability of import power is also an essential consideration for the development of renewable energy sources, which can complement the existing power generation capacity and reduce dependence on imports.

The average available import power to the Iraqi power system is a critical piece of information that provides insight into the capacity of the system to meet energy demands and the need for additional investment in power generation and transmission infrastructure.

Table 1.2. The import power to Iraqi power system [5].

Type of Import	Average available MW
Import power from Iran and Turkey	750
Import power from Kurdistan	150
Import power from Investment projects	5500
Total import MW	6400

Table 1.3 presents critical information on the annual load demand and actual generation in MW for the period from 2011 to 2022 in the Iraqi power system. The data clearly shows a significant gap between the load demand and the actual generation, which has resulted in load shedding to control the frequency of the power system. This gap has existed since 1990, after the first gulf war, and has been a significant challenge for the Ministry of Electricity. However, the Ministry of Electricity has developed a master plan to remove this gap by 2030, as indicated in the referenced source. This plan includes a range of measures, including the installation of new power generation capacity, the expansion of the transmission and distribution

network, and the development of renewable energy sources. By implementing these measures, the Ministry of Electricity aims to close the gap between load demand and generation, ensuring a reliable supply of electricity to customers and driving economic growth in the country. Table 1.3 highlights the critical need for investment in the power system to meet growing energy demands and reduce reliance on load shedding as a means of controlling the frequency of the power system.

Table 1.3. Load demand and actual generation from (2011–2022) [5].

Year	Load demand MW	Actual Generation MW
2011	15201	7065
2012	15370	8750
2013	17454	12075
2014	18653	12320
2015	21221	13400
2016	24020	14355
2017	25581	15625
2018	26341	16465
2019	27346	19170
2020	29000	19365
2021	33000	21145
2022	35000	21950

The load demand of the Iraqi power system currently stands at 35,000 MW, which far exceeds the available generation capacity and imported power of 21,950 MW, resulting in a significant shortage of 13,050 MW. This gap between load demand and actual generation is evident from Figure 1.4, which shows the trend from 2011 to 2022.

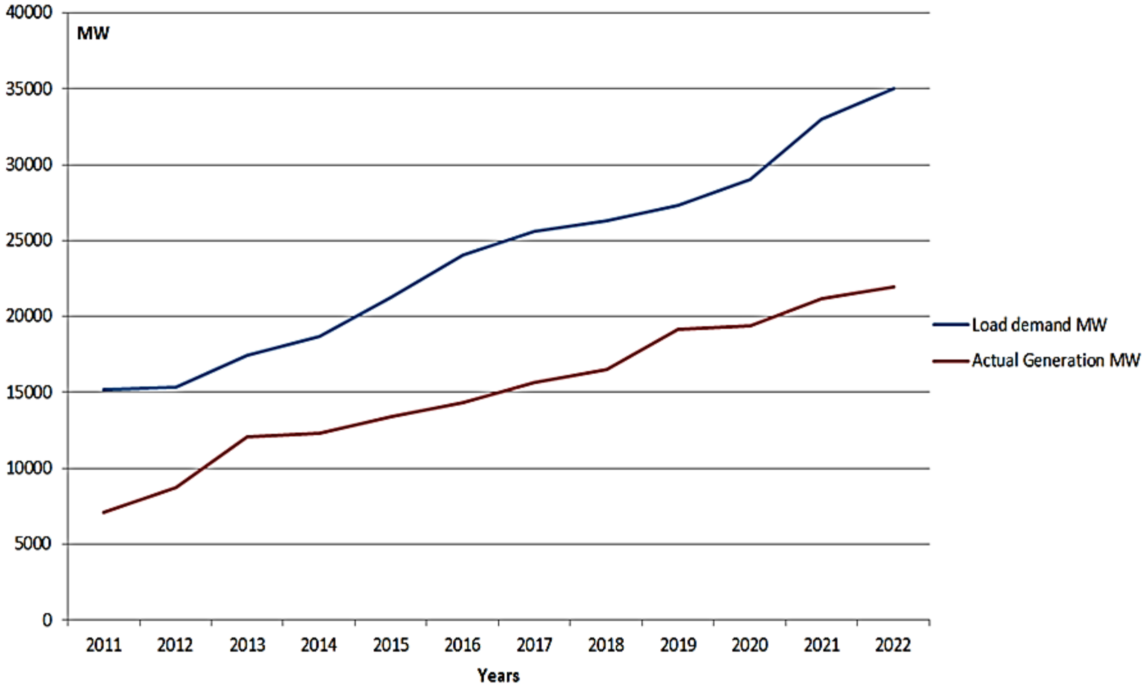

Figure 1.4. The gap between the load demand and actual generation from (2011-2022) [5].

The electric power industry in Iraq has been facing a plethora of challenges, ultimately leading to its crumbling state. The uncertain environment, caused by political instability and frequent conflict, has significantly hindered progress in this sector. Furthermore, the long-term economic blockade imposed on Iraq has resulted in a shortage of funds for investment in infrastructure and technology.

Terrorist attacks have also posed a significant threat to the power industry, causing damage to power plants and transmission lines. The issues in supplying suitable fuel to the manufacturing plants, in terms of both quantity and quality, have further exacerbated the situation.

The emphasis on generational expansion without an adequate plan for the transmission sector has resulted in a lopsided system. This has been compounded by the rapid increase in demand for electricity from residential, governmental, and commercial sectors, primarily driven by income growth since 2003.

The challenges of implementing an effective power rate structure have further complicated the issue, with consumers often refusing to pay for the electricity they consume. Water resource scarcity and its impact on hydropower generation have also contributed to the crisis.

Maintenance and refurbishment of the old power plants have been neglected due to a lack of funds and expertise, exacerbating the problems with the power supply. Additionally, the absence of electrical regulating provisions in the Iraqi legal system has further complicated matters, making it difficult to hold power companies accountable for their actions.

1.3. THESIS OBJECTIVES

Several previous studies have explored the generation of electricity from solar energy, recognizing its potential as a clean and renewable source of energy. Due to the relatively new and complex nature of this topic, these studies have approached it from various perspectives, analyzing different aspects such as technical feasibility, economic viability, and environmental sustainability. Most of these studies have concluded that transitioning from traditional energy sources to solar energy is a vital step towards preserving the environment.

The main objectives of this thesis are summarized as follows:

- To conduct analytical comparison among three methods of equipping a remote village with electric energy, by considering three parameters: technical, economic and environmental.
- To design a model for calculating the costs of three techniques (using national electric national grid, diesel generators, and utilizing PV solar technique)

Our study has several unique features that distinguish it from previous related research. Firstly, we conducted a comprehensive comparison of three methods for providing electricity to a remote village: national electricity delivery, diesel generators, and solar cells. This comparison included technical, economic, and environmental factors. Secondly, we developed a model to calculate the costs of each method based on the data from our study case. The model is adaptable to different data sets in the future. Thirdly, to the best of our knowledge, this is the first study to apply the case study approach to this topic in the Iraqi context. Lastly, we provide a brief overview of the current situation of the Iraqi power system and the future master plan for using renewable energy sources to supply remote villages.

1.4. THESIS SCOPE

Access to reliable and sustainable electricity is a fundamental human right and a crucial driver of economic growth and social development. However, providing electricity to remote villages in Iraq is a significant challenge, given the country's unique context and numerous obstacles, including uncertain environments, economic blockades, and issues with fuel supply and infrastructure. To overcome these challenges, this thesis takes a bold and innovative approach by focusing on three feasible methods for delivering electricity to remote areas: diesel generators, connection to the national grid, and solar photovoltaic systems with backup batteries. Through a rigorous feasibility study, utilizing advanced software tools such as MATLAB, PVsyst, and HOMER, we will evaluate the technical and economic viability of each method, taking into account the unique context and challenges of the Iraqi environment. By comparing the methods based on criteria such as cost/benefit, environmental pollution standards, and technical aspects, we aim to determine the most efficient and cost-effective option for delivering electricity to remote villages in Iraq. Through our research, we hope to provide practical solutions for the Iraqi energy sector and contribute to the global effort towards sustainable and equitable energy access for all.

1.5. THESIS OUTLINES

This work is containing five parts, as **Part One** is already explained, the chapters from two to five are briefly outlined as:

- Part Two this chapter will present the literature survey of the related works.
- Part Three describes the theoretical background of the of technical and

economic feasibility study to supply a remote village with electric power in three different ways.

- Part Four presents the methodology of evaluation the technical, economic and environmental aspects for the three proposed scenarios.
- Part Five summarizes the main conclusions of this work and the proposed future work extension.

PART 2

LITERATURE REVIEW

2.1. BACKGROUND

Climate change, which driven by the usage of fossil fuels, is one of the most serious problems confronting humanity today. The current ways of generating energy through use of fossil fuels are unsustainable, resulting in the production and buildup of greenhouse gases in the atmosphere, which may be the primary cause of global warming. Furthermore, traditional energy systems need the exploitation of the planet's natural resources, causing severe environmental damage. RES is the best solution that can used to reduce the carbon emission; in addition, the operating cost is small of free as in PV solar system and wind turbines. PV solar cells may utilize to satisfy energy demands when there is no electrical grid or when being distant from residential areas since they are economically viable. As a result, they can be built to address rural electrical demands or for signaling purposes. In this chapter, we will focus of the literature survey of the related works to the technical and economic feasibility to supply a remote area with electric power in different ways for last ten year.

The historical studies, which related to evaluate the Technical and economic feasibility study to supply a remote village with electric power in different ways started to stand out in general last two decades. Therefore, large amounts of literature, which deal with the topic, are in hand for researchers. A brief overview of selected relevant research work regarding Technical and economic feasibility study to supply a remote village with electric power in different ways for the last ten years is presented in this section, the literature classified according to the authors name and the published year

The survey conducted in this thesis is divided into two sections: a techno-economic survey and a technical survey.

2.1.1. PV Solar Energy

Solar energy is the most readily available continuous energy source on the planet, and it comes in two shapes: straight (solar radiation) and secondary (solar heat). This study will focus on PV technology to create energy and will be confined to direct utilization of solar radiation. The amount of direct sun energy available is enormous. In general, 120,000 terawatt of solar energy is absorbed on Earth. Nevertheless, due of very small raindrops and microscopic fog or mist, this resource reaches the land as a diffused flow. The photovoltaic solar system is a device that converts sunlight into energy directly via the photoelectric effect, which causes materials to release electrons. Over the last two decades, several academics have looked at the benefits of solar energy for home, commercial, and industrial use.

In the latter decade of the twentieth century, Japan and Germany were the first to employ large-scale PV energy generating. Both nations were pioneers in solar energy technology development. China has recently created a large solar power capacity, taking advantage of cheap labor and government subsidies, lowering the cost of solar power generation. The environmental and economic benefits of solar photovoltaic technology are evident. CO2 emissions and global warming impacts will be reduced by reducing the use of fossil fuels such as coal, petroleum, and natural gas to generate electricity. Because of the advancement and increased efficiency of solar energy generation systems, the expense of power generation has been greatly decreased when employing traditional solar PV technologies. In the United States, for example, the cost of electricity has decreased as a result of the usage of PV panels to generate electricity. Solar technologies, on the other hand, have drawbacks, such as land degradation, aesthetic appeal in structures utilizing this technology, and chemical impacts of their materials, among others. Commercially, the efficiency of a PV solar system is low and it about twenty percent.

Solar energy is the primary driver of the planet's atmospheric conditions; it is made up of light of various wavelengths. Approximately 70% of solar energy is absorbed by the Earth and atmosphere, 3% by the stratosphere, 16% by the troposphere, and the remaining 51% is absorbed by the Earth's surface. Figure.2.1. depicts the incoming energy that warms the Earth's atmosphere and provides energy for life.

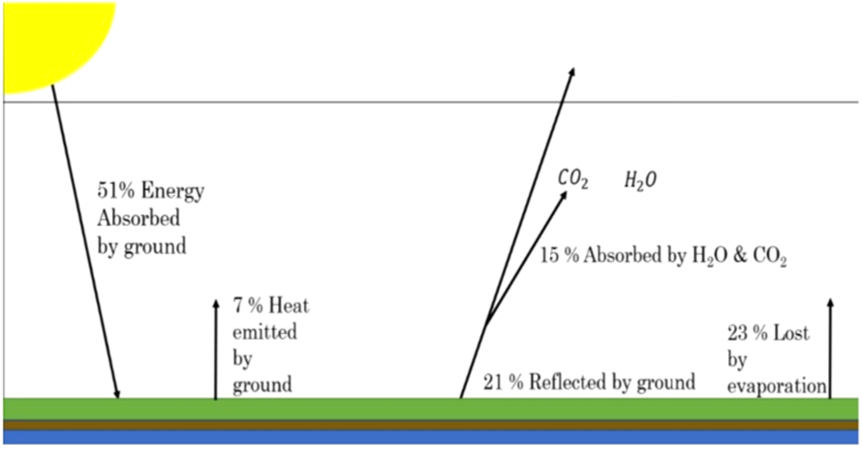

Figure 2.1. Simplified greenhouse effect in Earth's atmosphere [8].

2.1.1.1. Types of PV Systems

PV technology has come a long way since its initial application in powering satellites in space. Today, it is widely used to provide electricity to consumers through four types of PV systems: grid-connected, standalone, hybrid, and grid-tied with battery backup. In a grid-connected system, DC power generated by PV is converted to AC power using inverters, and any excess power can be sold back to the electricity supply company. Standalone systems, on the other hand, use batteries to store and supply electricity, without being connected to the grid. Hybrid systems combine PV generation with other types of generation, such as wind turbines or diesel generators, to reduce the overall consumption of non-renewable fuels. Grid-tied systems with battery backup, store PV-generated energy in batteries, which can be used during periods of low irradiance. Net metering allows unused PV power to be sold back to the grid, ensuring uninterrupted power supply during grid outages.

This work proposes a novel PV system that combines a grid-tied system with battery backup and supercapacitors. The performance of the proposed system is simulated and analyzed using MATLAB Simulink software, providing valuable insights for future development.

2.1.1.2. Efficiency of PV

For optimal efficiency in converting solar energy to electrical energy, solar panels should be positioned perpendicularly to the sun's rays. However, since the sun's position changes throughout the day, the direction of the solar panels must be adjusted regularly to maintain the optimal angle. To achieve this, solar trackers are used to adjust the position of the PV panels so that they align directly with the sun's light. This results in a significant increase in the maximum power delivered from the PV panel. Figure 2.2 provides clear evidence of the advantages of using a solar tracking system, as it shows how the duration of maximum power increases significantly when such a system is utilized. Therefore, solar trackers play a vital role in optimizing the efficiency of solar energy systems, allowing for the highest possible energy yields to be achieved.

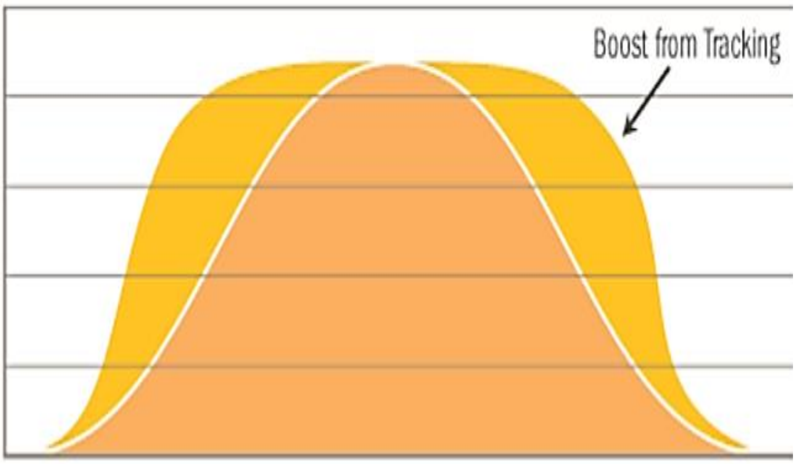

Figure 2.2. Daily power production compared to fix mount [9].

There are several types of solar trackers that can be used in PV systems, but two of the most common are single axis trackers and dual axis trackers. Single axis trackers are designed to track the sun's movement in a single direction, typically the azimuth angle. They are relatively simple in design and can be used in a variety of PV applications. In contrast, dual axis trackers are more complex and can track the sun's movement in both the elevation and azimuth directions. As shown in Figure 2.3, this allows for more precise positioning of the PV panels to maximize energy yields. Overall, both single axis and dual axis trackers have their advantages and can be used in a range of PV systems. The choice of tracker ultimately depends on factors such as system requirements, location, and budget [10].

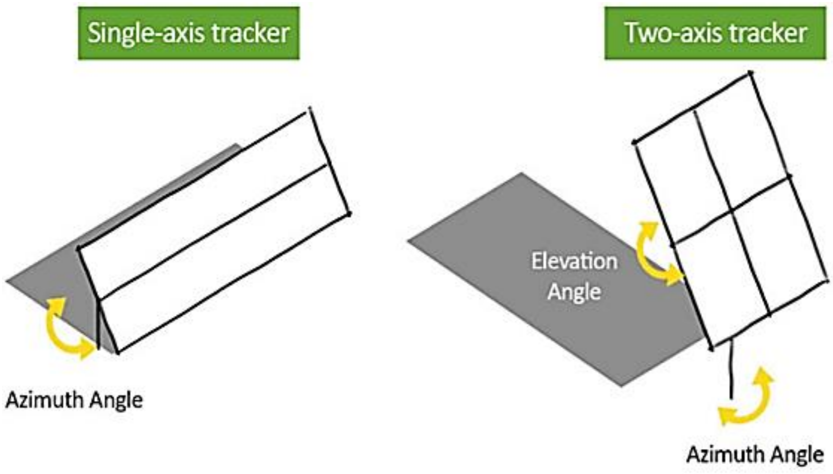

Figure 2.3. Single and dual axis trackers [11].

2.1.1.3. Renewable Energy Plan of Iraq Power System

The transition towards a renewable-based energy system requires not only the construction of supporting infrastructure but also the implementation of relevant regulatory regimes and the establishment of new markets and businesses. A comprehensive understanding of the socio-technical interdependence of the energy system and the key dynamics of system innovation is crucial to ensure a successful transition. A clear vision of the purpose and direction of the conversion process can foster constructive dialogue on future energy system advancements in Iraq and enable stakeholders to develop effective strategies for transitioning towards a renewable-based energy system [10].

In line with its renewable energy master plan, the Iraqi government aims to add PV systems with a total capacity of about 7,750 MW between 2024 and 2030 to supply remote villages with electricity [10].The proposed additional power from PV systems in various locations, as outlined by the Ministry of Electricity, is illustrated in Table 2.4 and Figure 2.5. By embracing this renewable energy plan, Iraq can move towards a cleaner, more sustainable energy system that will benefit both the environment and the country's economy.

Table 2.1. The additional PV power in MW from 2024-2030 plan [5].

Year	Total added power of PV in MW
2024	1000
2025	1525
2026	1300
2027	1350
2028	1000
2029	780
2030	800
Total MW	7755

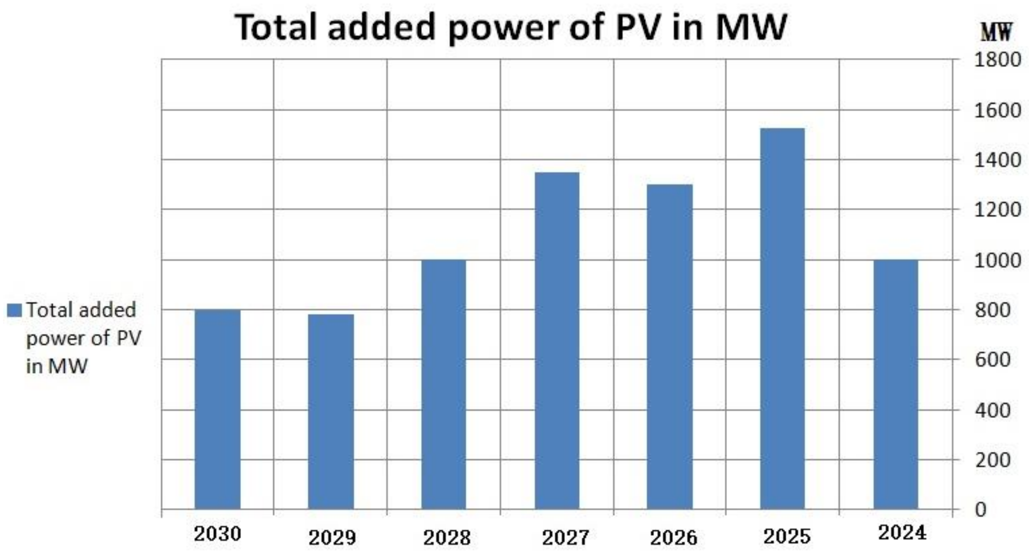

Figure 2.4. The additional PV power plan of Iraq [5].

The amount of energy that can be produced by a PV solar system is directly dependent on the level of irradiation that is present in the location where the system is installed. In Iraq, the maximum irradiation levels vary across different regions, and the kWh/kWp map of Iraq by PV solar system, as illustrated in Figure 3.5, provides a visual representation of these variations [10]. By referring to this map, it is possible to determine the maximum energy output that can be achieved by a PV solar system in a given location in Iraq. This information is essential when planning and designing a solar energy system, as it can help to ensure that the system is capable of producing the desired amount of energy and that it is optimized for the specific conditions of the installation site.

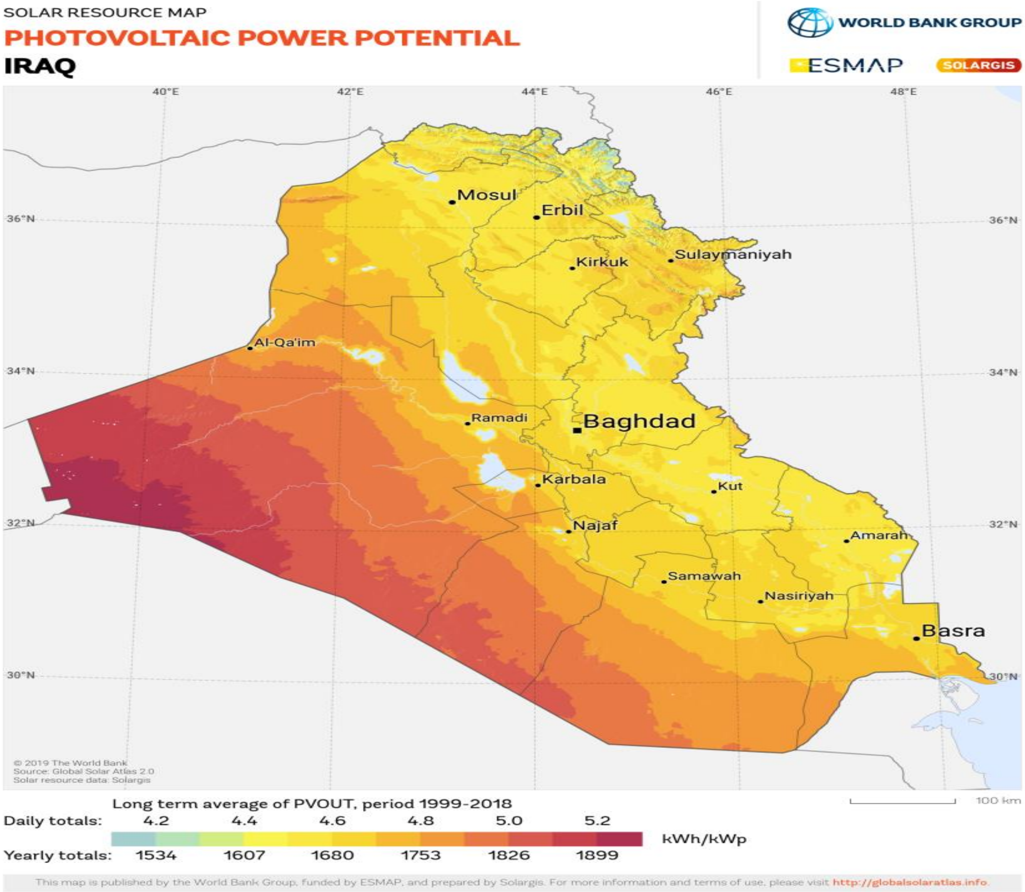

Figure 2.5. The kWh/kWp map of Iraq by solar system [12].

Iraq experiences long periods of sunshine, which has led to a significant demand for electrical energy, particularly in densely populated areas like Baghdad. Unfortunately, conventional power plants are unable to meet this demand due to their limited production capacity and the resulting degradation of equipment. As a result, there has been a growing interest in renewable energy sources, such as solar energy, across Iraq [13]. In terms of renewable energy potential, Iraq is among the richest countries globally. The Ministry of Electricity of Iraq is currently exploring various renewable energy sources, including PV solar systems, to help meet the nation's growing demand for electricity. However, solar energy is not the only renewable energy source under consideration, as shown in Table 2.5. The Iraqi government is also exploring wind and hydropower as potential energy sources for the nation's power system.

Table 2.2. Undergoing studies of using Renewable Energy in Iraqi Power System.

Undergoing studies	Status of each study
wind turbine	The study not completed, search about the optimum location and size in Wasit governorate.
Solar system (mirrors)	The location and size are selected (100 MW in Basrah governorate in south of Iraq)
Waste generation unit	The study not completed search about the optimum size and location in each governorate.

2.2. TECHNO-ECONOMICS SURVEY

A solar cell was installed onto the north-facing rooftop of an energy-efficient home in South Africa in this study [14]. The PV incorporated into the building distributes power to residential loads and the grid while simultaneously serving as the roof facade. Using investment analysis methodologies, this article gives an economic evaluation of the viability of the building's integrated photovoltaic generating system. Energy's initial investment and life cycle cost were calculated to be USD 6,578.9/kWp and USD 0.245/kWh, correspondingly. The payback time was eight years, with a 9.3 percent adjusted rate of return. According to metrics sensitivity analysis, a 50percentage reduction in module price translates into a 29% reduction in the life cycle cost of energy and a more than 50percentage decrease in the payback period.

The authors in this paper [15], explain that a hybrid RES is one of the most potential applications of renewable energy technology, particularly in distant places where grid expansion costs would be prohibitively expensive and the cost of fossil fuels would be prohibitively expensive. The four most extensively used technologies were used to identify inherent issues in mixing diverse renewable energy sources in a hybrid system (wind turbine, PV solar, biomass, and hydropower plant). Special considerations apply to the usage of the aforementioned technology in hybrid systems. The overarching goal of this project is to determine the present availability of commercial hybrid RES.

The authors of this study [16], address how to provide energy to safari campsites in distant rural parts of the UAE desert. Because of the high cost of fuel and the effects of generator vibrations on the desert environment, two renewable solutions were examined utilizing HOMER software. The first is a traditional renewable system comprised of PVs and battery storage. The second system is a hybrid of PVs and fuel cells, with hydrogen produced by water electrolysis. The economical conclusion reveals that the fuel cell system costs around 50% more than the PV/battery combination. Nevertheless, in addition to economic impacts, this study's presumed lead-acid batteries have a short life cycle and might pose major environmental problems if not removed appropriately.

This study [17], gives a Techno-economic analysis of a hybrid power generating system for a technical college, in Bhubaneswar-India. The techno-economic study is performed to determine the viability of a certain area for the implementation of a microgrid. The economic and technical viability of a hybrid generating system comprised of PV, Wind, Diesel, and grid sources is being investigated. This is accomplished using the HOMER (Hybrid Optimization Model for Energy Resource). Different scenarios are applied in this work, each scenario contains two or more two RES, the economic and technical aspects for each scenario are discussed in this work.

The authors in this study [18], show that, the most promising sustainable energy solutions is hydropower. Small hydro power plants, on the other hand, will be more viable than massive hydro power plants. Cameroon has a lot of hydroelectric potential, but access to energy in the country's rural areas is still quite poor. The goal of this project is to analyze the technical and economic feasibility of a Micro Hydro Power Plant in BAKASSA, a rural hamlet in Cameroon's West Region, in order to contribute to the area's long-term development. According to the result of this research, this Micro Hydro Power Plants project can be built with a total power capacity of 97 kW. The capital cost was estimated to be 88,440,068 African Frank, making it a successful project with such a nine-year payback time.

This article of this [19], evaluated the possible operating of Photovoltaic system Grid linked system in the northern region in Africa, city of Tozeur in the South of Tunisia, this area is associated with High air temperatures in the summer and strong solar irradiation potential with actual data of the Tunisian load demand condition, energy prices, and solar system components that are simulated as per the Tunisian market. This research includes a technical feasibility. For this we have selected to work with one of the most effective tools for this purpose is HOMER software, with the creation of an excel software to model the effect of realistic PV generators either with or without energy storage unit. A Grid-connected PV system with a capacity of ten MW was designed and evaluated in this study at Tozeur. Homer Software and an excel spreadsheet were used to create the numerical simulation. With a payback time of twenty-one years and a cost of $0.81 USD/kWh, the system is cost effective.

The selected case study by the authors of [20], was the Giri village in North central Nigeria, a hybrid RES system consisting of a wind turbine, PV, battery, and diesel generator is proposed in this work. The system was modeled and simulated utilizing HOMER simulation program. The system's best design was determined by the lowest energy cost and net present cost. The first system is consisting of PV with diesel generator and battery storage system, the second is a PV with wind turbine, diesel generator, and battery storage system, the third is a PV with wind turbine and battery storage system, and the fourth is a PV with battery storage system only, that were modeled by HOMER to find the best solution. The hybrid PV with diesel generator and battery storage system is ecologically and economically feasible for energy generation in the Giri village community, according to the economic analysis and environmental impact assessment.

This study [21], looked at the techno-economic and impact on the environment of several off-grid solutions in six distant rural locations of Iran's East Azerbaijan state. All conceivable combinations of wind turbines, PV panels, and diesel generators were modelled and assessed in this work. HOMER software was used to determine the best system design from an economic, technical, and environmental standpoint. Economic indicators included net present value, cost of equity, initial capital cost, and operational cost, while yearly CO2 emissions were chosen as the most important indicator for a long-term viewpoint. From an ecological and financial standpoint, hybrid renewable energy systems have been the most suitable option.

This paper [22], gives a techno-economic analysis of off-grids in Colombia's non-interconnected zone. Optimal hybrid generating systems have been developed for six locations, taking into account the use of diesel generators, solar panels, hydraulic turbines, wind turbines, and batteries. The results demonstrate that by reducing the number of operational hours of the diesel generators and using demand-side control, net present cost values lower than the existing ones (fueled mostly by diesel) may be attained in virtually all situations. Nevertheless, the complexity of modifying customers' consumption habits limits demand-side management to a great extent. When the usable life and system costs are considered, the results demonstrate that lithium batteries can be a good alternative to lead-acid batteries. It is vital to note the optimization tactics may involve a demand-side management program to lower operating expenses.

The supply of produced electricity for Al Baha University in the Kingdom of Saudi Arabia was studied using computer-aided HOMER Software in five alternative configurations at autonomous and grid-connected modes in this study [23]. The climatic statistics in Saudi Arabia are studied by taking sun radiation, wind speed, and temperature into account. This research also includes the mathematical and economic considerations for the proposed system. The solutions under consideration include traditional grid, PV arrays, wind turbines, battery storage, and hybrid versions. The simulation outcomes show that the suggested Grid/PV combinations produce reduced energy costs for all chosen sites when compared to other setups. The other aspect of the evaluation is the environmental analysis, it also shows that the Grid/PV configurations have fewer impacts; the period of the study is twenty-five years.

This study [24], presents the design and economic analysis of a hybrid solar-wind and diesel generator power system for off-grid electrification in Ethiopia. The hybrid system was designed to provide reliable and sustainable electricity to a rural community. The authors analyzed the cost of the system and its performance in different scenarios, including varying wind and solar conditions. The results showed that the hybrid system was more cost-effective and reliable than a stand-alone diesel generator or a stand-alone solar-wind system. The authors concluded that the hybrid system could provide a sustainable and cost-effective solution for off-grid electrification in Ethiopia.

This study [25], conducted a feasibility analysis of a hybrid energy system for off-grid rural electrification in southern Pakistan. The hybrid system comprises solar panels, wind turbines, and diesel generators to meet the electricity demand of remote rural communities. The study analyzed the technical, economic, and environmental feasibility of the system, as well as the social impact on the rural communities. The results showed that the hybrid system is technically feasible and economically viable, with a positive net present value and a reasonable payback period. The study recommends the implementation of the hybrid energy system as a sustainable solution to the electrification problem in the rural areas of southern Pakistan.

The study [26], analyzed the technical and economic feasibility of a hybrid system comprising wind, solar, and biomass energy sources for a remote village in India. The results show that the proposed system could provide reliable and sustainable electricity at a lower cost than traditional diesel generators. Additionally, the study highlights the importance of integrating multiple renewable energy sources to improve system reliability and reduce the reliance on a single energy source. The study concludes that the implementation of integrated renewable energy systems could provide a cost-effective and sustainable solution for off-grid rural electrification in remote areas.

The study [27], proposes a hybrid renewable energy system (HRES) comprising a PV-biomass system for rural electrification in a remote region of Thailand. The aim of the study is to design and optimize the system from a technical, economic, and environmental standpoint. The results show that the system can provide electricity to the targeted households with an estimated annual energy yield of 1136 kWh. The optimized HRES includes a 2.6 kWp PV system, 0.5 kWp battery bank, and a 3.5 kW gasifier-based biomass system. The economic analysis shows that the HRES has a levelized cost of energy (LCOE) of 0.4 USD/kWh, which is lower than the LCOE of a diesel generator-based system. The study also conducts an environmental analysis, which indicates that the HRES reduces CO2 emissions by 0.46 tons per year compared to a diesel generator-based system. The study concludes that the PV-biomass off-grid HRES is a viable and sustainable option for rural electrification in the studied region.

The study [28], aims to perform an economic analysis of an integrated renewable energy system for electrifying remote rural areas with scattered populations. The study considers the use of various renewable energy sources such as solar, wind, micro-hydro, and biomass as the primary energy sources to produce electricity. The researchers used the HOMER software tool for optimization of the proposed system, and the results show that the integrated renewable energy system is the most cost-effective solution for providing electricity in remote rural areas. The system design includes a combination of solar, wind, micro-hydro, and biomass energy sources, and it can meet the load demand of rural areas at a lower cost than other available options. The study concludes that the integrated renewable energy system can be a sustainable solution for electrifying remote rural areas.

This study focused on conducting a feasibility analysis of a solar PV/biogas hybrid energy system for rural electrification in Ghana. The aim of the study was to evaluate the technical and economic feasibility of the hybrid system for providing electricity to rural communities in Ghana. The study employed a combination of field data collection and computer simulations to evaluate the performance of the system under different scenarios. The results showed that the hybrid system could provide a reliable and cost-effective source of electricity for rural communities in Ghana, especially in areas where grid extension is not economically feasible. The study recommended the adoption of the hybrid system as a viable solution for rural electrification in Ghana [29].

These studies [30], [31], provides a comprehensive review of the prospects for rural electrification using stand-alone and hybrid energy technologies. It examines the potential of renewable energy technologies such as solar, wind, hydro, and biomass, as well as hybrid systems that combine these technologies. The study analyzes the economic, social, and environmental factors that affect rural electrification and discusses the policy and regulatory frameworks that can support the adoption of renewable energy technologies. The review finds that stand-alone and hybrid energy technologies have the potential to provide sustainable and affordable electricity to remote rural areas, where conventional grid electricity is not available or not cost-effective. However, the success of rural electrification projects depends on various factors such as the availability of resources, the level of community involvement, and the adoption of appropriate business models. The study concludes that the integration of renewable energy technologies with conventional grid systems could provide a reliable and affordable solution to rural electrification.

This study [32], proposes an optimized off-grid microgrid based on biogas, solar, and hydro power for rural electrification. The research analyzes the energy requirements of a target village in Ethiopia and uses HOMER software to design and optimize the microgrid. The results show that the proposed microgrid has a levelized cost of electricity (LCOE) of $0.29/kWh, which is cheaper than other alternatives. Additionally, the microgrid has a lower carbon footprint and is more reliable than a diesel generator. The study concludes that the proposed microgrid can provide a sustainable and affordable solution for rural electrification in areas with similar characteristics.

These papers [33], [34], aim to investigate the feasibility and economic viability of utilizing renewable energy resources for off-grid energy systems. The first paper focuses on using renewable-based hydrogen for domestic energy in Italy, while the second paper investigates the economic feasibility of off-grid hybrid renewable energy resources. Both papers use techno-economic analysis to evaluate the feasibility of their proposed solutions. The first paper shows that renewable-based hydrogen has great potential for domestic energy systems in Italy, with potential economic benefits. The second paper concludes that off-grid hybrid renewable energy systems are economically viable and can provide reliable power to remote areas. Overall, both papers support the use of renewable energy resources for off-grid electrification and highlight the importance of economic feasibility in the implementation of these systems.

The paper [35], investigates the impact of using an integrated photovoltaic (PV) system for Avro City in Duhok, Iraq. The study is based on an energy audit conducted in the city to evaluate the energy demand of the households. The authors propose the integration of a PV system to the existing diesel generators to reduce fuel consumption and decrease the dependence on the national grid. The performance of the PV system is evaluated using simulation tools, and economic analysis is conducted to determine the feasibility of the proposed system. The results of the study showed that the integration of the PV system could reduce the reliance on diesel fuel and decrease greenhouse gas emissions. The economic analysis also indicates that the proposed system is economically feasible and could be implemented in similar off-grid areas

2.3. TECHNICAL SURVEY

The authors' goal in this work [36], is to develop and examine the technical and economical possibilities of small-scale off-grid PV. The research approach included a PVsyst software simulation with four aspects, namely two solar panel brands and two battery system brands. The design will generate 2 kWh/kWp/day of electrical energy with a total expenditure of less than 1- kVA generator during a twenty-four-year project term. For the system project time, the net present values in all variants are calculated. As a result, this system was deemed uneconomical since it did not produce a profit from employing a diesel generator or battery system. Nonetheless, off-grid solar power plants were more lucrative than generator or battery power sources charged by the State Electricity Enterprise.

In this research [37], the study of technical and economic feasibility studies of a PV solar production system was carried out in this research using a 100 kW PV power plant in Adana, Turkey. In the 100 kW PV power plant, the cost of energy production was determined at 0.14 Turkish lira/kWh. When electricity is generated from solar energy, the cost of production of electricity decreases, and energy savings are realized. The use of fossil fuels for power generation will be decreased significantly as a result of the energy savings. CO2 is the principal greenhouse gas that leads to climate change, as we all know. The combustion of fossil fuels increases the secretion of carbon into the atmosphere, causing CO2 concentrations to rise. As a result, CO2 emissions will be decreased by 119,830 kg per year.

A novel approach in this study [38], to optimize the performance of a PV system by employing a Model Predictive Control (MPC) strategy. The paper builds upon previous studies and highlights the limitations of traditional Proportional Integral Derivative (PID) control strategies in handling the nonlinearities and uncertainties inherent in PV systems. The authors demonstrate that the use of a Three-Level Neutral

Point Clamped (NPC) Inverter in combination with an MPC controller provides a more efficient, less complex, and higher performing solution for PV systems connected to the grid. The paper presents simulation results under different climatic conditions, showing that the MPC controller can achieve better control of the PV system compared to other control strategies. Overall, the paper makes a significant contribution to the growing body of research on PV systems optimization and is relevant to researchers, engineers, and practitioners working in the field of renewable energy.

An approach of this study [39], for optimizing the performance of a PV inverter using Proportional-Integral (PI) controllers and Pulse Width Modulation (PWM) techniques. The authors employ Particle Swarm Optimization (PSO) to obtain the optimal values of PI controller parameters that can reduce the total harmonic distortion and improve the inverter's power quality. The paper presents a comprehensive mathematical analysis of the proposed approach, including a detailed description of the PSO algorithm and its implementation. The authors also present simulation results that demonstrate the effectiveness of the proposed approach in enhancing the PV inverter's performance. The results show that the proposed method can achieve a significant reduction in harmonic distortion, improved power quality, and higher efficiency compared to other optimization methods. The paper's contribution lies in proposing a novel approach that combines advanced control techniques with optimization methods to improve the performance of PV inverters. This approach can help overcome the limitations of traditional control methods and improve the overall performance of PV systems. The paper is relevant to researchers, engineers, and practitioners working in the field of renewable energy and provides a valuable contribution to the research on PV inverter optimization.

A new approach in [40], for controlling the power flow of a PV system featuring both on-grid and off-grid modes. The authors use a hybrid control strategy that combines a Maximum Power Point Tracking (MPPT) algorithm and a Power Flow Control (PFC) algorithm. The MPPT algorithm maximizes the PV system's output power by tracking the maximum power point of the solar panel, while the PFC algorithm controls the power flow of the system between the grid and the battery bank. The paper presents a detailed mathematical analysis of the proposed approach, including the derivation of the MPPT and PFC algorithms. The authors also provide simulation results that demonstrate the effectiveness of the proposed approach in achieving power flow control under different operating conditions, including on-grid and off-grid modes. The results show that the proposed approach can effectively manage the power flow of the PV system while ensuring maximum power output and battery charging. The paper's contribution lies in proposing a novel approach that integrates two control algorithms to improve the performance of PV systems in both on-grid and off-grid modes. The proposed approach can be useful for designing more efficient and reliable PV systems for various applications. Overall, the paper provides a valuable contribution to the research on PV system control and is relevant to researchers, engineers, and practitioners working in the field of renewable energy. The proposed approach can help optimize the power flow and improve the performance of PV systems, which is crucial for the widespread adoption of renewable energy.

A new control technique to enhance power quality in decentralized microgrids operating in island mode in this study [41]. The proposed approach incorporates a power conditioning unit and a virtual impedance loop to improve voltage and frequency regulation, filter out harmonics, and mitigate transient disturbances. The authors provide a comprehensive mathematical analysis and simulation results to demonstrate the effectiveness of the proposed approach in improving the power quality of decentralized microgrids. The proposed technique can be useful for designing more efficient and reliable microgrids for various applications. The paper provides a valuable contribution to the research on microgrid control and is relevant to researchers, engineers, and practitioners working in the field of renewable energy. The proposed approach can help enhance the power quality and improve the reliability of decentralized microgrids, which is crucial for the widespread adoption of renewable energy in remote and off-grid areas.

A new standalone PV system based on a single-phase split-source inverter using MPC. The proposed system uses a predictive control algorithm to regulate the output voltage and frequency and achieve fast dynamic response. The paper provides a comprehensive simulation study that shows the effectiveness of the proposed system in regulating the output voltage and frequency under different operating conditions.

The paper's contribution lies in proposing a reliable and efficient solution for regulating the output voltage and frequency of standalone PV systems [42].

The author in [43], presents a detailed analysis of power losses in the inverter circuitry and conducts a comprehensive simulation study to evaluate the performance of the proposed algorithm. The simulation results show that the proposed algorithm achieves a significant improvement in efficiency by adjusting the duty cycle and frequency of the PWM signal based on the power level of the load. This paper's contribution lies in proposing a simple yet effective control algorithm for inverter-based LED lighting systems that can enhance efficiency at low power levels. This research is relevant to the field of power electronics and LED lighting systems and can be useful for researchers, engineers, and practitioners interested in improving the efficiency of inverter-based LED lighting systems. Overall, this paper provides valuable insights into the design and optimization of inverter-based LED lighting systems for low power applications.

A detailed analysis of technical challenges and solutions associated with integrating small-scale PV systems into the secondary distribution network in this study [44]. The author provides valuable insights into the impact of PV systems on grid stability, voltage regulation, and power quality, along with a discussion of regulatory policies and standards. The paper also compares various control strategies used for grid integration of PV systems and highlights key research gaps in this field. This paper offers an informative and insightful review of the technical and regulatory aspects of small-scale PV systems' integration into the secondary distribution network.

A comprehensive overview of techniques for reducing total harmonic distortion (THD) in solar PV systems. The authors analyze the different types of PV inverters and their impact on THD reduction, along with the effects of non-linear loads on system stability. The paper highlights existing challenges and opportunities for future research in this area, making it a valuable resource for researchers, engineers, and practitioners in the field of renewable energy systems [45].

A comprehensive review of biogas cleaning technologies for small-scale off-grid solid oxide fuel cell (SOFC) applications. The authors provide an overview of the current state of biogas cleaning technologies, including their performance, operating conditions, and limitations. The paper also includes an economic analysis of different biogas cleaning technologies, taking into account the capital and operational costs of each technology. The authors conclude that biogas cleaning technologies have the potential to significantly improve the performance and reliability of SOFC systems, while also reducing their environmental impact. However, the selection of the appropriate biogas cleaning technology depends on a variety of factors, such as the type and quality of the biogas feedstock, the required level of cleaning, and the available resources. The authors suggest that future research should focus on developing more efficient and cost-effective biogas cleaning technologies, as well as on identifying the optimal combination of biogas cleaning technologies for specific SOFC applications [46].

This study [47], provides an overview of the different control strategies that have been proposed for microgrids with PV-wind hybrid generation systems. The paper discusses the various control strategies, including conventional control methods such as PI control and advanced control methods such as MPC and fuzzy logic control (FLC). The authors highlight the advantages and disadvantages of each control method and discuss the key factors that affect the performance of microgrid control strategies, such as load variations, renewable energy source fluctuations, and communication delays. The paper also presents a comprehensive comparison of the different control strategies based on their complexity, efficiency, and adaptability to different operating conditions.

PART 3

METHODOLOGY

3.1. INTRODUCTION

Despite the fact that renewable energy sources are steadily gaining popularity on a worldwide scale, environmental problems and climate change continue to be major obstacles [48], [49]. The most prevalent environmental disasters include contamination, resource shortages, climate change, and ecological pollution. Ecological problems are the detrimental effects of human activity on the biosphere. Human destruction of the environment is a worldwide and ongoing problem [50]. There are several perspectives on how human activity affects the land. The major one is the 50-year-old temperature increase and global warming, which are mostly the result of human activity [51].

There was a gap that needed to be filled in this investigation based on earlier studies. While various economic studies for off-grid hybrid electrification structures with DG, PV, and grid supply have conducted, their authors have not concurrently and thoroughly performed a financial and environmental viability analysis for a single village for off-grid rural regions in the middle of Iraq. The main goal of this study is to investigate the ideal composition of contemporary renewable energy systems by studying a standalone hamlet in the Iraqi province of Kerbala. The research was carried out using three programs (MATLBAB, HOMER and MS-EXCEL). Additionally, beginning capital, energy costs ($/kWh), and net present cost (NPC) were taken into consideration as the optimization measures.

The optimization between the available resources is therefore taken into consideration as the foundation for the technological and engineering feasibility study of the project and the ensuing financial, economic, and social studies [52]. The decision is to cease working on the phases of the feasibility analysis following the market and look for alternative solutions if the market research's findings are not promising. Therefore, whether the project is for profit or for good deeds in the society, the first step in all phases of feasibility studies is to perform a market analysis [53].

3.2. ECONOMIC AND ENVIRONMENTAL ANALYSIS

HOMER software uses the actual discount rate to convert one-time charges and yearly costs. The "Nominal discount rate" and "Expected inflation rate" parameters are utilized by HOMER to compute the yearly real discount rate. In order to obtain discount factors and yearly costs from net present costs, HOMER applies the actual discount rate [53]. The formula utilized by HOMER to relate the nominal interest rate to the yearly real interest rate is shown below.

$$i = \frac{i' - f}{1 + f} \tag{3.1}$$

The nominal discount rate (i), which represents the rate at which money can be borrowed, and the expected inflation rate (f) are used by HOMER to determine the yearly real discount rate (i'). The actual discount rate is utilized by HOMER to convert one-time charges and yearly costs. The net present cost (NPC) is a representation of the system's life cycle cost, which is calculated by subtracting the present value of all revenues earned over the system's entire lifespan from the present value over all costs incurred during the same time period. HOMER determines the overall NPC by summing up all discounted cash flows for every year of the project's lifespan. This can be expressed mathematically as shown in Equ.3.5.

$$C_{NPC} = \frac{T_{AC}}{CRF} \tag{3.2}$$

T_{AC} is for total annualized cost ($/year), that is the summation of the yearly costs of every component, and CRF stands for capital recovery factor (See Equ.3.5), that is determined as follows in Equ.3.6.

$$COE = \frac{T_{AC}}{E_{pv}} \tag{3.3}$$

PV is one of the cleanest and environmentally friendly sources of energy. It has minimal to zero emissions of harmful gases such as CO2, CO, NOX, or SO2, making it an ideal alternative to traditional energy generation systems. Studies have shown that greenhouse gas (GHG) emissions from PV systems vary between 60.1-87.3 g-CO2, eq/kWh, depending on the installation techniques used. It is important to note that the manufacturing process of PV panels accounts for about 84% of the total energy consumption and GHG emissions. To calculate the reduction in CO2 emissions, Equation 3.7 is used. When considering the economic feasibility of investing in solar systems, two key indicators to consider are the internal rate of return (IRR) and the payback duration obtained from a suitable economic analysis. These metrics will help to ensure that the investment in solar systems is profitable.

$$CO_2(emission) = F_E \times AEP \times N \tag{3.4}$$

While; (AEP), the system's yearly energy output, (N), the number of years (F_E), and the emission factor (F_E) are all set at 0. 699 kg CO2-eq/kWh.

3.3. SOLAR RADIATION AND TEMPERATURE DATA

The daily solar energy average in Kerbala province exhibits fluctuations as illustrated in Figure 3.1. The maximum solar radiation occurs between 11:00 to 12:00 a.m., with a decline in the remaining hours. The level of irradiation is highest in summer and lowest in winter, with a maximum value of 1000w/m2 [13]. The average daily solar radiation plays a vital role in determining the size of the PV array. For this study, the temperature remains constant at 25Co.

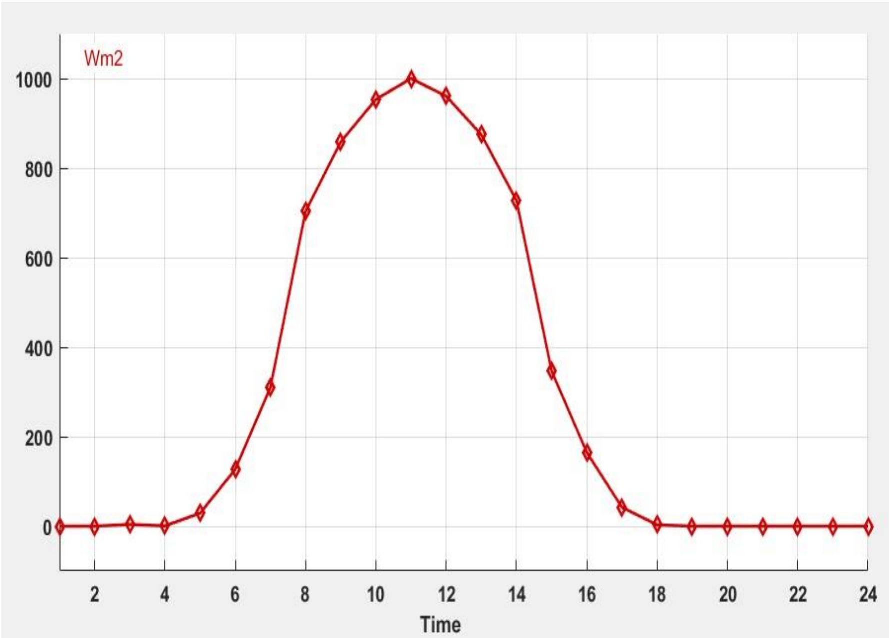

Figure 3.1. Daily irradiation curve.

3.4. PV SYSTEM TECHNICAL MODELLING

This study focuses on determining the optimal source of electricity supply based on cost, considering three options: diesel generator, PV system, and the main power grid. The proposed hybrid renewable energy system consists of a PV array, a DC/AC inverter, and a storage battery, with each component optimized based on various climatic data.

The PV array generates energy to fulfill power demands, and any excess electricity is either used to charge the energy storage or sent back to the main power grid. In this chapter, a detailed mathematical model for each component of the hybrid system is presented, along with an economic analysis of various grid-connected hybrid renewable energy system topologies. Figure 3.2 illustrates the proposed hybrid system that includes a PV system, battery, diesel generator, and power grid.

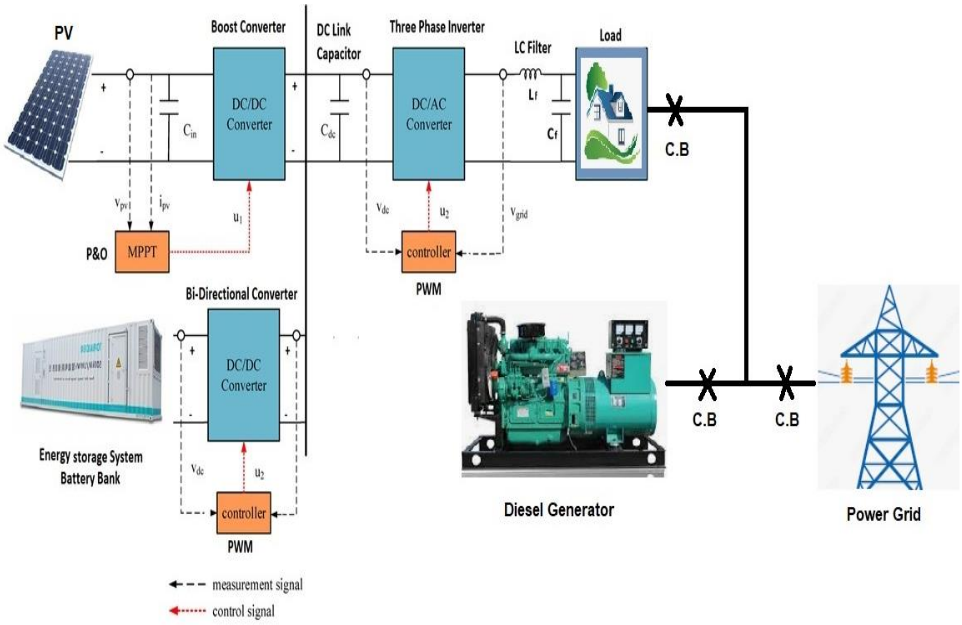

Figure 3.2. Proposed system configuration.

3.4.1. PV Panels

PV arrays are designed to convert solar energy into electrical energy. There are two types of solar energy that are commercially applied: solar photovoltaic panels (PV) and Concentrating Solar Powers (CSP). Since PV technology can be installed on residential rooftops, this article focuses on it. The PV panel converts solar photon energy into electrical energy using a photodiode. A typical PV system consists of a PV array, power electronics, and battery bank. A solar panel is constructed by connecting PV modules in series and/or parallel to achieve the required voltage and current. The number of solar panels needed can be calculated using Equation 3.8.

$$N = \frac{Total\ generated\ power\ (watt)}{Maximum\ power\ for\ each\ array\ (watt)} \tag{3.5}$$

The Photovoltaic system farms are made up of parallel and series panels that are integrated and organized in a particular way to generate the specialized voltage and current needed in the design stage (See Equ.3.9.)

$$N = Np \times Ns \tag{3.6}$$

Where; Np is number of primary turns, Ns is number of secondary turns;

$$V_{PV} = Ns \times V_{mppt} \tag{3.7}$$

$$I_{PV} = Np \times I_{mppt} \tag{3.8}$$

$$P_{PV} = V_{PV} \times I_{PV} \tag{3.9}$$

Where; V is the voltage, I is the current, and P is the power can be calculated (See Equ.3.10-3.12). I-V characteristics of the selected PV model and the maximum output power is shown in Figure 3.3.

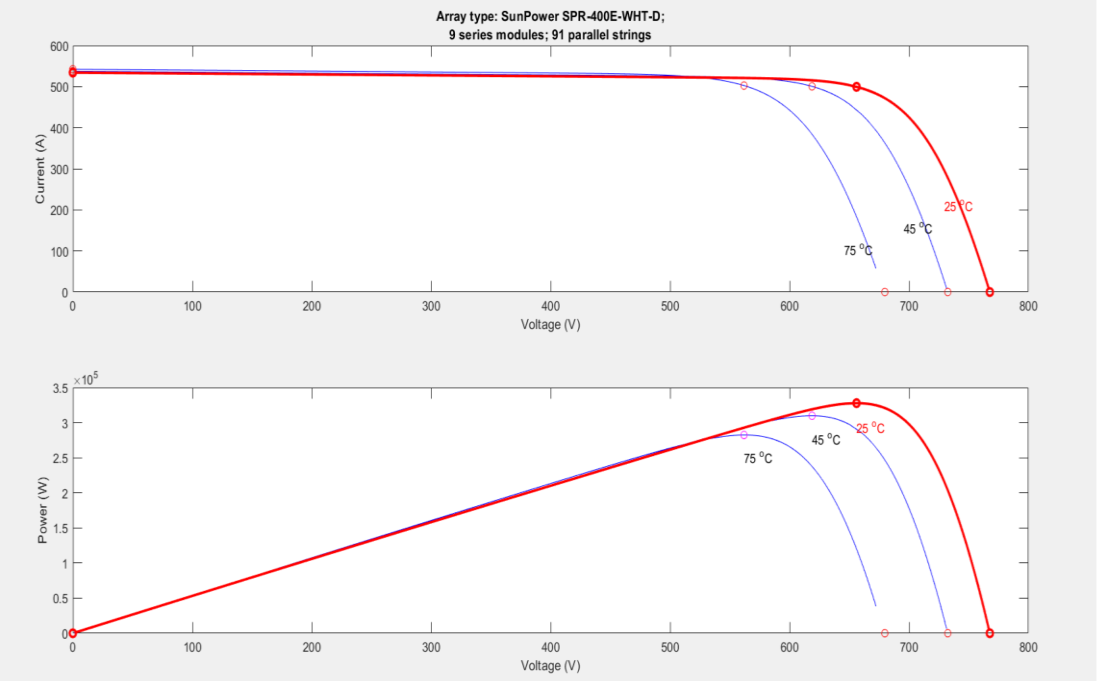

Figure 3.3. Characteristics of “SunPower SPR-400 E-WTH-D” PV model.

3.4.2. DC-DC Boost Converter Design

To maximize the power output of a PV system, a technique called Maximum Power Point Tracking (MPPT) is employed in boost converters. This involves adjusting the duty cycle (D) to extract the maximum amount of power generated by the PV system. Figure 3.4 illustrates the equivalent circuit of a step-up DC-DC boost converter used in this process.

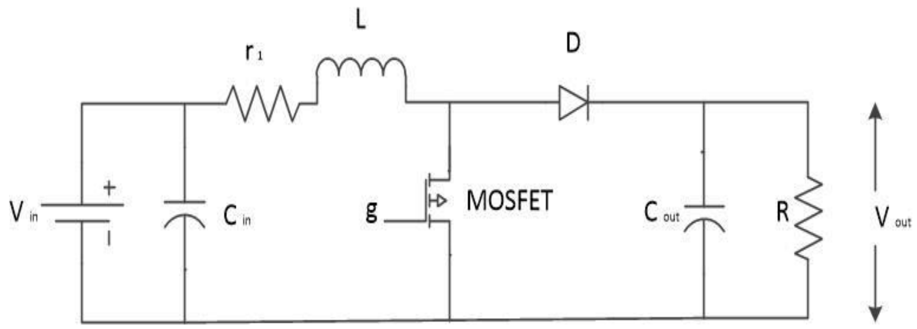

Figure 3.4. DC/DC Boost Converter.

Boost output voltage is assumed to be double of the input voltage to reduce the losses of high current in the circuit, and then the duty cycle (D) (See Equ.3.13)

$$D = 1 - \frac{V_{in}}{V_{out}} \tag{3.10}$$

Then the duty cycle is 0.18 or 18%. The inductor and the output capacitor of the boost converter are given (See Equ.3.14-3.15)

$$L_{min} = \frac{D\,(1-D)^2\,R}{2\,f} \tag{3.11}$$

$$C = \frac{D}{R\left(\frac{\Delta V_O}{V_O}\right)f} \tag{3.12}$$

3.4.3. Inverter Control

This study proposes a control approach for the inverter based on the virtual synchronous generators' two main relationships, namely (P-f) droop and (Q-V) droop. These relationships are considered as significant controls for stand-alone systems. In synchronous generators, the frequency is controlled by the input power to the prime mover, while the voltage is controlled by the injected reactive power from the excitation system. To regulate the inverter's output, which includes voltage and frequency, the active and reactive power must be adjusted with reference values.

Despite the construction differences between inverters and synchronous generators, the working principle remains the same, as explained in the subsequent sections. Figure .3.5 illustrates the proposed block diagram of the droop inverter, which comprises power calculation, droop controller, and inner loops for current and voltage.

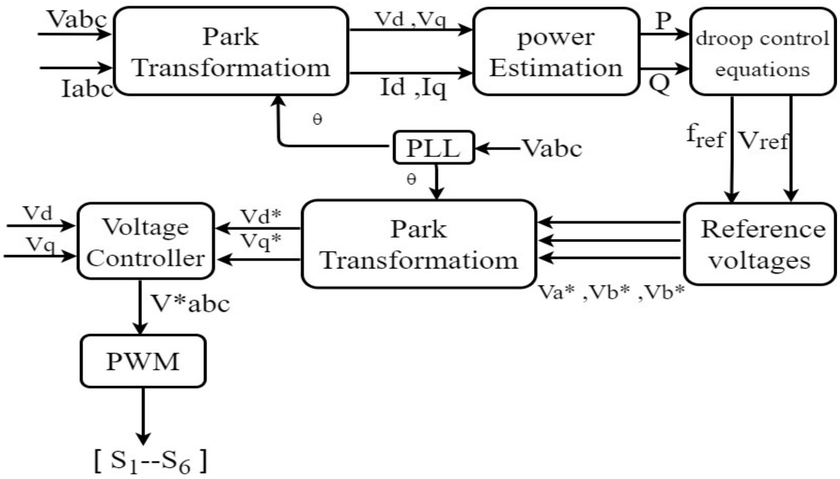

Figure 3.5. The proposed droop controller of the three-phase inverter.

3.4.3. Battery System

As depicted in Figure 3.6, a battery is an electrochemical device that utilizes oxidation-reduction processes to change chemical energy into electricity and electricity into chemical energy.

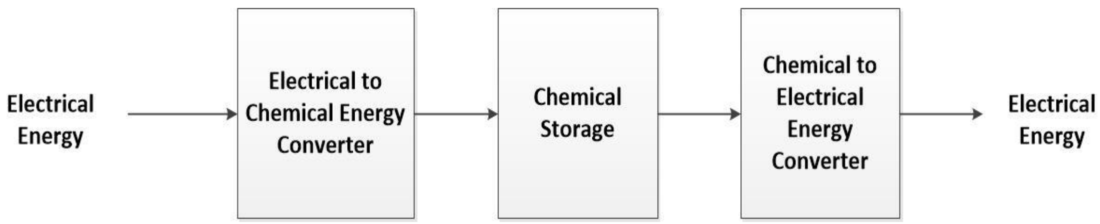

Figure 3.6. Principle of Battery.

There are several types of batteries that can be utilized in power systems, including lead acid batteries, nickel-cadmium (Ni-Cd) batteries, nickel-metal hydride (Ni-MH) batteries, lithium-ion batteries, and lithium polymer batteries [13].

Each type of battery has different technical specifications such as voltage, depth of charge, capacity, and life cycle. In practical applications, the battery is connected to a nonlinear circuit system that includes a terminal resistor (Rb) and a regulated voltage source (VESS). The regulated voltage of the energy storage system can be expressed mathematically (see Equation 3.16).

$$V_{ESS} = V_0 - V_p \left(\frac{Q}{Q - \int I_b \, dt}\right) + A \times exp\left(-B \int I_b dt\right) \qquad (3.13)$$

Where; A is the magnitude in the index field, (B) is the inverse of constant value in the index field, (Ib) is the charging/discharging current, (V_0) is the nominal voltage, (Vp) is the polarization voltage, (Q) is the battery capacity, $\int I_b dt$) is the actual charging and discharging capacity. The following is the general solution to determine the necessary battery capacity:

$$Battery\ Capacity = \frac{Power\ Required * duration}{Depth\ of\ charge * S.O.C} \qquad (3.14)$$

The state of charge (S.O.C) is a crucial factor in determining how much of the total capacity of a battery is available, while the depth of charge provides an indication of the amount of energy used from a battery in relation to its maximum capacity (refer to Equ.3.17). Furthermore, the life cycle of a battery refers to the maximum number of full charge-discharge cycles before its rated capacity drops below 80% of its specified initial capacity. To model the proposed PV system, the MATLAB Simulink program was employed, as illustrated in Figure 3.7.

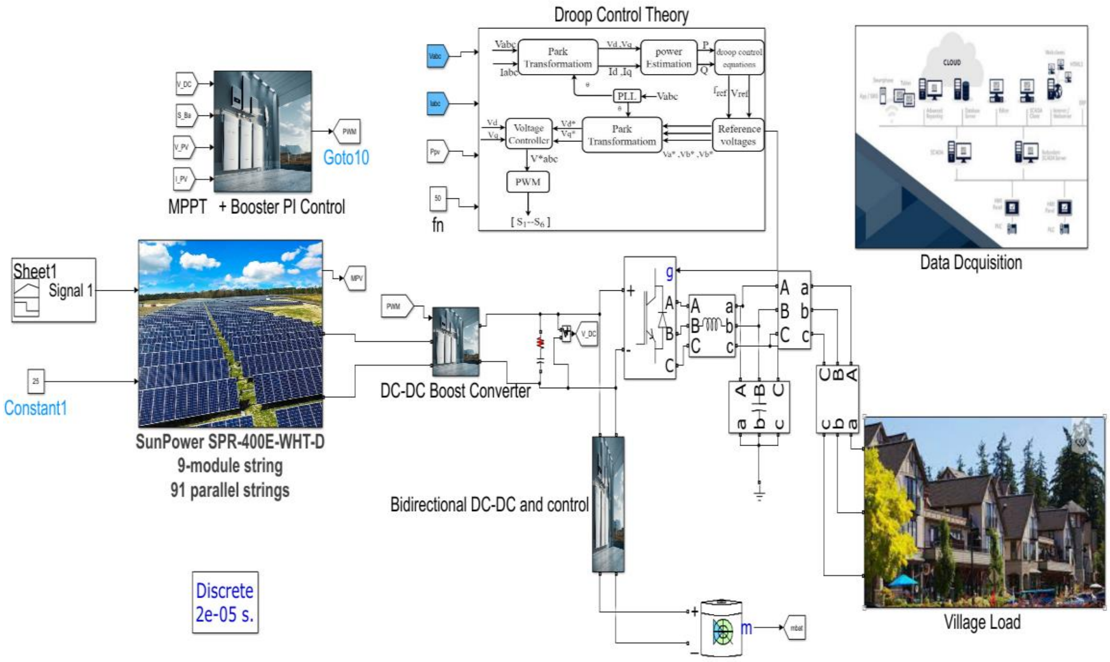

Figure 3.7. The proposed PV system using MATLAB program.

3.4.2. Tilt Angle

The tilt angle is an important factor in the design and installation of photovoltaic (PV) systems. It refers to the angle at which the PV panels are mounted relative to the horizontal plane. The tilt angle affects the amount of solar radiation that the panels receive and therefore has a significant impact on the performance of the PV system. The optimal tilt angle depends on several factors, including the latitude of the installation site, the season, and the local climate. The mathematical formula for calculating the optimal tilt angle is based on the latitude of the installation site and the time of year. In general, the tilt angle of a PV system should be set to maximize the amount of solar radiation that the panels receive throughout the year. The optimal tilt angle varies depending on the location of the installation site. For example, in regions closer to the equator, where the sun is more directly overhead throughout the year, a lower tilt angle may be more suitable. In regions farther from the equator, where the angle of the sun varies more throughout the year, a higher tilt angle may be more appropriate as shown in Figure.3.8;

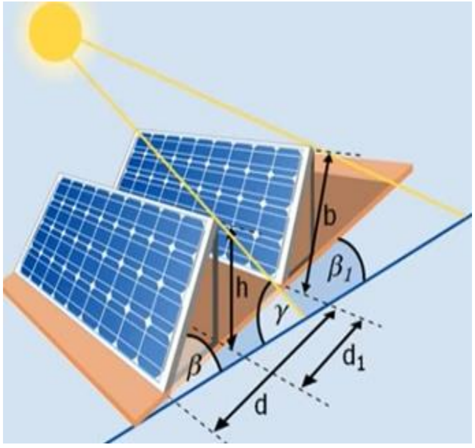

Figure 3.8. PV panels calculations [54].

It's worth noting that the optimal tilt angle is just a guideline, and actual installations may deviate from this angle due to site-specific factors such as shading, roof orientation, and aesthetic considerations. In some cases, it may be necessary to compromise on the optimal tilt angle to achieve other project goals or requirements.

The tilt angle is just one of many factors to consider in the design and installation of a PV system. Other important factors include the orientation of the PV panels, the size of the system, the type of PV technology used, and the system's electrical configuration. A well-designed and properly installed PV system can provide clean, renewable energy for many years to come, helping to reduce greenhouse gas emissions and promote a sustainable energy future. Table.3.3 presents tilt angle specifications by PV-Syst program;

Table 3.1. Tilt angle PV & PV installation specifications.

Solar cell type	**SunPower, SPR-P5-353UPP**
Cell orientation	330 cell (66*5)
Module dimension	(2384*1092*35) mm
Latitude Angle	30 Degree
No. of vertical modules	2
Length of edge	2 m
Axial angle	23.5 Degree
Gamma	36.5 Degree
Hight	1.996 m
Mounting support clearance	2.697439 m
Pitch	6.154613 m

3.5. LOAD PROFILE

The suggested hybrid system took into account the village's entire 24-hour load requirement of 50 houses and 2 additional municipal entities. The load profiles of the houses and healthcare facilities were generated in order to approximate the hourly energy consumption profile of a typical rural Iraqi family and healthcare institution. The load study also took into account the southern region's distant location's unique electricity demand profile. The loads typically included refrigerators, tiny fluorescent bulbs, fans, televisions, with other small equipment's for each home. The majority of the loads typically ran for a few hours each day, and a significant portion of the distant area's electrical demand was ascribed to lighting, cooling, and a few governmental loads. The village's highest load demand was experienced between the hours of 10:00 and 12:00 am, while its lowest load demand was experienced between the hours of 18:00 and 4:00 am, based on the previous information, the required Inverter size is calculated as shown in the Table.3.2.

Table 3.2. Load & Inverter Size Calculations.

Houses Number	**Maximum Load of Single House (Watt)**	**Full house load (Watt)**	**No. of Government Facility**	**Total Village Load (Watt)**	**Inverter Size (Watt)**
50	4,420	221,000	2	261,360	339,768

Figure 3.9 shows the daily proposed total load profile for the 50 homes with 2 governmental facilities loads.

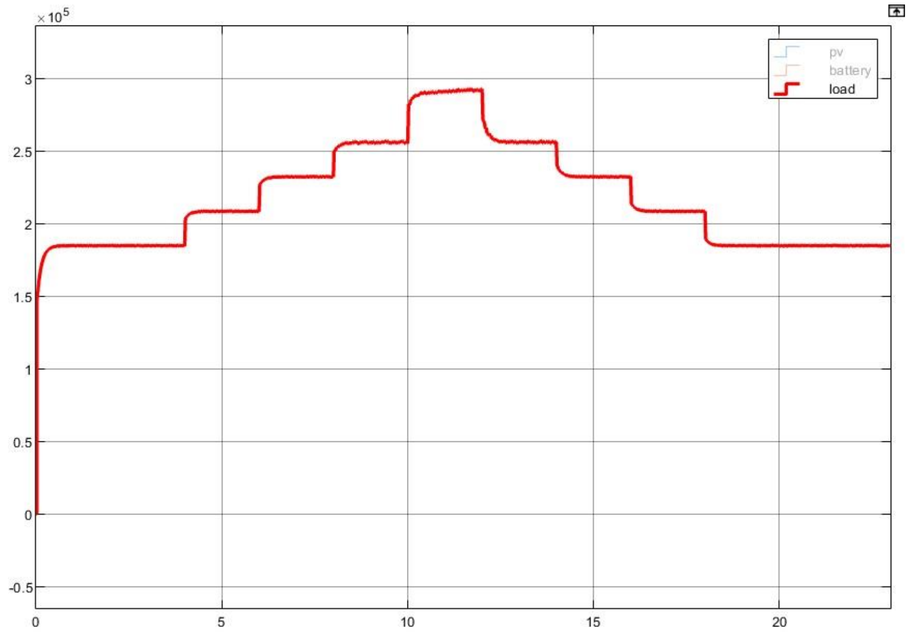

Figure 3.9. Proposed load profile.

PART 4

RESULTS AND DISCUSSION

4.1. INTRODUCTION

The establishment of a decentralized energy system in isolated rural regions with little to no connectivity to the power grid can enhance the standard of living for those there. In order to generate power, renewable energy technologies might be crucial, as expanding the grid or employing diesel generators is not a financially viable alternative. This study's primary objective is to examine the optimum structure of modern renewable energy systems by focusing on a small hamlet in the Kerbala district of Iraq. Three different approaches to providing a remote village with electricity were compared on a technical, physical, and environmental level. The first method involved connecting the village to the national electricity grid; the second involved using diesel generators, and the third involved using solar energy.

Three programs were used in the study (MATLAB, HOMER, and PVsyst) for evaluations including further optimization methods, initial capital, energy expenses ($/kWh), and NPC were taken into account. While keeping in mind the limitations of emissions of environmental pollutants, our goal was to achieve electrification at the lowest possible cost. In this study, the hybrid optimization of multiple energy resources (HOMER) modeling program was used to examine both the technical specifics and the economic viability of establishing such a power system.

4.2. ECONOMIC ANALYSIS

Economic analysis is a method used to compare the costs and benefits of different systems. In the case of energy systems, such as PV (photovoltaic) systems, diesel generators, and the national grid, economic analysis can help determine which system is the most cost-effective option. To conduct an economic analysis of these three energy systems, two key costs are typically considered: initial cost and 25-year cost. Initial cost refers to the cost of installing the system, while 25-year cost refers to the total cost of owning and operating the system over a 25-year period.

Diesel generators are a non-renewable energy option that generates electricity from diesel fuel. The initial cost of installing a diesel generator is often lower than that of a PV system or connecting to the national grid. However, diesel generators have higher fuel costs and maintenance costs, resulting in a higher 25-year cost. Overall, an economic analysis can help determine the most cost-effective energy system for a particular location and usage scenario.

4.2.1. HOMER Pro

To assess the feasibility of a hybrid energy system and optimize its layout, the team used HOMER software. This powerful program is well-suited for designing, scaling, and planning hybrid renewable energy systems by assessing their techno-economic viability. By minimizing the objective function of the constraints, the team aimed to optimize the system configuration, with the Net Present Cost (NPC) over the lifespan of each component serving as the key metric of interest. NPC represents the present value of all installation and operation costs for the equipment over its lifetime.

To conduct the simulation, the team considered the availability of resources at the chosen location and the load profile. Based on a techno-economic and environmental analysis that was tailored to the selected location of the hamlet in Kerbala, Iraq, the HOMER simulation program was used to identify the optimal design for a hybrid energy system. The team conducted a comparative study, comparing different energy source combinations, including a standalone diesel generator and connection to the national electrical grid. The team had already proposed and examined various hybrid systems, but they only considered the design configuration ideas, specifically the various ways in which different energy resources could be integrated.

To effectively manage the feasibility study and improve micro-grid systems before installation, HOMER completes three crucial steps: running simulations, conducting sensitivity analysis, and optimizing the modeled network. The software interface enables easy input of electricity usage data, while the software's powerful tools are used to analyze the hybrid microgrid system.

The hybrid renewable system can be broadly categorized into three basic equipment categories: demands, elements, and grids. In this instance, the elements include PV, grid, batteries, and converters, while the electric load serves as the demand.

The HOMER-modeled technology was skillfully tailored to meet the specific needs of the existing system. Appropriate constraints were employed for the sensitivity analysis based on the system requirements for life cycle cost analysis. Following the comprehensive HOMER-based research, a post-analysis was conducted to generate a final conclusion, which took into account the cost of market energy. Figure 1.1 effectively illustrates the remarkable features of HOMER.

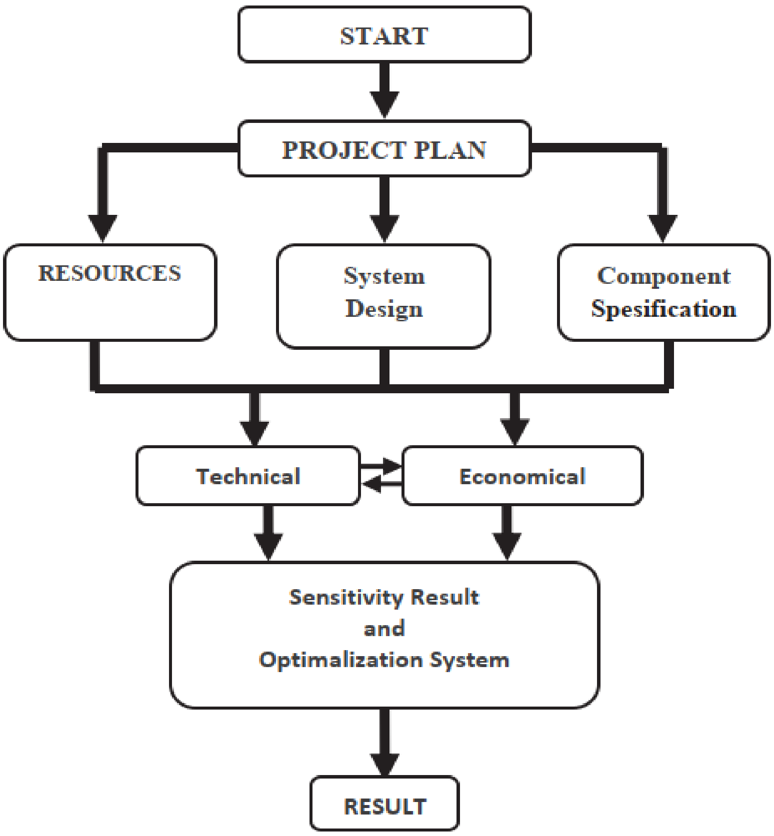

Figure 4.1. Steps of HOMER software.

Figure 4.2. shows the input / output parameters of the HOMER software, the inputs are: load, RES, components parameters, and optimization parameters, on the anther hand the output which are: optimal configuration, total capital cost, net present cost, fuel cost, cost of energy, renewable function, excess energy.

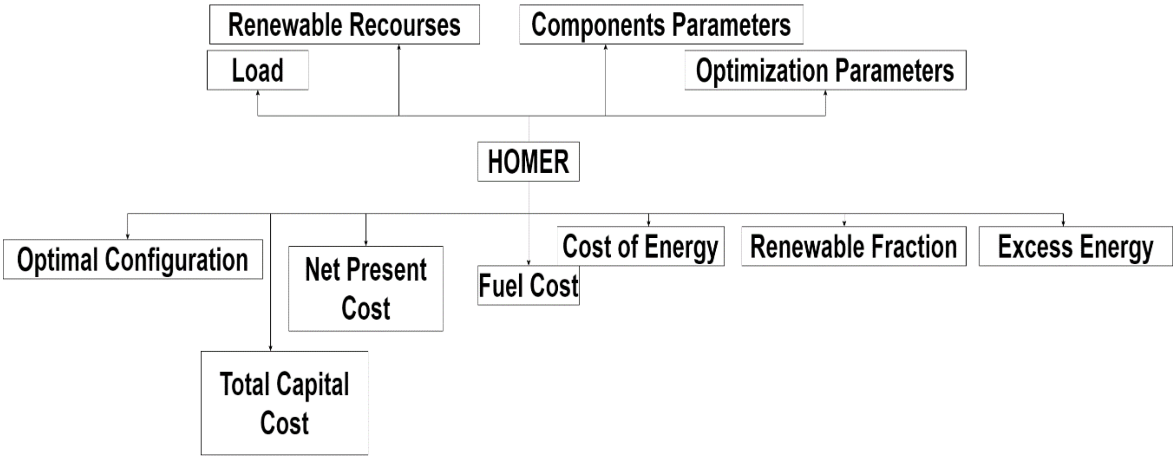

Figure 4.2. Input / Output HOMER parameters.

4.2.2. Generator Diesel

The economic analysis of the diesel generator system encompassed two main components, namely the initial cost and the total cost over a 25-year period. In comparison to photovoltaic (PV) systems and the national grid, the diesel generator system was found to have the lowest initial cost. However, over the 25-year period, the diesel generator system exhibited the highest total cost, making it less cost-effective than the PV system and national grid. This finding holds true if the factors of environmental damage and off-grid scenarios are not considered.

The analysis involved two generators, each with a power capacity of approximately 350 KVA. The workload was distributed between the two generators over the required period, and maintenance costs were factored in. The results of the economic analysis are depicted in the table 4.1. However, these findings highlight the importance of conducting economic analyses to determine the most efficient energy system in a given location and usage scenario.

Table 4.1. Diesel Generator cost Calculations.

Cost of Diesel Generator					
Size of the Generators	No. of Generators	Price of One Generator ($)	Total ($)		
350kVA	2	42000	84000		
Generator Type	Period	Oil Consumption	Consumption (L/year)	Price Per Year $	Total Price ($)
1	6:00 am-6:00pm	54 L/h	236,520	73,321	1,833,030
2	6:00 pm-6:00am	37 L/h	162,060	50,239	1,255,965
		Sum	398,580	123,560	3,088,995
Total Price of Generator	Replacement ($)	Per One Year ($)	Per 25 Years ($)		
	42000	207,560	3,130,995		

4.2.3. National Grid

The economic analysis conducted in this study involved a thorough examination of the cost implications of connecting the village to the national grid. Specifically, the analysis focused on the scenario where the village is located 20 km away from the national grid, and the initial costs required for electricity supply to the village were carefully calculated.

It is worth noting that this scenario is only deemed cost-effective if there are few isolated villages and the national grid has surplus capacity. In such cases, connecting to the national grid may prove to be an attractive option for electricity supply. However, if there are too many isolated villages, or the national grid is already operating at full capacity, the costs of connection may be prohibitive. Table 4.2. presents the initial cost of national grid.

Furthermore, the economic analysis also considered the total cost over a 25-year period, which included the price per kilowatt-hour (kWh) of electricity. This approach provides a more holistic and accurate assessment of the long-term costs associated with connecting to the national grid.

In summary, the economic analysis conducted in this study provides valuable insights into the most cost-effective energy system for a particular location and usage scenario. The findings can inform decision-making in the energy sector and help identify the optimal solution that balances cost and environmental sustainability.

Table 4.2. National Grid initial cost calculations.

	Constant Cost							
	Material	No.	Unit	Price with instillation cost		Test cost		Total price
				ID	$	ID	$	
1	Lattice pole 11KV with accessories	140	number	800000	540.54	150000.00	101.351351	75777.02703
2	Pole with accessorries 11 KV	540	number	525000	354.73	540000	364.864865	191918.9189
3	Low voltage lattice pole	10	number	600000	405.41		0	4054.054054
4	Low voltage pole	40	number	375000	253.38		0	10135.13514
5	Alminume wire 120 mm	67000	meter	2500	1.69	25000	16.8918919	113192.5676
6	Twisted cable (3*120+70+16)	2000	meter	10000	6.76	50000	33.7837838	13547.2973
7	Cable (1*150)	160	meter	35000	23.65	50000	33.7837838	3817.567568
8	On load cut off	1	number	3500000	2364.86	100000	67.5675676	2432.432432
9	Link fuse (cut out)	1	set	150000	101.3513514	100000	67.5675676	168.9189189
10	Copper wire (35mm)	20	meter	9000	6.081081081	35000	23.6486486	145.2702703
11	Pin insulator	600	number	12000	8.108108108		0	4864.864865
12	Disk insulator	240	set	45000	30.40540541		0	7297.297297
13	Transformer (250KVA)	1	number	9000000	6081.081081	250000	168.918919	6250
14	Circuit breaker	2	number	600000	405.4054054	125000	84.4594595	895.2702703
15	Link fuse base	1	number	150000	101.3513514		0	101.3513514
16	Transformer base	1	number	200000	135.1351351		0	135.1351351
17	Earth rod	1	number	60000	40.54054054		0	40.54054054
18	Terminal connection (AL-AL)	1700	number	3000	2.027027027		0	3445.945946
19	Terminal 150mm	40	number	4000	2.702702703		0	108.1081081
20	Terminal 50mm	15	number	1800	1.216216216		0	18.24324324
21	Trasformer(400KVA)	2	number	1250000	844.5945946	250000	168.918919	1858.108108
22	Circuit breaker	2	number	700000	472.972973	200000	135.135135	1081.081081
23	Link fuse(cut out)	2	number	225000	152.027027		0	304.0540541
24	Transformer base	2	number	150000	101.3513514		0	202.7027027
25	Earth rod	2	number	60000	40.54054054		0	81.08108108
26	Three phase smart meter	2	number	127000	85.81081081		0	171.6216216
27	Suspension hock	60		5000	3.378378378		0	202.7027027
28	Suspension clamp	20		10000	6.756756757		0	135.1351351
29	Connector big size	24		4000	2.702702703		0	64.86486486
30	House connection connector	40		6000	4.054054054		0	162.1621622
31	Concrete	250	cube meter	100000	67.56756757		0	16891.89189
32	Single phase smart meter	50	number	80000	54.05405405		0	2702.702703
	Total							462204.05

4.2.4. PV System

The PV system stands out as the most expensive initial cost, yet its total cost over 25 years proves to be the best affordable. Notably, this scenario boasts of zero environmental harm - a crucial distinction for numerous isolated villages without access to the national electric grid. Furthermore, the Iraqi national grid grapples with a host of issues, particularly concerning demand and supply, which this thesis seeks to address. As illustrated in Table 4.3, the PV system specifications have been meticulously determined based on precise load and demand calculations.

Table 4.3. General PV system specifications.

Total Energy Consumed (Wh/day)	1910440		
			Series
Required Energy From PV Panels (Watt)	477610	No. of PV Panels	885
Total Capacity of the Battery (Ah)	161691	No. of Battery	539

One must not underestimate the exceptional suitability of Iraq's environmental conditions for PV systems, as previously emphasized, owing to the region's high-quality climate. The scientific and economic precision demanded in analyzing the viability of PV systems necessitates meticulous attention to detail. Hence, Table 4.4 meticulously outlines the initial cost analysis of PV systems, leaving no stone unturned.

Table 4.4. PV system initial cost calculations VS specifications.

Solar Energy Cost				
	Solar Ceils Specifications			
1	Size of the Cell (Watt)	Price of Single One ($)	No. of Ceils "PV"	Total Price of PV-Array ($)
	540	200	886	177200
	Battery Specifications			
2	Size of Battery (Ah)	Price of Single One ($)	No. of Batteries	Total Price of Batteries ($)
	300	200	540	108000
3	Inverter Specifications			
	Size of the Inverter (Kw)	Price of Single One ($)	No. of Inverters	Total Price of Inverter ($)
	50	8000	7	56000
4	System Support Compon	60000		60000
	Total PV-System Cost ($)			401200

To provide a comprehensive cost assessment, it is imperative to incorporate the expenses incurred in maintaining and replacing components with shorter lifespans, including batteries and inverters.

As depicted in Table 4.5, the total cost of a PV system has been meticulously calculated, taking into account all associated costs.

Table 4.5. PV System total cost calculations VS specifications.

Replacement			
	Lifetime (Yrs)	No. of Times	Total Price ($)
Battery	5	4	432000
inverter	15	1	56000
Total Cost With lifetime 25 Year ($)			488000
	Initial Cost ($)	Replacement Cost($)	Total Cost ($)
	401,200	488,000	889,200

4.2.5. Final Economic Analysis

The economic analysis of providing electricity to isolated villages in Iraq was conducted by considering prices and characteristics specific to the country, while taking into account the currency difference between the Iraqi dinar and the US dollar and the annual inflation rate. The analysis produced an initial cost estimate for each option, and it revealed that while diesel generators were the least expensive option, they also had the highest environmental impact and long-term costs due to the ongoing costs of fuel and maintenance. In contrast, PV systems emerged as the most suitable option due to the favorable environmental conditions in Iraq, the large number of isolated villages, and the challenges faced by the national grid in terms of supply and demand.

The economic analysis was carried out both manually and by utilizing the HOMER program, which produced similar results. However, due to the unique conditions in Iraq, some differences emerged between the manual and program calculations, which required careful consideration. Table 4.6 and Figure 4.3 provide a comprehensive overview of the economic analysis, including the initial cost, total cost over 25 years, and environmental impact for each option.

Table 4.6. HOMER VS Manual final economic analysis calculations.

	Final Comparison					
	Grid Manual	Grid Homer	Generator Manual	Generator Homer	PV System Manual	PV Homer
Initial Cost Per One Year ($)	530,890	550,848	207,560	124,286	401,200	340,037
Final Cost Per 25 Year ($)	2,179,355	2,182,843	3,214,995	3,107,163	889,200	558,939

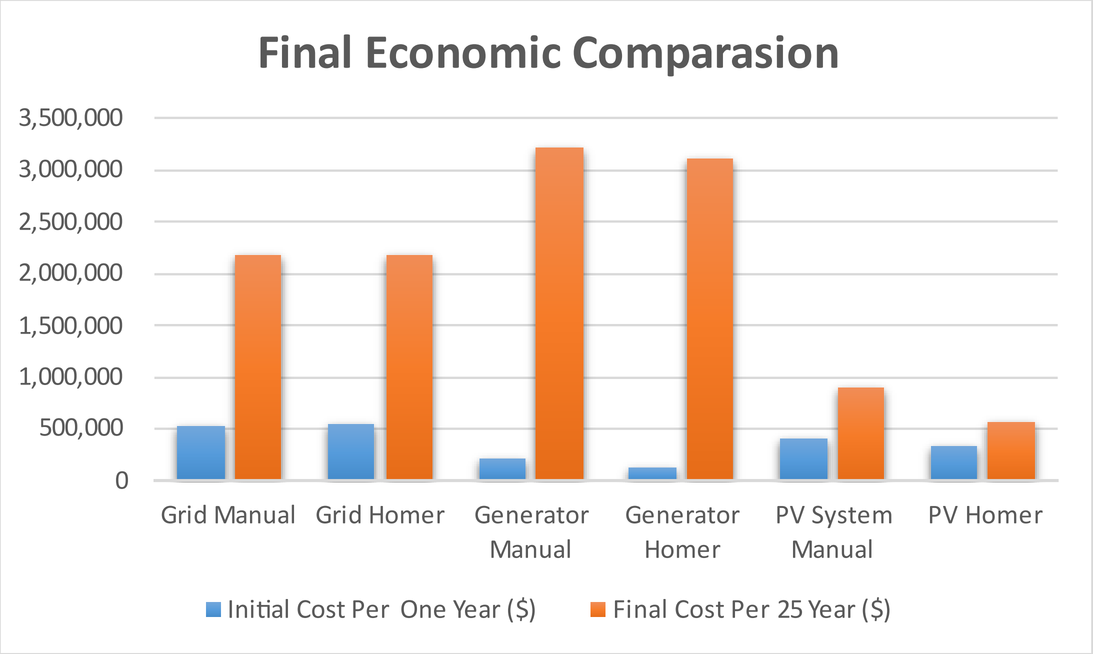

Figure 4.3. HOMER VS Manual final economic analysis chart.

Overall, the analysis highlights the importance of taking a sustainable and long-term approach to providing electricity to isolated villages in Iraq. While diesel generators may seem like a cost-effective option in the short term, their long-term costs and environmental impact make them an unsustainable choice. On the other hand, PV systems offer a sustainable and eco-friendly solution that is well-suited to Iraq's environmental conditions and the challenges faced by the national grid.

4.2.6. Levelized Cost of Electricity

The levelized cost of electricity (LCOE) analysis conducted using the HOMER program has revealed that PV systems are the most cost-effective option, with an LCOE of 0.02, while the national grid has an LCOE of 0.16, and diesel generators have the highest LCOE of 17.83.

This analysis underscores the significant economic benefits associated with deploying PV systems to provide electricity to isolated villages in Iraq. Not only do PV systems have the lowest LCOE, but they also offer sustainable and eco-friendly operation and can function independently of the national grid, which is especially crucial given the challenges the grid faces with regard to supply and demand. In contrast, the high LCOE associated with diesel generators highlights their significant long-term costs and environmental impact, despite their short-term cost-effectiveness.

This analysis serves as a reminder of the importance of taking a sustainable and forward-thinking approach to the provision of electricity in Iraq. By leveraging the favorable environmental conditions in the country and adopting technology such as PV systems, it is possible to build a more sustainable and resilient energy infrastructure that will benefit both the environment and the economy in the long run.

4.3. PV SYSTEM MATLAB/SIMULINK ANALYSIS

Based on the economic analysis, the implementation of PV systems was found to be the optimal scenario. To ensure the successful implementation of this system, MATLAB/Simulink was utilized as a powerful and effective environment for the implementation of stand-alone load PV systems.

The implementation was based on the same specifications that were considered in the economic analysis, further ensuring the accuracy and reliability of the implementation. By utilizing this approach, the implementation of the PV systems can be expected to be efficient and successful, leading to sustainable and cost-effective electricity provision in the target area. To ensure efficient and sustainable electricity provision in isolated villages, it is crucial to have a well-designed and implemented PV system. The backbone of any PV system is the MPPT algorithm, which is responsible for maximizing the amount of electrical power that can be drawn from the system. In this implementation, MATLAB/Simulink was used as a fertile and efficient environment to design and simulate the PV system. Figure 4.4. presents the (voltage, current, and power) of PV system.

To further enhance the performance of the PV system, power converters are used to regulate the flow of energy. Specifically, the DC-DC Booster plays a critical role in reducing the voltage before reaching the inverter, thereby ensuring that the system operates at optimal levels. Any excess energy is stored in batteries, which also require a power converter to regulate the charging process. In this implementation, the diode is replaced with a transistor, which allows for precise control over the charging process through a PI controller. Figure 4.5. presents (voltage, current, SOC, and power) of the battery.

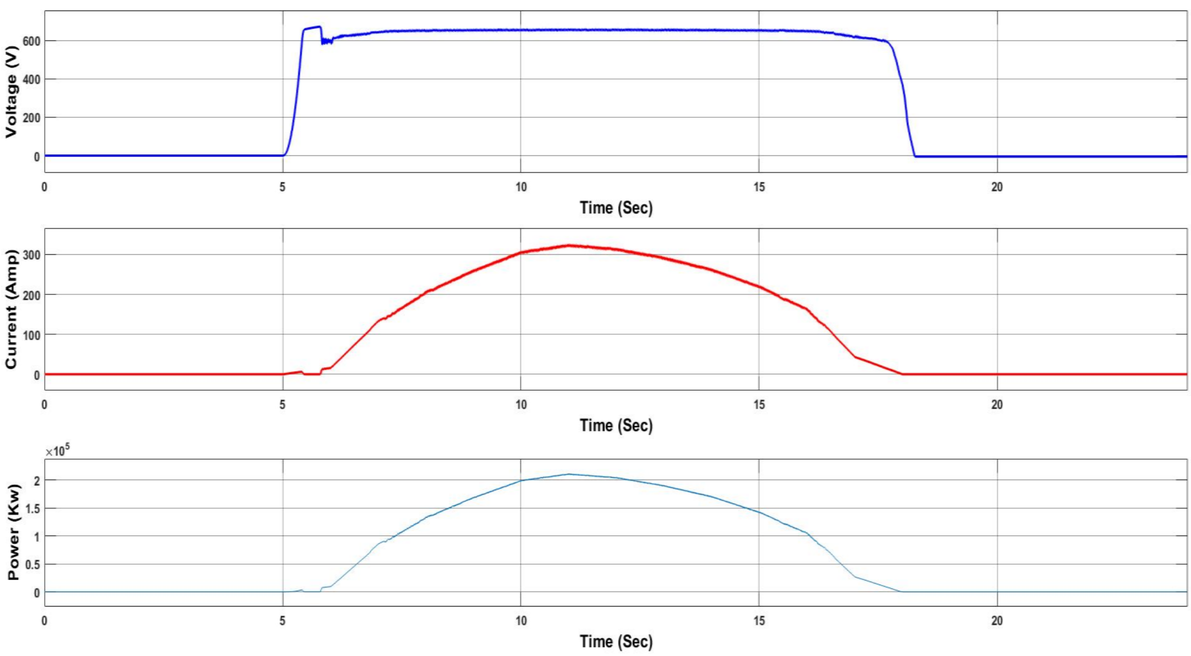

Figure 4.4. PV system voltage, current, and power.

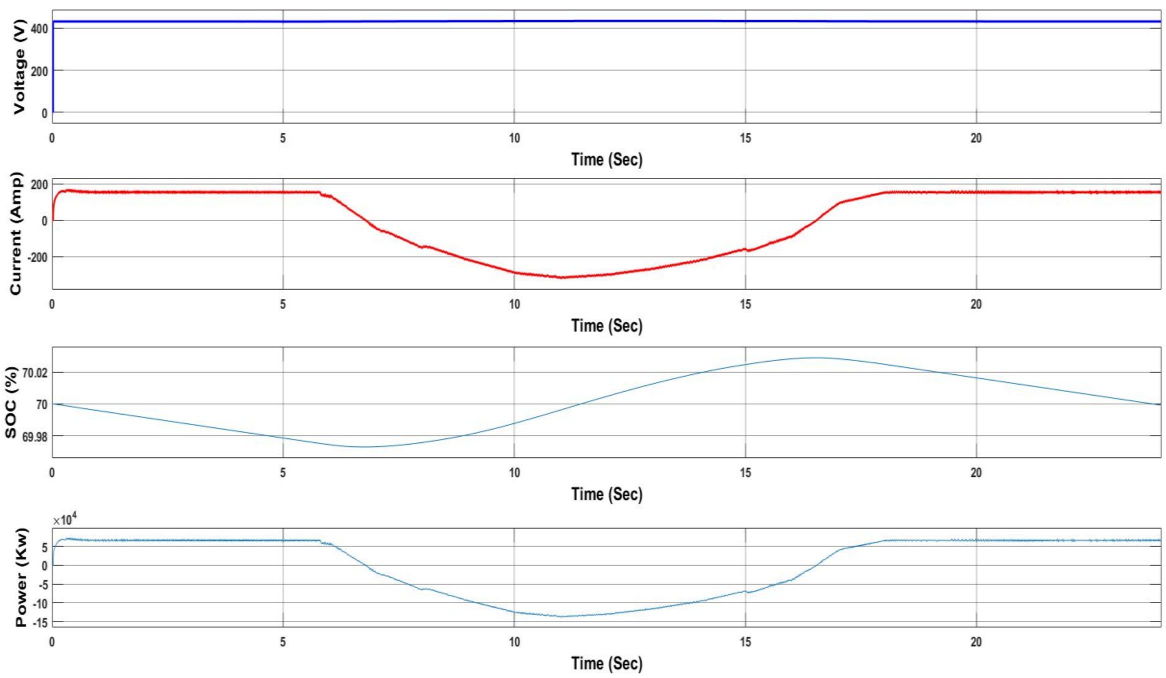

Figure 4.5. PV system (voltage, current, SOC, and power).

With all these components working together seamlessly, the PV system implemented through MATLAB/Simulink offers a reliable, efficient, and effective solution for sustainable electricity provision in isolated villages. By adopting this technology, communities can enjoy the benefits of reliable electricity provision while reducing their reliance on traditional energy sources, which are costly and unsustainable.

A critical aspect of this project is the intricate process of controlling the inverter that supplies power to the load. The success of the system relies on highly efficient and reliable load control, which requires the use of complex algorithms. The implementation of the drop theory method in this project has proven effective. This method is based on the Park-Clark transformation theory of real power and reactive power, with the addition of an LC filter inverter to minimize total harmonic distortion (THD). The drop theory method offers a sophisticated approach to inverter control, ensuring optimal performance and reliability of the system in providing sustainable electricity to isolated villages. Figure 4.6. presents (voltage, current, and power) of the load which is the village.

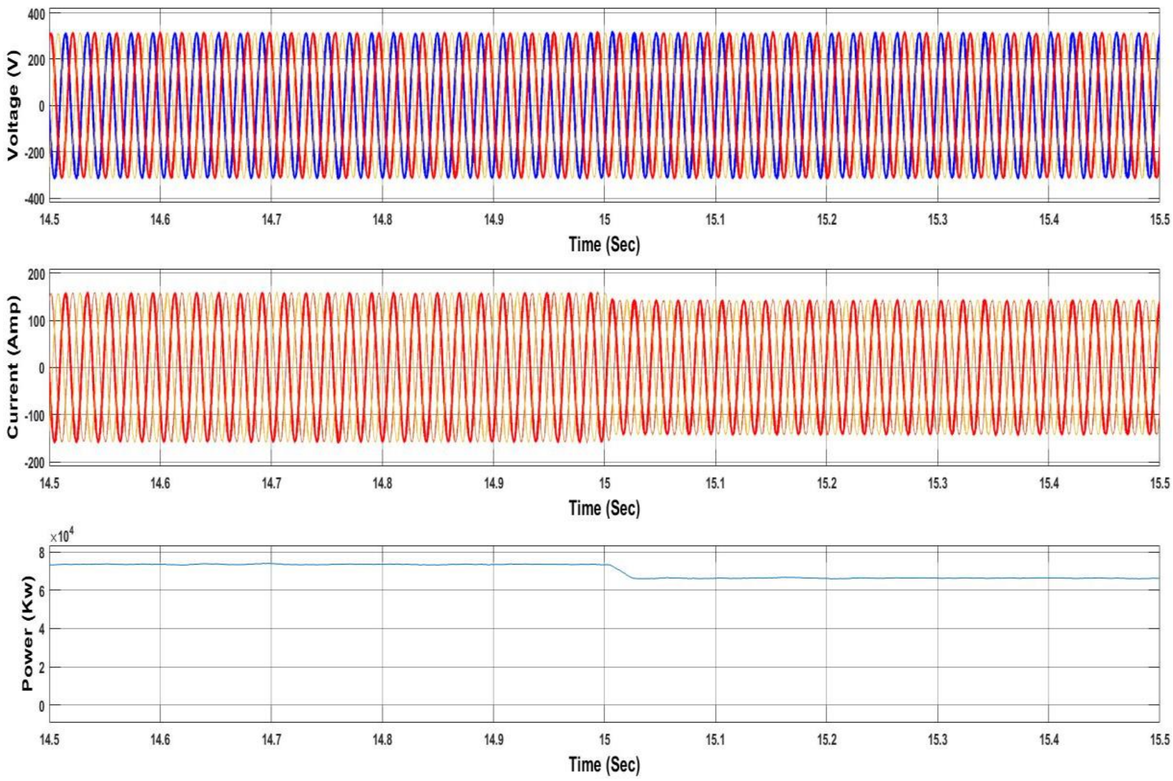

Figure 4.6. Village load (voltage, current, and power).

The simulation of the implemented system demonstrates its remarkable efficiency in supply and tracking, coupled with a significant reduction in Total Harmonic Distortion (THD) in the supply and demand between the load, PV system, and batteries, as depicted in Figure 4.7. The graph clearly displays the power distribution for each component - the load, PV system, and batteries. Furthermore, Figure 4.8 illustrates the energy flow between the load and PV system, highlighting the system's ability to efficiently manage and distribute energy. These visual representations showcase the system's exceptional performance and its potential to provide sustainable and reliable electricity provision in isolated villages.

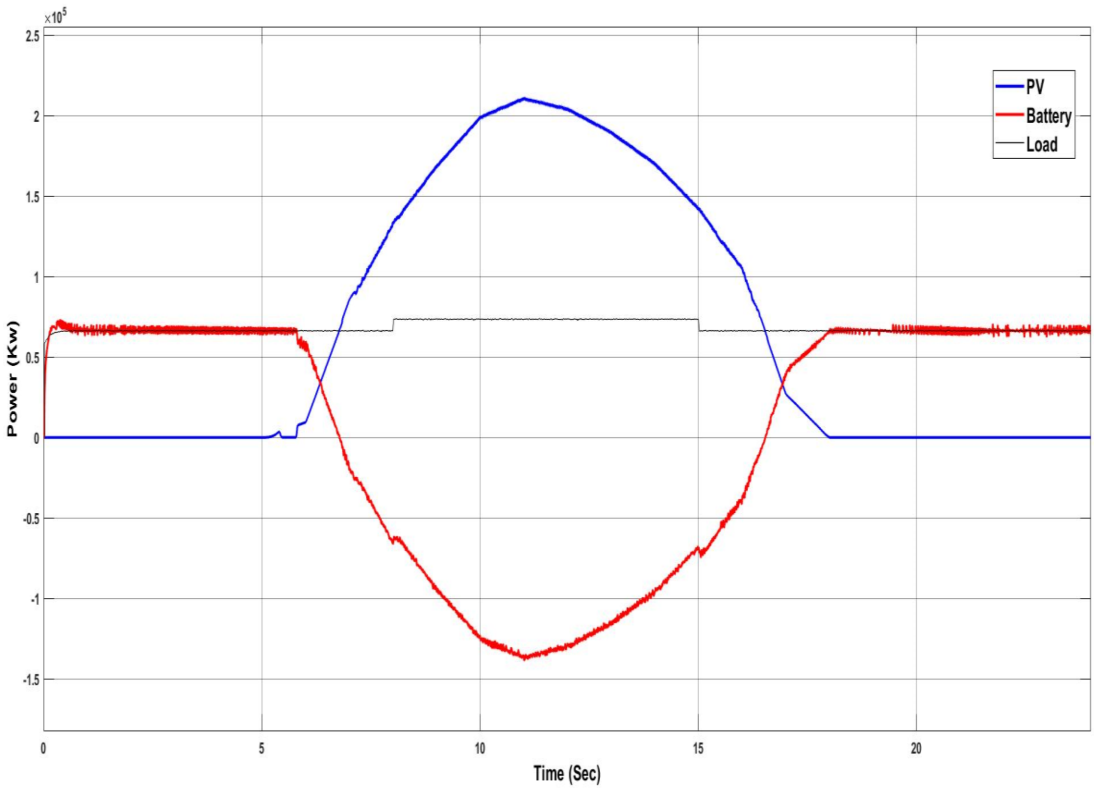

Figure 4.7. Power of (PV, Battery, and Load).

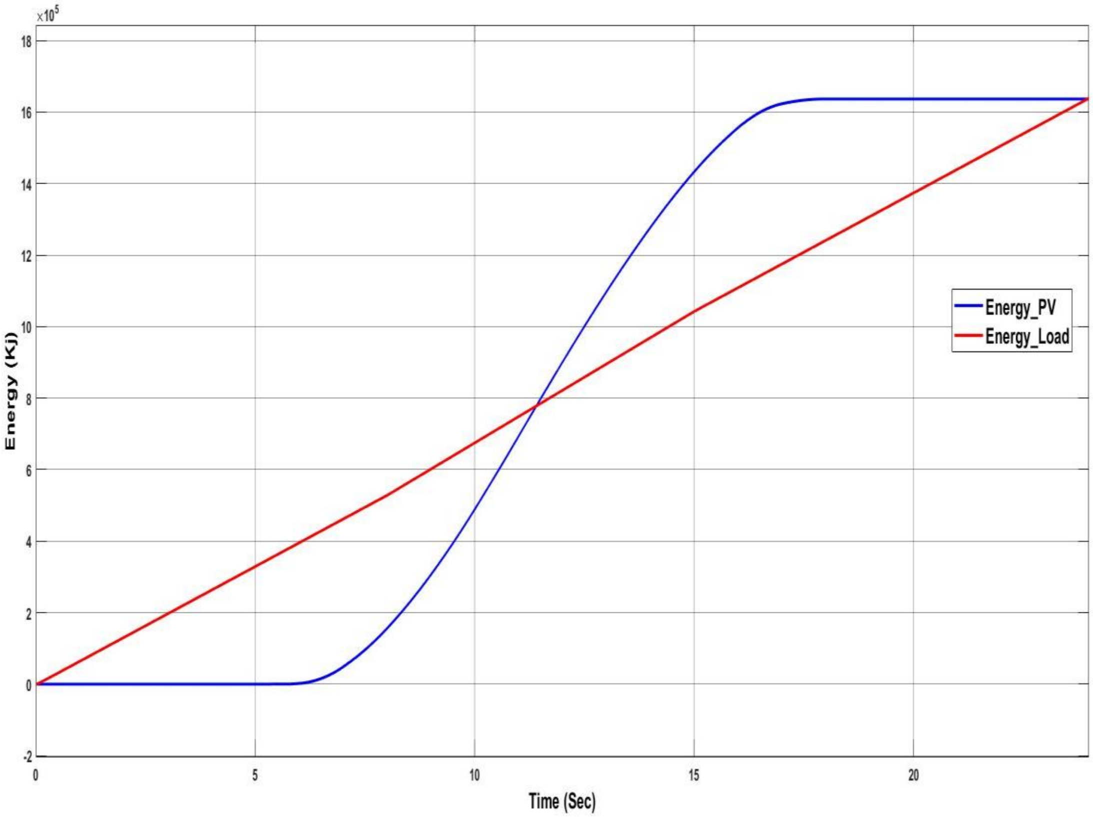

Figure 4.8. Energy of (PV and Load).

4.4. PV SYSTEM LOSSES

PV systems are a popular choice for generating electricity from renewable sources. However, like any power generation system, PV systems experience losses that reduce their overall efficiency. Understanding these losses is important for system designers and operators, as it can help identify areas for improvement and optimize system performance. The losses in a PV system can be broadly classified into two categories: internal losses and external losses. Internal losses are those that occur within the PV system itself, such as losses in the PV cells, wiring, and electronics. External losses, on the other hand, are those that are outside the PV system, such as shading, soiling, and temperature effects.

Internal losses in a PV system can be caused by several factors, including the efficiency of the PV cells, the quality of the wiring, and the performance of the electronic components. For example, PV cells typically have an efficiency of between 15-20%, meaning that 80-85% of the incoming sunlight is lost as heat. Wiring losses can occur due to resistance in the wiring, which can cause a drop in voltage and reduce system performance. Electronic losses can occur due to factors such as mismatch between the inverter and the PV array, or losses in the power conditioning units.

External losses in a PV system can be caused by factors such as shading, soiling, and temperature effects. Shading can occur due to nearby trees, buildings, or other obstructions that block sunlight from reaching the PV panels. Soiling can occur due to dust, debris, or other contaminants that accumulate on the surface of the panels and reduce their efficiency. Temperature effects can occur due to changes in temperature, which can cause the efficiency of the PV cells to decrease.

Overall, understanding the various types of losses in a PV system is crucial for maximizing system efficiency and optimizing system performance. By identifying and addressing these losses, system designers and operators can improve the overall performance of PV systems and increase their competitiveness as a source of renewable energy. Figure 4.9. presents PV system losses based-on our specifications;

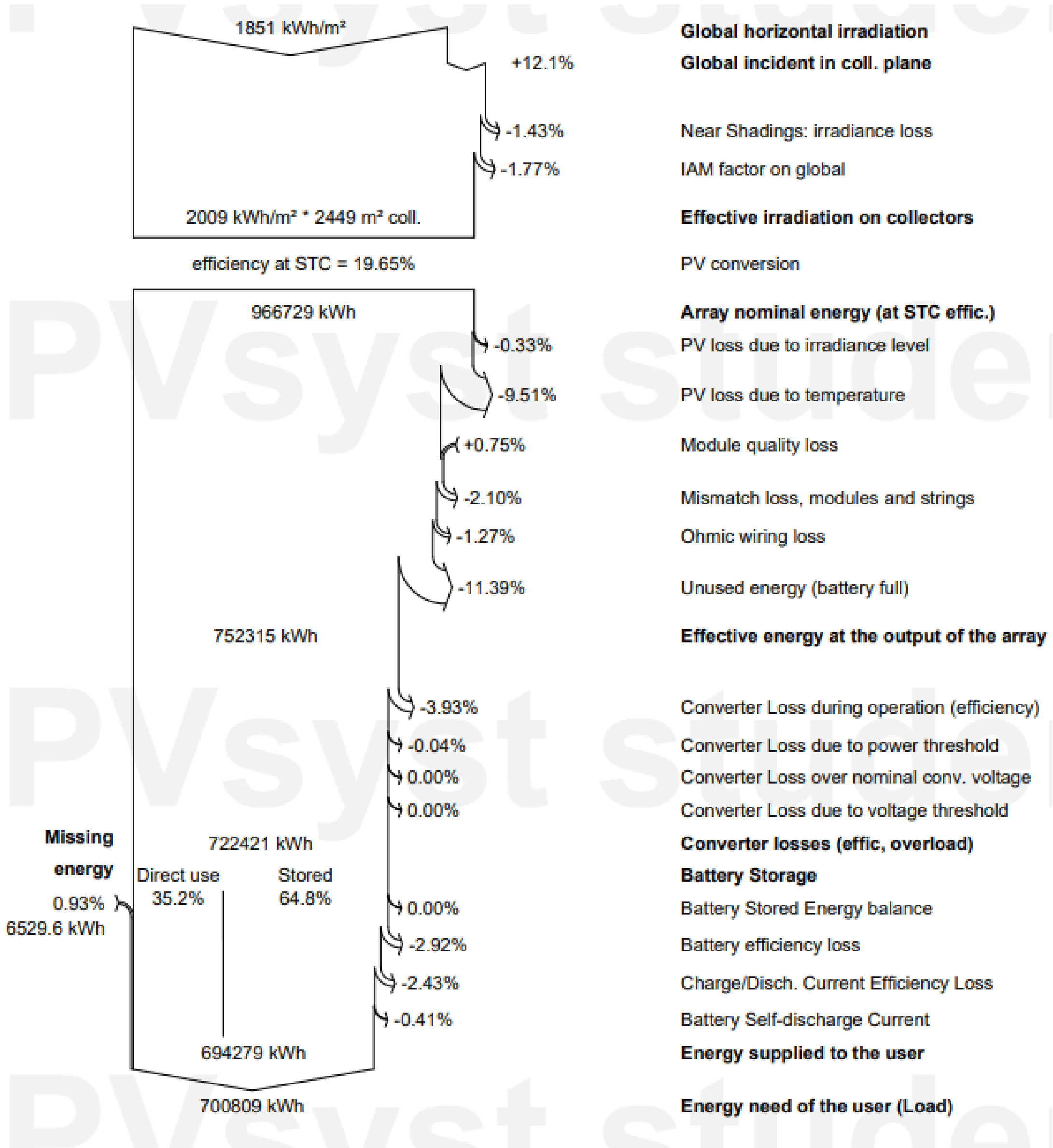

Figure 4.9. PV system losses.

4.5. ENVIRONMENTAL ANALYSIS

In a comparative study conducted for an isolated village in Iraq, the analysis revealed significant differences in CO2 emissions between a Diesel Generator, the National Grid, and a PV system. The Diesel Generator, which was used to meet the electricity demands of the village, was found to contribute approximately 1,013,073 kilograms of CO2 emissions per year. This high emission level can be attributed to the combustion of diesel fuel, which typically has a relatively high emissions factor. The study highlights the environmental impact of relying on traditional diesel generators for power generation, emphasizing the urgent need for cleaner and more sustainable energy alternatives.

In contrast, the National Grid, which provides electricity to the village from the centralized power generation sources, accounted for around 440,599 kilograms of CO2 emissions annually. These emissions arise from the overall energy mix of the grid, which includes a combination of fossil fuel-based sources such as natural gas and coal, as well as a proportion of renewable energy. The findings of the study underscore the importance of transitioning to a greener grid by increasing the share of renewable energy sources and implementing emission reduction strategies.

However, the PV system emerged as the clear winner in terms of CO2 emissions, as it recorded zero kilograms per year. The PV system, consisting of solar panels that harness sunlight to generate electricity, operates without any direct emissions during its operation. While there may be embodied emissions associated with the production and installation of the PV system, these emissions are typically much lower compared to the emissions produced by traditional energy sources. The study highlights the immense potential of PV systems in mitigating carbon emissions and promoting sustainability in off-grid or isolated settings like the village in Iraq.

Based on the study's results, it becomes evident that transitioning from a Diesel Generator to a PV system can significantly reduce CO2 emissions, providing substantial environmental benefits. Furthermore, integrating renewable energy sources into the National Grid can help decrease the overall carbon footprint of the village. The study emphasizes the importance of adopting renewable energy solutions, not only for environmental reasons but also for the long-term well-being and sustainability of communities in Iraq and beyond.

PART 5

CONCLUSION AND FUTURE WORK

The economic and technical analysis of providing electricity to isolated villages in Iraq is crucial, given the large number of isolated communities and the challenges faced by the national grid. The study conducted an economic analysis of three methods: PV systems, diesel generators, and national grid, using three programs (HOMER Pro, PV-syst, and MATLAB). The following summarizes the findings of each method.

- PV System: PV systems are a sustainable and cost-effective solution for providing electricity to isolated villages in Iraq. Although the initial cost may be high, the total cost over 25 years is significantly lower, and the environmental impact is minimal. Given Iraq's favorable environmental conditions, PV systems offer an ideal alternative to traditional sources of electricity.
- Diesel Generator: While generators are a reliable source of electricity for isolated villages, their operating costs are high, and their environmental impact is significant. Generators require frequent fuel and maintenance, which makes them less cost-effective and sustainable in the long run.
- National Grid: The Iraqi national grid faces multiple challenges, including issues with supply and demand, which makes meeting the country's electricity needs a significant challenge. Many isolated villages lack access to the national grid, making the provision of electricity difficult. Finding alternative solutions, such as PV systems, is critical for the sustainable development of Iraq.

In conclusion, the study recommends the use of PV systems as a sustainable and cost-effective solution for providing electricity to isolated villages in Iraq. While generators are a traditional source of electricity, they are expensive to operate and have a significant environmental impact. The national grid struggles to meet the country's electricity needs, particularly in isolated areas, highlighting the need for alternative solutions like PV systems.

To achieve sustainable and reliable electricity provision in isolated villages, Iraq must take decisive action. This includes increasing investment in PV systems to ensure long-term sustainability, building local capacity for installation and maintenance to reduce costs and create employment opportunities, developing policies to encourage the adoption of sustainable energy solutions, and exploring new technologies such as energy storage and hybrid systems. The economic and environmental benefits of these actions are clear and cannot be ignored. Failure to act will result in continued reliance on costly and unsustainable traditional energy sources, which will have negative impacts on both the environment and the economy. Iraq must prioritize the implementation of these suggestions to achieve sustainable and reliable electricity provision in isolated villages, which will contribute to the overall economic development of the country.

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RESUME

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