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Theme

A comparative study between different storage systems for feeding an isolated area

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I will always remember everyone who contributed to thisachievement and Who can help you overcome this memory?

I would like to thank my father for supporting me in allcircumstances until I achieved my dream.

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Your experience and evaluation of your trip. Your comments

Your words and constructive advice help to enrich thismemory.

I would first like to thank my memory frames Amari chuaib

Out of impatience, I apologize and offer some advice forthose who contribute.

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It clears my mind.

Dedications

I had this memory of my family,
which came froma source.

It is essential that you feel and enjoy
your gardenat all times.

They are in the State, they are the
advisors andtheir presence weighs
on them.

A strong loop does not allow
overcomingobstacles and
achieving

My goals. This memory is a
recognition of hisinfluence on us

My life and the path of my
heart express myeternal
gratitude

I have all my friends

Abd El Basset

Dedications

This thesis is dedicated to my beloved parents, whose constant love, support, and encouragementhave been my greatest source of strength throughout this journey.

To my friends and colleagues, who provided endless motivation and companionship during thechallenging times.

And to my mentors and professors, whose guidance and wisdom have been invaluable to myacademic and personal growth.

Thank you all for believing in me.

Aissam

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Abbreviations

Ppv: is power output of solar photovoltaic

η: efficiency of solar photovoltaic

HT: total hourly solar radiation

A: surface area of solar photovoltaic

Hb: the beam part of solar radiation (kWh/m2)

Rb: tilt factors for beam radiation

Hd: diffused part of solar radiation (kWh/m2)

Rd: tilt factors for diffused radiation

Rr: the tilt factor for reflected part of solar radiations.

Isc : Short circuit current

Voc : Open circuit voltage

Imp : Maximum current output

Vmp : Maximum voltage output

V : Referential voltage of the panel

General introduction

General Introduction

Energy is one of the most basic requirements of humanity due to its impact on every part of our lives, such as heat, air conditioning, cooking food, transportation, and generating electricity. Energy sources such as conventional or renewable sources cannot be used directly to perform work. It is clear that in order to meet the world's growing energy needs, we will need to use all available resources in the near future. However, we will need to convert these energy resources more efficiently. It is also clear that renewable resources must continue to increase their share of total energy consumption. The study aims to provide a comprehensive comparison to determine the optimal solution for energy storage in renewable energy applications. One of the most important objectives of the study is to evaluate the technical andeconomic performance of different energy storage systems, identifying the system with the most Cost effectiveness and efficiency in renewable energy applications and providing recommendations to improve energy storage technologies to achieve greater sustainability. The first chapter provides a comprehensive background on renewable energy and the importance of its use in reducing dependence on fossil fuels. Discusses the challenges associated with producing energy from renewable sources. The chapter explores different types of renewable energy, providing definitions and discussions of their advantages and disadvantages. For example, wind energy is covered in detail, including its operating principles and the components and different types of wind turbines. This section explains howwind energy, being non-polluting and widely available, represents a promising source of renewable energy. The second chapter includes the types of storage systems and the importance of developing modern storage systems to ensure stable energy supply. The third chapter deals with mathematical modeling of the components of the hybrid energy system, including: That's photovoltaic solar panels, inverters, electronic switches, and storage systems. It emphasizes the importance of modeling these components to analyze system performance under different weather conditions. The chapter presents detailed models of solarpanels, inverter models, inverters, switches, and storage systems, with an emphasis on battery storage systems. The chapter concludes that these mathematical models improve the performance of the hybrid system, and the simulation results using MATLAB Simulink will be compared with the results of HOMER PRO in the next chapter, which includes the results drawn from the analysis of the five different systems in terms of cost and operational efficiency. This includes tables and graphs illustrating the differences between systems, aswell as an economic analysis highlighting the most cost-effective and environmentally reliable systems. A comprehensive discussion of the results and their interpretation in light of the specific objectives of the study. It explains the reasons behind differences in performance and cost between different systems, and provides recommendations for improving energy storage technologies. It also discusses the environmental and economic benefits of using renewable energy. The importance of this study lies in renewable energy storage technologies to achieve environmental and economic sustainability. Recommendations are provided for future research and development in this area to improve efficiency, effectiveness and expand renewable energy applications.

Chapter I: Overview on Renewable energies

I.1. Introduction

Fossil fuels, including coal, oil, and natural gas, are the primary sources of energy produced today. These resources, nevertheless, are limited and running out fast. An alternative is offered by renewable energy sources, which offer a sustainable means of supplying electricity without destroying the environment or depleting natural resources. The definitions, kinds, categories, benefits, and drawbacks of renewable energy sources are all covered in thischapter.

I.2. Identification of Renewable energies

Renewable energies comes from natural processes that replenish themselves continuously. These energy sources, which include geothermal, hydraulic, wind, biomass, and solar energy, may all provide power without having a significant negative impact on the environment or depleting natural resources.

Figure I.1: Different renewable energies

The picture shows different types of renewable energies:

- Hydropower (through dams and running water).
- Conventional electrical energy (power plants).
- Solar energy (solar panels).
- Wind energy (wind turbines).

I.3 Different types of Renewable energies

I.3.1 wind energy

Wind energy is produced by the flow of air and converted into electrical power by use of turbines. There are two types of wind turbines: vertical and horizontal axis. The latter is more often used because of its efficiency and cheaper cost.

3.1.1 The operating principle and wind turbine components

The operating principle of wind energy is based on the transformation of energy kinetics in electrical energy can be summarized in the following diagram:

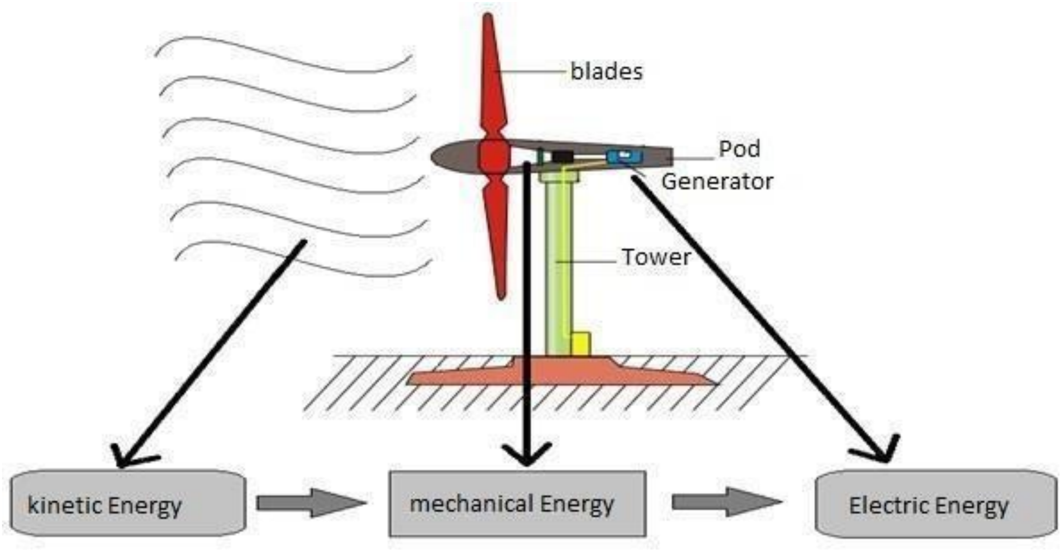


Figure I.2: Operating principle of a wind turbine for electricity production **[2].**

Blades: Rotate in response to wind.

Pod: Has the generator within.

Generator: Produces electricity from mechanical energy.

Tower: Holds the blades and pod in place.

The wind turbine consists of blades made of composite materials like plastic fibers, wood glass, or carbon, designed for resistance. They are attached to a hub to form a rotor, which rotates around the rotor axis when there is enough wind. The nacelle system converts mechanical energy into electrical energy, and the casing protects the gearbox, generator, and other components from degradation. It includes a hub for regulating rotation speed, a rotor that converts kinetic energy into mechanical energy, brakes for high wind speeds, a multiplier for reduced torque, and a generator for electrical production. The orientation system is a toothed crown with a motor that locks the blades facing the wind. The mast is a steel tube with a crucial height for wind speed. The coupling cabinet connects the turbine to theelectrical network or storage system using a transformer.

3.1.2 Wind energy around the world

The wind energy industry has grown significantly, especially in 2019 (wind energy expanded by approximately 60 GW). The following table lists the major producing nations for wind energy:

Table I.1 Main countries produced electricity from wind power in 2018 [4].

Country	**Power(TW/h)**	**National production (%)**
China	365.8	28
UNITED STATES	303.4	24
Germany	126	9

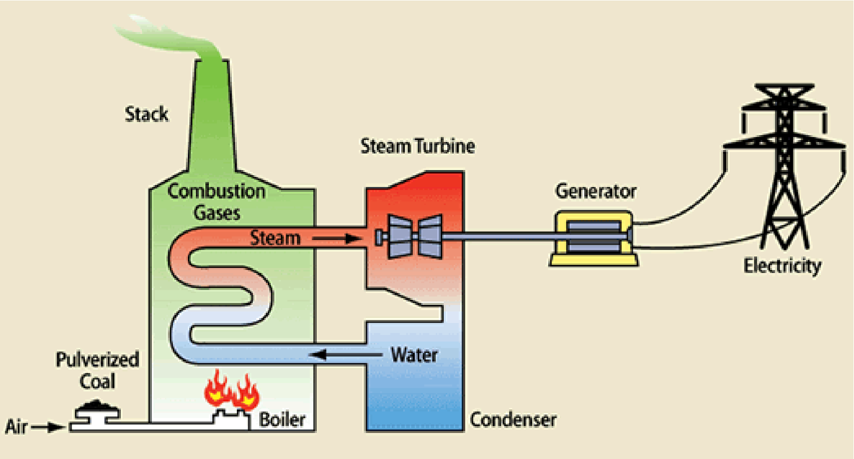
I.3.2 The biomass

Organic resources including wood, agricultural waste, and municipal solid waste are the sources of biomass energy. These materials may be burned to provide energy and heat, or theycan be processed to make biofuels.

Figure I.3 Different types of biomass.

3.2.1 The principle of biomass

The principle of action of biomass is on a biomass power plant plan shown in the following figure :



FigureI.4 How a biomass power plant works.

First, the biomass is burned this process produces a high temperature which transforms the water into steam, then electricity is produced tanks to the turbines which provide energy to the generator

3.2.2 Biomass around the world

Bioenergy accounted for 518.5 TW/h, or 1.9% of the world's power generation, in 2018. The United States, China, and Brazil are the top three countries that use bioenergy to produce electricity:

TableI.2 Main countries produced electricity from bio-energy sources in 2018 **[4].**

Country	Power (TW/h)	National production(%)
China	90.6	**1**
United States	59.5	**1**
Brazil	53.9	**9**

I.3.3 Geothermal energy

The heat that the Earth has stored is the source of this energy. It is not reliant on the weather and may be utilized to generate power or for direct heating.

3.3.1 Principle of operation

Thermal stations, which use a generator coupled to a turbine to produce electricity, are the source of geothermal energy. The stations take heat from the ground and transmit it to water, turning it into steam and then partially into mechanical energy through a turbine.

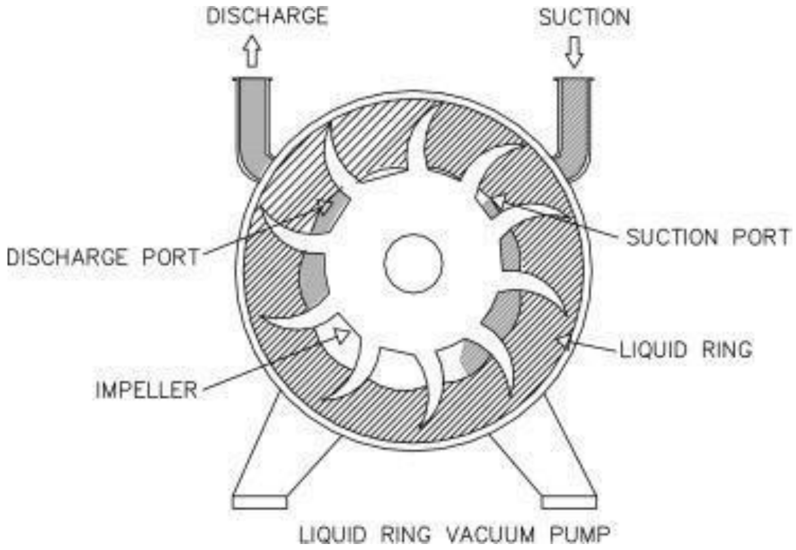


Figure I.5 Diagram explaining the principle Of operation

3.3.2 Types of geothermal power plants

There are three main types of power plants:

Conventional power plant ;

Direct vaporization, dry steam plant;

Flash vaporization and flash steam plant;

Power plant using binary cycle.

3.3.3 Dry steam plant (dry stem plants)

The first power plant used a vaporization technique, channeling water vapor from dry steam wells directly into a tank, allowing the steam to escape into the turbine, typically above 150°C.

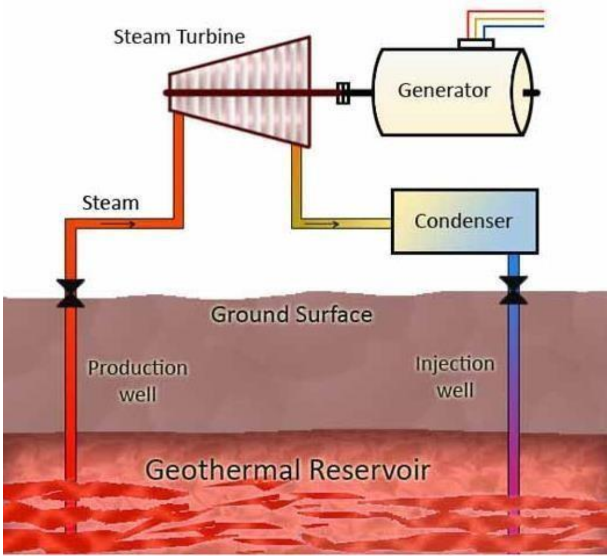
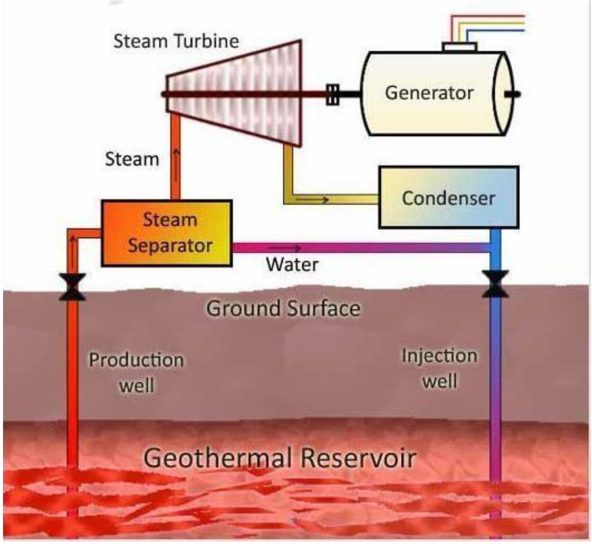


Figure I.6 Descriptive diagram of a Dry steam plant **[7].**

3.3.4 Flash stem plant

The most common geothermal power plant extracts hot water from depths using the flash technique, converting it into steam. This steam powers a turbine and an electric generator. The steam is then directed to a condenser, where it condenses back into water, and reheated. The energy is then stored in a geothermal energy tank, with production capacities ranging from 20 to 110 MW.



FigureI.7 Descriptive diagram of a Flash stem plant **[7].**

3.3.5 Binary cycle geothermal power plants

Binary cycle power plants utilize deep geothermal reservoirs with medium-temperature geothermal fluid and a lower boiling working fluid. Hot fluid is heated in a heat exchanger, vaporized, and passed through a turbine for electricity production, unlike other power plants**[7].**.

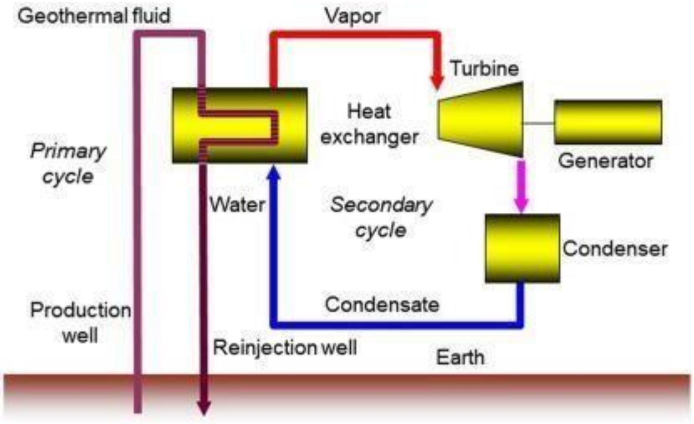


Figure I.8 Descriptive diagram of Binary cycle **[7].**

3.3.6 Geothermal energy around the world

In 2018 the global production of electricity from geothermal energy represented 88.9 TW/h, its capacity increased by 682 MW in 2019.

Table I.3 Main countries produced electricity from geothermal sources in 2018 **[4].**

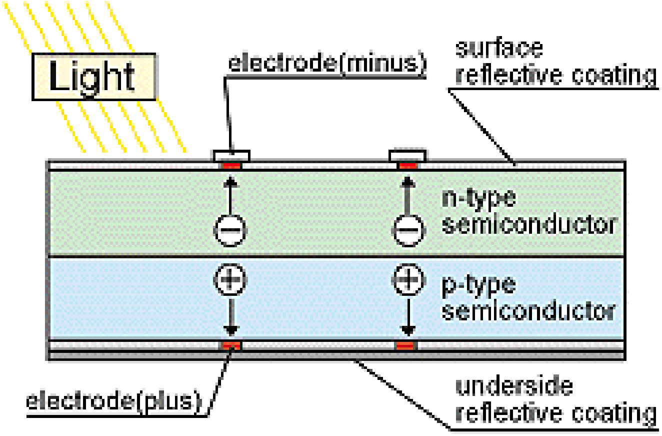
Country	Production (TW/h)	National production (%)
UNITED STATES	18.7	-
Indonesia	14.0	5
Philippines	10.7	11

I.3.4 Solar energy

Solar energy harnesses sunlight through photovoltaic cells or solar thermal systems to produce electricity. It has seen significant growth, especially in countries like China, the USA,and Japan.

3.4.1 The principle of solar energy

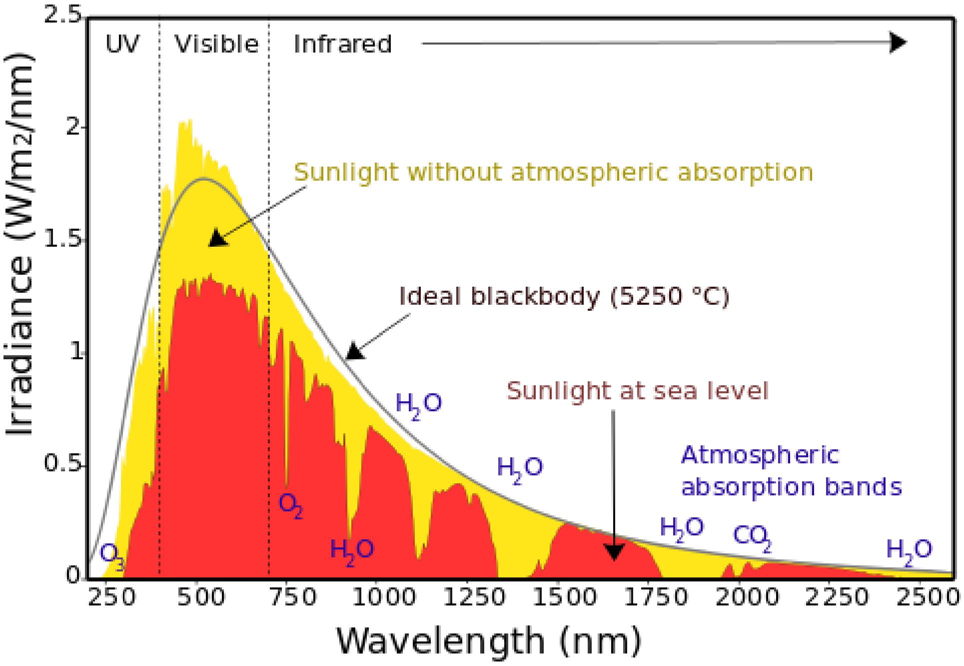
Solar energy is harnessed by capturing the radiant energy emitted by the sun and converting it into usable forms of energy such as electricity and heat. The principle of solar energy revolves around the conversion of sunlight into electrical or thermal energy through different technologies, primarily photovoltaic cells and solar thermal systems.



FigureI.9 The principle of solar energy

The visible region of the electromagnetic spectrum, between 400 and 700 nm, is where the sun mostly emits radiation. The larger the energy carried by photons, the shorter the wavelength of the radiation. This energy can be conveyed as heat, causing matter's atoms to get excited and heated. When exposed to solar radiation, sensors convert the photons' energy into thermal or electrical energy **[8].**

The energy of photons is transferred to matter's atoms and molecules, causing them to move more vigorously, resulting in increased heat. This heat is converted into thermal energy within the material. Sensors like solar thermal panels absorb solar energy and convert it into heat, which can be used for heating water or generating electricity. Photovoltaic cells convertenergy from photons directly into electricity through the photovoltaic effect. Peak solar emission in the visible spectrum is a fundamental concept in solar physics. The relationship between photon energy and wavelength is a fundamental principle of quantum mechanics. The mechanisms by which materials convert absorbed photon energy into thermal or electrical energy are fundamental to solar panels and thermal collectors.

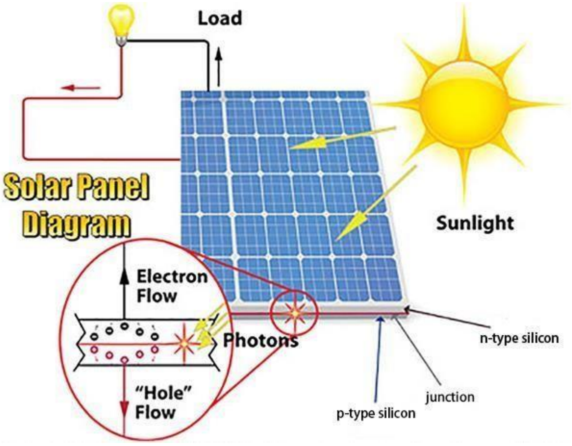


FigureI.10 Distribution of sunlight energy according to wavelength as it enters the Earth's atmosphere and at sea level.

3.4.2 Types of solar energy

Solar energy can be produced in three forms: photovoltaic solar energy, which uses solar cells to convert solar radiation into electrical power, and solar thermal energy, which uses infrared solar radiation to heat water, air, or other fluids, with the latter being simpler in technology.

The "FONT -ROMEU" solar oven in France**[9]** uses thermodynamic solar energy, which involves large power plants with curved mirror solar ray concentrators that heat fluids to high temperatures, generate steam, and produce electricity using a steam turbine.



FigureI.11 Types of solar energy

3.4.3 Solar energy around the world

In 2019, nearly 115 GW of photovoltaic panels were installed worldwide, and the global installed capacity in terms of photovoltaic solar power amounts to 627 in 2019. The three largest countries producing electricity from solar photovoltaics are China, the United States, and Japan according to the following table:

Table I.4 Main countries produced electricity from solar origin in 2018 **[4].**

Country	Production (TW/h)	National production (%)
China	176.9	2
UNITED STATES	81.2	2
Japan	62.6	6

I.4 Classification of Renewable energies sources

According to IRENA's 2020 Annual Renewable energies Statistics Report, Renewable energies increased by 7.6% in the previous year. Asia is the largest region, making about 54% of all new installations.in 2019 90% of all renewable energy came from solar and wind power **[4].**

Wind and solar energy are Renewable energies sources in which to put money since they can efficiently meet the world's energy needs without using fossil fuels:

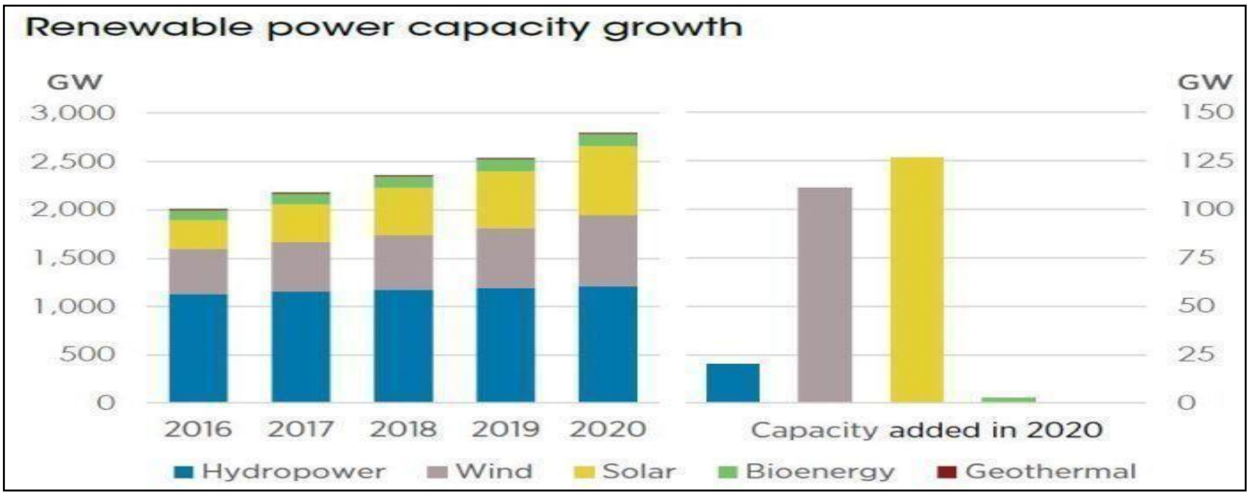


Figure I.12 Global Renewable energies production capacity **[11].**

Significant technical advancements in solar and wind energy have increased their efficiency and decreased their cost, enabling deployment at different scales, from modest home installations to big facilities. Because of its dependence on endless resources, it is characterized by significant environmental advantages, including as a reduction in carbon emissions and sustainability. Furthermore, the Renewable energies industry has a role in improving economic stability and national security by boosting energy independence and opening up job possibilities. Because of cheap technological prices and government policies that support them, renewable energy projects provide good financial returns. Additionally, the industry is growing quickly, environmental rules are being adopted, and consumers are favoring green energy, all of which create profitable investment prospects.

I.5 Advantages and disadvantages

There are several benefits to using renewable energy beyond merely having clean energy sources. It helps to lower greenhouse gas emissions, enhance air quality, and generate new employment possibilities in the alternative energy sector. These technologies do, however, have several disadvantages and difficulties, such as the high cost of infrastructure and storage technologies and the potential to negatively affect the environment and wildlife.

5.1 Advantages:

5.1.1 Environmental Benefits: Renewable energies reduces greenhouse gas emissions and air pollution.

5.1.2 Inexhaustible Supply: These sources are continuously replenished, unlike finite fossilfuels.

5.1.3 Energy Security: Diversifies energy sources, reducing dependence on imported fuels.

5.1.4 Economic Growth: Creates jobs and promotes sustainable economic development.

5.1.5 Cost-Effectiveness: Technological advancements have made renewable energy morecompetitive with traditional energy sources.

5.2 Disadvantages

5.2.1 Intermittency: Some sources, like solar and wind, are weather-dependent.

5.2.2 High Initial Costs: Significant investment is needed for infrastructure development.

5.2.3 Geographic Limitations: Certain technologies, such as hydropower, require specificgeographic conditions.

5.2.4 Storage Challenges: Efficient storage solutions are still being developed to manageenergy supply consistently.

I.6. Conclusion

This chapter examines the most significant Renewable energies sources and covers the advantages and difficulties associated with them. We began by providing an overview of the critical need to transition from fossil fuels to alternative energy sources because of thedepletion of fossil fuels' dangerously finite conventional supplies. Next, we went over the definitions and categories of renewable energy sources, such as solar, geothermal, biomass, wind, and solar energy, and we explained how each one works and how it is used globally. This lowers greenhouse gas carbonates and, consequently, air quality since fresh energies are still accessible and immediately favorable to light. Nonetheless, there are issues with storage, possible effects, and personal data. Ultimately, it may be said that new energies are a potentialanswer to the energy problems of the future, but one that will only be fully realized via ongoing study and solving clever technological obstacles. Sen will go into further depth on storage methods that are not necessary to solve the availability and stability of energyproblem in the upcoming chapter.

The next chapter will focus on the storage system.

Chapter II: Overview of storage system

II.1. Introduction

Because of growing concerns about the environmental effects of fossil fuels and the reliability and longevity of electricity systems around the globe, engineers and politicians are concentrating more and more on energy storage. Energy storage can actually assist with wind and solar power's intermittent nature. In some cases, it can also react fast to large fluctuations in demand, speed up grid response times, and reduce the need for backup power plants. The efficiency of an energy storage facility is defined by its ability to react quickly to variations in demand, the total amount of energy it can hold, the rate at which energy is lost during storage, and the ease with which it can be recharged.

Solar photovoltaic systems only provide electricity throughout the day at their peak. Every day, the total production is different. Although wind energy is erratic, it may occur anywhere, at any time of day. On the other hand, average performance is not always consistent; for instance, a single location in Germany might see a daily variation of about 20 GW **[12].** The sporadic increase in renewable energy makes it difficult to keep supply and demand in balance. Energy storage is necessary since the frequency management capability is reduced when traditional power plants close. Peak power use, such as during the summer when air conditioners run nonstop or at night when people turn on lights and appliances, can also be met by energy storage. Power plants must scale as When production ramps up to meet peak energy demand, the price of power rises. Because utilities may buy power during off-peak hours when it is less expensive and sell it to the grid at times when it is more in demand, energy storage increases grid efficiency **[13].**

II.2 Overview of Energy Storage Systems

2.1 Chronological order of Energy Storage Systems

In the late 19th century, the field of electrochemical energy storage began to grow quite quickly. Benjamin Franklin, an American physicist, coined the term "battery" in 1749 while experimenting with electricity and a series of connected capacitors. In 1800, Alessandro Volta, an Italian scientist, created the first functioning battery **[14].**

Table II.1. Chronological order of ESS

Year	Types of battery	Description	Ref
1800	Volta cell	The invention of the first battery led to the Volta cell, which used a brine solution as an electrolyte and had alternating copper and zinc discs divided by cardboard.	**[18, 19]**
1836	Daniel cell	Regularly identified as a zinc-copper battery that takes advantage of a porous barrier between two electrolytes, the Volta celldeveloped into the Daniel cell. John Frederic Daniell, a British chemist, invented the Daniel Cell.	**[20]**
1866	Leclanche cell	Daniel cell transforms into a Leclanche cell invented by a French engineer containing an ammonium chloride conducting solution: the electrolyte, a negative zinc terminal and a positive manganese dioxide terminal.	**[21]**
1859	Lead-acid	The first rechargeable battery based on lead-acid was invented by the French physician Gaston Plantє́, a still used device. They were all primary batteries until then, meaning they were not typically rechargeable.	**[18, 19]**
1899	Nickel–cadmium (NiCd)	The nickel-cadmium (NiCd) battery using nickel as the positive electrode (cathode) and cadmium as the negative electrode (anode) was invented by Sweden’s Waldemar Jungner.	**[22]**
1901	Nickel-iron	Thomas Edison replaced cadmium with iron, which	**[19, 22]**

	(NiFe)	was called nickel-iron (NiFe).	
1967	Nickel–metal hydride, NiMH	Nickel-metal-hydride development began in 1967. It acts as a substitute for NiCd because it only has mild toxic metals and provides higher specific energy.	**[23]**
1980	Li-ion	American physicist John Bannister Goodenough invented the lithium-ion nervous system.	**[24]**
1980	Lithium-polymer	The lithium-polymer battery invention came in the 1980s. Sony integrated Goodenough's cathode and a carbon anode into the world's first commercial lithium-ion rechargeable battery in 1991.	**[25]**
1954 - latest	Solar fuel	Solar fuels, inspired by environmental concerns, have recently gained interest. This is still under development and study. In the 1950s, Bell Laboratories discovered that semiconducting materials were more powerful than selenium, such as silicon. They succeeded in making a solar cell that was 6percent efficient. The brains behind the silicon solar cell at Bell Labs were inventors Daryl Chapin, Calvin Fuller and Gerald Pearson.	**[26]**

Luigi Galvani (1737–1798) and Alessandro Conte di Volta (1745–1827) are credited with these early measurements, and their names live on in history as the origins of the terms "volt" and "galvanic element." Galvani discovered that a frog leg starts to move when it comes into contact with certain metals. Conversely, Volta investigated the results that came about when certain Different metals are filled with salt solutions. Without these tests, the lead/acid/lead dioxide (lead-acid battery) process will not be discovered **[15].** The energy storage system's timeline is displayed in Table 1.

2.2 Comparison and characteristic of Energy Storage System

Therefore, in order to establish standards for choosing the optimal technology, it is essential to closely examine the core traits of ESSs. The technical characteristics of these ESSs, such as their maximum power rating, discharge duration, energy density, and efficiency, may also be used to characterize them. Table II.2 focuses on ESSs that can currently provide at least 20 MW of essential storage capacity. To aid any novice in comprehending the features, aglossary of technical data ESSs is provided **[16, 17].**

Table II.2. Chronological order of ESS

	Max Power Rating (MW)	**Discharge time**	**Max cycles or lifetime**	**Energy density (watt-hour per liter)**	**Efficiency**
Pumped hydro	3,000	4h-16h	30-60 years	0.2-2	70-85%
Compressed air	1,000	2h-30h	20-40 years	2-6	40-70%
Molten salt	150	hours	30 years	70-210	80-90%
Li-ion battery	100	1min-8h	1,000-10,000 years	200-400	85-95%
Lead-acid	100	1min-8h	6-40 years	50-80	80-90%
Flow battery	100	hours	12,000-14,000 years	20-70	60-85%
Hydrogen	100	min-week	5-30 years	600(at bar)	25-45%
Flywheel	20	secs-mins	20,000-100,000 years	20-80	70-95%

2.2.1 Max power rating (MW or kW) : The rate at which energy is stored in the storage medium is determined by a storage system's maximum power rating. It is also frequently calculated as the peak value, Pmax(W), which is frequently used to signify maximum power, and the average value.

2.2.2 Discharge time (energy per unit): Discharge time is the length of time the storage system needs to completely empty its energy at its rated power. τ (s) = Wst/Pmax, where Wst is the total energy stored and Pmax is the maximum discharge power, is the maximum power during the length of the discharge.

2.2.3 Max cycles / Lifetime (cycles/years): A storage system's lifetime is determined by estimating its performance and is expressed as the number of years based on its rated power and capacity.

2.2.4 Energy density (kWh/L): The term "energy density" describes the quantity of energy that a storage substance can hold per unit volume.

2.2.5 Efficiency (%): The energy discharge efficiency of an energy storage system (ESS) is the ratio of the energy it released to the total energy it held. n = Wut/Wst, where Wut is useful released energy and Wst is total stored energy, is the ratio of released energy to stored energy.

2.3 ClassiFIcation of ESSs

An endless search for innovative storage system solutions that are more efficient and meet particular needs has been prompted by the rising need for energy storage. Numerous ESS technology varieties coexist and may be categorized according to their specific purposes, reaction times, energy storage formats, length of storage, and other factors **[16].** There are several uses for the energy storage system. A few of them could have been specifically chosen for a certain use. However, in a larger framework, some others are the framework in issue.

The kind of transformed energy is the main factor used to categorize ESS. Energy can be transformed into magnetic or electrical fields, as well as thermal, chemical, mechanical, or electrochemical energy. The categorization of the ESS is shown in Figure II.1.

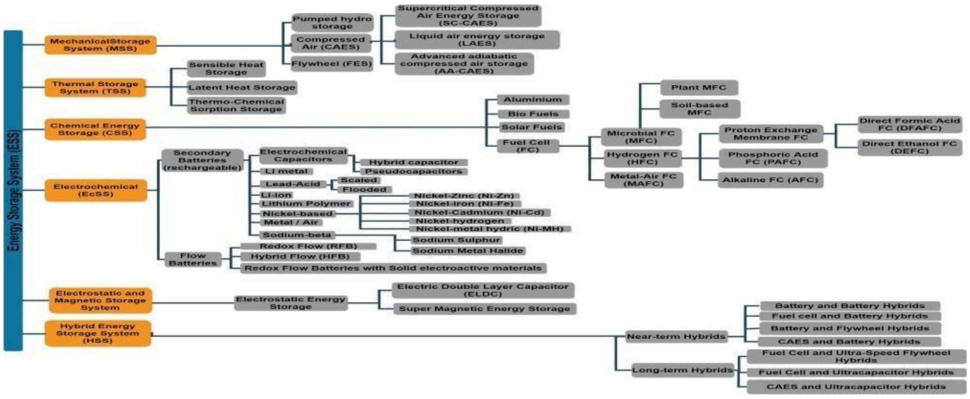


Figure II.1. The classification of energy storage systems.

II.3 comparison and assessment of ESSs

Many studies have been performed specifically for the purpose of drawing up a thoroughcomparison between the various types of ESS.

3.1 Comparison between power density and energy density

FigureII. 2 compares the energy density and power density of several ESS methods. The volume of the storage system is less when the density of power and energy is greater. Extremely dense ESS technologies, perfect for mobile applications, are located on the upper right. The large, high-capacity storage system is situated at left-bottom. The flow batteries, CAES and PHS, are large-area and have a poor energy density. Its volume requires additional storage systems. However, Li-ion batteries are already employed in a wide range of applications due to their high power density and enormous energy density.

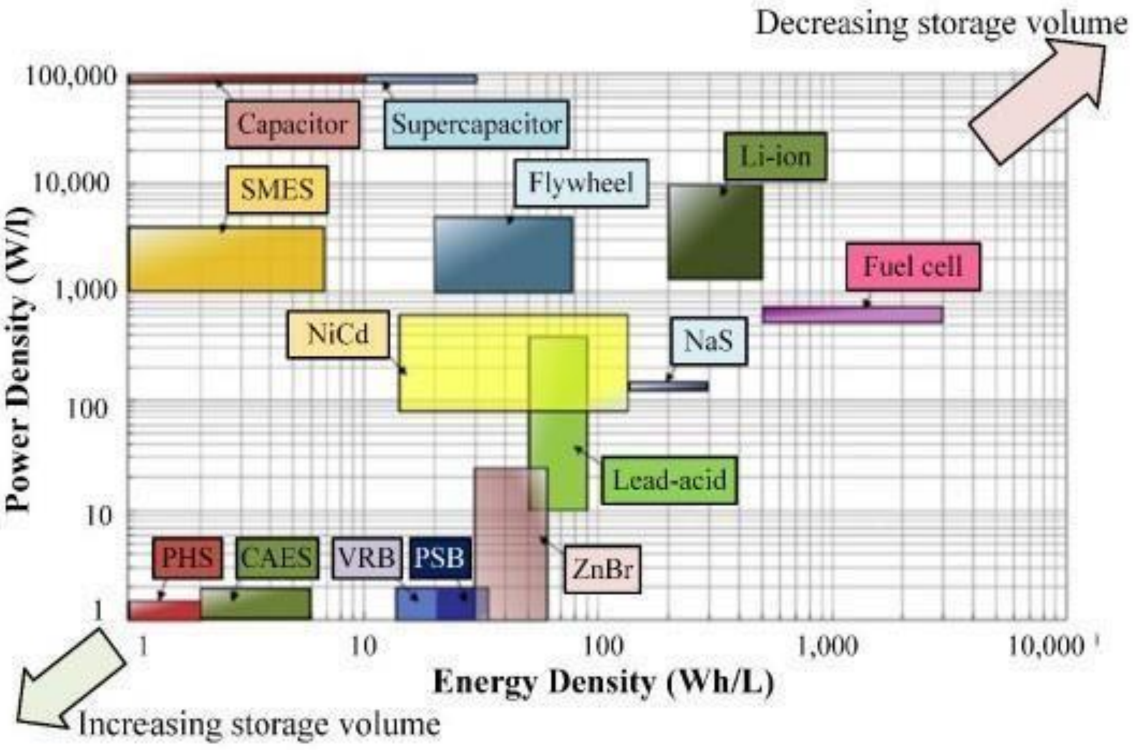


Figure II.2. Comparing the ESS technologies between power density and energy density **[16,27].**

3.2 Comparison between the system power rating and discharge time

Based on the discharge period at rated power and power rating, FigureII. 3 illustrates how ESSs are often applied on large, medium, and small sizes.

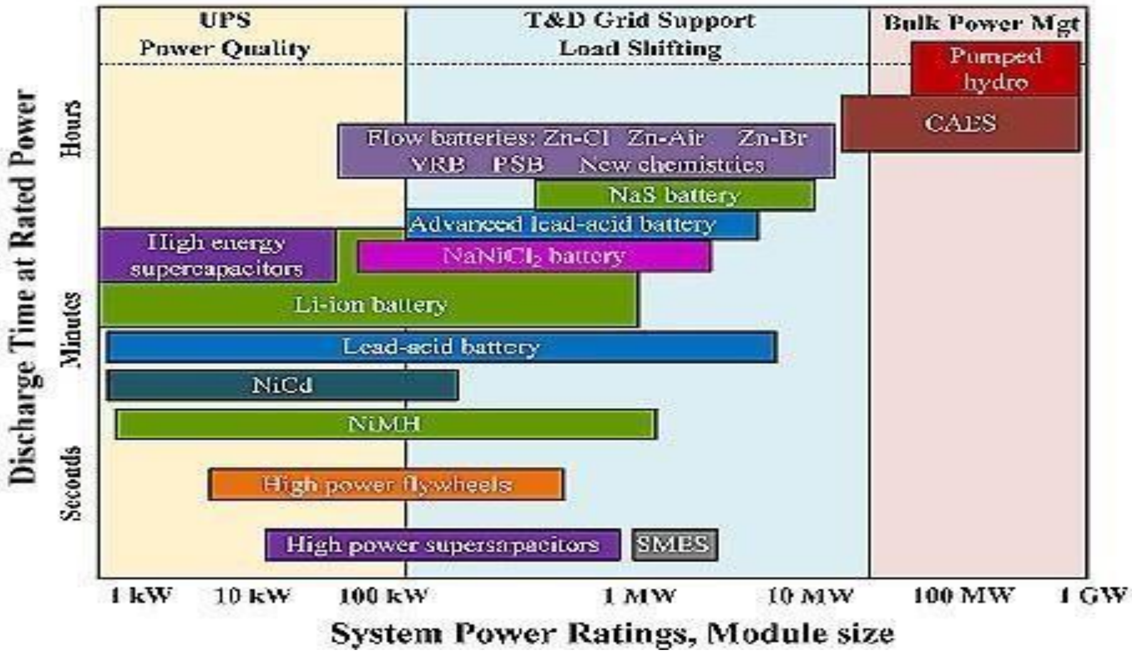
Lead-acid, lithium (Li-ion), and sodium sulfur (NaS) batteries are examples of electrochemical storage technologies that are best suited for medium- to long-duration applications. For applications requiring a brief discharge duration at rated power, flywheels, supercapacitors, and SMES are among the high-power storage technologies that are appropriate. PHS and CAES are situated in the middle of the storage system's medium and large discharge periods at rated power.

Supercapacitors, Ni-Cd, lead-acid, and Li-ion batteries are among the ESSs that are now on the market for use in power quality applications. Flywheels also seem like a viable solution for such purposes.

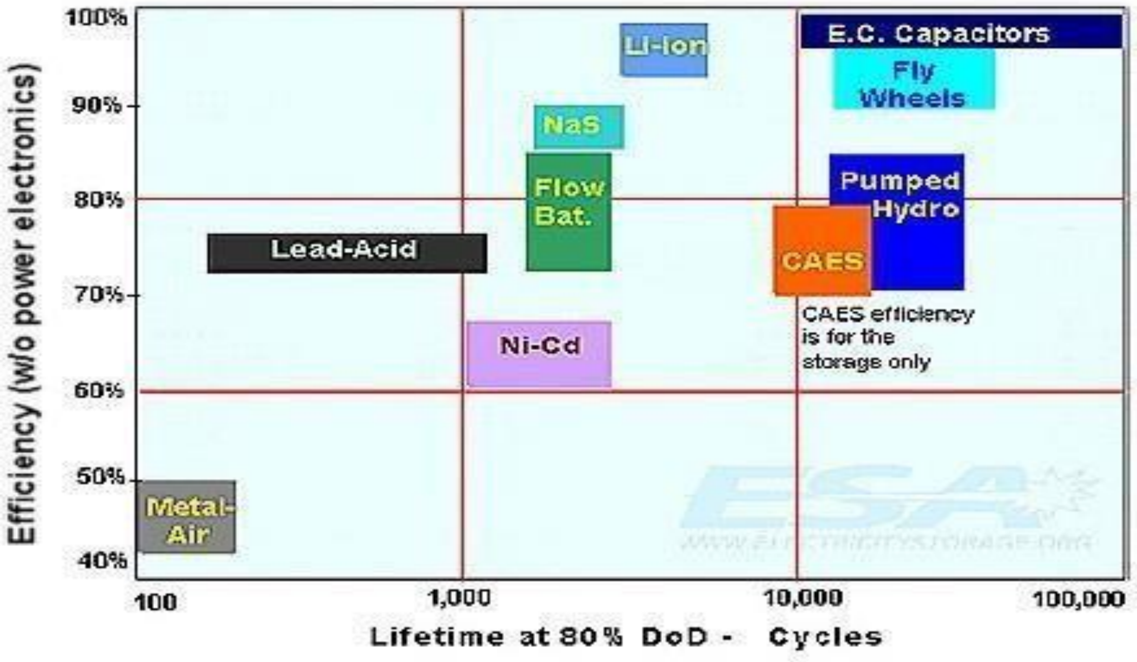
3.3 Comparison of life expectancy and efficiency of energy

The comparison between ESS life expectancy and energy efficiency is shown in FigureII. 4. This two-parameter, among others, is crucial to take into account before selecting a storage technology since it influences the overall expenses of storage.

The two high-power ESS technologies—Flywheels and EC Capacitors—stand out for their respective performance ranges of 90–95% and 84–97%. At the moment, fewer than 55% of diabatic CAES systems are efficient. On the other hand, an efficiency of around 70% is anticipated from the new adiabatic CAES facility **[27].** With an estimated efficiency of over 90% or even 97%, Li-ion batteries are the most efficient electrochemical storage device currently available. PHS systems have an efficiency range of 70–87%, and future efficiency gains may be possible with the introduction of an adjustable speed machine. The average lifespan can be provided for ESSs in either years or cycles. In a conventional battery.



FigureII.3. Comparison of ESSs regarding the rating of the power system and time of dischargeat rated power **[16, 28].**

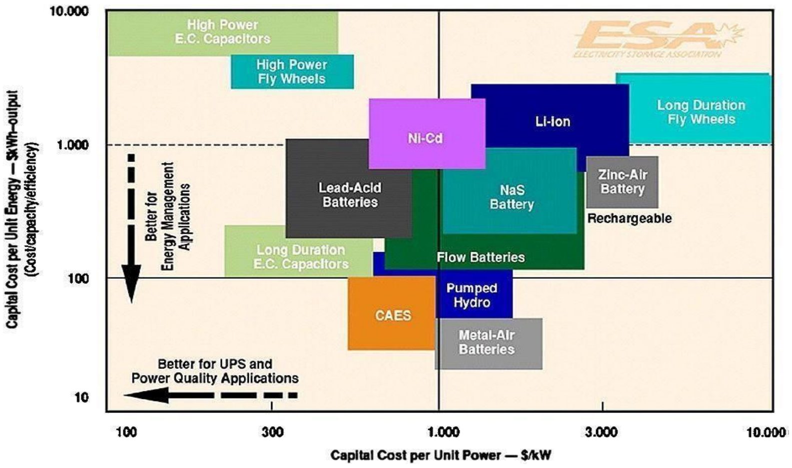


FigureII.4. Comparison between life expectancy and energy efficiency **[28].**

In terms of technology, lead-acid batteries with a cycle life of up to 2000 cycles are the longest. Li-on and NAS batteries, however, have a higher cycle count than lead-acid batteries.While EC capacitors have a lifespan of around 100,000 cycles, CAES, PHS, and flywheels have very long lifespans of between 10,000 and 30,000 cycles **[16].**

3.4 Comparison of the investment cost of ESSs

Figure II.5 compares the investment costs of energy-storage systems. Investment expenses associated with storage are an important economic factor that affects the total cost of producing energy. As a result, some storage system types can only turn a profit when given a specific minimum amount of resources. It is necessary to evaluate the system's overall cost in order to produce an accurate cost analysis.

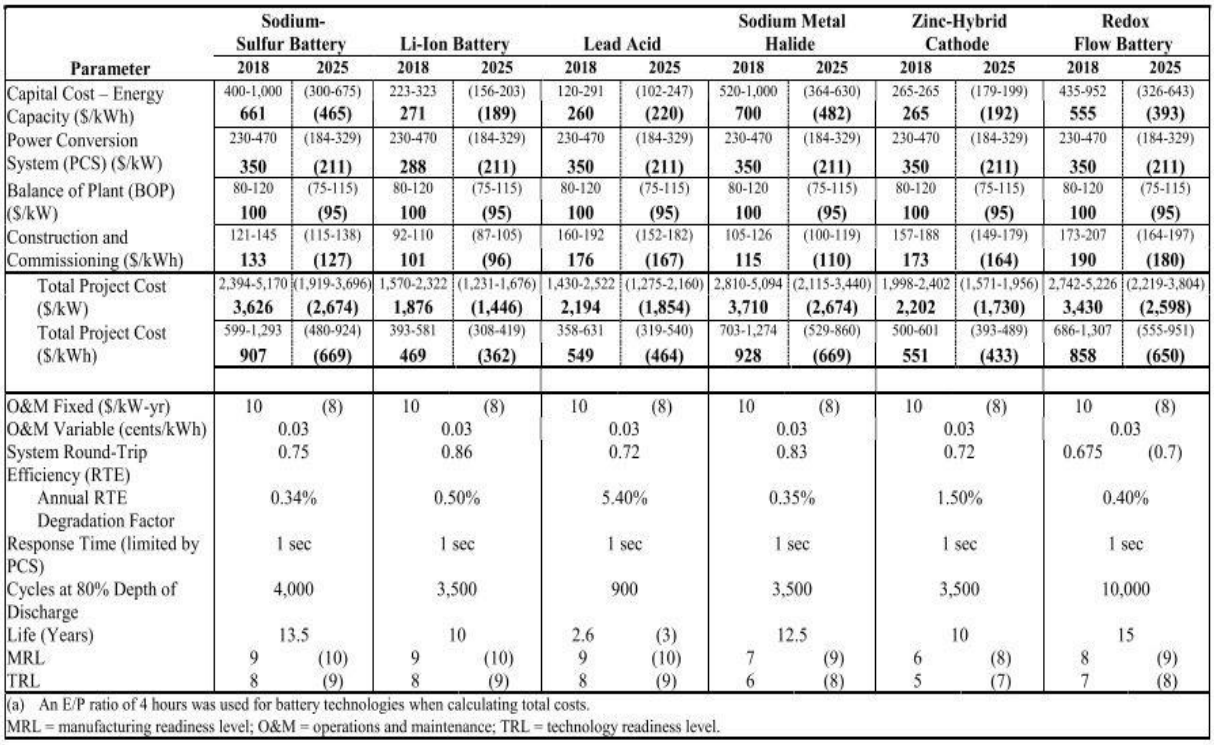


FigureII.5. Comparison between Capital Cost per Unit Energy and Capital Cost per Unit Power **[17].**

When it comes to the investment cost per unit of energy, high-power flywheels and EC capacitors have the highest cost, at several thousand dollars per kWh. Metal-air batteries, on the other hand, are the less expensive storage choice. Additionally, CAES's storage solution comes at a very low cost. In terms of capital cost per unit power, zinc-air batteries, Li-ion batteries, and long-duration flywheels are the most expensive technologies. High-power EC capacitors are the least expensive, with the exception of long-duration EC capacitors and high-power flywheels.FigureII. 6 **[29]** presents 2018 data and 2025 predictions for various cost and parameter ranges by technology, including power conversion system, capital cost– energy capacity, balance of plant, construction, and commissioning.

3.5 Comparison based on specific power and energy

Capacitor technology has the largest specific power among high-power technologies, with over 100,000 (W/kg), whereas TES has the lowest specific power, with 10–30 (W/kg) **[16].** The fuel cell has very high specific energy in the 800-10,000 (Wh/kg) range. Increased specific energy affects the amount of weight stored. A comparison of specific power and energy is presented in Figure II.7.



Parameter	Sodium-Sulfur Battery		Li-Ion Battery		Lead Acid		Sodium Metal Halide		Zinc-Hybrid Cathode		Redox Flow Battery	
	2018	2025	2018	2025	2018	2025	2018	2025	2018	2025	2018	2025
Capital Cost – Energy Capacity ($/kWh)	400-1,000 **661**	(300-675) **(465)**	223-323 **271**	(156-203) **(189)**	120-291 **260**	(102-247) **(220)**	520-1,000 **700**	(364-630) **(482)**	265-265 **265**	(179-199) **(192)**	435-952 **555**	(326-643) **(393)**
Power Conversion System (PCS) ($/kW)	230-470 **350**	(184-329) **(211)**	230-470 **288**	(184-329) **(211)**	230-470 **350**	(184-329) **(211)**	230-470 **350**	(184-329) **(211)**	230-470 **350**	(184-329) **(211)**	230-470 **350**	(184-329) **(211)**
Balance of Plant (BOP) ($/kW)	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**	80-120 **100**	(75-115) **(95)**
Construction and Commissioning ($/kWh)	121-145 **133**	(115-138) **(127)**	92-110 **101**	(87-105) **(96)**	160-192 **176**	(152-182) **(167)**	105-126 **115**	(100-119) **(110)**	157-188 **173**	(149-179) **(164)**	173-207 **190**	(164-197) **(180)**
Total Project Cost ($/kW)	2,394-5,170 **3,626**	(1,919-3,696) **(2,674)**	1,570-2,322 **1,876**	(1,231-1,676) **(1,446)**	1,430-2,522 **2,194**	(1,275-2,160) **(1,854)**	2,810-5,094 **3,710**	(2,115-3,440) **(2,674)**	1,998-2,402 **2,202**	(1,571-1,956) **(1,730)**	2,742-5,226 **3,430**	(2,219-3,804) **(2,598)**
Total Project Cost ($/kWh)	599-1,293 **907**	(480-924) **(669)**	393-581 **469**	(308-419) **(362)**	358-631 **549**	(319-540) **(464)**	703-1,274 **928**	(529-860) **(669)**	500-601 **551**	(393-489) **(433)**	686-1,307 **858**	(555-951) **(650)**
O&M Fixed ($/kW-yr)	10	(8)	10	(8)	10	(8)	10	(8)	10	(8)	10	(8)
O&M Variable (cents/kWh)	0.03		0.03		0.03		0.03		0.03		0.03	
System Round-Trip Efficiency (RTE)	0.75		0.86		0.72		0.83		0.72		0.675	(0.7)
Annual RTE Degradation Factor	0.34%		0.50%		5.40%		0.35%		1.50%		0.40%	
Response Time (limited by PCS)	1 sec		1 sec		1 sec		1 sec		1 sec		1 sec	
Cycles at 80% Depth of Discharge	4,000		3,500		900		3,500		3,500		10,000	
Life (Years)	13.5		10		2.6	(3)	12.5		10		15	
MRL	9	(10)	9	(10)	9	(10)	7	(9)	6	(8)	8	(9)
TRL	8	(9)	8	(9)	8	(9)	6	(8)	5	(7)	7	(8)

(a) An E/P ratio of 4 hours was used for battery technologies when calculating total costs.
MRL = manufacturing readiness level; O&M = operations and maintenance; TRL = technology readiness level.

FigureII.6. Overview of the 2018 data and 2025 forecasts compiled by technology for parameterranges **[29].**

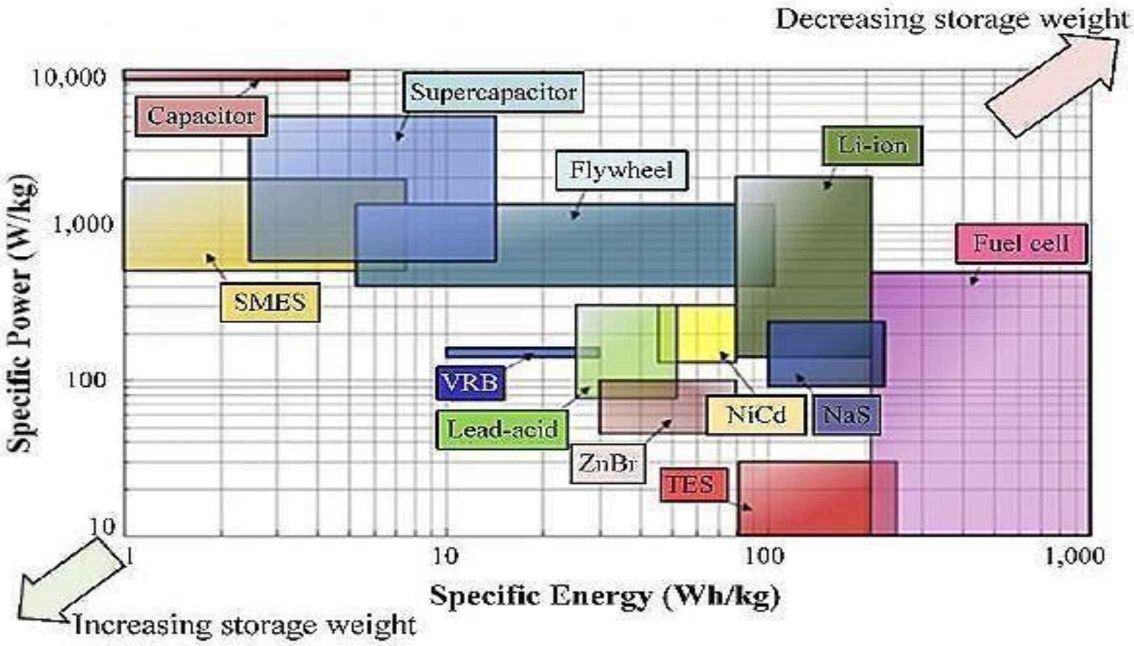
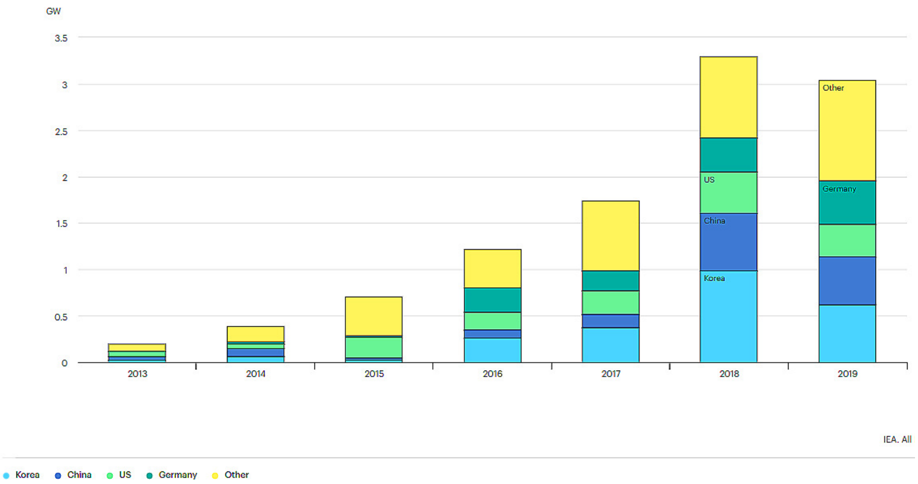


Figure II. 7. Comparison between specific power and energy.

II.4 Deployment of ESSs

For the first time in a decade, the world market for storage is contracting. Globally, power systems added 2.9 GW of storage capacity in 2019, which is around 30% less than in 2018. The reasons behind this include because storage is still considered an early-stage technology, available in just a few major markets and heavily dependent on governmental backing. Energy storage, on the other hand, gives system operators the adaptability and speed of reaction they need to effectively manage load fluctuation and generation. The cost of ESSs has lately dropped more quickly, which is indicative of the advancements in wind and solar power during the last ten years.



FigureII.8. The 2013-2019 annual deployment of ESS by the country **[30].**

Over the past several years, energy storage installations have begun to gain traction in the market. With the exception of 2019, Figure 8 displays the IEA's most recent statistics, which highlights the deployment trend of battery energy storage. The yearly deployment of energy storage has topped 1 GW for the first time in 2016. After the 2018 reporting year, when Korea accounted for one-third of all installed capacity globally, yearly deployments in the country fell by eighty percent. The decline resulted from growing anxiety in 2018 about many grid- scale fires at storage facilities. Despite a thorough examination of the incidents and safety precautions, five additional fires broke out in 2019. the pairing of energy storage resources with renewable energy producing facilities, This has been a major factor in the rise of energy storage and aids in generating stabilization and ensures more strong capacity during periods of high demand. India specifically began incentivizing this use in 2019 and holds a large-scale auction with 1.2 GW of solar plus storage. The storage capacity must account for 50% of the total power. Singapore has set a target of 200 MW of storage by 2025. Global information company IHS Markit's Energy Storage Business, with its headquarters in London, estimates that installations will increase globally by more than 5 GW by 2020 [20]. The field of mobile communication is the other significant potential use for ESS. The research Consider the cloud radio access network (C-RAN) described in [21–28], in which the remote radio heads (RRHs) are capable of trading energy with the grid and are outfitted with renewable energy resources. Nevertheless, RRHs are not equipped with regularly recharging storage devices in their suggested systems. With the development of battery technologies, ESSs may be deployed at RRHs or put at the master base station (MBS) in the C-RAN. By obtaining terminals that are always changing, the self-energy storage management is supposed to regulate uneven local renewable energy supply to satisfy the energy demand.

II.5 Advantages and disadvantages

Energy storage systems (ESS) are crucial for balancing supply and demand,enhancing grid stability, and integrating renewable energy sources. Each type of ESS comes with its own set of advantages and disadvantages. Here's a general overview:

5.1 Advantages:

5.1.1 Grid Stability: Storage systems help stabilize the electrical grid by storing excess energy during periods of low demand and releasing it during peak demand, reducing grid fluctuationsand improving reliability.

5.1.2 Integration of Renewable Energy: Storage systems facilitate the integration of renewable energy sources, such as solar and wind, into the grid by mitigating their intermittency, enabling a smoother transition to a cleaner and more sustainable energy mix.

5.1.3 Peak Shaving: By storing energy during off-peak hours and discharging it during peak demand periods, storage systems can reduce the need for expensive peak power generation facilities, resulting in cost savings and reduced reliance on fossil fuels.

5.1.4 Backup Power: Storage systems can provide backup power during grid outages or emergencies, enhancing grid resilience and ensuring the continuity of electricity supply to critical facilities and services.

5.1.5 Flexibility and Fast Response: Certain storage technologies, such as batteries and supercapacitors, offer fast response times and high cycling capabilities, allowing for rapid adjustments to changes in energy demand or supply.

5.1.6 Decentralization: Distributed storage systems, deployed at or near the point of energy generation or consumption, can reduce strain on centralized grid infrastructure and increase energy independence for individual consumers or communities

5.2 Disadvantages:

5.2.1 Cost: The initial capital cost of storage systems can be relatively high, depending on the technology and scale of deployment. However, costs have been rapidly declining in recent years and are expected to continue decreasing with technological advancements and economies of scale.

5.2.2 Limited Storage Capacity: Some storage technologies have limitations on their storage capacity or energy density, which may constrain their ability to provide extended backup power or support large-scale grid applications.

5.2.3 Efficiency Losses: Energy conversion and storage processes inevitably involve some degree of energy loss, resulting in lower overall efficiency compared to direct energy transmission. Minimizing these losses is an ongoing challenge for storage system developers.

5.2.4 Environmental Impact: The production and disposal of certain storage technologies, such as batteries, can have environmental implications, including resource depletion, pollution, and waste management issues. However, many efforts are underway to improve thesustainability and recyclability of storage systems.

5.2.5 Geographic Constraints: Certain storage technologies, such as pumped hydro storage, require specific geographic and topographic conditions for implementation, limiting their applicability in certain regions.

5.2.6 Safety Concerns: Some storage technologies, particularly those involving chemical reactions or high-pressure systems, pose safety risks if not properly designed, operated, and maintained. Mitigating these risks requires stringent safety protocols and standards.

II.6 Conclusion

This study provides a large deal of important information on ESSs, taking into account the dependability of the electrical system and prior work on ESSs. The world must be persuaded to embrace ESSs in order to transition to renewable energy sources, which will need a thorough grasp of the ideas behind this technology. Based on the primary specifications, a certain kind will be encouraged by the comparison of several sorts of technical factors. An overview of the yearly ESS deployment has been provided. The ESS may not necessarily be the best long-term option among the competing storage systems of today. This suggests, however, that evaluating the regional and national potential will be crucial in the long run, even though the flexibleness's investment signals are now weak.

The next chapter includes mathematical modeling.

Chapter III:
Mathematical modeling

III.1. Introduction

The process of modeling the generators and power converters that make up a hybrid system allows for analysis by providing simulated values under a range of meteorological conditions, including temperature and global radiation. Different Mathematical Modeling Techniques (Logistic And Dynamic) Are Used To Analyze Hybrid Power Systems; For This Hybrid System, We Use The Logistic System Since Time Series Of Meteorological Data Change Every Hour (Time-Series Model) Where we discuss in this chapter :

Modeling of PV

Modeling of converter

Modeling of inverter

Modeling of chopper

Modeling of storage system

III.2 PV modeling

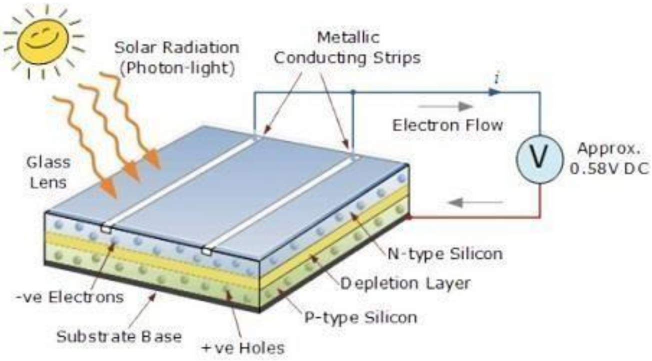
These models aim to analyze and improve the performance of photovoltaic (PV) solar panels that convert sunlight directly into electricity.

2.1 Photoelectric identification system

The term "photovoltaic" originated from a physics activity known as the "photo effect." Its primary power transformation within the material is from photon to electron. In general, photovoltaic systems use semiconductor materials to convert solar radiation into electrical energy.

2.2 Photovoltaic cell structure

A photovoltaic cell's fundamental components are a conducting layer on top and a p- conducting base material. To reduce shading losses, a finger-type contact system is installed on the irradiated side of the cell, even if the entire cell on the back is covered with a metallic contact. Transparent conductive layers and full cover are also employed (figure III.1).



FigureIII.1 construction-of-solar-cell

2.3 Mathematical models

They are many mathematical models for solar photovoltaic. This part summarizes the main used models:

2.4 The first model

The first model uses the following equation **[36]** to determine solar photovoltaic output power based on data on sun irradiation:

$$PPV = \eta HTA \text{ and } HT = HbRb + HdRd + (Hb + Hd)Rr \quad (1)$$

Alongside:

Ppv: is power output of solar photovoltaic

η: efficiency of solar photovoltaic

HT: total hourly solar radiation

A: surface area of solar photovoltaic

Hb: the beam part of solar radiation (kWh/m2)

Rb: tilt factors for beam radiation

Hd: diffused part of solar radiation (kWh/m2)

Rd: tilt factors for diffused radiation

Rr: the tilt factor for reflected part of solar radiations.

2.5 The second model

In 2014, Khatib and Elmenreich devise a novel approach to compute solar photovoltaic power production based on six characteristics (two meteorological parameters and four technical parameters characterizing the system's equipment) **[37]:**

1. Power peak of photovoltaic

2. Efficiency of inverter

3. Efficiency of cables

4. Temperature coefficient

5. Global irradiation

6. Ambient temperature

We use the following two equations [37,38] to characterize this model:

$$\mathrm{P}_{pv}(t) = \left[P_{peak}\left(\frac{G_t}{G_{stander}}\right) - \alpha_t[T_c(t) - T_{stander}]\right] \times \eta_{inv} \times \eta_{wire} \tag{2}$$

$$Tc(t) = T_{amb}(t) + ((\frac{NOCT-20}{800}) \times G_t) \tag{3}$$

2.6Third model

This model uses the following equations to determine the solar field as well as the current and voltage of the photovoltaic panel:

$$\mathrm{I}_{ref} = \mathrm{I}_{sc}\left\{1 - C_1\left[\exp\left(\frac{V_{ref}}{C_2 V_{oc}}\right) - 1\right]\right\} \tag{4}$$

Isc : Short circuit current

Voc : Open circuit voltage

Imp : Maximum current output

Vmp : Maximum voltage output

V : Referential voltage of the panel

Alongside:

$$C_1 = \left(1 - \frac{I_{mp}}{I_{sc}}\right) e^{\left(\frac{-V_{mp}}{C_2 V_{oc}}\right)} \quad and \quad C_2 = \frac{\frac{V_{mp}}{V_{oc}} - 1}{\ln\left(1 - \frac{I_{mp}}{I_{sc}}\right)} \qquad (5)$$

The following equations are used to modify the previously mentioned equations for varying temperature and radiation levels:

$$\Delta \mathrm{T} = \mathrm{T} - T_{ref}$$

$$\Delta \mathrm{I} = \alpha\left(\frac{G}{G_{ref}}\right)\Delta \mathrm{T} + \left(\frac{G}{G_{ref}} - 1\right)I_{sc}$$

$$\Delta \mathrm{V} = -\beta \Delta \mathrm{T} - R_s \Delta I \qquad (6)$$

where α and β stand for the voltage and current temperature coefficients, respectively. We apply the revised voltage and current equation, which is shown below, for varying temperatures and radiation levels

$$\mathrm{V}_{new} = \mathrm{V}_{ref} - \Delta V$$

$$\mathrm{I}_{new} = \mathrm{I}_{ref} - \Delta I$$

Characteristic

2.7 Current-voltage characteristic

Figure 2 shows the properties of the current-voltage. It explains how to use a photovoltaic cell in relation to meteorological factors (such as ambient temperature and illumination level). The following three crucial points (figure III.2) define the solar cell's I = f (V) curve:

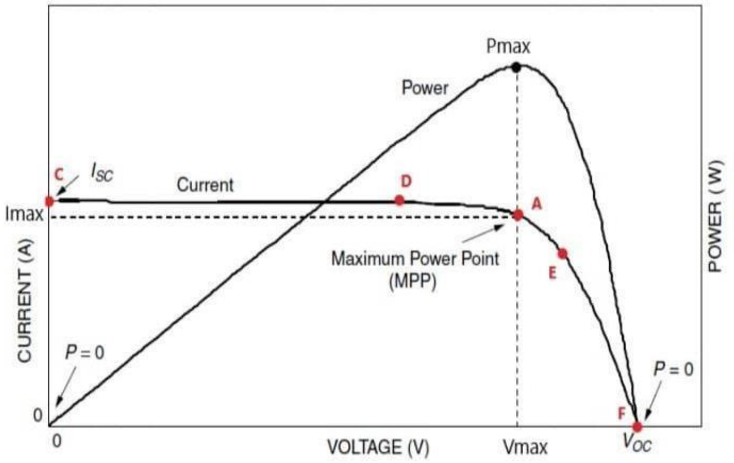
- Short circuit current in point “C”
- Open circuit voltage in point “F”
- Maximum power in point “A”

In the I(V) curve, we see three zones, which are:

1. The first zone, which is located between the "C" and "D" points, is where the solar cell generates current in response to the amount of irradiation.

2. The solar cell functions as a voltage generator in the second zone, designated "EF."

3. The final zone is an ideal zone with a high value for solar cells, located between the "D" and "E" points.



figureIII 2 Curve of the solar cell

2.8 Efficiency and losses

According to the following equation, fill factor is the product of ISC short circuit current and open circuit voltage (VOC) at the highest power point level:

$$\mathrm{FF} = \frac{\text{Power at the maximum power point}}{P_{opt}} = \frac{I_{max}V_{max}}{I_{sc}V_{oc}} \tag{10}$$

For crystalline silicon solar modules, the fill factor value ranges from 70 to 75%, while for multi junction amorphous-Si modules, it ranges from 50 to 60% **[39].**

As shown in the following equation, photovoltaic cell performance, also known as power conversion efficiency, is the ratio of the maximum power supplied by the cell to the incident light power:

$$\eta_m = \frac{P_{max}}{P_{in}}$$

Numerous approaches were created to maximize solar cell efficiency, as the following table illustrates:

TableIII.1: Efficiencies of solar cells **[50]**

Material	**Type**	**Efficiency(%)**	
		LAB	Manufacturing
Silicon	Moncrystalline	24.7	14.0-18.0
Polysilicon,simple	Polycrystalline	19.8	13.0-15.5
MIS inversion layer(silicon)	Moncrystalline	17.9	16.0
Concentrator solar cell(silicon)	Moncrystalline	26.8	25.0
Silicon on glass substrate	Transfer technol	16.6	8.0
Amorphous silicon, simple	Thin film	13.0	8.8
Tandem 2 layers, amorphous silicon	Thin film	13.0	10.4
Tandem 3 layers, amorphous silicon	Thin film	14.6	21.0
Gallium indium phosphate/gallim arsenide	Tandem cell	30.3	10.7
Cadmium-telluride	Thin film	16.5	12.0
Copper indium di-selenium	Thin film	18.4	14.0-18.0

III. 3Transformer modeling

A boost converter works by comparing output variables with a reference input to generate an error signal, which is filtered and amplified to produce a continuous control signal. This signal is then converted using PWM to determine the switching duty cycle. However, the nonlinear nature of the system makes analysis difficult. Continuous linear models can describe the dynamic behavior of a boost converter, but their validity is limited to a small region around the steady-state operating point. To overcome these limitations, some authors have explored nonlinear techniques for control loop fitting. Techniques include Lyapunov functions for global stability, Lyapunov-based control design, numerical simulation of parameter bounds, small-signal models modified for large-signal behavior, and stability graphs for stable design under large-signal operation.

III.3.1 Linear boost converter modeling

3.1.1 Basic modeling

The boost converter examined in this research, which is presumptively designed to run in continuous conduction mode, is depicted in FigureIII.3 **[41].** The output voltage is denoted by Vc, the line voltage by E, and the load disturbance by iS. A known value, VCref, must be maintained for the output voltage. The A load represented as a linear resistor R is linked to the boost converter. C and L stand for the capacitance of the capacitor and the inductance of the inductor, respectively. Their corresponding series resistances, rC and rL, are deemed minimal enough to be disregarded. As a result, the capacitor voltage Vc and the inductor current iL are the boost converter's observable states **[42].**

FigureIII.4 illustrates the two possible configurations for the boost converter: examples (a) and (b) correspond to the switch SW being switched ON and OFF, respectively. The binary signal u(t), also known as the switching function, is what powers the boost converter **[43].** To create the gate-driving signals, a modulating signal must be compared to a sawtooth voltage waveform signal, as illustrated in figureIII.3.

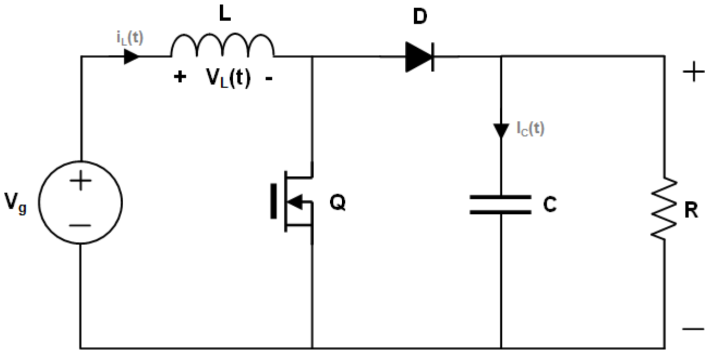


Figure III.3 Boost converter topology

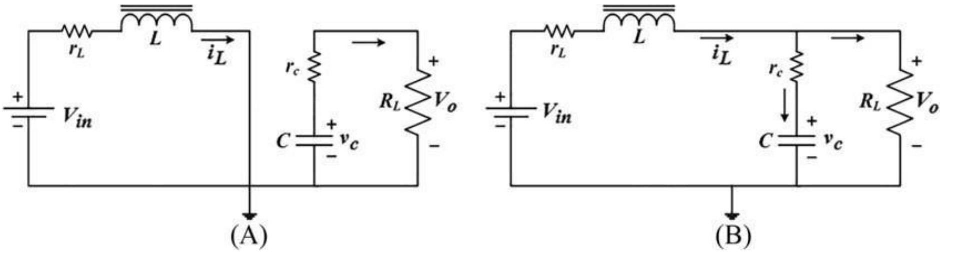


Figure III.4 Boost converter configuration (a) switch turned ON (b) switch turned OFF

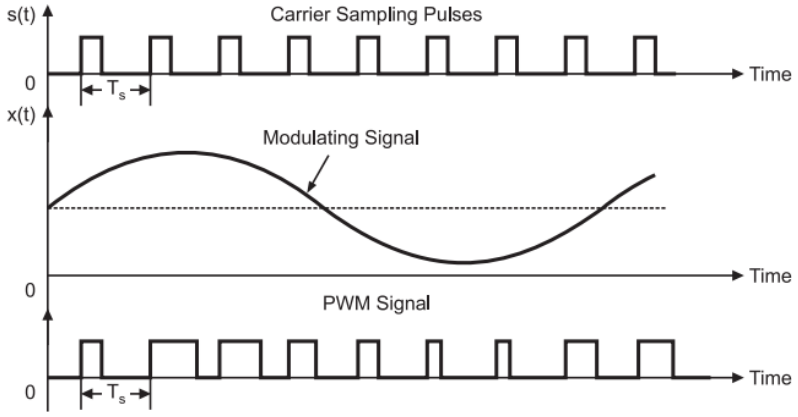


Figure III.5 Waveforms of the PWM process

Considering u(t) to be periodic, where T is the switching time and α is the duty ratio:

$$u(t) = \begin{cases} 1, 0 \leq t < \alpha T \\ 0, \alpha\, T \leq t < T \end{cases} \qquad u(t-T) = u(T)$$

The state variables are the capacitor voltage VC and the inductor current IL. The following is a list of the state equations [44] for the two circuit schemes:

$$u = 1 \colon \begin{cases} \dot{I}_L = \frac{E}{L} \\ \dot{V}_C = \frac{V_C}{RC} \end{cases} \qquad u = 0 \colon \begin{cases} \dot{I}_L = \frac{E}{L} - \frac{V_C}{L} \\ \dot{V}_C = \frac{I_L}{C} - \frac{V_C}{RC} \end{cases} \tag{1}$$

By multiplying the ON system equations by- u and the OFF system equations by 1 u, the equations from (1) can be condensed into a single form:

$$\begin{cases} \dot{I}_L = \frac{E}{L} u - \frac{E - V_C}{L} (1-u) \\ \dot{V}_C = -\frac{V_c}{RC} u + \left(\frac{I_L}{C} - \frac{V_C}{RC} \right) (1-u) \end{cases} \tag{2}$$

Using the preceding equation, we can calculate

$$\begin{cases} \dot{I}_L = -(1-u) \frac{V_c}{L} - \frac{E}{L} \\ \dot{V}_C = (1-u) \frac{I_L}{C} - \frac{V_C}{RC} \end{cases} \tag{3}$$

The bilinear form is made possible by equation (3) **[45]:**

$$\begin{bmatrix} \dot{I}_L \\ \dot{V}_C \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ -\frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix} + \begin{bmatrix} 0 & \frac{1}{L} \\ -\frac{1}{C} & 0 \end{bmatrix} \begin{bmatrix} I_L \\ V_C \end{bmatrix} u + \begin{bmatrix} \frac{E}{L} \\ 0 \end{bmatrix} \tag{4}$$

3.1.2 Small signal modeling of boost converter

The following notations for the averages of the state variables are used in order to carry out the small-signal analysis of the boost converter **[46]:**

iC = IC vC = V_C

The small-signal averaged model is derived from (3) as follows:

$$\begin{cases} \dot{i_L} = -(1-u)\frac{V_c}{L} - \frac{E}{L} \\ \dot{v}_C = (1-u)\frac{i_L}{C} - \frac{v_C}{RC} \end{cases} \qquad (5)$$

The steady-state input-output characteristic can be obtained by canceling the derivatives in equation (5) **[47].** It is the location of the equilibrium points in the system, shown by the subscribert t e.

$$\begin{cases} i_{Le} = \frac{E_e}{(1-u_e)^2 R} \\ v_{Ce} = \frac{E_e}{(1-u_e)} \end{cases} \qquad (6)$$

The boost converter's static behavior is provided by equation (6). In order to extract the small-signal model, the large-signal model of the boost converter will be derived around the equilibrium point. "~" indicates the minor differences. close to the point of balance. The system's variables can all be expressed in the following manner around the equilibrium point [48]:

$$\begin{cases} \alpha = \alpha_e + \tilde{\alpha} \\ u = u_e + \tilde{u} \\ i = i_{Le} + \tilde{i_L} \\ V_C = V_{Ce} + \widetilde{V_C} \\ E = E_e + \tilde{E} \end{cases} \qquad (7)$$

It's simple to express the state-space model as:

$$\begin{cases} L\dot{\tilde{i_L}} = \left(E_e + \tilde{E}\right) - (1 - u_e - \tilde{u})(v_{Ce} + \tilde{v}_C) \\ C\dot{\tilde{v_C}} = (i_{Le} + \tilde{i_L})(1 - u_e - \tilde{u}) - \frac{(v_{Ce}+\tilde{v}_C)}{R} \end{cases} \qquad (8)$$

We utilize the Taylor series development, restricted to the first order, in the vicinity of the selected equilibrium operating points. One gets what they want:

$$\begin{cases} L\dot{\tilde{i_L}} = E_e + \tilde{E} - (1 - u_e)v_{Ce} - (1 - u_e)\tilde{v}_C + v_{Ce}\tilde{u} + \tilde{v}_C\tilde{u} \\ C\dot{\tilde{v}}_C = (1 - u_e)i_{Le} + (1 - u_e)\tilde{\imath}_L - \frac{\tilde{v}_C}{R} - i_{Le}\tilde{u} - \frac{v_{Ce}}{R} - \tilde{\imath}_L\tilde{u} \end{cases} \qquad (9)$$

We can simply find the small-signal average model of the boost converter by using relations (6) in the system of (9) and ignoring tiny changes:

$$\begin{cases} L\dot{\tilde{i_L}} = -(1 - u_e)\tilde{v}_C + v_{Ce}\tilde{u} + \tilde{E} \\ C\dot{\tilde{v}}_C = (1 - u_e)\tilde{\imath}_L - \frac{\tilde{v}_C}{R} - i_{Le}\tilde{u} \end{cases} \qquad (10)$$

$$\begin{cases} \dot{\tilde{i_L}} = -\frac{u'_e}{L}\tilde{v}_C + \frac{v_{Ce}}{L}\tilde{u} + \tilde{E} \\ \dot{\tilde{v}}_C = \frac{u'_e}{C}\tilde{\imath}_L - \frac{\tilde{v}_C}{R_eC} - \frac{i_{Le}}{C}\tilde{u} \end{cases} \qquad (11)$$

The boost converter's linearity is translated in the final equation. It will be simple to control as a result. We may also acquire the original plant circuit from (11) in order to examine the stabilization of the system. The supply circuit variation is denoted by the letter E~. The sporadic character of the wind may be the cause **[49].** This disruption needs to be conveniently considered. Assume that there are no output current disturbances in order to begin designing the control strategy.

One possible rewrite of equation (11) is as follows:

$$\begin{cases} \dot{x} = Ax + B\alpha \\ y = Cx \end{cases} \qquad (12)$$

A, B, and C are the matrices of the averaged state space model in tiny signal, with their values provided by: where x and y are the state vector and output vector, respectively:

III.4 Inverter modeling

The electrical circuit is responsible for the impressive amplitude conversion of DC power to AC power. There are two sorts of inverters that we can observe in frequency: voltage source And current source **[50]** Inverters are often divided into three groups: voltage source, current source, and impedance source **[51]** (figureIII.6). Additionally, there is a different classification for inverters linked to solar PV systems based on whether they are connected to the grid (figure III.6) or stand alone, as indicated in tablesIII.2**[52,53]:**

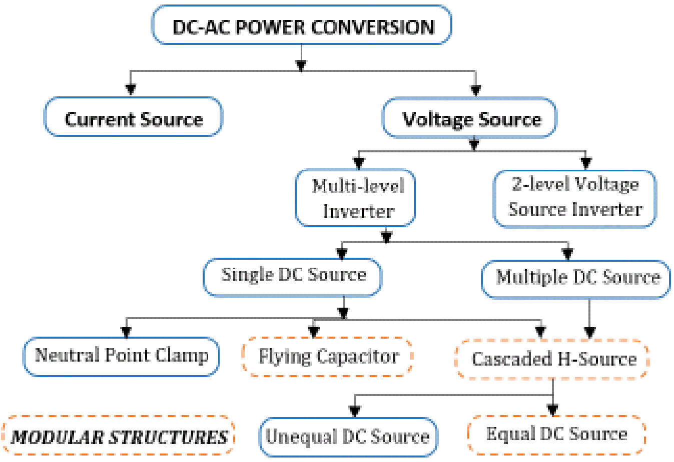
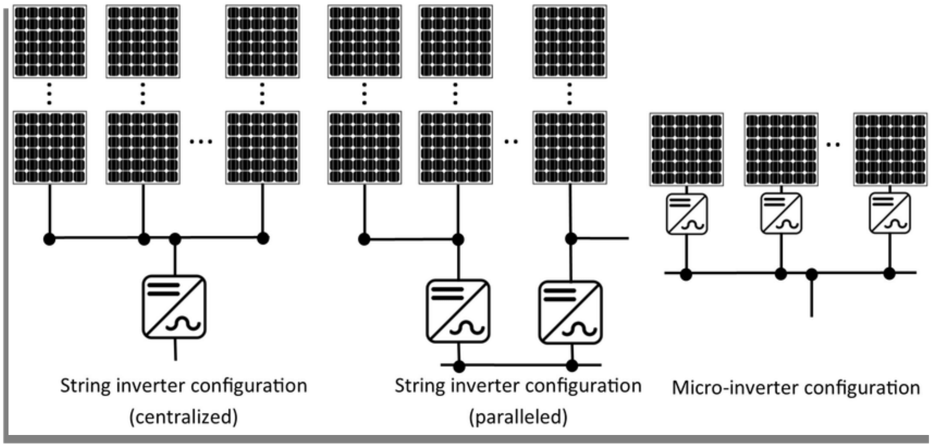


Figure III.6 Classification of the inverters **[51]**

TableIII.2: Characteristic of wind turbine generator **[52,53]**

Topology	**Advantages**	**Drawbacks**	**Capacity variation**
Centralized	Low cost	In case of failure of inverter there is no option of feeding power to the utility grid	30 kW-1 MW
String	Higher system efficiency	Low power output	1 kW-5 kW

Multi-string	Flexible system	The reliability of the system decreased as all the strings are coupled to a single inverter	Maximum 50 kW
AC module	Reduced costs and improved reliability	High cost	More than 500 W



FigureIII.7 Inverter design configurations **[54]**

4.1Mathematical model

We define the "fi" function, which employs one or zero as indicated in the following equation, to instruct each interrupter in the inverter:

$$f_i = \begin{cases} 1 \ \ if\ T_i \ \ is\ close\ and\ T_i' \ are\ open \\ 0\ if\ T_i \ \ is\ close\ and\ T_i' \ are\ close \end{cases} \qquad (1)$$

The inverter's voltage output is equivalent to:

$$\begin{cases} V_{aN} = F_1 V_{df} \\ V_{bN} = F_2 V_{df} \\ V_{cN} = F_3 V_{df} \end{cases} \qquad (2)$$

The following formulas are used to compute voltage line-to-line:

$$U_{ab} = V_{aN} - V_{bN} = V_{df}(F_1 - F_2)$$
$$U_{bc} = V_{bN} - V_{cN} = V_{df}(F_2 - F_3) \qquad (3)$$
$$U_{ca} = V_{cN} - V_{aN} = V_{df}(F_3 - F_1)$$

We derive new equations for the inverter output voltage based on the last equation:

$$\begin{cases} V_{aN} = V_a = \frac{U_{ab} - U_{ca}}{3} \\ V_{bN} = V_b = \frac{U_{bc} - U_{ab}}{3} \\ V_{cN} = V_b = \frac{U_{ca} - U_{bc}}{3} \end{cases} \qquad (4)$$

The last equations are written as matrices:

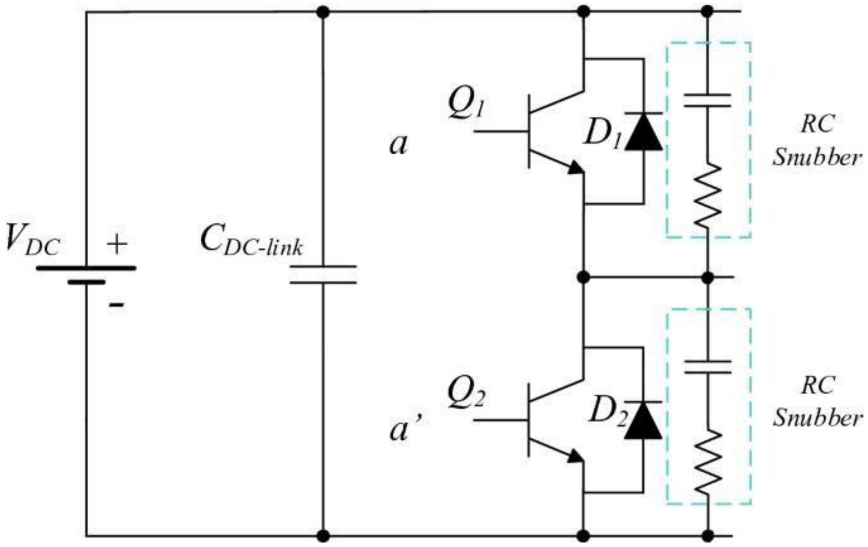
$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{3} V_{df} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} \rightarrow V_{abc} = V_{df.}[T_c][F]$$

Alongside:

$$[T_c] = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ -\frac{1}{2} & 1 & -\frac{1}{2} \\ -\frac{1}{2} & -\frac{1}{2} & 1 \end{bmatrix}$$

Tc: Convert matrix from one continuous type to another.

FigureIII.8 depicts the inverter's Simulink model.



FigureIII.8 Three phase interrupter bridge inverter

III.5 Helicopter modeling

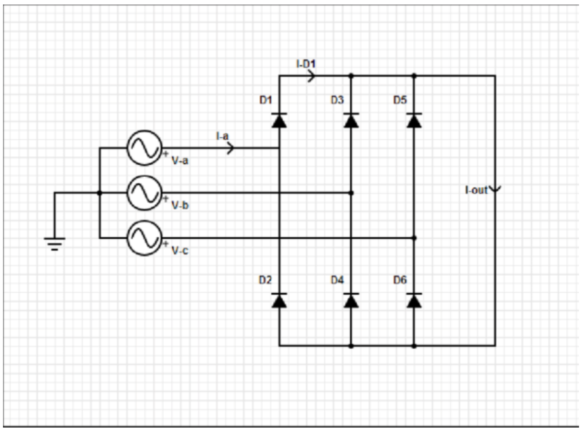
In power electronics, an electronic chopper is used to change a fixed DC input voltage into a variable DC output value. Applications include power supply management, renewable energy systems, and DC motor control are just a few of the many uses for it. There are various steps in the modeling process:

5.1mathematical model

Equations below illustrate the use of three-phase balanced voltage (figure III.10) in therectifier supply with V1, V2, and V3:

$$\begin{cases} \boldsymbol{V_1(t) = V_m sin\omega t} \\ \boldsymbol{V_2(t) = V_m sin(\omega t - \frac{2\pi}{3})} \\ \boldsymbol{V_3(t) = V_m sin(\omega t - \frac{4\pi}{3})} \end{cases} \qquad (1)$$

—



FigureIII.10 Three phase diode bridge rectifier

Maximum phase voltage is equal to the rectifier's positive output voltage, or VA.

According to the following formulae, VB, or voltage of the rectifier's negative output, equals the minimum voltage phase

$$VA = (V1, V2, V3) \qquad (1)$$

$$VB= (V1, V2, V3) \qquad (2)$$

$$VAB = (V1, V2, V3) - (V1, V2, V3) \qquad (3)$$

Using the following formula, we incorporate a filter for the rectifier's output in order to lessen harmonic and voltage perturbation:

$$\frac{U}{V_{AB}} = \frac{1}{LCS^2+\frac{L}{R}S+1} \quad (4)$$

Alongside:

L,C: The filter parameter.

R :stands for comparable resistor.

III.6 Storage system modeling

To make sure the system can efficiently store and release energy as needed, modeling a storage system—especially one for energy storage—involves a number of stages and factors. The modeling of battery storage systems, which are frequently utilized in connection with renewable energy sources like solar and wind power, will be the main topic of discussion here.

6.1 Types of Energy Storage Systems

6.1.1 Battery Storage: Lead-acid, nickel-cadmium, lithium-ion, and flow batteries.

6.1.2 Thermal Storage: Molten salt, phase change materials.

6.1.3 Mechanical Storage: Pumped hydro, flywheels, compressed air energy storage (CAES).

6.1.4 Chemical Storage: Hydrogen storage, synthetic fuels.

We will concentrate on modeling a battery storage system because batteries are widely used in contemporary energy storage technologies.

6.2 MathematicalModeling

6.2.1State of Charge(SoC)

The battery's state of charge (SoC) is expressed as a percentage of its overall capacity.

The SoC at time tt is given by:

$$SoC(t) = SoC(t-1) + \frac{P_{in}(t) - P_{out}(t)}{C_{batt}}$$

where P is located The charging power is denoted by $(t$) P in (t), the discharging power is denoted by (R) P out (t), and the battery capacity is represented by C batt.

6.2.2 Battery Efficiency:

Round-trip efficiency(η) accounts for energy losses during charging and discharging.

Effective power input/output considering efficiency:

$$P_{eff-in}(t) = \eta_{charge} \cdot P_{in}(t)$$

$$P_{eff-out}(t) = \eta_{discharge} \cdot P_{out}(t)$$

6.2.3 Battery Degradation:

Over time and with repeated use, battery capacity decreases.

Empirical or semi-empirical models can be used to simulate capacity deterioration, such as:

$$C_{batt}(t) = C_{batt}(0) \cdot (1 - D_{rate} \cdot N_{cycles}(t)))$$

where the rate ofThe degradation rate per cycle, or D rate, is equal to k cycles (t).The number of charge-discharge cycles at time t is equal to N cycles (t).

III.7 Conclusion

At the end of this chapter, we draw the conclusion that numerous mathematical models were found for every component of the hybrid system, and that each model explains a certain physical phenomenon. The construction of these renewable generators demonstrates both limitations and advancements in their characteristics.generators to maximize effectiveness. Numerous power converter control models were also noted. The results will be comparedwith HOMER PRO results in terms of technical parameters (total production, unmet load, etc.), economical parameters (investment cost, levilized cost, etc.), and ecological parameters (fuel consumption and carbon dioxide emission).

The next chapter includes Simulation results.

Chapter IV: Simulation results

IV.1 Introduction

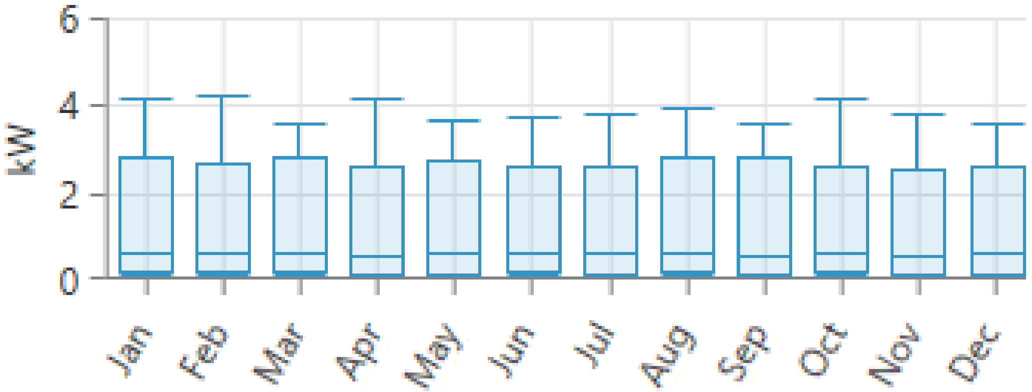
This final chapter explores the performance, efficiency, and adaptability of five customstorage systems. The comparison aims to understand the complexities of storage infrastructures under different conditions, including scalability, reliability, cost-effectiveness and environmental sustainability. Through the HOMER PRO program, we have conducted numerous rigorous experiments and analyses, and the authors aim to uncover deep insightsthat can guide strategic decision-making regarding the implementation or enhancement of storage solutions in isolated areas. The chapter provides a detailed explanation of the methodological framework, system selection criteria, experimental setup configuration, and performance evaluation metrics. It also highlights the differences between the two systems, the strengths and weaknesses, and potential opportunities for comparison and improvement of the different systems. The results provide valuable insights for strategic planning and future research in this area as this chapter includes software simulation, load profile, system components, simulation results and comparison between different systems.

IV.2 Simulation software

A potent program for hybrid and renewable web analysis is called Homer Pro. Underwriters Laboratories Inc.'s HOMER Energy created this program (UL). The technical-financial viability of electronic systems, such as battery storage and discrete generators, as well as renewable energy initiatives like solar, wind, hydro, and biomass, are frequently examined using this program. Additionally, certain programs are glad to model our system. One such tool is MATLAB Simulink, which is also frequently used to simulate hybrid and electrical systems. It stands out for being able to simulate and evaluate a wide range of hybrid system components, such as power converters and generators made of solar and wind energy. It enables users to create precise models that guarantee systems fulfill particular requirements and increase system efficacy. Various techniques are available for analyzing the performance of storage systems, including models of battery degradation that replicate the reduction in battery capacity due to frequent usage and time. By using these models, storage systems' architecture may be strengthened and their long-term stability and dependability as a sourceof energy guaranteed. Lastly, it can be concluded that the employment of these programs hasa major impact on the design and analysis of hybrid and renewable systems, allowing for the improvement of their economic and technical efficacy as well as the assurance of their environmental sustainability.

IV.3 Load profile

An Energy Needs Assessment is a critical step in designing a solar power and energy storage our system, especially for an isolated area in southern Algeria.. It involves analyzing and quantifying the energy requirements of the area to ensure that the system is appropriately sized and designed to meet those needs. Here's a detailed explanation of what is for assessing the energy needs in the Hassi Ben Abdallah region at coordinates:



FigureIV.1: Load analysis in the Hassi Ben Abdullah area over months.

FigureIV.2. A map representing the location of the city of Hassi Ben Abdullah

TableIV.1 lists the major appliances that are often found in a home along with how much energy they use in the summer and winter.

TableIV.1 Description of appliance uses in house

	Power (W)	Number	Winter season (Hrs./day)	Total consumption (Wh)	Summer season (Hrs./day)	Total consumption (Wh)
Bulb economic	45	6	5	1350	5	1350
Bulb halogen	75	5	5	1875	2	750
Refrigerator 250 L	150	1	24	3600	24	3600
Television + sat reserved	150+ 100	2	4	1000	5	2500
Computer	80	1	3	240	5	400
Ironer	1200	1	1	1200	1	1200
Dryer	1300	1	1	1300	1	1300
Washer machine	2000	1	1	2000	1	2000
Kitchen appliances	800	2	1	1600	1	1600
Pump	1000	1	1	1000	1	1000
Air conditioner (12000BTU)	1300	2	0	0	12	31200
Total	**8050**	**23**	**46**	**16165**	**58**	**44900**

The aforementioned data indicates that the demand for appliances in the winter is mostly for lights and refrigerators (21% and 24%, respectively; see figure IV.3). Some experts believe that if refrigerators ran for eight hours a day, this usage might be decreased. Due to the high temperatures in the summer, air conditioners are the most in demand (figure IV.4).

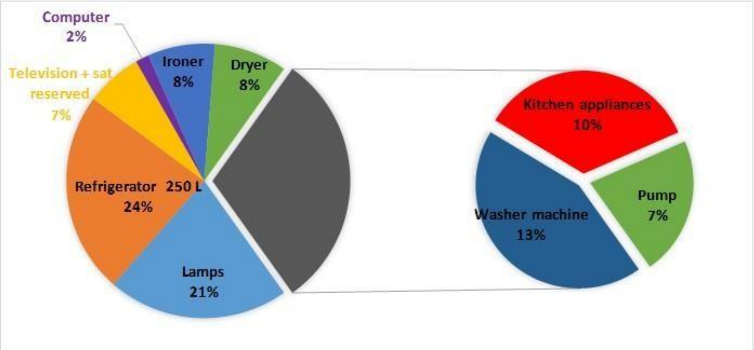


Figure IV.3 Distribution of used appliance in winter

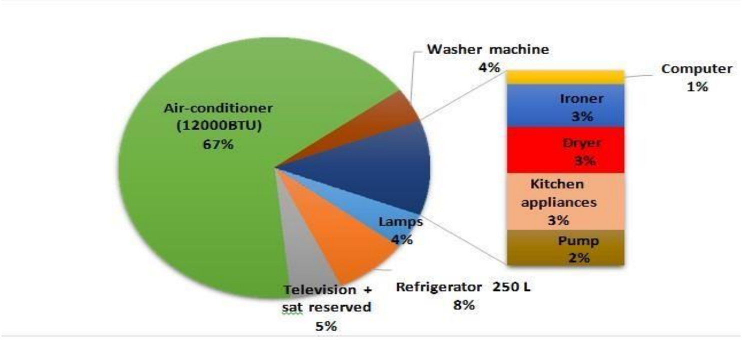
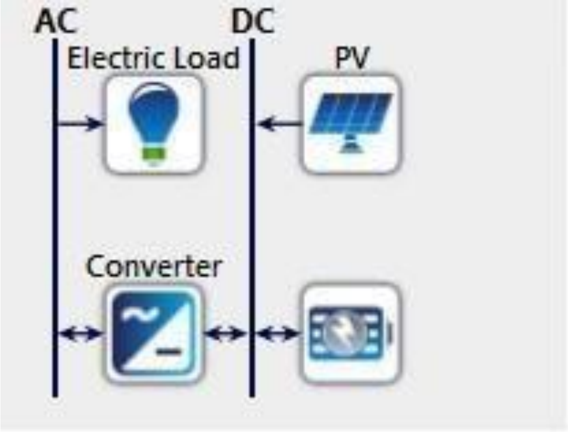


Figure IV.4 Distribution of used appliance in winter

IV.4 System components



FigureIV.3 System Design and Select appropriate solar panels, batteries, inverters, and other.

This figure Iv.3 content : This diagram shows a simplified system that includes photovoltaic (PV) panels, an electrical load, an inverter, and an energy storage unit. Photovoltaic panels convert sunlight into direct current (DC) electricity, which is stored in an energy storage unit (battery). A converter is used to convert DC electricity into alternating current (AC) to meet the needs of home appliances and AC electrical networks. Electricity generated from photovoltaic panels or stored in the battery is used to power electrical appliances, ensuring clean and sustainable energy. This system promotes energy efficiency and energy independence, and is an essential component of modern renewable energy solutions.

4.1 Pv solar

The software determine the number and type of solar panels based on the power requirements of our system. We also took into consideration factors in our isolated study area such as availability of sunlight, space constraints, and budget.

Table IV.2: Photovoltaic system Properties **.**

Name	Generic flat plate PV
Abbreviation	PN
Panel Type	flat plate
Rated Capacity	1 KW
Manufacturer	Generic
Cost Capacity 1Kw Capital	1030 US
Electrical bus	AC

4.2 Converter

It converts direct current (DC) output from solar panels into alternating current (AC) that we can use by home appliances.

Table IV.3: Settings Power Conversion Devices

Name	System Converter
Abbreviation	Converter
Cost Capacity 1Kw Capital	483.04 US
Lifetime	15 years
Efficiency	95 %
Relative capacity	100 %

Efficiency	95 %

4.3 Storage system

Energy storage, specifically batteries, is a crucial component in a solar power our system, particularly for isolated areas. Batteries store the excess energy generated by solar panels during the day for use when sunlight is not available, such as during the night or cloudy days. Here is a detailed settings the types of batteries used in our energy storage systems :

In Table IV.4, several data are displayed . These details also help in understanding the technical specifications, costs and service life associated with each type of battery, which helps in making the decision on implementing an energy storage system .

in columns listing the different types of batteries used in our energy storage system Types of batteries include lead acid,

Capacity (kWh): This represents the kilowatt-hour (kWh) storage capacity of each kind of battery.

Nominal Voltage (V): Each battery type's nominal voltage expressed in volts (V).

Nominal Capacity (kWh): This is another way to quantify the batteries' storage capacity in kilowatt-hours (kWh), just like capacity.

Maximum Capacity (Ah): This indicates the batteries' maximum capacity in ampere-hours (Ah), or the maximum amount of electrical charge that the battery is capable of holding.

Maximum Charge Current (A): The highest current that may safely be used to charge a battery, expressed in amperes.

Maximum Discharge Current (A): The highest safe current (measured in amperes) that the battery is capable of providing during a discharge.

Capital: The initial capital cost of each type of battery is displayed in this column, most likely expressed in dollars ($).

Replacement: Indicates the price in dollars ($) for changing each kind of battery.

O&M ($/year): This represents, presumably in US dollars, the annual cost of operation and maintenance for each type of battery.

The Maximum Charge Rate (A/Ah) indicates the highest possible rate of battery charging, potentially based on the ampere-hour (Ah) rating.

Time (years): The anticipated number of years that each kind of battery should last.

Table IV.4: Settings the five different battery types

Type	Li-ion	Lead Acid	Zinc-bromine flow	Lead acid (gel)	lithium iron phosphate
Capacity (kWh)	1	1	1	1	1
Nominal voltage(v)	720	12	100	2	167
Nominal capacity (kwh)	55	1	50	2,03	142
Maximaum capacity(ah)	76.4	83.4	500	1,01E+03	850
Maximaum charge current(A)	82	16.7	150	/	110
Maximaum discharge current(A)	200	24.3	300	/	170
Capital	60,000.00	300.00	300.00	312.00	40,000.00
Remlacement	48,000.00	240.00	300.00	312.00	0.00
O&M($/year)	10.00	10.00	10.00	400.00	800.00
Maximaum	1	1	/	/	/
Time(years)	20.00	10.00	30.00	/	20.00

IV.5 Simulation results

Selecting and sizing batteries for energy storage in an isolated solar power system requires careful consideration of various factors including capacity, depth of discharge, cycle life, efficiency, cost, safety, and maintenance.

5.1 System with battery lead acid

In Table IV.5, data including lead-acid battery type are shown. These details also help in understanding the technical specifications, costs and service life associated with each type of battery, which helps in making the decision on implementing an energy storage system.

TableIV.5 Lead acid battery settings

settings Battery		Lead Acid Battery
Architecture	PV (kW)	16.76
	Battery	44
	Converter (kW)	6.61
	Dispatch	CC
Cost	NPC (US$)	85.46
	COE (US$)	0.34
	Operating cost (US$/yr)	20.72
	Initial capital (US$)	33.65
System	Ren Frac (%)	100
	Total Fuel (L/yr)	0
PV	Capital Cost (US$)	17.26
	Production (kWh/yr)	28.58
Battery	Autonomy (hr)	22.41
	Annual Throughput (kWh/yr)	60.06
	Nominal Capacity (kWh)	44.03
	Usable Nominal Capacity (kWh)	26.42
Converter	Converter/Rectifier Mean Output (kW)	0.76
	Converter/Inverter Mean Output (kW)	0.58

5.2 System with battery Li-ion

In Table IV.6, data including Li-ion battery type are shown. These details also help in understanding the technical specifications, costs and service life associated with each type of battery, which helps in making the decision on implementing an energy storage system.

TableIV.6 Li-ion Battery settings

settings Battery		Li-ion Battery
Architecture	PV (kW)	7.86
	Battery	1
	Converter (kW)	5.59
	Dispatch	CC
Cost	NPC (USD)	79.43
	COE (USD)	0.62
	Operating cost (USD yr)	67.50
	Initial capital (USD)	70.80
System	Ren Frac (%)	100
	Total Fuel (L/yr)	0
PV	Capital Cost (USD)	80.99
	Production (kWh/yr)	1391
Battery	Autonomy (hr)	44.35
	Annual Throughput (kWh/yr)	65.80
	Nominal Capacity (kWh)	55.03
	Usable Nominal Capacity (kWh)	52.28

Converter	Converter/Rectifier Mean Output (kW)	0.76
	Converter/Inverter Mean Output (kW)	0.70

5.3 System with battery Zinc-bromine flow

In Table IV.7, data including Zinc-bromine flow battery type are shown. These details also help in understanding the technical specifications, costs and service life associated with each type of battery, which helps in making the decision on implementing an energy storage system..

TableIV.7 Zinc-bromine flow Battery settings

settings Battery		Zinc-bromine flow Battery
Architecture	PV (kW)	5.36
	Battery	80
	Converter (kW)	4.22
	Dispatch	CC
Cost	NPC (USD)	42.42
	COE (USD)	0.32
	Operating cost (USD /yr)	84.95
	Initial capital (USD)	31.56
System	Ren Frac (%)	100
	Total Fuel (L/yr)	0
PV	Capital Cost (USD)	55.24
	Production (kWh/yr)	94.88
Battery	Autonomy (hr)	30.54

	Annual Throughput (kWh/yr)	86.59
	Nominal Capacity (kWh)	40.00
	Usable Nominal Capacity (kWh)	36.00
Converter	Converter/Rectifier Mean Output (kW)	0.68
	Converter/Inverter Mean Output (kW)	0.79

5.4 System with battery Free Vented Lead acid (gel)

In Table IV.8, data including .battery type are shown. These details also help in understanding the technical specifications, costs and service life associated with each type of battery, which helps in making the decision on implementing an energy storage system.

TableIV.8 Free Vented Lead acid (gel)Battery settings

settings Battery		Free Vented Lead acid (gel) Battery
Architecture	PV (kW)	14.00
	Battery	15
	Converter (kW)	6.69
	Dispatch	CC
Cost	NPC (USD)	11.49
	COE (USD)	0.90
	Operating cost (USD yr)	72.42
	Initial capital (USD)	22.33

System	Ren Frac (%)	100
	Total Fuel (L/yr)	0
PV	Capital Cost (USD)	14.42
	Production (kWh/yr)	24.76
Battery	Autonomy (hr)	18.04
	Annual Throughput (kWh/yr)	59.00
	Nominal Capacity (kWh)	30.38
	Usable Nominal Capacity (kWh)	24.30
Converter	Converter/Rectifier Mean Output (kW)	0.71
	Converter/Inverter Mean Output (kW)	0.60

5.5System with battery lithium iron phosphate

In Table IV 9, data including the type of lithium iron phosphate battery are shown. These details also help in understanding the technical specifications, costs and service life associatedwith each type of battery, which helps in making the decision on implementing an energy storage system.

TableIV.9 lithium iron phosphate Battery settings

settings Battery		lithium iron phosphate Battery
Architecture	PV (kW)	9.18
	Battery	1
	Converter (kW)	6.52
	Dispatch	CC

Cost	NPC (USD)	65.07
	COE (USD)	0.51
	Operating cost (USD yr)	97.55
	Initial capital (USD)	52.60
System	Ren Frac (%)	100
	Total Fuel (L/yr)	0
PV	Capital Cost (USD)	94.51
	Production (kWh/yr)	16.23
Battery	Autonomy (hr)	12.04
	Annual Throughput (kWh/yr)	74.91
	Nominal Capacity (kWh)	14.19
	Usable Nominal Capacity (kWh)	14.19
Converter	Converter/Rectifier Mean Output (kW)	1.01
	Converter/Inverter Mean Output (kW)	0.66

After performing simulations for five different batteries, we note the results, where theproposed capacity of the solar panels for Li-ion is 7.86 kW, Lead Acid is:61.61kw, Zinc- bromine flow is:5.36kw , Free Vented Lead acid (gel)is14.00kw, Ithium iron phosphateis9.18kw.

We noticed that the number of batteries in each structure varies depending on the type of battery. At a 100% charge level, there is 1 battery in Architecture 1 , 44 batteries in Architecture 2,80 batteries in Architecture 3, 15 batteries in Architecture 4 and 1 batterie in Architecture5

The power produced by the panels is 6580.48 Li-ion, 6006.595 lead acid, 8659.345 Zinc-bromine flow, 5900.14 Free Vented Lead acid (gel), 7491.102 Ithium iron phosphate.

The number of charging hours Li-ion is 44.35 hours, Lead Acid is22.41 hours, Zinc- bromine flow is30.54 hours, Free Vented Lead acid (gel)is18.04 hours, Ithium iron phosphateis 12.04 hours

NPC represents the total cost of a power project over its lifetime, adjusted for the time value of money. There is 79.43 USD in Architecture 1, 85.46 USD in Architecture 2, 42.42 USD in Architecture 3, 11.49 USD in Architecture 4, 65.07 USD in Architecture 5. Through previous studies and from the results obtained, it was noted that the cost of architecture 4 is the most appropriate in this region under the conditions mentioned previously.

COE is the average cost of producing energy from a given source over the life of a project. Itis calculated by dividing the NPC by the total energy production of the project. COE is a key metric for evaluating the economic viability and competitiveness of different power generation technologies. Lower COE indicates lower costsper unit of energy produced. There is USD 0.62 in Architecture 1, there is USD 0.34 in Architecture 2, there is USD 0.32 in Architecture 3, there is USD 0.90 in Architecture 4, there is USD 0.51 in Architecture 5. Depending on the results obtained in NPC, we can say By comparing the unit-owned energy costs, Architecture 3 is the most economical unit in termsof cost.

This is the annual expenditure required to operate and maintain the power project. Operating costs include expenses such as fuel costs, maintenance costs, labor costs and other recurring expenses needed to keep the project running smoothly. There is USD 67.50/year in Architecture 1, there is USD 20.70/year in Architecture 2, there is USD 84.95/year in Architecture 3, there is USD 72.42/year in Architecture 4 and there is USD 97.55/year 1year In Architecture 5. Depending on the comparison of annual costs, Architecture 2 can be considered the best annual cost.

Initial capital refers to the initial investment required to buildor install a power project. It includes costs such as equipment purchase, construction, installation, land acquisition, permits, and engineering expenses. Initial capital is an important component of the total project cost and often determines the financial viability of the project. There are USD 70.80 for Architecture 1, USD 33.65 for Architecture 2, USD 31.56 for

Architecture 3, USD 22.33 for Architecture 4, and USD 52.60 for Architecture 5. Architecture 4 is a saving unit Cost of initial capital.

TableIV.10 Comparison table between architectures

Architecture	1	2	3	4	5
NPC	79,73	85,46	42,42	11,49	65,07
COE	0.62	0,34	0,32	0,90	0,51
Operating cost	67,50	20,70	84,95	72,42	97,55
Initial Capital	70,80	33,65	31,56	22,33	52,33
SUM	218,65	140,15	159,25	107,14	215,46

After comparing all Architectures and the total costs, we concluded that Architecture 4 is the least expensive. Summary of the benefits and drawbacks of each battery type mentioned:

Table IV.11: Comparison of five Battery in terms of Positives and negatives

Type Battery	**Positives**	**negatives**
lead acid	✓ Cost-effective option initially. ✓ Well-established technology with a long history of use. ✓ Generally reliable in providing energy storage	✓ Limited cycle life compared to other battery technologies. ✓ Requires regular maintenance such as topping up with distilled water. ✓ Lower energy density compared to newer battery types.

Li-ion	✓ High efficiency in energy storage and retrieval. ✓ Long service life withreduced maintenance. ✓ Abilitytowithstand harshoperatingconditions.	✓ High cost compared to some other technologies. ✓ Initial investment may be substantial.
Zinc-bromine flow	✓ . High capacity for energy storage. ✓ Ability for fast charging and discharging.	✓ High cost compared to lead-acid batteries.
Free Vented Lead acid (gel)	✓ Long service life. ✓ Ability to withstand harsh operating conditions.	✓ Higher cost compared to some other technologies. ✓ May be heavier and larger in size compared to lithium batteries
Ithium iron phosphate	✓ Ability to endure numerous charge and discharge cycles. ✓ Excellent performance and storage capability.	✓ High cost compared to other batteries. ✓ May require additional space for installation due to its larger size.

IV.6 Conclusion

This chapter concludes by examining the performance of five storage systems, focusing on the value of each system in different scenarios. We applied simulations using HOMER PRO simulation software to achieve the feasibility study, both technically and financially. The results show notable differences in system prices, configurations, and operational effectiveness. The previously mentioned differences lie in the conditions studied and the environment focused on the experiment, the galaxies, among which we mention the following:

First: We notice that the cost increases for the batteries in Architecture No. 01 and 05, and the reason for this is that in Architecture No. 01 there is a higher cost in NPC (Net Present Cost) and Initial Capital, or for Architecture No. 05 there is a higher cost in NPC. (Net Present Cost) and Operating cost.

Second: We note that the cost is low for the batteries in architecture No. 02 and 04, and the reason for this is that they are inexpensive in all standards of these areas.

We conclude that, based on the criteria through which the comparison was made, architectureNo.04 is the most cost-effective.

General conclusion

Conclusion and perspectives

In short, renewable energy is essential to meet the world's energy needs and reduce its dependence on fossil fuels. The growing energy crisis has an environmentally acceptable and sustainable answer in the form of alternative energy sources, such as wind and solar energy. The usefulness and efficiency of these systems in producing energy and reducing carbon emissions has been proven through many research and mathematical models.

Investing in renewable energy contributes to achieving sustainable economic growth by improving energy independence, generating new job opportunities, and cleaning the environment. Many existing problems can be solved and the use of renewable energy can be increased globally through continued technological advances and innovative energy storage technologies.

The primary goal of the research was to evaluate and audit five different energy storage technologies with respect to their effectiveness, affordability, and environmental reliability. Advanced simulation tools including MATLAB Simulink and HOMER PRO were used in the study to evaluate the economic and technical performance of the systems.

Through experience, we obtained results including:

1. Cost performance: System 4 was determined to be the most economical system, with the lowest total cost compared to other systems. This technology showed cheap investment costs and great operational efficiency.

2. Operating efficiency: Based on performance and operating efficiency, systems 2 and 4 were found to be the most effective, making them the best options for use in remote locations.

3. Impact on the environment: The study found that the use of contemporary energy storage technologies can reduce dependence on fossil fuels, which helps reduce carbon emissions and achieve environmental sustainability.

It is also recommended in the future to work more on studying energy storage deviceseffectively and continuously, including creating new products for advanced energy devices and technologies to enhance performance. Also, to ensure obtaining more comprehensive and accurate results, the scope of the research can be expanded to include additional technical systems and different operating settings. The research is longer The social and economic benefits of using renewable energy in different communities - such as improving the quality of life and creating jobs - are crucial.

The results of this study emphasize the necessity of investing in renewable energy storage technology as a means to achieve environmental and economic sustainability. By ensuring greater stability and reliability in energy supplies, these technologies can be continuously improved, helping to create a richer and more sustainable future. Energy storage systems may become more efficient and effective through further research and development, which will make renewable energy a reliable and feasible solution to meet the world's energy demands.

Abstract

The research focuses on the need for renewable energy to meet global energy consumption. The study evaluates the performance of different energy storage systems in various architectural environments, focusing on operational efficiency and economic feasibility. The research used HOMER PRO software to perform technical and financial feasibility analysis of various energy storage systems, analyzing net present cost, startup costs, and operating expenses. The results showed significant differences in the cost and performance of different configurations, with configuration No. 01 and 05 having higher costs due to higher net present cost and start-up capital. The study concluded that configuration No. 02 and 04 were more commercially viable due to their less expensive hulls. The most economically feasible configuration was Option 04, supported bythe use of HOMER PRO. The study emphasizes the importance of contemporary storage systemsin maintaining a stable and reliable energy supply, especially given the dispersed nature of renewable energy sources. The study aims to facilitate future research on energy storage technologies, addressing ongoing issues and leveraging technical advances. Efficient and renewable storage solutions are essential for transitioning to renewable energy sources, like solar and wind.

Keywords: storage systems ; feeding the isolated area; Batteries; Energy Storage ; lead acid.

Résumé

La recherche se concentre sur la nécessité d'énergies renouvelables pour répondre à la consommation énergétique mondiale. L'étude évalue les performances de différents systèmes de stockage d'énergie dans divers environnements architecturaux, en se concentrant sur l'efficacité opérationnelle et la faisabilité économique. La recherche a utilisé le logiciel HOMER PRO pour effectuer une analyse de faisabilité technique et financière de divers systèmes de stockage d'énergie, en analysant le coût actuel net, les coûts de démarrage et les dépenses d'exploitation. Les résultats ont montré des différences significatives dans le coût et les performances des différentes configurations, les configurations n° 01 et 05 ayant des coûts plus élevés en raison d'un coût actuel net et d'un capital de démarrage plus élevés. L'étude a conclu que les configurations n° 02 et 04 étaient plus viables commercialement en raison de leurs coques moins chères. La configuration la plus économiquement réalisable était l'option 04, prise en charge par l'utilisation de HOMER PRO. L'étude souligne l'importance des systèmes de stockage contemporains pour maintenir un approvisionnement énergétique stable et fiable, compte tenu notamment de la nature dispersée des sources d'énergie renouvelables. L’étude vise à faciliter les recherches futures sur les technologies de stockage d’énergie, en abordant les problèmes actuels et en tirant parti des avancées techniques. Des solutions de stockage efficaces et renouvelables sont essentielles à la transition vers des sources d’énergie renouvelables, comme l’énergie solaire et éolienne.

Mots clés : systèmes de stockage ; nourrir la région isolée Batteries; Stockage d'Energie ; plomb-acide.

ملخص

ويركز البحث على الحاجة إلى الطاقة المتجددة لتلبية الاستهلاك العالمي للطاقة. تقوم الدراسة بتقييم أداء أنظمة تخزين الطاقة المختلفة في بيئات معمارية مختلفة، مع التركيز على الكفاءة التشغيلية والجدوى الاقتصادية. استخدم البحث برنامج HOMER PRO لإجراء تحليل الجدوى الفنية والمالية لمختلف أنظمة تخزين الطاقة، وتحليل صافي التكلفة الحالية، وتكاليف بدء التشغيل، ونفقات التشغيل. أظهرت النتائج اختلافات كبيرة في تكلفة وأداء التكوينات المختلفة، حيث أن التكوينين رقم 01 و05 لديهما تكاليف أعلى بسبب ارتفاع صافي التكلفة الحالية ورأس المال المبدئي. وخلصت الدراسة إلى أن التكوينين رقم 02 و04 كانا أكثر قابلية للتطبيق تجاريًا بسبب هياكلهما الرخيصة. كان التكوين الأكثر جدوى من الناحية الاقتصادية هو الخيار 04، المدعوم باستخدام HOMER PRO. وتسلط الدراسة الضوء على أهمية أنظمة التخزين المعاصرة للحفاظ على إمدادات طاقة مستقرة وموثوقة، لا سيما بالنظر إلى الطبيعة المتناثرة لمصادر الطاقة المتجددة. وتهدف الدراسة إلى تسهيل البحوث المستقبلية في تقنيات تخزين الطاقة، ومعالجة القضايا الحالية والاستفادة من التقدم التقني. تعد حلول التخزين الفعالة والمتجددة ضرورية للانتقال إلى مصادر الطاقة المتجددة، مثل الطاقة الشمسية وطاقة الرياح.

الكلمات المفتاحية: أنظمة التخزين؛ تغذي المنطقة المعزولة بالبطاريات؛ تخزين الطاقة؛ حمض الرصاص.

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