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SIZING AND DESIGN OF A RENEWABLE HYBRID POWER SYSTEM

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DEDICATION

This thesis is dedicated to:

My lovely parents who have never failed to give their financial and moral support,

My beloved brothers, relatives, friends and colleagues who provided invaluable insights, encouragement, and believing in me.

Your friendship has made the challenges more bearable and the victories more meaningful,

To the Electrical Engineering Department Staff and,

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All the people in my life who touch my heart,

I dedicate this research.

Ndebele Bongani M

DEDICATION

Not all words can express gratitude, love, respect, recognition, sacrifices... Also, it is quite simply that:

I dedicate this work to my very dear parents for all their support throughout my journey To my very dear mother for whom no sentence can describe the degree of love and affection I feel. For all its good deeds and all the tenderness and affection with which you have filled me throughout my life. May Allah grant you better health, happiness and long life.

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List of Symbols and Abbreviations

A: Panel surface

AC: Alternating current

A/C: Air conditioners

Bat: Battery

CSP: Concentrating Solar Power

Cu: Copper

CRF: Capital recovery factor

COE: Cost of Energy or Cost of Energy

CT−ann: Annualized total cost of the system.

°C: Degree Celsius

C_{Bat}: Capacity of the battery.

DC: Direct Current

DG: Diesel Generator

DOD: Depth of Discharge

EMS: Energy management strategy

GHI: Global Horizontal Irradiance

Hz: Hertz

HOMER: Hybrid Optimization Model for Electric Renewables

kW: kilo-watt

kWh: kilo watt hour

MW: Mega-watts

NPC: Net Present Cost

NREL: National Renewable Energy Laboratory

NASA: National Aeronautics and Space Administration

η_{Inv}: Efficiency of the inverter,

η_{Bat}: Efficiency of the battery,

O&M: Operation and Maintenance

PV: Photovoltaic

P_{Bat}: Power of the battery.

$P_{DG}(t)$: The output power of the generator,
P_R A: The rated power of the generator,
ΔP: Resultant Power

SOC: State of Charge

TNPC: Total Net Present Cost

V: Voltage

WT: Wind Turbine

W:Watt

Abstract

The main objective of this work is the study of the hybrid system (multi-source) and to optimize the use of available energy resources, to ensure stable, efficient and sustainable electricity production. This research work mainly aims to make a contribution to the understanding and energy management of hybrid stand-alone systems with renewable energies with electrochemical storage for an isolated area, the chosen location is the university residence 19 MAY 1956. To do this, this thesis proposes a method for energy management of a hybrid photovoltaic-wind autonomous system.

To this end, the state of the art on the optimal management of energy flows in hybrid renewable energy systems as well as various energy management strategies are presented. The hybrid renewable energy stand-alone system studied in this project consists of a photovoltaic subsystem (photovoltaic panels and power converter). Each component of this hybrid system was studied, modeled, and simulated in the MATLAB/Simulink environment. The system is composed of renewable sources (solar and wind) and storage elements (batteries), which is combined with a Diesel Generator.

We developed an energy management algorithm for the overall hybrid system under MATLAB/Simulink (for the modelling and optimization of the proposed system) and HOMER (for the geolocation and techno-economic criteria of the case study) .

Résumé

L’objectif principal de ce travail est l’étude du système hybride (multi-source) est d’optimiser l’utilisation des ressources énergétiques disponible, pour assurer une production d’électricité stable, efficace et durable. Ce travail de recherche vise principalement à apporter une contribution à la compréhension et à la gestion d'énergie des systèmes autonomes hybrides aux énergies renouvelables avec stockage électrochimique pour une zone isole l’endroit choisi est la résidence universitaire 19 MAI 1956. Pour ce faire, ce mémoire propose une méthode de gestion d'énergie d’un système autonome hybride photovoltaïque-éolien. Pour cela, l’état de l’art sur la gestion optimale des flux d’énergie dans les systèmes hybrides à énergies renouvelables ainsi que différentes stratégies de gestion d’énergie sont présentés.

Le système autonome hybride à énergies renouvelables étudié dans le cadre de ce projet est constitué d’un sous-système photovoltaïque (panneaux photovoltaïques et convertisseur de puissance). Chaque composant de ce système hybride a été étudié, modélisé et simulé dans l’environnement MATLAB/Simulink. Le système est composé de sources renouvelables (solaires et éoliennes) et des éléments de stockage (les batteries), lequel est associé à un Générateur Diesel. Nous avons développé un algorithme de gestion d’énergie pour le système hybride global sous MATLAB/Simulink (pour la modélisation et optimisation du système proposer) et HOMER (pour la géolocalisation et les critères technico-économiques cas de notre étude).

General Introduction

Currently, the world is looking for alternative energy sources as the demand for energy continues to grow and economic growth has become synonymous with ever-increasing energy consumption. The latter is still dependent on fossil fuel reserves or intermittent sources. But intermittent sources do not deliver a constant power, they do not allow continuous electricity production. The major problem of these renewable energy sources is due to their random nature, which influences the availability of these energy resources according to the annual or daily periods, and in order to ensure the continuity of service even when production is zero, on the one hand; and on the other hand, to avoid the loss of the surplus energy caused, it is necessary to add a storage element and/or a conventional energy source. This situation cannot continue, a more judicious use of energy and a transformation of the energy sector are essential.

In our present work, the aim is to present a solution that is based on the use of several sources of renewable energy, in order to meet the requirements of a given load. But the uncertain availability of renewable energy sources (solar, wind) makes it necessary to integrate a storage device into our photovoltaic-wind system. This will make it possible to cover the energy craters, and to ensure a good quality of service. Hybrid energy systems find their importance by overcoming the intermittency, uncertainty, and low availability of each renewable energy source, making these systems more reliable. Photovoltaic and wind generators are practically complementary, as sunny days often have a weak wind, but cloudy days and nights probably have strong winds. This study is oriented towards residential hybrid energy systems completely isolated from the grid. However, small hybrid systems have become more attractive to consumers (prices are becoming more and more acceptable).

The objective of the chosen multi-source system is to supply a well-defined load with energy from the combination of energy input and demand, which is a function of time (day, season and year). Each source of energy varies according to the time of day, the season and the year. The balance between the energy input of each source and the demand is not always possible. The lack of energy will be compensated by introducing storage in the system or by adding DGs. Although the generator and diesel engine are not renewable energy sources per se, they are usually used in hybrid systems as a backup power supply. During our work, we study the wind-photovoltaic hybrid energy system with a storage tank for better reliability. Finally, we will present an algorithm for the overall energy management of a domestic load.

I.1 Introduction

Renewable energy is essential to meet today's environmental and energy challenges and represents a sustainable source of energy from natural resources such as solar, wind, water and biomass. Its increasing adoption is crucial for mitigating the effects of climate change, reducing dependence on fossil fuels, and promoting long-term energy security. This introduction addresses the growing importance of renewable energy in a world facing pressing ecological and economic challenges.

Nuclear energy is produced from an ore called uranium. The fission of uranium atoms releases a very large amount of energy that is used to heat water to produce electricity. Nuclear energy does not emit carbon dioxide, but it suffers from a bad image because of the risks involved. Indeed, the risks of accidents linked to their work but the consequences of an accident would be catastrophic. On the other hand, the treatment of waste from this method of production is very expensive: the radioactivity of the treated products remains high for many years. Finally, uranium reserves are, like oil reserves, limited (less than 100 years old at the current rate of consumption).

For electricity production today, the future is therefore not promising for fossil fuel resources, whose reserves are constantly dwindling and whose prices fluctuate enormously according to the economic situation. Preparation for the future in the areas of energy production must be planned today in order to be able to cope gradually with the inevitable energy changes. Each innovation and each advance in research will only have an impact in about ten years at best, the time it takes to carry out the necessary tests and to consider putting it into production without risk to the user, both for his health and for the electrical installations.

Because of all these problems, and in order to limit the use of energy from combustible sources, some countries have turned to a new form of energy called "Renewable" [1:2].

I.2 Renewable energies

Renewable energies are those that are almost inexhaustible. They depend on elements that nature constantly renews: wind, sun, wood, water, the heat of the Earth. Oil produces a thermal energy: heat. By using renewable energies, we combat the greenhouse effect, in particular by reducing the release of carbon dioxide into the atmosphere, and renewable energies make it possible to manage local resources intelligently and create jobs.

The development and exploitation of renewable energies has grown strongly in recent years. Within 25-35 years, any sustainable energy system will be based on the rational use of traditional sources and an increased use of renewable energy. The choice of the type of production will depend on the energy source to be exploited where it is potentially exploitable [3].

I.2.1 Wind energy

Wind energy has been known for thousands of years through windmills and shipping, and is an indirect form of solar energy, since winds are generated by differences in pressure and temperature in the atmosphere caused by solar radiation. Wind energy refers to the kinetic energy carried by air masses, i.e., winds, around our planet. It is a renewable energy that is increasingly being used to produce green electricity on a large scale [4].

FIGURE I. 1: WIND ENERGY

It can be transformed and used for several purposes:

- Transformation into mechanical energy: wind is used to propel a vehicle (sailboat or sand yacht), to pump water (pumping wind turbines to irrigate or water livestock) or to turn the millstone of a mill.
- Electrical energy production: the wind turbine is coupled with an electric generator to create direct or alternating current. The generator is connected to a power grid or operates as part of a "stand-alone" system with a backup generator (e.g., generator), battery bank, or other energy storage device. A wind turbine that produces electricity is sometimes referred to as a wind turbine Wind energy can be used in two ways:
- Conservation of mechanical energy: Wind is used to move a vehicle, to pump water, or to turn the millstone of a mill.
- Transformation into electrical energy: the wind turbine is coupled to an electric generator to produce direct or alternating current. The generator is connected to a power grid or

operates autonomously with a backup generator and/or a battery bank or other energy storage device [5].

I.2.2 Hydropower

Hydro power is a renewable energy source with very low greenhouse gas emissions. This renewable energy source harnesses the movement of water powered by the Sun and gravity through the water cycle, tides and ocean currents.

Whether they use natural waterfalls or artificial waterfalls (hydroelectric dams), the flow of rivers or ocean currents (tide, thermohaline circulation, etc.), hydroelectric power plants produce mechanical energy that is mostly converted into electricity (hydroelectricity) [6].

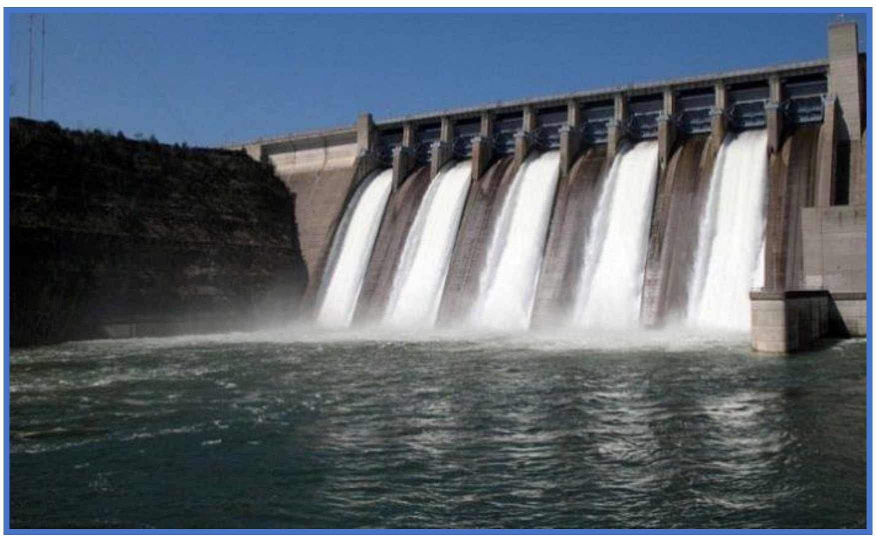

FIGURE I. 2: HYDROPOWER

I.2.3 Geothermal energy

Geothermal energy, from the Greek geo (earth) and thermos (heat) is a word that designates both the science that studies the internal thermal phenomena of the Earth, and the technology that aims to exploit it. By extension, geothermal energy also sometimes refers to geothermal energy from the Earth's energy that is converted into heat.

To capture geothermal energy, a fluid is circulated in the depths of the Earth. This fluid can be that of a natural confined hot water table, or water injected under pressure to fracture hot, impermeable rock. In both cases, the fluid heats up and rises loaded with calories (thermal energy). These calories are used directly or partially converted into electricity [7].

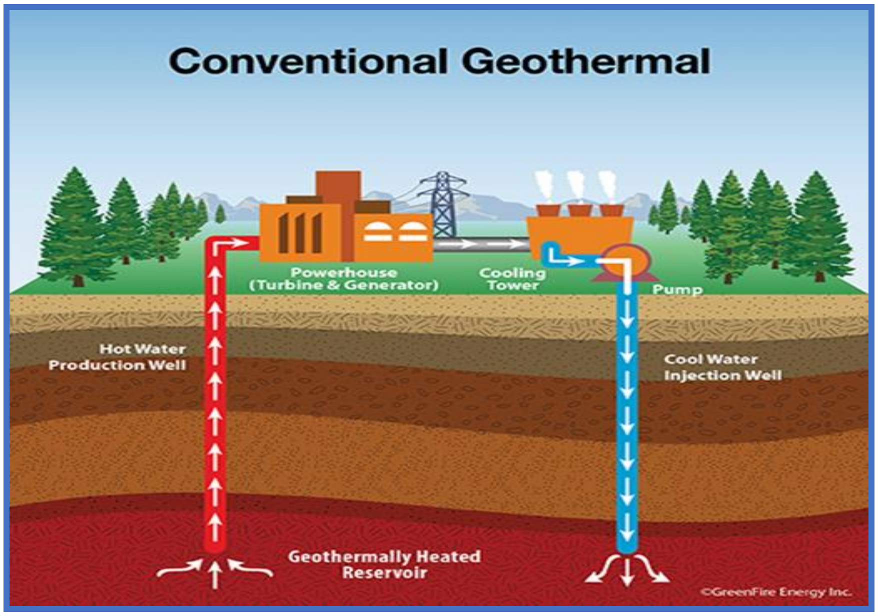

FIGURE I. 3**:** GEOTHERMAL ENERGY

I.2.4 Biomass energy

Biomass energy is the oldest form of energy used by humans since the discovery of fire in prehistoric times. This energy makes it possible to produce electricity thanks to the heat released by the combustion of these materials (wood, plants, agricultural waste, organic household waste) or biogas resulting from the fermentation of these materials, in biomass power plants.

- Biomass by combustion: Waste is directly burned by producing heat, electricity, or both (cogeneration). This concerns wood, waste from the wood processing industries and agricultural plant waste (straw, sugar cane, peanuts, coconuts, etc.).

- Biomass by anaerobic digestion: The waste is first transformed into biogas by fermentation using microorganisms (bacteria). The biogas is then burned. This biogas is similar to natural gas and is mainly composed of methane. This concerns household waste, animal manure and slurry, sludge from sewage treatment plants, paper and cardboard, etc. [8].

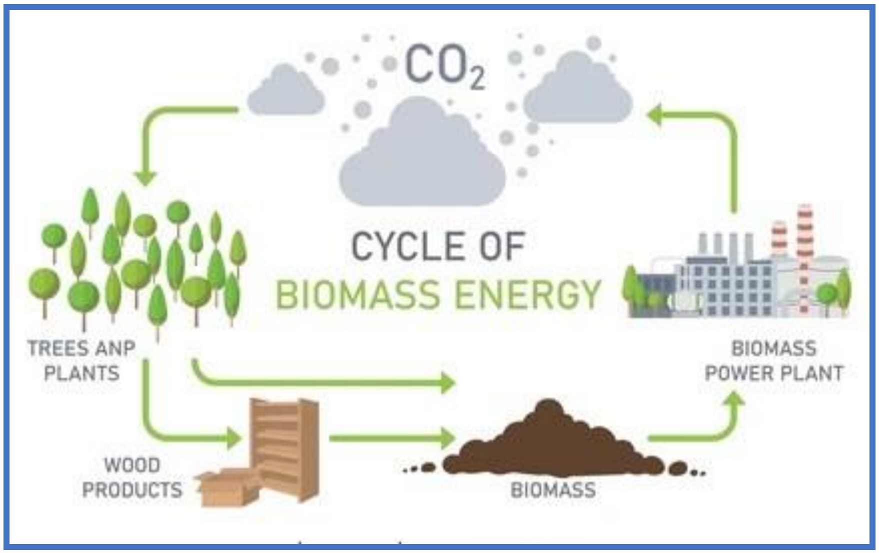

FIGURE I. 4**:** BIOMASS ENERGY

I.2.5 Solar energy

Photovoltaic solar energy is a form of renewable energy that produces electricity by transforming part of the sun's radiation through a PV (photovoltaic) cell. All the cells are connected to each other on a photovoltaic panel.

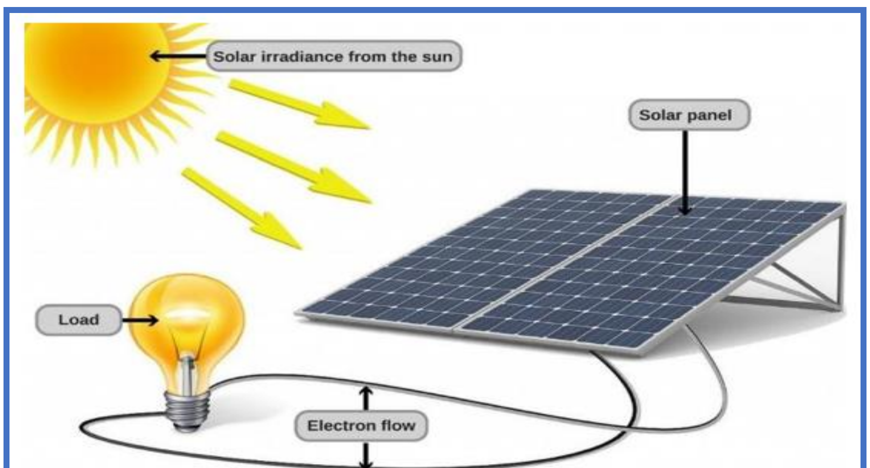

FIGURE I. 5: SOLAR ENERGY

Specific sensors are used to absorb the energy of the sun's rays and redistribute it according to three main modes of operation:

- **Solar photovoltaic** (photovoltaic solar panels): solar energy is captured for the production of electricity.

- **Solar thermal** (solar water heater, heating, solar thermal panels): the heat from the sun's rays is captured, redistributed, and more rarely used to produce electricity.

- **Aerovoltaics** : is a mixture of photovoltaic solar panels that produce electricity and solar thermal panels to heat the home [9].

I.2.3.1 The photovoltaic cell

The PV cell is the smallest component of a photovoltaic system. It is made of semiconductor materials and directly converts light energy into electrical energy.

- Several cells are connected together to form a photovoltaic solar panel (or module)[10].

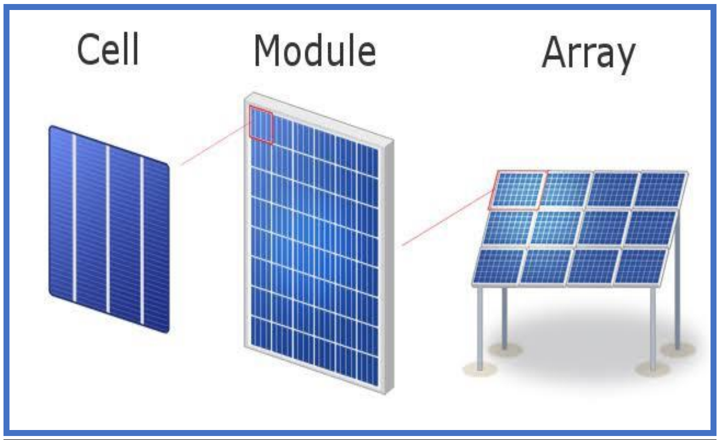

FIGURE I. 6: STRUCTURE OF PV CELL, MODULE AND ARRAY

I.2.3.2 Operation of a solar installation

A PV (Photovoltaic) installation is made up of 4 essential elements which are the PV panels, the regulator, the batteries and the inverter.

- **The photovoltaic panel:** transforms solar energy into electrical energy. It plays the role of a generator in the photovoltaic system because it provides direct current at very low voltage.

- **The regulator:** regulates the level of energy stored by the batteries, prevents overcharging or discharging too deep from the batteries, It is an essential element for the life of the battery.

- **Batteries:** are used to store electrical energy, ensuring the power supply of the receivers in all circumstances.

- **The inverter:** converts direct current to alternating current with the desired frequency.

I.3 The potential of renewable energies in Algeria

Algeria has a significant potential for renewable energies, especially solar energy, but it is very little developed. The main renewable resources existing in Algeria are presented in the next section.

I.3.1 Solar Potential

Algeria has one of the largest solar deposits in the world. The duration of sunshine over almost the entire national territory exceeds 2000 hours annually and reaches 3900 hours (highlands and Sahara).

The energy received daily on a horizontal surface of 1 m^2 is of the order of 5 kWh over most of the national territory, i.e. nearly 1700 kWh/m^2/year in the north and 2263 kWh/m^2/year in the south of the country [6]. Also, the energy received annually on a horizontal surface of 01 m^2, i.e., nearly 03 kWh/m^2 in the North and exceeds 05.6 kWh/m^2 in the Great South (TAMENRASSET). Figure I.4 shows the average annual direct irradiation (Period 2002-2011). The distribution of solar potential by climatic region in Algeria is shown in Table I.1 according to the amount of sunshine received annually [7].

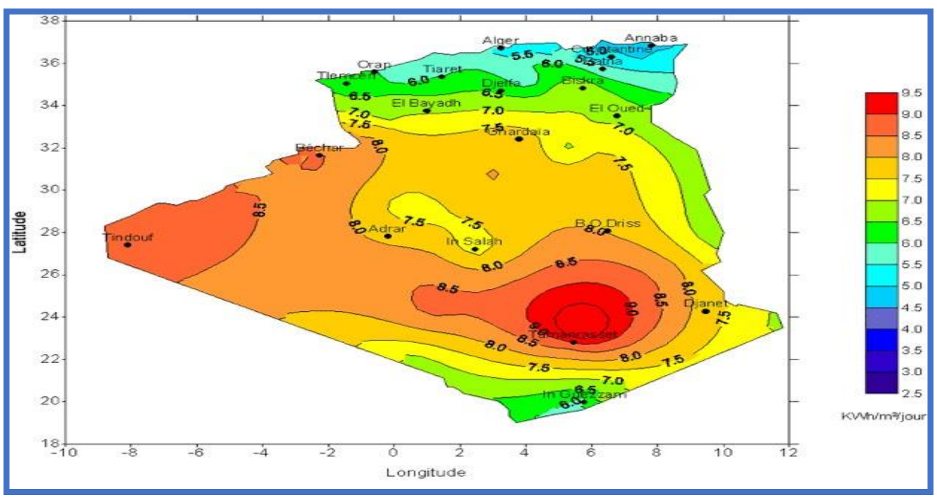

FIGURE I. 7**:** MAP OF AVERAGE ANNUAL DIRECT IRRADIATION (PERIOD 2002-2011) [7]

TABLE I. 1: THE DISTRIBUTION OF SOLAR POTENTIAL IN ALGERIA [7]

Regions	Coastal regions	High Plateaus	Sahara
Surface area (%)	4	10	86
Average duration of sunshine (hours/year)	2650	3000	3500
Average irradiation received (KWh /M^2/year)	1700	1900	2263

I.3.2 Wind Potential

The wind resource in Algeria varies greatly from one place to another. This is mainly due to a very diverse topography and climate. Indeed, the vast country is divided into two major and distinct geographical areas. The North Mediterranean is characterized by a coastline of 1200 km and a mountainous relief represented by the two chains of the Tellian Atlas and the Saharan Atlas. Between them are the plains and the continental highlands. The South, on the other hand, is characterized by a Saharan climate.

The map shown below (see Figure I.8) shows that the south is characterized by higher velocities than the north, especially in the southeast, with velocities exceeding 07 m/s and exceeding the value of 08 m/s in the region of Tamanrasset (In Amguel). In the North, the average speed is low. However, there are microclimates on the coastal sites of Oran, Bejaïa and Annaba, on the highlands of Tébessa, Biskra, M'sila and Elbayadh (06 to 07m/s), and the Great South (>8m/s) [7].

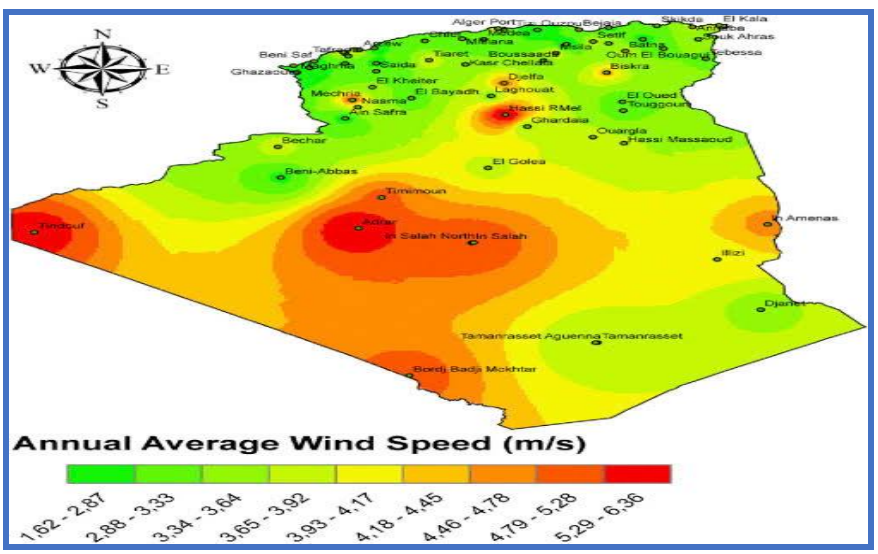

FIGURE I. 8: THE MAP OF THE MEAN ANNUAL WIND SPEED

I.4 Renewable Energy Program in Algeria

Algeria has embarked on the path of renewable energies in order to provide comprehensive and sustainable solutions to environmental challenges and the problems of preserving fossil energy resources through the launch of an ambitious programme for the development of renewable energies which was adopted by the Government in February 2011 and revised in May 2015. then placed as a national priority in February 2016 during the Select Council of the Government. The updated version of the renewable energy programme consists of installing around 22,000 MW of renewable energy capacity by 2030 for the national market, with the option of export being maintained as a strategic objective, market conditions permitting [7].

Through this renewable energy program, Algeria intends to position itself as a major player in the production of electricity from the photovoltaic and wind sectors by integrating biomass, cogeneration, geothermal energy and solar thermal.

These energy sectors will be the engines of sustainable economic development capable of driving a new model of economic growth. By 2030, 37% of installed capacity and 27% of electricity production for national consumption will be from renewable sources [8].

The adopted programme for the development of renewable energies and energy efficiency has emerged in its experimental and technology watch phase, new and relevant elements on the national and international energy scene, requiring the revision of the programme for the development of renewable energies and energy efficiency [7].

These include:

- A better understanding of the national potential in renewable energies through the studies undertaken.
- The reduction in the costs of the photovoltaic and wind energy sectors, which are increasingly asserting themselves on the market to constitute viable sectors to be considered (technological maturity, competitive costs, etc.);
- The costs of the CSP (Solar Thermal) sector, which remain high, are associated with a technology that is not yet mature, particularly in terms of storage, with a very slow growth in the development of its market.

Fig I.9 shows national generation in MW from renewable and non-renewable sources.

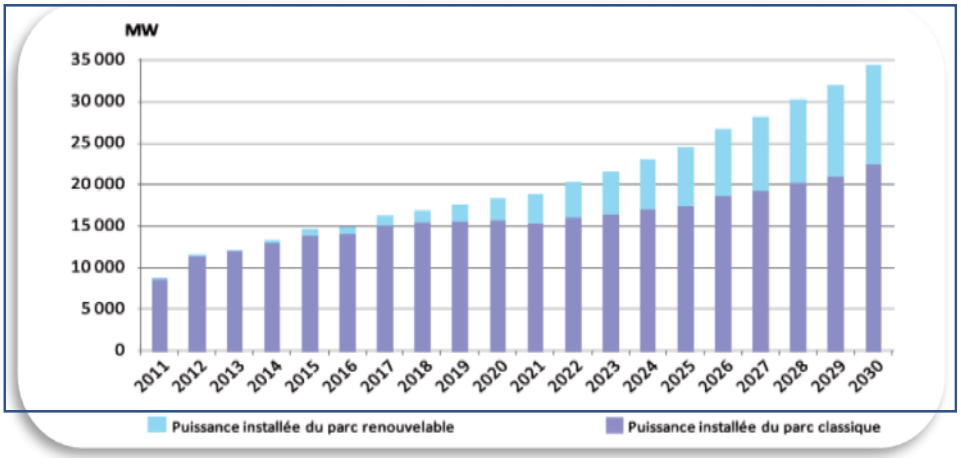

FIGURE I. 9**:** THE STRUCTURE OF THE NATIONAL GENERATION FLEET IN MW [9]

The renewable energy projects for the production of electricity dedicated to the national market have been and will be carried out in two stages:

- First phase 2015-2020: This phase will see the construction of a capacity of 4000 MW, between photovoltaic and wind, as well as 500 MW, between biomass, cogeneration and geothermal energy.

- Second phase 2021-2030: The development of the electricity interconnection between the North and the Sahara (Adrar), will allow the installation of large renewable energy plants in the regions of In Salah, Adrar, Timimoune and Béchar and their integration into the national energy system. The following table gives the cumulative capacities of the renewable energy program, by type and phase over the period 2015-2030.

TABLE I. 2: CUMULATIVE CAPACITY OF THE RENEWABLE ENERGY PROGRAMM [7]

	1st phase 2015-2020	**2nd phase 2021-2030**	**Total**
PV	3000	10575	13575
Wind Turbine	1010	4000	5010
CSP	-	2000	2000
Cogeneration	150	250	400
Biomass	360	640	1000
Geothermal energy	05	10	15
Total	4525	17475	22000

I.5 Conclusion

In this first chapter, we have highlighted the importance of renewable energies, especially since they are environmentally friendly and have great importance in preserving hydrocarbons and replacing them with natural energies. We also mentioned the issues and the energy context in Algeria and the types of renewable energies can be found in Algeria as well as the renewable energy production systems among water, photovoltaic and wind systems, which will be the subject of our thesis.

II.1 Introduction

Hybrid (multi-source) systems represent an innovative and integrated system in the field of energy production to optimize efficiency, reliability and sustainability. These systems, often combining renewable energy such as solar and wind with conventional sources such as diesel generators, offer a flexible and adaptable solution to meet diverse energy needs in a variety of contexts, from remote areas, to industrial facilities to power grids.

II.2 Problems and choice of subject of study

Renewable energy sources such as solar and wind are weather-dependent and can therefore be intermittent, posing challenges to ensure a constant supply of electricity. Efficient storage of renewable energy is essential to compensate for fluctuations in production and meet demand during periods of low production. Although the cost of renewables has fallen significantly in recent years, their large-scale deployment still requires significant investment, especially for infrastructure development.

Renewable energy sources, such as photovoltaics or wind turbines, do not deliver constant power. Their combinations with different sources make it possible to obtain continuous electricity production. Hybrid energy systems are generally self-contained from large interconnected grids and are often used in remote areas The advantage of a hybrid system over a pure wind or pure photovoltaic system depends on many fundamental factors. The shape and type of the load, the wind regime, the solar radiation, the cost, the availability of energy, the relative cost of the wind machine, the photovoltaic field, the electrochemical storage system, and other efficiency factors. Minimizing the cost of storage and optimizing its capacity is the main reason for the combination of wind and photovoltaic systems [11].

In our work, we are interested in the multi-source system composed of Photovoltaic and Wind energy, knowing that photovoltaic and wind energies have experienced a fairly high growth rate in recent years, thanks to the technological development relating to a better exploitation of these two sources.[12]

Photovoltaic and wind systems are highly coveted in the world, and particularly in Algeria which has a strategic geographical position that allows their development. [13].

The objective of the chosen multi-source system is to supply a well-defined load with energy resulting from the combination of energy input and demand (the load) which is a function of time (day, season and year). Each energy source (wind and photovoltaic energy) varies according to the time of day, the season and the year. The balance between the energy input of each source and the demand (type of load) is not always possible [14]. The lack of energy will be compensated by the introduction of storage in the system or by the addition of DG [15].

Although the generator and diesel engine are not renewable energy sources per se, they are typically used in hybrid systems as backup power.

II. 3 Multi-source systems

A hybrid energy system is defined as a facility that uses two or more of the technologies of energy generation. The term "multi-source system" is generally used to define a system that uses two or more complementary energy supply technologies. The multi-source renewable energy system for the production of electrical energy corresponds to a coupling between different energy sources, such as wind turbines, photovoltaic panels, diesel generator and a storage system (batteries and/or flywheel). The main difficulty of these systems is to be able to produce the energy needed for the load at all times, which is why they are often associated with a diesel generator whose purpose is to ensure continuity of service [12].

The combination of several renewable energy sources therefore makes it possible to optimize electricity generation systems as much as possible, both technically and economically [16].

II.3.1 The different combinations of multi-source systems

There are several combinations:

- Photovoltaic-generator set
- Wind - diesel
- Wind – photovoltaïque-diesel
- Photovoltaic-wind, battery storage (See Figure II.1),
- Photovoltaics - wind power, hydrogen storage, etc.

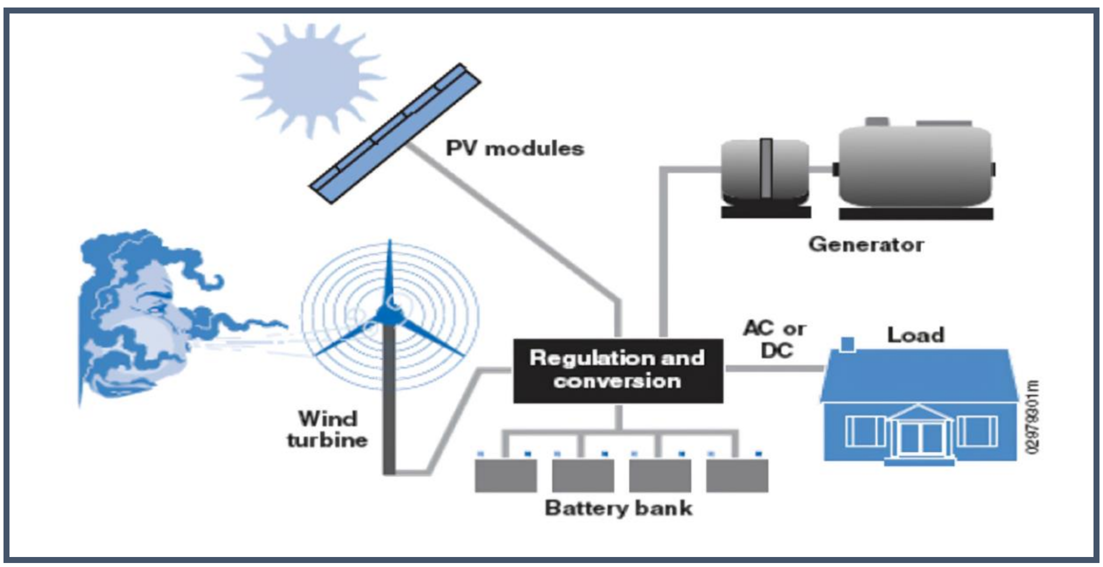

FIGURE II. 1: SYNOPTIC DIAGRAM OF THE HYBRID ENERGY SYSTEM [14].

II.3.2 The different configurations of multi-source or hybrid systems

Electric generators in a multi-source or hybrid system can be connected in a variety of ways, whether they are pure renewable, pure non-renewable, or mixed.

There are two types of hybrid energy systems consisting of renewable energy sources, with or without storage [17]:

II.3.2.1 DC bus architecture

In the hybrid system shown in the figure. II.2, the power supplied by each source is centralized on a DC bus. Thus, AC power conversion systems first supply their power to a rectifier to be converted to DC. The inverter must supply AC loads from the DC bus and must follow the set for amplitude and frequency. The batteries and inverter are sized to power loads [18].

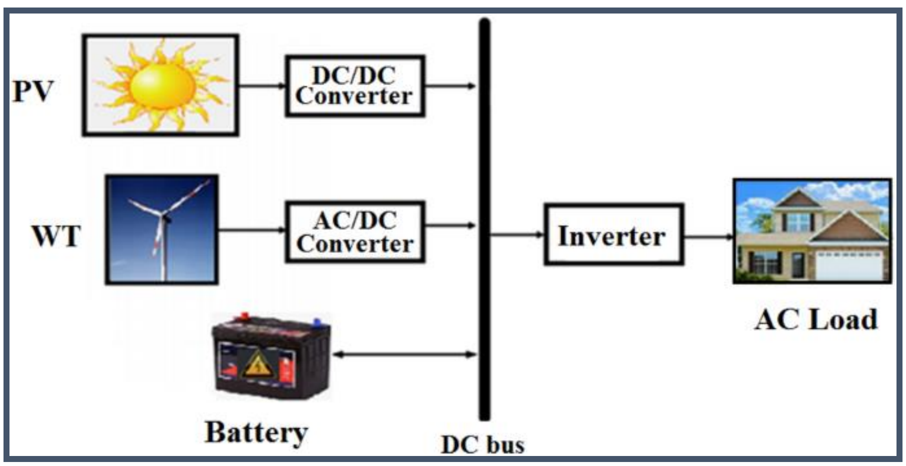

FIGURE II. 2: CONFIGURATION OF THE DC BUS HYBRID SYSTEM.

II.3.2.2 Mixed direct current (DC)/alternating current (AC) bus architecture

The two-bus, DC and AC configuration is shown in Figure II. 3. This one has superior performance compared to the previous configuration. In this configuration, renewable energy sources can power a portion of the load directly to AC, increasing the efficiency of the system. The converters located between the two buses (the rectifier and the inverter) can be replaced by a bidirectional converter, which in normal operation performs the DC/AC conversion (inverter operation). When there is a surplus, the batteries charge (operate as a rectifier). The bidirectional inverter can power peak loads [19].

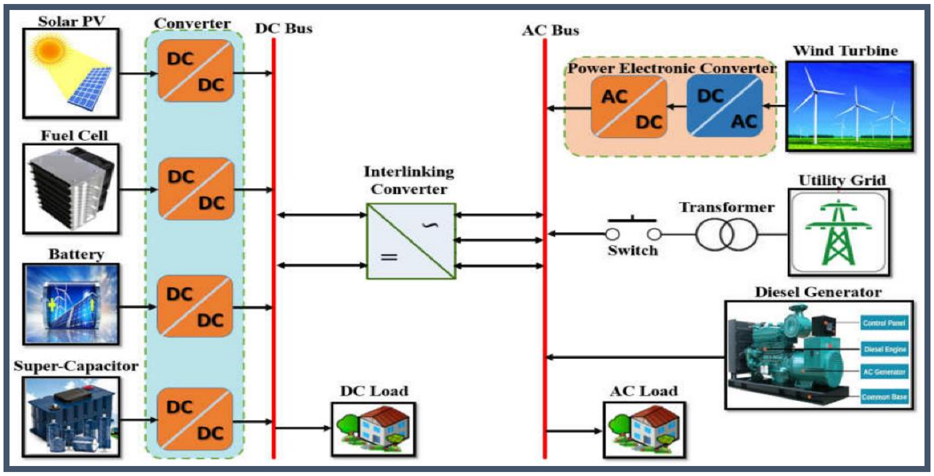

FIGURE II. 3: CONFIGURATION OF THE HYBRID DC AND AC BUS SYSTEM

II.3.3 Classification of multi-source renewable energy systems

Multi-source renewable energy systems: These can be divided into two categories: stand-alone (isolated site) and grid-connected [13]. The classification of multi-source renewable energy systems by power band is shown in Table II.1 below:

TABLE II. 1: CLASSIFICATION OF MULTI-SOURCE RE SYSTEMS BY POWER RANGE [20].

Power Plant Power multi source (KW)	**Application**
Low: Less than 5	Stand-alone systems: telecom stations, Water pumping. other isolated application
Medium: 10-250	Isolated microgrids: power supply for an isolated village, rural areas, ...
Large: greater than 500	Large isolated networks (e.g., island networks)

II.4 Description of the multi-source system studied

In this work, we will focus on the study of the energy management of a hybrid photovoltaic-wind-diesel system with storage (battery). The system we are interested in includes two parts for the production of energy (wind-photovoltaic) through storage (battery) accompanied by diesel generator. The purpose of the study is the optimization of multi-source systems based on photovoltaic panels, wind turbines and diesel batteries and generators. The multi-source system studied is the multi-source system shown in Figure II.4.

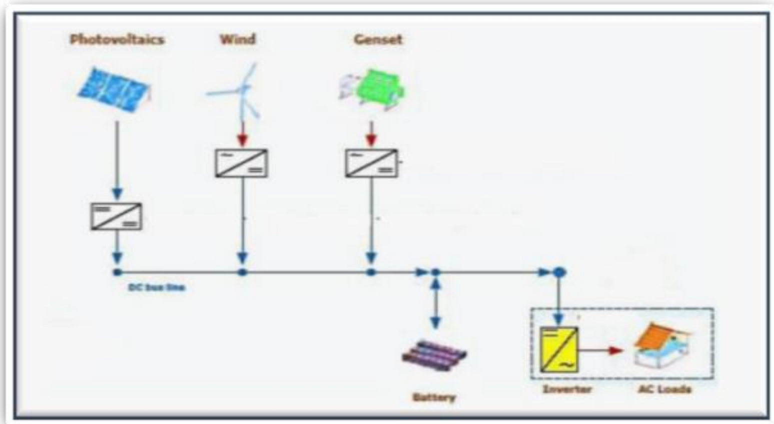

FIGURE II. 4: DIAGRAM OF ELECTRICAL ENERGY CONVERSION HYBRID (WIND-PHOTOVOLTAIC)

The system studied consists of photovoltaic panels, wind turbines and batteries and a diesel generator. The architecture chosen is of the DC type. Choppers are used to raise the voltage of the DC bus. The battery is charged via a charge controller connected to the DC bus. A DC/AC converter (inverter) can generate a voltage of 220V, 50Hz alternating which will be distributed [21].

II.5 Properties of each component of the multi-source system studied

II.5.1 Photovoltaic system

Photovoltaic solar energy refers to the electricity produced by transforming part of the sun's radiation with a photovoltaic cell. Several cells are connected to each other and form a photovoltaic solar panel (or module). Several modules that are grouped together in a photovoltaic solar power plant are called photovoltaic fields.

FIGURE II. 5: SOLAR PANELS

The solar panel is made up of several cells. The cells are made from two layers of silicon, one P-doped (usually boron-doped) and the other N-doped (usually phosphorus-doped). When the photons are absorbed by the semiconductor, they transmit their energy to the atoms in the PN junction in such a way that the electrons in these atoms are released and create electrons (N charges) and holes (P charges). This then creates a potential difference between the two layers. This potential difference is measurable between the positive and negative terminal connections of the cell [13].

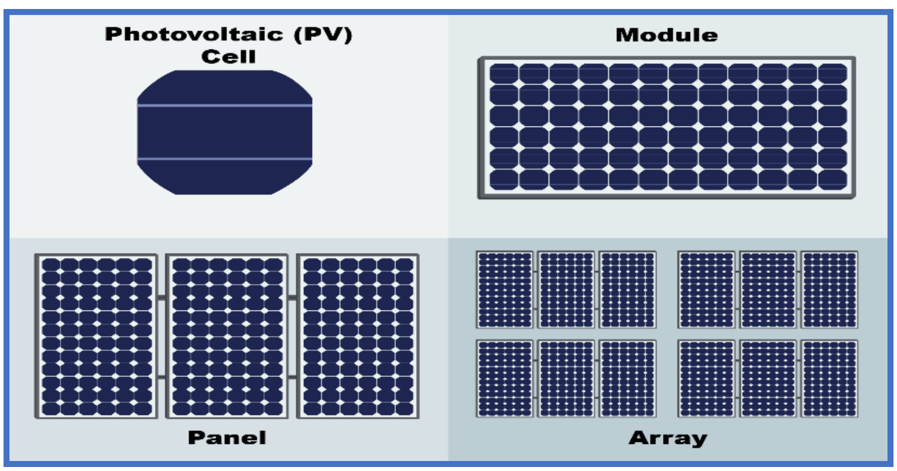

FIGURE II. 6: PHOTOVOLTAIC CYCLE

II.5.1.1 Principle of operation

Photovoltaic solar energy is the energy obtained by converting light into electricity. This energy is obtained through the physical phenomenon called the photovoltaic effect. Reported by Edmond Becquerel in 1839, the principle is quite simple and consists of the emergence of a potential difference at the ends of a structure of semiconductor material, produced by the absorption of light [12].

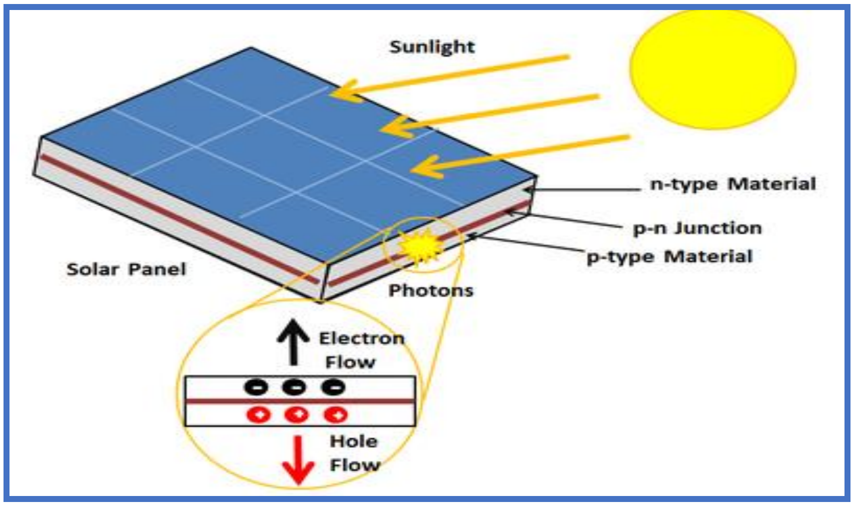

FIGURE II. 7: ILLUSTRATION OF A PHOTOVOLTAIC CELL

II.5.1.2 Solar radiation

The sun sends us energy in the form of electromagnetic radiation. The wavelength of the radiation ranges from 0.22 am to 10 am. Figure (II.8) shows the variation in the spectral distribution of this radiation. The incident solar radiation at the boundary of the atmosphere is equal to 342 W.m^{-2}. The Earth's surface absorbs only 168 W.m^{-2}, this radiation is composed of 60% direct radiation and 40% in the form of diffuse radiation [15].

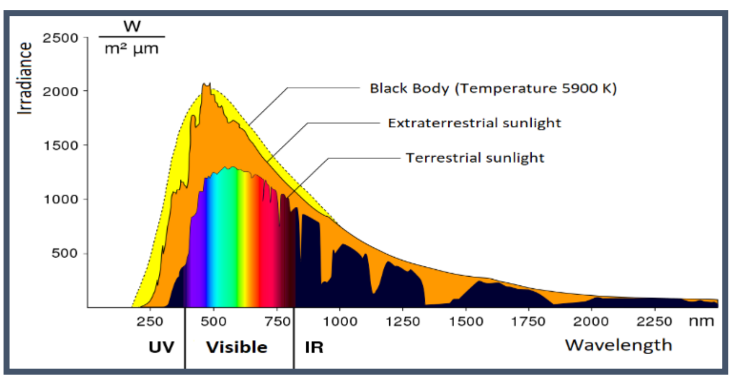

FIGURE II. 8: SPECTRAL REPRESENTATION OF RADIATION

The spectrum of solar radiation at the Earth's surface is made up of different components (Figure II-8). Direct radiation comes directly from the Sun, while diffuse radiation is scattered by the sky and the external environment. Yet another radiation is reflected by the external environment (land or sea) as a function of the local albedo. Total terrestrial radiation is referred to as global radiation.

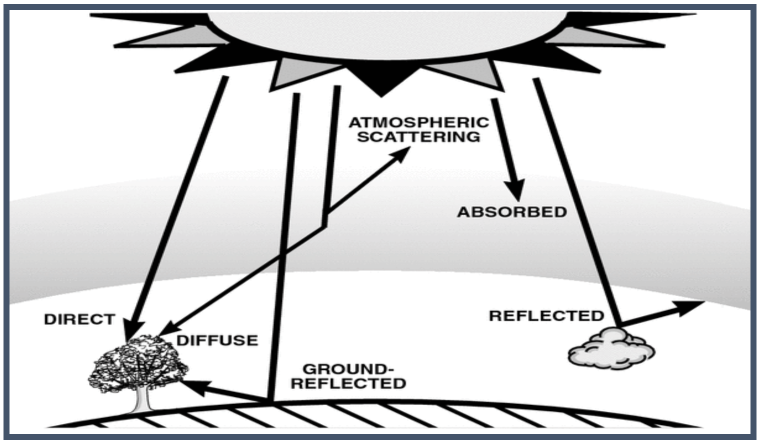

FIGURE II. 9: COMPONENTS OF SOLAR RADIATION AT GROUND LEVEL

II.5.1.3 Different types of photovoltaic cells

There are three main photovoltaic cell technologies:

A. Monocrystalline cells:

These cells are closest to the theoretical model. They are composed of a single crystal divided into two layers, and allow to obtain high yields, in the range of 15 to 22%.

FIGURE II. 10: MONOCRYSTALLINE PHOTOVOLTAIC CELLS

This technology has the following characteristics:

- First generation of solar cells.
- Shape of round, square or pseudo-square wafers, with a uniform blue-grey surface.
- Excellent yield of 15% and up to 24% in the laboratory.
- This is a laborious and difficult production method, and therefore, very expensive.
- Requires a large amount of energy to obtain a pure crystal.[16]

B. Polycrystalline cells:

These cells are made from a block of silicon crystallized into several crystals with different orientations. They are prepared by sawing a block of cast silicon into thin layers. They have a shiny blue-grey (multi-colored) pearlescent sheen.

FIGURE II. 11: POLYCRYSTALLINE PHOTOVOLTAIC CELLS

This technology has the following characteristics:

- Lower cost of production.
- Requires less energy.
- Yield of 13% and up to 20% in the laboratory [14].

C. Amorphous cells:

These cells are composed of a glass or synthetic material support on which a thin layer of silicon is arranged (the organization of the atoms is no longer regular as in a crystal). They have a uniformly dark surface.

FIGURE II. 12: AMORPHOUS PHOTOVOLTAIC CELLS

This technology has the following characteristics:

- Efficiency of only 6% per module and 14% in the laboratory.
- Much lower cost of production.
- Applied in small consumer products: watches, calculators.
- They have the advantage of being more responsive to diffuse and fluorescent light. Therefore, they perform best at high temperatures.[12]

II.5.1.4 Advantages and disadvantages of photovoltaic systems

A. Benefits:

- The modular nature of the photovoltaic panels allows for simple installation and adaptability to various energy needs. The systems can be sized for applications ranging from milliwatts to megawatts.
- Photovoltaic technology has ecological qualities, as the final product is non-polluting, silent and does not cause any disturbance to the environment.
- High reliability: it has no moving parts that make it particularly suitable for remote areas. This is the reason for its use on spacecraft.
- Their operating costs are very low due to low maintenance and they do not require fuel, transportation or highly specialized personnel [13].

B. disadvantages:

- The manufacture of the photovoltaic module is a high-tech and requires
- High-cost investments.
- The actual conversion efficiency of a module is low, in the range of 10-15%, photovoltaic generators are competitive with diesel generators only for low energy demands in remote areas.
- The non-availability of the source on a permanent basis.
- Space occupancy for large installations [15].

II.5.2 Storage batteries

A battery is a device that converts chemical energy directly into electrical energy. It contains one or more cells. Each cell is made up of three main parts: a positive electrode (terminal), a negative electrode, and a liquid or solid separating them called an electrolyte. When a battery is connected to an electrical circuit, a chemical reaction occurs in the electrolyte causing ions (in this case, an atom with a positive electric voltage charge) to pass through it in one direction.

With electrons (particles with a negative charge) flowing through the external circuit in the other direction. This electric movement the charge causes an electric current to flow through the cell and into the circuit. Different types of batteries are produced for different applications. They can be used to store solar energy.[17]

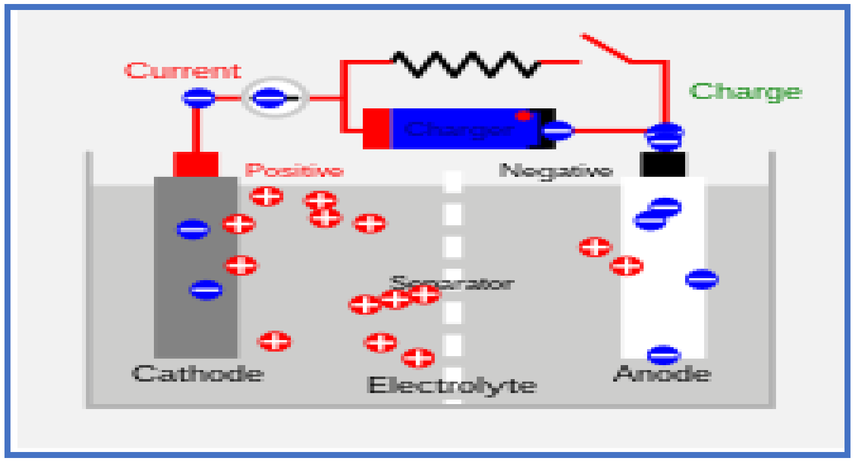

FIGURE II. 13: BASIC ELECTROCHEMICAL CELL

II.5.2.1 Different types of batteries

There are two types of batteries:

- Primary batteries (disposable batteries): designed to be used once and discarded.
- Secondary Batteries (Rechargeable Batteries): Designed to be used Charged and used multiple times. Most of the batteries used today with the hybrid power system come from the rechargeable battery. There are several types of rechargeable batteries.[14]

II.5.2.2 Requirements for Solar Batteries

The need for battery maintenance can be a major limitation for standalone PV systems. To be able to be used in the long term, batteries must meet the following requirements:

Low cost per kWh; a long service life; high overall efficiency; very low self-discharge; low maintenance cost; Ease of installation and operation.

The ambient temperature disrupts the operation of the battery, especially when it is cold because the chemical reactions will be slowed down. A battery therefore has a much lower capacity when cold than when hot. Solar installations in Algeria must therefore take this criterion into account by providing for a larger capacity [16].

II.5.2.3 Principle of operation of batteries

A battery is a set of electrochemical cells capable of storing electrical energy in chemical form, and then partially releasing it afterwards, thanks to the reversibility of the reactions involved.

These reactions consist of oxidations and reductions at the electrodes, the current flows in the form of ions in the electrolyte and in the form of electrons in the circuit connected to the battery. The energy capacity of the battery (expressed in watt-hours, Wh) depends on the amount and nature of the chemical elements in the cell.

The anode is the electrode at which oxidation (loss of one or more electrons) occurs and from which the electrons will feed the external circuit (the charge). The cathode is the electrode at which the reduction (gain of one or more electrons) occurs; The electrons returning from the charge arrive at this electrode. In discharge, the anode is the negative terminal of the battery and the cathode is the positive terminal. On the other hand, in charge, the negative electrode is the cathode, while the positive electrode is the anode, with the electrons flowing in the other direction

II.5.2.4 Battery Characteristic

A lead-acid battery is essentially characterized by the following parameters:[16], [18]

- **a- Rated Capacity (CN):** This represents the amount of electricity obtained after a total discharge of a battery initially charged to the maximum. Capacity is measured in Ampere Hour (Ah) during a set time of discharge. It depends mainly on the intensity of the discharge current.
- **b- Nominal Voltage (VN):** Batteries have a nominal voltage of 2, 6, 12 or 24V. An important parameter is the charging voltage, which is defined as the voltage needed to overcome the resistance that opposes the battery load.
- **c- Internal resistance**: It is formed by the ohmic resistance of the battery components (terminals, electrodes, holders and electrolyte) and by a virtual resistance that varies according to the state of charge and the different polarizations and concentrations. The internal resistance increases with the lowering of the outside temperature, the discharge and the aging of the battery.
- **d- Depth of Discharge (DOD):** This represents the amount of energy discharged from a battery. It is expressed as a percentage of its capacity. For example, a 20 Ah discharge from a 100 Ah battery corresponds to a 20% depth of discharge. A battery should not suffer deep discharges because its lifespan decreases rapidly with its discharge time. Maximum depth of discharge (DOD max) is the amount of energy that can be discharged without damaging the battery. The usable capacity of the battery, Cu (Ah), is:

$$C_U = C_N . DOD_{max} \qquad \text{(II.1)}$$

e- State of Charge (SOC): This represents the amount, in percentage, of energy accumulated in the battery at a given time. When the battery is fully charged, the SOC is equal to the maximum state of charge (SOC max), it is 100%. Batteries cannot be fully discharged, which is why manufacturers recommend not discharging batteries below a certain determined limit called minimum SOC min state of charge which is always between 30% and 40%. SOC min is calculated based on SOC max, and depth of discharge, DOD:

$$\boldsymbol{SOC_{min}} = (1\text{-DOC}) . \boldsymbol{SOC_{max}} \quad \text{(II.2)}$$

f- Lifespan: It is equal to the number of charge/discharge cycles that the battery can sustain before losing 20% of its rated capacity. For a battery operating under optimal conditions, its lifespan is estimated to be between 03 to 06 years.

II.5.3 Wind turbine system

A wind turbine, more commonly known as a wind turbine, is a device designed to convert the kinetic energy of the wind into mechanical energy, it is generally used to generate electricity and falls under the Renewable Energy Category.

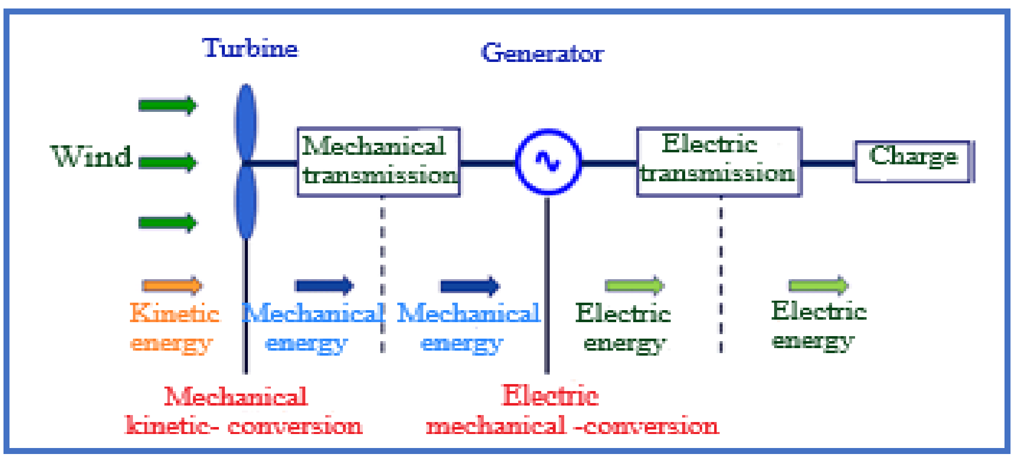

FIGURE II. 14: CONVERSION OF WIND KINETIC ENERGY

II.5.3.1 The different types of wind turbines

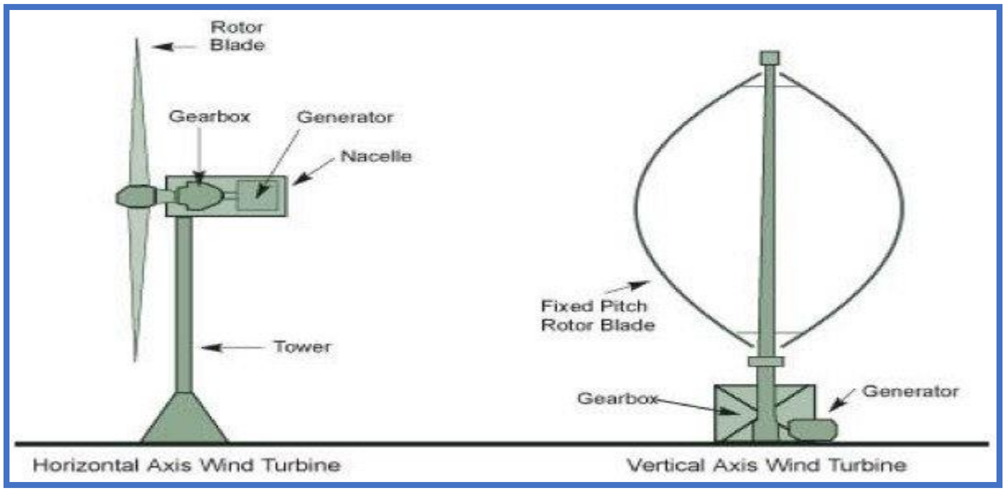

FIGURE II. 15: REPRESENTATION OF WIND TURBINE CONCEPTS HORIZONTAL AXIS AND VERTICAL AXIS [19].

A- Horizontal axis wind turbines:

Horizontal axis wind turbines are mainly composed of a tower at the top of which a nacelle is installed. This nacelle supports the turbine rotor – hub and blades – and includes the drive system as well as the generator. The axis of rotation of the turbine rotor is therefore horizontal [15].

B- Vertical axis wind turbines:

Vertical axis wind turbines, the rotor axis of rotation is perpendicular to the ground. This allows the drive system as well as the generator to be placed at ground level. They are suitable for all winds and do not require an orientation device.

II.5.3.2 the main parts of the wind turbine:

A high-speed wind turbine is mainly made up of three parts: the blades (between 1 and 3), the nacelle and the tower. Each of these parts must be carefully studied and modelled in order to obtain a better performance and reliability of the system as well as a low investment cost.

A- The tower: is usually a steel tube or possibly a wire mesh, it should be as high as possible to avoid disturbances near the ground. However, the quantity of material used represents a significant cost and the weight must be limited. A compromise is usually to take a tower (mast) that is very slightly larger than the diameter of the wind turbine rotor.

B- The nacelle: includes all the mechanical elements used to couple the wind rotor to the electric generator: slow and fast shafts, bearings, gearbox. The disc brake, different from the aerodynamic brake, which allows the system to be stopped in the event of overload. The generator which is usually an asynchronous machine and the hydraulic or electrical systems of orientation of the blades (aerodynamic brake) and the nacelle (necessary to keep the surface swept by the wind generator perpendicular to the direction of the wind). In addition, there is an air- or water-cooling system, an anemometer and the electronic wind turbine management system.

C- The rotor: a rotating part of the wind turbine placed high up in order to capture strong and regular winds. It is composed of blades (usually 3) made of composite material that are set in motion by the kinetic energy of the wind. Connected by a hub, they can each be 25 to 60 m long on average and rotate at a speed of 5 to 25 revolutions per minute.

D- A control cabinet: containing all the power electronics converters (inverter, rectifier), as well as the power, current and voltage regulation systems and the orientation of the blades and the nacelle**.**

E- A speed multiplier: a cooling radiator and a braking system.

II.5.3.3 Principle of operation

The machine consists of 3 blades (usually) carried by a rotor and installed at the top of a vertical mast. This assembly is fixed by a gondola that houses a generator. An electric motor is used to orient the upper part so that it is always facing the wind. Blades are used to transform the kinetic energy (energy that a body possesses as a result of its movement) of the wind into mechanical energy.

The wind causes the blades to rotate between 10 and 25 revolutions per minute. The speed of the blades depends on the size of the blades. The larger the blades, the slower they will rotate.

The generator transforms mechanical energy into electrical energy. Most generators need to run at high speeds (1,000 to 2,000 revolutions per minute) to generate electricity. Thus, the role of the multiplier is to accelerate the slow movement of the blades. The transmission of electricity generated via submarine cables to land [20].

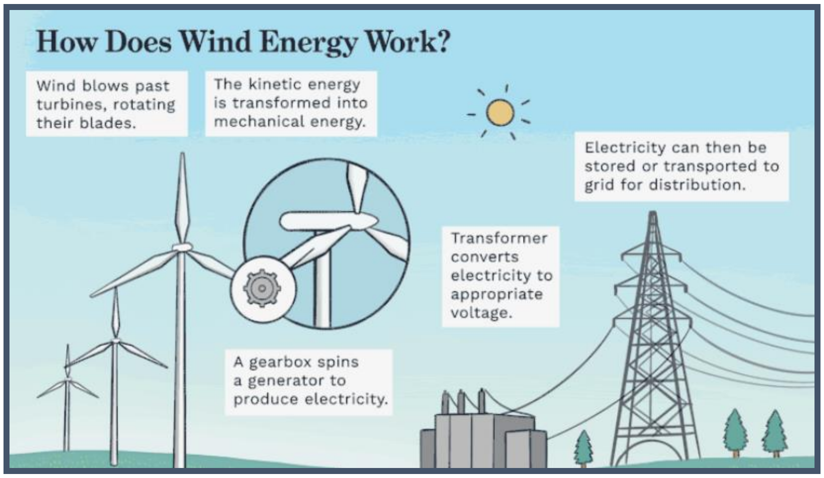

FIGURE II. 16: PRINCIPLE OF OPERATION OF A WT

II .5.4 Generator set

The function of generators is to produce electricity during a power cut. In industry in particular, they ensure the continuity of production. For sensitive applications (IT, processes, hospitals, etc.), the generator is often associated with an inverter. The inverter provides quality energy, without disturbances, but limited in time due to its autonomy. The presence of a generator upstream ensures the supply of energy in the event of a prolonged grid outage, thus taking over from the inverter. The generator set has a combustion engine, diesel or gas, which drives the alternator. The speed regulation of this motor, which determines the frequency of the alternator voltage, is not instantaneous (up to several seconds).

II.6 Advantages and disadvantages of a hybrid system

A. Advantages :

- Not dependent on a single energy source.
- Capable of satisfying evolving loads.
- Simple operation, reduced maintenance and overhaul work.
- Low life-cycle costs of electricity for applications.

B. Disadvantages:

- High cost of capital compared to diesel generators.
- More complex than isolated electrical systems; Requires battery storage and electricity conditioning.

II. 6. Conclusion

Hybrid systems using renewable energy sources offer a promising solution to meet the challenges of sustainable energy supply. By combining different energy sources such as solar, wind, and sometimes even hydropower or biomass, these systems can provide a more stable and reliable power supply, while reducing greenhouse gas emissions and reliance on fossil fuels. However, their effectiveness and cost-effectiveness depend on a variety of factors such as resource availability, technologies used, and local environmental conditions. To maximize their potential, it is essential to invest in the research, development and deployment of these systems, while adopting policies that support the transition to a clean energy economy.

III.1 Introduction

This chapter details a brief introduction to the Hybrid Optimization Model for Electric Renewables (HOMER) software, explains the research techniques, including data modeling, component descriptions, site resources and economic parameters.

HOMER software was developed by the U.S. National Renewable Energy Laboratory (NREL). HOMER, which is a computer micro power optimization model, helps you design off-grid and grid-connected systems. You can use HOMER to perform analyses to explore a wide range of designs questions which include technologies that are most cost-effective, size of system components to be used, the adequate renewable resource or resources and the outcome to the project's economics if costs or loads change.

HOMER's optimization and sensitivity analysis capabilities help you answer these difficult questions. [21:22] A number of technologies are available for optimization purpose but HOMER makes it easy to evaluate the possible configurations. HOMER can simulate hundreds of thousands of solutions depending on the situation at hand. It can simulate the intended system based on the estimation of installation cost, replacement cost, Operation and Maintenance (O&M) cost, fuel, and interest rate.

Following the simulation step, the optimization step displays a sorted list of configuration results based on Total Net Present Cost (TNPC). HOMER examines the many types of system configurations from the lowest to the highest TNPC.

The system configuration based on TNPC, on the other hand, varies depending on the sensitivity variable chosen by the user. The sensitivity phase is an optional step in which sensitivity variables such as wind speed, solar radiation, fuel costs, and so on are presented to see how the optimal system changes when these variables vary. [23:25]

III.2 Proposed Case study – Sidi Amar, University Residence

FIGURE III. 1: THE 19 MAY 1956 RESIDENCE UNIVERSITY

The 19 May 1956 Residence University is located in Sidi Amar, in the province of Annaba, Algeria. The city of Annaba, located in the north east of Algeria, experiences four seasons in a year. The four seasons include [26]:

The spring season begins in March and ends in May, and it follows the winter season. It's usually marked by scattered clouds in the sky, warm air temperatures, and a drop in precipitation levels. For the three months of the Spring season, the average minimum temperature is around 12°C, and the average maximum temperature is around 20°C.

Summer season: This season begins in June and finishes in August, shortly following spring. It is characterized by aridity and a lack of rain and dry high air temperature and pressure. Throughout these months, temperatures can reach 30°C to 35°C or even higher on some days, with a low average temperature of around 20°C.

Autumn season: This season begins in September and extends in November, and it follows the summer season. Low cloud formations and sporadic rainfall are typical characteristics. The overall average minimum temperature for the three months of winter is around 16°C, while the entire average maximum average temperature is around 23°C.

Winter season: This season follows the autumn season, beginning in December and ending in February It is characterized by plentiful rainfall, and mountainous regions experience snow and chilly air at times

III.2.1 Location plot

In order to develop the hybrid system, the location considered is Sidi Amar Algeria. The latitude and longitude are shown in figure below:

FIGURE III. 2: SITE LOCATION SELECTED FOR OPTIMIZATION PURPOSE

III.2.2 Estimation of Electric Load

The load profile consumption is broken down into four seasons. Seasonal fluctuations, combined with residential schedules, cause some load consumption to vary throughout the year. For example, since the winter season is marked by cold temperatures, the radiators are turned on while the air conditioners (A/C) are turned off. In the summer season, characterized by high temperatures, the university usually takes a long or end of academic year vacation that usually lasts the entire summer season. Though the university is closed for the summer, some international students remain hence the university residence remains open. As a result, summer loads such as air conditioning will use power. In the autumn and spring seasons, the load consumption is estimated to be the same and seasonal loads such as the radiators and A/C are non-operational because of the moderate temperatures in these two seasons. The load consumption of outdoor lighting remains consistent throughout the year.

TABLE III. 1: TIME SERIES LOAD PROFILE OF THE CASE STUDY

HOUR	**ELECRICAL LOAD (kW) FOR A DAY**			
	Summer Months	**Autumn Months**	**Winter Months**	**Spring Months**
0	8.0	8.0	8.0	8.0
1	8.0	8.0	8.0	8.0
2	8.0	8.0	8.0	8.0
3	8.0	8.0	8.0	8.0
4	8.0	8.0	8.0	8.0
5	8.0	8.0	8.0	8.0
6	8.0	28.0	28.0	28.0
7	0.1	31.0	31.0	31.0
8	2.0	45.0	45.0	45.0
9	2.0	73.5	173.0	73.5
10	2.0	63.0	163.0	63.0
11	2.0	60.0	160.0	60.0
12	26.0	33.0	133.0	33.0
13	25.0	29.0	129.0	29.0
14	28.0	41.0	140.0	41.0
15	28.0	41.0	140.0	41.0
16	2.0	28.0	28.0	28.0
17	0.1	10.8	10.8	10.8
18	0.1	10.8	10.8	10.8
19	8.0	8.0	8.0	8.0
20	8.0	8.0	8.0	8.0
21	8.0	8.0	8.0	8.0
22	8.0	8.0	8.0	8.0
23	8.0	8.0	8.0	8.0

The load data entered into the HOMER is based on various appliances and their durations over 24 hours. HOMER utilizes the load data to simulate daily, seasonal, and yearly profiles to calculate average and peak loads. The load profile remains constant at night and goes on increasing during the day time. It again drops little bit in afternoon and increases again in the evening. This pattern continues for 12-month period and it is possible to view the variation in daily, seasonal and yearly profile in the figures below:

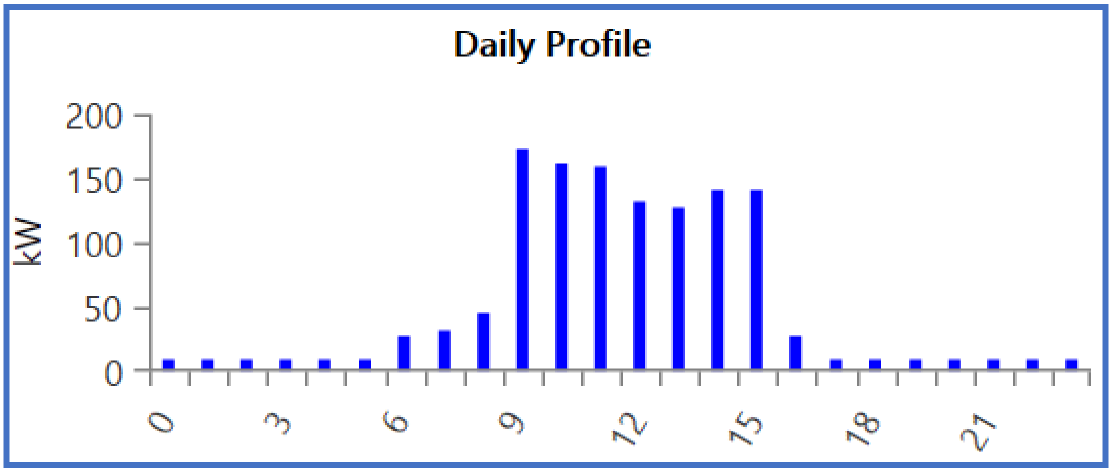

FIGURE III. 3: DAILY LOAD CURVE (HOMER)

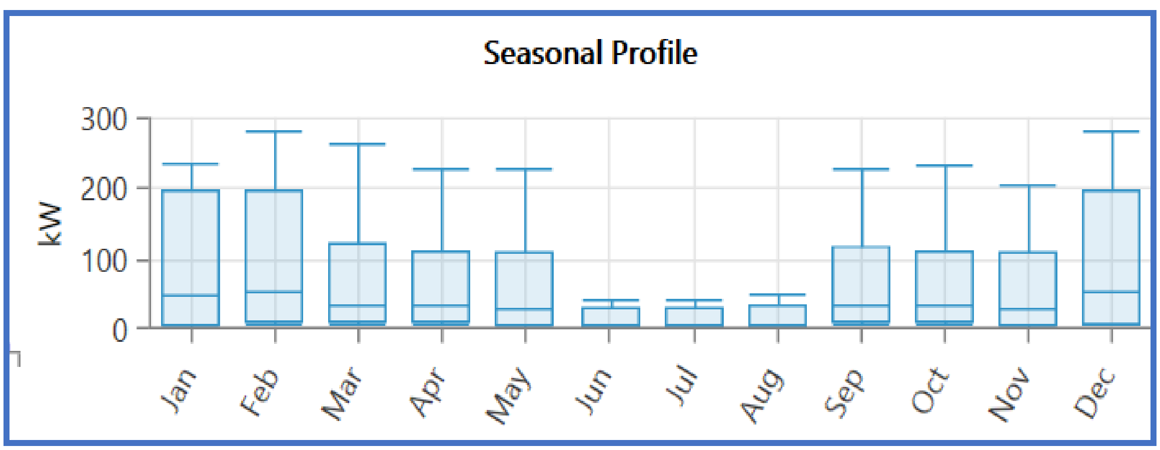

FIGURE III. 4: SEASONAL LOAD CURVE (HOMER)

The average daily energy consumption is 756.25kWh/day and a peak load of 279.88 kW was produced after taking into account a random variation in the load with a 10% day-to-day base and a 20%-time step.

III.3 System Description and Specification

Solar and wind are the renewable energy sources considered in the design which is a standalone system HOMER takes into consideration the various factors such as technical feasibility, climate, load consumption and diesel prices, net present cost of developing certain system and cost of energy. Depending on all these factors the HOMER system picks the best feasible solution by trying various combinations from the designed system consisting of PV, WT, Diesel Generator, Converter, Battery system.

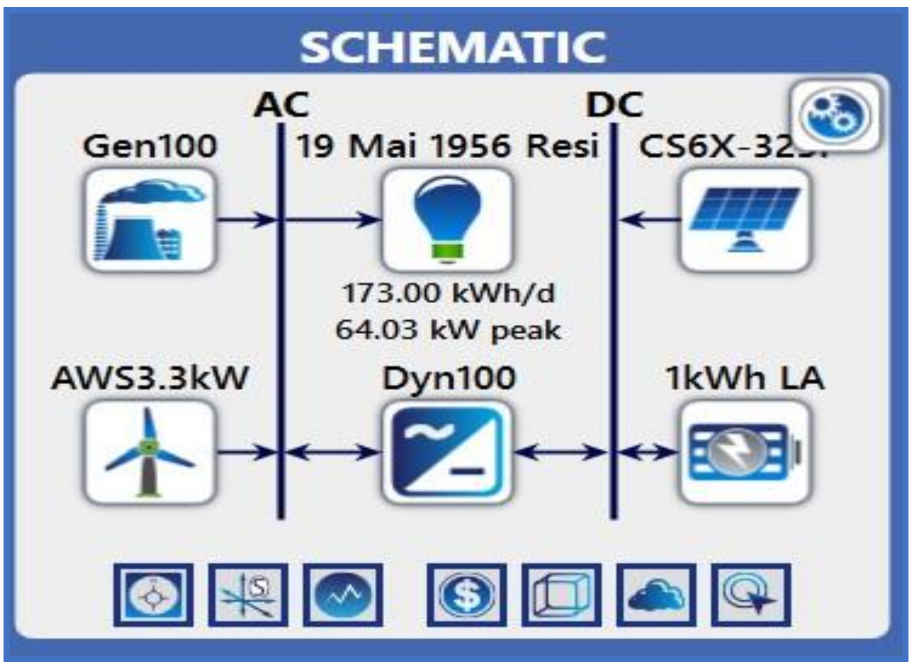

FIGURE III. 5: THE PROPOSED CONFIGURATION FOR THE SIDI AMAR UNIVERSITY RESIDENCE

III.3.1 Properties of Components

The components used in this study were chosen straight from the HOMER library, and each has its own set of costs, capacity, lifespan, and other properties.

III.3.1.1 Solar PV properties

The Canadian-Solar MaxPower CS6X-325P PV modules was selected to arrive at the most optimal solution. Due to conditions such as ambient temperature influence, dust, shading, wiring losses, and PV degradation, the PV panels are bound to suffer losses. This PV's derating factor is 88%, and its temperature coefficient is -0.41% per degree Celsius. The efficiency of this PV system in standard conditions is 16.94%. There are 72 polycrystalline cells in this PV module with a capacity of 325 watts. The PV system is set at $600 per kW, with an O&M fee of $10 per year.

III.3.1.2 Wind Turbine properties

For the simulations in this study, an AWS HC 3.3kW rated capacity WT is used, and the capital cost is set at $ 7000 per kW, replacement cost at $ 7000 and O&M at $20 per year for economic analysis, with an O&M cost of $ 100 per year. Hub height of this turbine is 12 m and life span of 20 years

III.3.1.3 Generator properties

The generator considered for this simulation is the Generic 100kW Fixed Capacity Genset. The capacity of this generator is 100kW and cost about $40 000. The minimum load ratio considered is 25% for an operating life time of 15,000 hours. The O&M cost as $2 per hour. Fuel cost of $1 per liter.

III.3.1.4 Battery Storage properties:

For this simulation, a generic 1kWh lead acid battery with a nominal voltage of 12V, a maximum capacity of 83.4 Ah, an efficiency of 80%, a maximum charge current of 16.7A, and a lifetime of 10 years was used. As both the PV and the battery are connected to the DC bus in one configuration, their output voltages should be the same, thus the battery's 12V is connected in three strings to provide a 36V voltage, just like the PV system voltage. The cost of this battery is defined at $ 500, and its initial state of charge is 100%, with a minimum state of charge of 40%.

III.3.1.5 Converter:

A bi-directional converter allows power to flow in both directions, making it easier to convert AC to DC for battery charging and supply AC to supply AC loads by converting DC to AC. A Dynapower SPS-100 with a capacity of 100 kW and an efficiency of 96.5% with a relative capacity of 100% was investigated. The converter has a 15-year life expectancy, with a considered capital cost of $ 600, a replacement cost of $ 500, and an annual O&M expense of $ 30. The capacity of this converter is slightly higher (approximately 19%) than the peak load.

III.4 Resources of the Location

Sidi Amar is located at the coordinates 36°48.9'N and 7°42.7'E, and the time zone is GMT/UTC (UTC+01:00) is used to access the location resources. The solar, wind, and temperature resource data is obtained through HOMER from the National Aeronautics and Space Administration (NASA) prediction of worldwide energy resources. The HOMER tool requires the site's average monthly temperatures to calculate feasibility.

III.4.1 Solar Radiation Data

Global Horizontal Irradiance (GHI) represents the total quantity of solar radiation incidents on a horizontal surface. The average monthly GHI is based on data collected over 22 years.

TABLE III. 2: MONTHLY AVERAGE GLOBAL HORIZONTAL IRRADIANCE DATA OF SIDI AMAR

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Clearness index	0.477	0.511	0.562	0.527	0.563	0.603	0.633	0.594	0.584	0.540	0.487	0.480
Daily radiation (kWh/m^2)	2.280	3.150	4.250	5.210	6.250	6.980	7.410	6.080	5.000	3.570	2.450	2.300

FIGURE III. 6: SIDI AMAR MONTHLY DAILY SOLAR RADIATION AND CLEARNESS-INDEX

The clearness index is a dimensionless value between 0 and 1 that defines the clearness of the atmosphere. The clearness index has a high value when the weather is clear and sunny, and a low value when the weather is cloudy. The annual average radiation is 4.53 kWh/m^2 /day. In general, Sidi Amar solar radiation is adequate from March to October, i.e., adequate energy can be harnessed during this time. However, from November to January, the solar radiation is small.

III.4.2 Wind Speed Data

Measured from a height of 50m above the surface, the average wind speed over 30 years from January 1984 to December 2013 is presented in table 8 and figure 42. The average yearly wind speed is 5.02 m/s, with the lowest average wind speed of 3.18 m/s occurring in August and the highest average wind speed of 6.09 m/s prevailing in December.

TABLE III. 3: MONTHLY AVERAGE WIND SPEED

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug		Sept	Oct	Nov	Dec
Wind Speed (m/s)	5.990	6.030	5.650	5.420	4.580	4.050	3.910	3.800		4.140	4.700	5.800	5.900

FIGURE III. 7: AVERAGE WIND SPEED DATA FOR SID AMAR

Given that most micro wind turbines have a minimum set-in motion wind speed of roughly 2 m/s, the wind speeds of Sidi Amar are viable for wind power generation.

III.4.3 Temperature Data

The consequence of rising temperatures increases in PV cell temperature, which can result in a PV module's performance degrading. Thus, cooling can help preserve the efficiency of a PV module by regulating the temperature of the PV cell at severe temperatures. The temperature data for Sidi Amar indicates that losses during solar energy generation are minimal, based on the commonly used temperature coefficient to measure the loss of efficiency in PV modules set for over 25°C by solar panel manufacturers. The monthly temperatures were gathered during 30 years, from January 1984 to December 2013

TABLE III. 4: MONTHLY AVERAGE TEMPERATURE DATA

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Average Temperature (ºC)	10.28	10.50	12.52	14.90	18.78	22.94	26.26	26.80	23.47	19.95	16.60	12.75

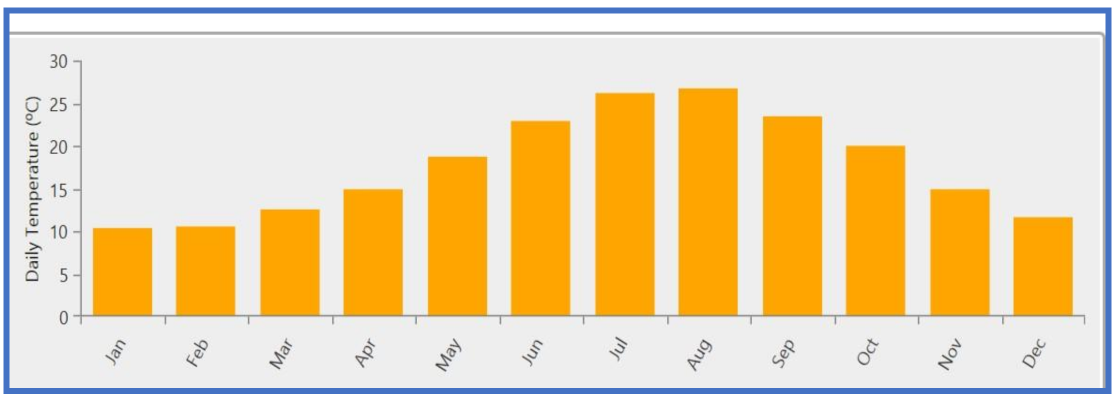

FIGURE III. 8: AVERAGE MONTHLY MEAN TEMPERATURES DATA FOR SIDI AMAR

The annual average temperature is 17.75°C on a scaled basis. The minimum average daily temperature is 10.28°C in January, while the maximum average daily temperature is 26.8°C in August. The temperature data is higher from May to October and lower from November to March.

III.5 Economics Analysis

Net Present Cost (NPC) and the Levelized Cost of Energy or Cost of Energy (COE) are the two key economic factors utilized in the HOMER tool for economic analysis and optimal configurations. NPC is the most cost-effective metric in the HOMER tool for optimization

III.5.1 Net Present Cost

NPC is the total cost and revenue of a project across its whole life cycle, and it is represented by the expression;

$$\boldsymbol{NPC} = \frac{\boldsymbol{CT-ann}}{\boldsymbol{CRF(i,t)}} \qquad \text{(III.1)}$$

Where; $CT{-}ann$ = Annualized total cost of the system.

CRF = Capital recovery factor

i = Annual interest rate or discount rate

t = Project life time.

The annual effective interest rate is a percentage of the balance at the end of the year in which interest is paid or earned and it is represented as;

$$\boldsymbol{i} = \frac{\boldsymbol{i' - f}}{\boldsymbol{1 + f}} \qquad \text{(III.2)}$$

Where; i' = Nominal interest rate

f = Annual inflation rate.

The capital recovery factor is the number of yearly payments required at a discount rate in order to achieve present value after a given number of years. It is given by;

$$\boldsymbol{CRF(i,n)} = \frac{\boldsymbol{i(1+n)n}}{\boldsymbol{(1+n)\,n-1}} \qquad \text{(III.3)}$$

Where; n = number of years.

III.5.2 Levelized Cost of Energy

The Levelized Cost of Electricity (COE) is an economic metric that compares the long-term costs of producing electricity using various generation techniques and it is mathematically expressed as:

$$\boldsymbol{COE} = \frac{\boldsymbol{C_{ann.tot}}}{\boldsymbol{E_{prim,AC})+E_{prim,DC}}} \qquad \text{(III.4)}$$

Where:

$C_{ann,tot}$= Total annualized cost ($/year)

$E_{prim,DC}$ = DC primary load served (kWh/year)

$E_{prim,AC}$ = AC primary load served (kWh/year)

III.6 Results and Discussion

The simulation is performed by comparing the optimal configuration from available AC and DC hybrid systems i.e., WT, Diesel Gen-set, PV system and Battery storage system. The simulation was performed for a project life time of 25 years. HOMER software simulated 6234 solutions in a time span of about 15 min and found 4428 feasible solutions based on the geographic location, technical feasibility and Economics. It took into consideration various constraints considered while modelling each system. The HOMER results show cases for Optimized results and sensitivity analysis. The cases are as shown below:

TABLE III. 5: THE SIMULATION RESULTS USING THE HOMER SIMULATOR

Component	Value
PV (kW)	*66.2*
Wind turbine 3.3 kW (units)	*3*
Diesel generator (kW)	*100*
Battery storage (units)	*134*
Converter (kW)	*41.5*
NPC ($)	*344,541*
COE ($/kWh)	*0.42*
Operating Costs ($/year)	*11,752*
Initial Capital ($)	*192,611*

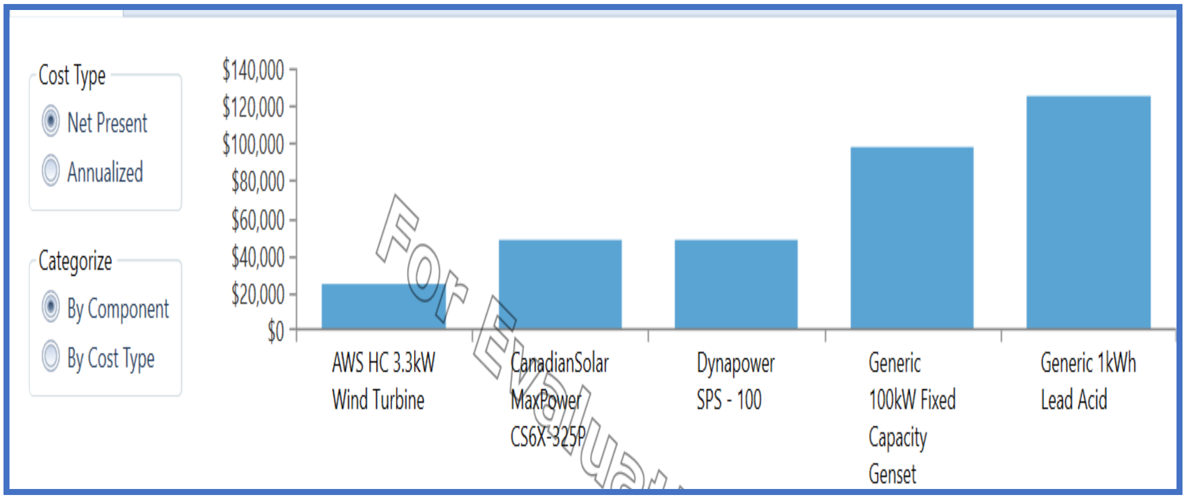

FIGURE III. 9: COST SUMMARY OF STANDALONE HYBRID SYSTEM

From table III.5, the simulation findings also show a $ 334,540.70 NPC, a $ 0.4221 LCOE, a $ 11,752.43 annual operating cost. Since not only renewable energy sources were used in the scenario, the renewable energy fraction is 82.5%. Fig III.8 summarizes the total cost of the standalone hybrid system, indicating details of the economic variables about each component that adds up to the NPC value. Compared to the other components in this design, the overall cost of a generic lead-acid battery is the highest.

III.7 Conclusion

Optimization of microgrid is useful in understanding the renewable resource penetration in power industry. The HOMER simulation provides the necessary flexibility in carrying simulations with efficient tools. This helps in understanding the system and constructing different models. The hybrid system can reduce the dependency on fossil fuels to great extent and supply individual power to AC or DC systems as required. The hybrid optimized systems are capable of providing the energy efficiently between their respective busses.

The HOMER simulation carried out for this project takes into account the technical feasibility of the system and economic analysis of the system.

IV.I Introduction

In this chapter, the architecture of the proposed systems In the context of studying the optimization of multi-source systems based on photovoltaic panels, battery wind turbines and diesel generators. For this fact, we followed an algorithm implemented under Matlab-Simulink that deals with the different possible situations that we are called upon to face. The diagram in Figure IV.1 shows the overall diagram of energy sources and storage system. Figures IV.2 and IV.3 represent the system diagram block studied.

IV.2 Architecture of the proposed systems

The system optimization procedure of this work has the following objective;_The management of the energy produced by the system, in order to be able to provide the consumer with the energy he needs. Considering the strategy adopted in this study, the diesel generator set always fills the deficit and therefore the demand is always satisfied.

Hourly data of the horizontal global solar irradiation, ambient temperature and wind of an isolated Algerian site are available. Simplifying assumptions have been taken into account in order to carry out this simulation, which are:

- The load profile and the potential of the sources are assumed to remain unchanged over the period considered
- We considered that the power of photovoltaic modules and wind turbines are maximum powers
- The diesel generator is connected directly to the load
- The load is constant and equal to 200kW

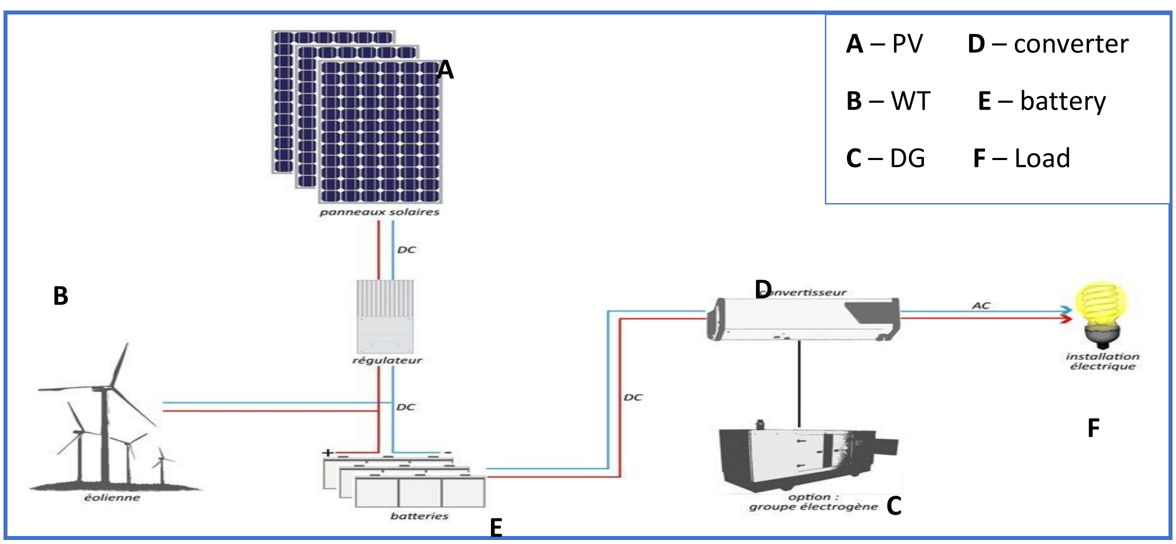

FIGURE IV. 1: GLOBAL MULTI-SOURCE SYSTEM DIAGRAM

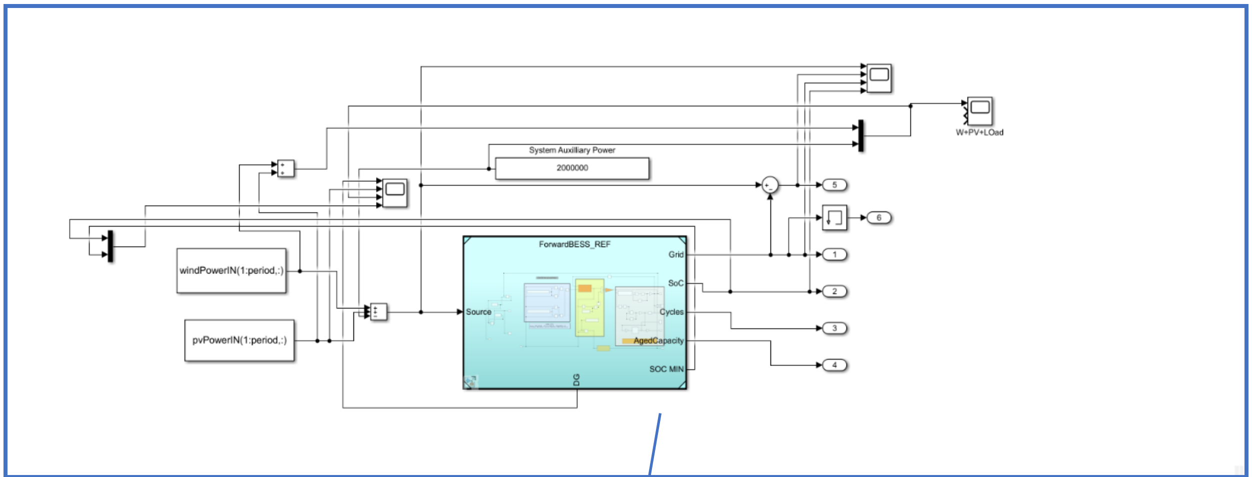

FIGURE IV. 2**:** THE BLOCK DIAGRAM OF THE OVERALL SYSTEM

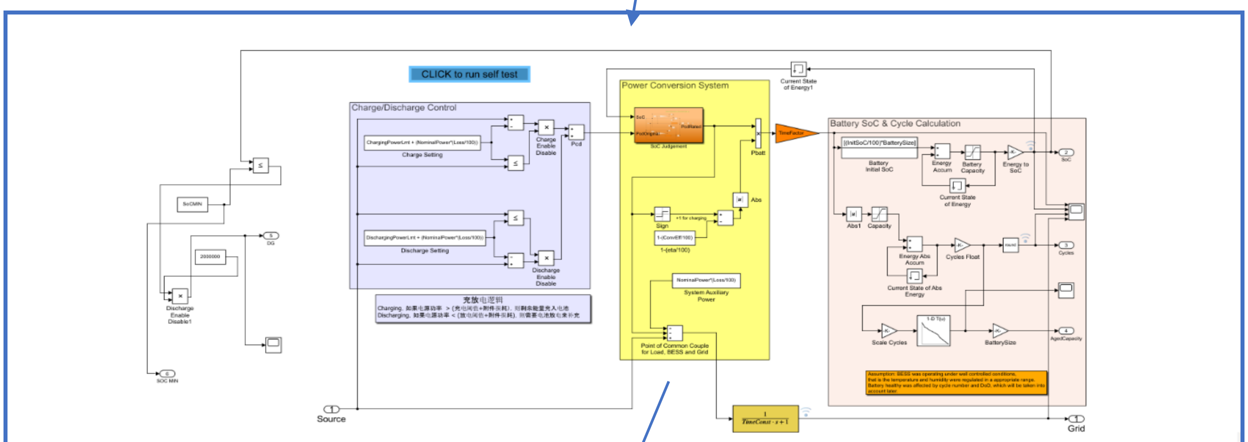

FIGURE IV. 3: STORAGE SYSTEM MODEL BLOCK IN SIMULINK

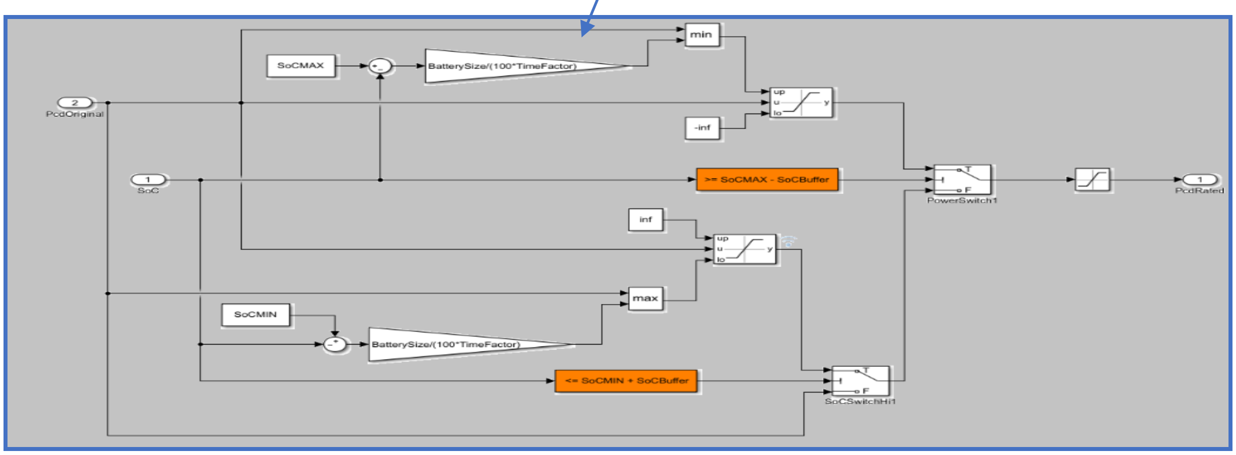

FIGURE IV. 4: STATE OF CHARGE MODEL BLOCK $SOCmax\ et\ SOCmin$

The storage capacity in kWh is 30000;
The efficiency of the power converter is 0.93;
The percentage of power lost due to inefficiencies is 5%
The initial SOC state of charge of the battery is 80%
The Minimum SOC Limit is 5%
The maximum SOC limit is 95%

TABLE IV. 1: STORAGE CAPACITY SETTINGS

C_{batnom} (kWh)	30000
C_{batmax} (kWh)	28500
C_{batmin} (kWh)	1500
DOD (%)	95

IV.3 Modelling of the storage tank system

The battery system is an important unit in the self-contained microgrid and provides power to the load when there is insufficient energy generated from renewable energy sources. The battery capacity can be calculated as follows:

$$C_{Bat} = \frac{AD \times P_L}{\eta_{inv} \times \eta_{Bat} \times DOD} \qquad \text{(IV.1)}$$

where P_L: is the demand power of the load,

η_{Inv}: is the efficiency of the inverter,

η_{Bat}: is the efficiency of the battery,

DOD: is the depth of discharge of the battery,

AD: is the number of days of battery life, which is defined as the number of days that the battery will be able to provide the required power demand of the charge without deficit.

It is obvious that energy produced from renewable energy sources (PV and WT) depends on wind speed and solar radiation, which are intermittent in nature; Therefore, the days of autonomy are of great importance and must be taken into account when sizing the battery bank to overcome the problem of producing energy deficit from these sources. In case of excess energy production, the excess is used to charge the battery. The power produced by the battery bank can be expressed as follows:

$$P_{Bat} = \left(P_{pv}(t) + P_{wt}(t)\right) - \frac{P_L(t)}{\eta_{inv}} \quad \text{(IV.2)}$$

where $P_{pv}(t)$, $P_{wt}(t)$ and PL(t) represent the power produced by PV, WT and load power demand, respectively, and η_{Inv} is the efficiency of the inverter.

When $P_{Bat}(t) < 0$, it indicates that there is a deficit in energy production.

Otherwise, if $P_{Bat}(t) > 0$, it indicates that energy production exceeds energy demand.

In the rare cases where $P_{Bat}(t) = 0$, the power produced from renewable sources is equal to the demand for load power.

To check the status of the battery bank, the battery's state of charge (SOC) is an important parameter that affects the performance of the battery and indicates its current capacity. Indeed, the SOC can be defined according to the state of charge and discharge as follows:

Charging process, if; $P_{pv}(t) + P_{wt}(t) > PL(t)$:

$$C_{Bat}(t) = C_{Bat}(t-1) + (P_{RE}(t) - \left(\frac{P_{Load}(t)}{\eta_{inv}}\right))\eta_{cha}\Delta t \quad \text{(IV.3)}$$

Process of discharching, if; $P_{pv}(t) + P_{wt}(t) < PL(t)$:

$$C_{Bat}(t) = C_{Bat}(t-1) + (P_{RE}(t) - \left(\frac{P_{Load}(t)}{\eta_{inv}}\right))/\eta_{dech})\Delta t \quad \text{(IV.4)}$$

and are the charging and discharging efficiency $\eta_{cha}\ \eta_{dech}$

η_{inv} is the efficiency of the converter,

During the charging and discharging process, the capacity of the batteries is subject to the following stresses; to protect them from damage that can shorten their lifespan**:**

$$C_{batmin} \le C_{bat}(t) \le C_{batmax} \quad \text{(IV.5)}$$

C_{batmin} and C_{batmax} are the maximum and minimum capacity of the batteries.

C_{batmin} is determined by:

$$C_{batmin} = (1 - DOD).C_{batmax} \quad \text{(IV.6)}$$

IV. 4 Model of Diesel Generator

The power output of diesel depends on the total renewable power, the charging profile, the system control strategy and the state of charge of the battery. Fuel consumption for one hour depends on the rated power and the power generated.
This dependence is expressed by the relationship [27:29]:

$$F(t) = 0.246P_{DG}(t) + 0.08415.P_R \qquad \text{(IV.7)}$$

Where:

$F(t)$: Fuel consumption in l/hr;
$P_{DG}(t)$: The output power of the generator, kW;
P_R A: The rated power of the generator, kW;

The power generated from the generator shall be delineated in the range as follows:

$$P_{DGmin}(t) \le P_{DG}(t) \le P_{DGmax}(t) \qquad \text{(IV.8)}$$

In our study, the diesel is connected directly to the load.

IV.5 Hybrid System Energy Management Strategy

The energy management strategy is one of the main criteria to be taken into account when designing or sizing a standalone microgrid that aims to ensure the distribution and management of the energy flow between the different elements of the standalone microgrid system studied. The main objectives of the proposed EMS can be summarized as follows:

- Improved system efficiency, resulting in low-cost and energy-saving benefits.
- Maximizing the use of renewable energy sources (PV and WT).
- Protection of the battery bank and minimization of its degradation.
- Minimisation of fuel consomption.

In our study, four modes of energy management strategy were used:

<u>Mode 1</u>

In this mode, the energy produced from renewable energy sources (PV and WT) is sufficient to meet the needs of the load demand. The additional energy is used to charge the battery bank system.

Mode 2

In this mode, the power generated by renewable energy sources exceeds the charging demand requirements when the battery is fully charged. In this case, the excess energy is consumed in a landfill load.

Mode 3

In this mode, the power generated by renewable energy sources is less than the demand requirements. In this case, the battery bank will cover the energy production deficit to meet the requirements of the load demand.

Mode 4

In this mode, the power generated from renewable energy sources is not enough to meet the load demand requirement and at the same time, the storage level of the battery bank is low. In this case, the diesel generator will work to cover the power generation gap to meet the load demand requirements and further ensure the charging of the battery bank.

Figure IV.5 shows the flowchart of the algorithm used in our study. This strategy can be explained by the following steps:

$$\Delta P = P_{RE}(t) - P_L(t) \qquad \text{(IV.9)}$$

Where:

$P_{RE}(t)$ is total renewable energy.

$$P_L(t) = \frac{P_{load}}{\eta_{inv}} \qquad \text{(IV.10)}$$

P_{load}: Is the power of the load;
$P_L(t)$: Is the power at the input of the inverter;
$P_B(t)$: Is the power input or output of the battery.

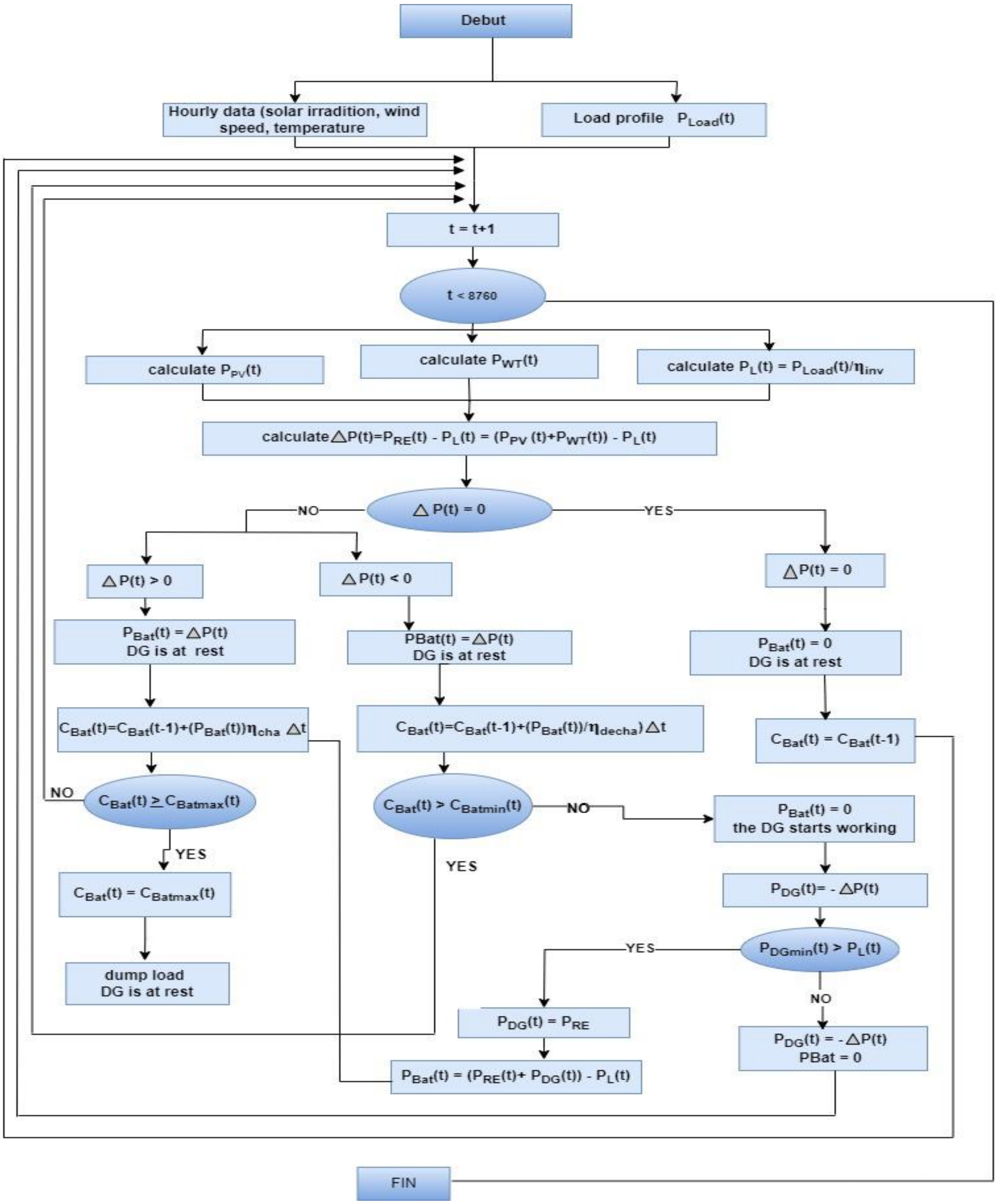

FIGURE IV. 5: THE FLOWCHART OF THE PROPOSED ALGORITHM USED IN THIS STUDY. SOURCE (PV/WT/DG/BAT)

1- If $\Delta P = 0$, the batteries are neither charged nor discharged ($P_B(t) = 0$), the state of charge of the batteries depends on the previous value $C_{bat}(t) = C_{bat}(t-1)$. The diesel generator is shut down.

2- -If $\Delta P > 0$, the extra power will be used to charge the batteries ($PB(t) = \Delta P(t)$. The diesel generator is shut down and the state of charge is calculated according to equation (IV.3). When the state of charge of the batteries reaches its maximum value $C_{bat}(t) \leq C_{batmax}$, the surplus power is offloaded

3- If $\Delta P < 0$, the power deficit will be provided by the battery bank or by the diesel generator according to the following strategies:

- If the state of charge of the battery bank is greater than its minimum $C_{batmin} \leq C_{bat}(t)$, the batteries are discharged ($PB(t) = \Delta P$) and the state of charge is calculated according to equation (IV.4), the diesel generator is shut down.
- If the battery bank's state of charge is equal to its minimum $C_{batmin} = C_{bat}(t)$, the diesel generator starts up and the batteries will not be charged or discharged ($P_B(t)=0$). The electrical power produced by the diesel generator, CEO (t), is equal, in this case, to the difference between the powers $P_L(t)$ and $P_{RE}(t)$.
- If the power demanded by the load is less than the minimum power of the diesel generator, the generator will operate at its rated power, P_R, the batteries will be charged and the P_B power will be calculated as follows:

$$P_{DG}(t) = P_R \text{ and;} \tag{IV.11}$$

$$P_B = (P_{RE}(t) - P_R(t)) - P_L(t) \tag{IV.12}$$

IV. 6 Simulation Outcome and Discussions

IV.6.1 Photovoltaic system power:

The following figure shows the curve of the simulated wind power for a duration of one day (see Figure IV.3).

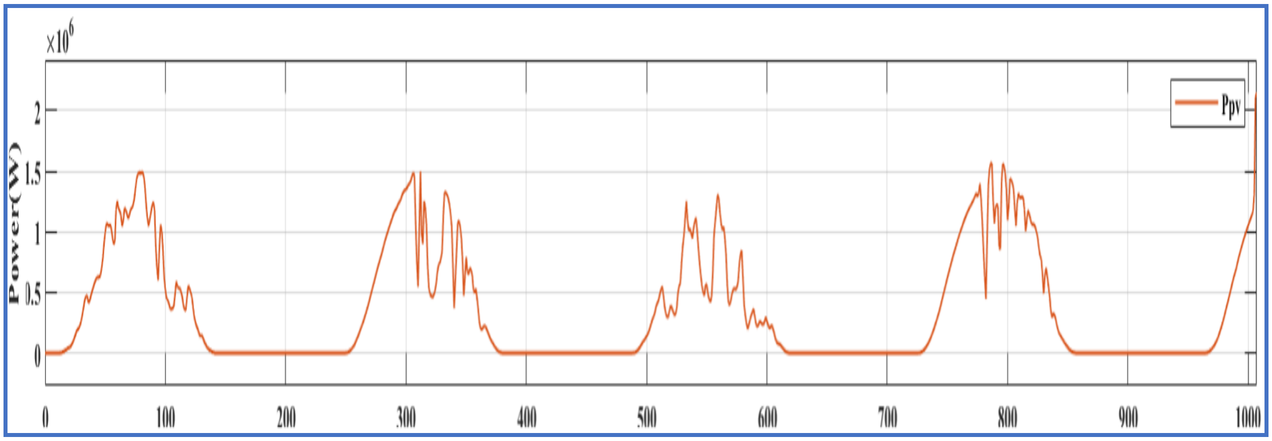

FIGURE IV. 6**:** POWER SUPPLIED BY THE PHOTOVOLTAIC SYSTEM.

IV.6.2 Power of the wind turbine

We have assumed that the sunlight varies according to the time of day, it is measured on the day when the sky is clear so as to reach a maximum of 530 W/m2 at t= 4.104s. Figure IV.7 shows the power curve delivered by the PV system during a day.

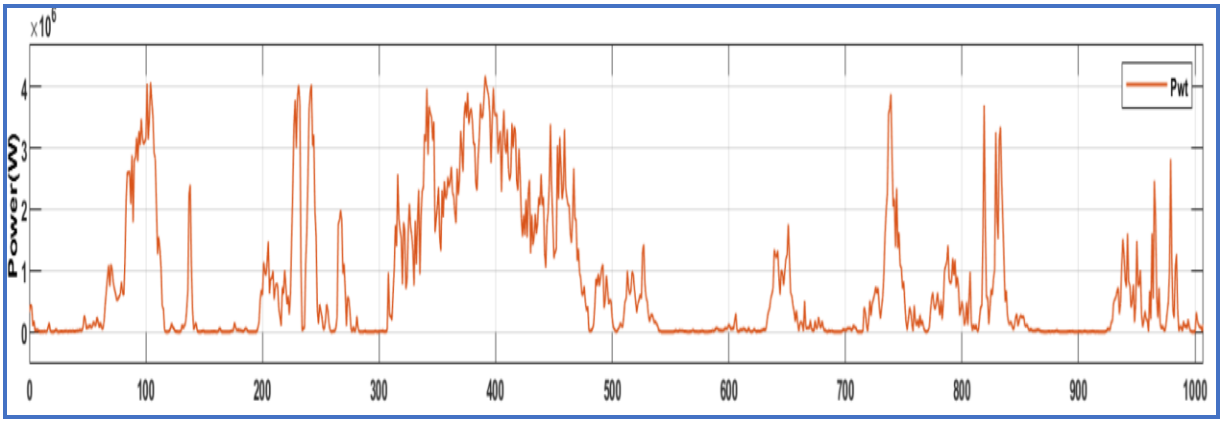

FIGURE IV. 7**:**POWER SUPPLIED BY THE WIND SYSTEM

IV.6.3 Power of the load

In this case, the power of the load is constant all day at 200,000W.

IV.6.3.1 The power of the renewable energy source (PV and WT)

From these results and from Figures (IV.6 and IV.7) which present the renewable powers, the photovoltaic and wind power produced by the system in the case of the configuration obtained, it can be seen that the photovoltaic energy and wind energy at certain times of the day are very low and cannot meet the needs of the load.

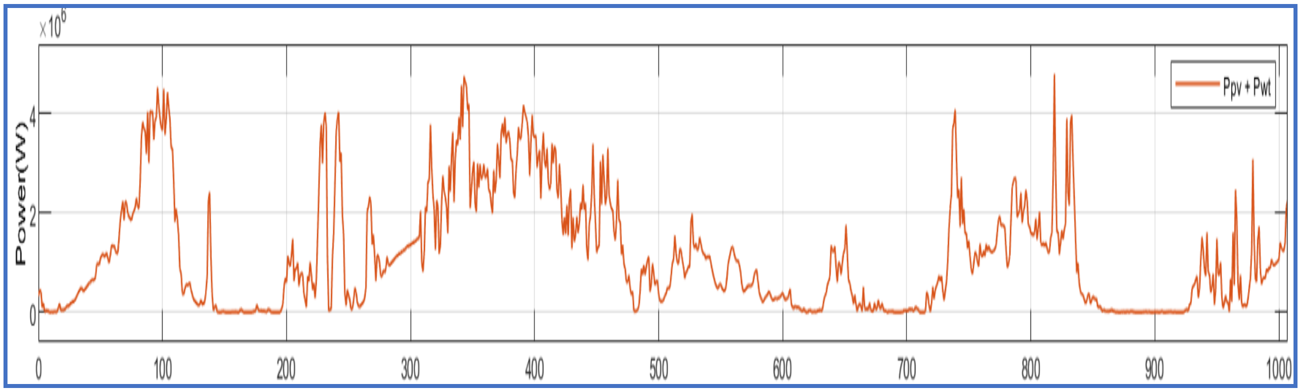

FIGURE IV. 8: THE TOTAL POWER BETWEEN PHOTOVOLTAIC AND WIND POWER (P_{RE})

And Figure IV.8 shows the curve of P_{RE}, the total power between photovoltaic and wind power. And the constant charging power

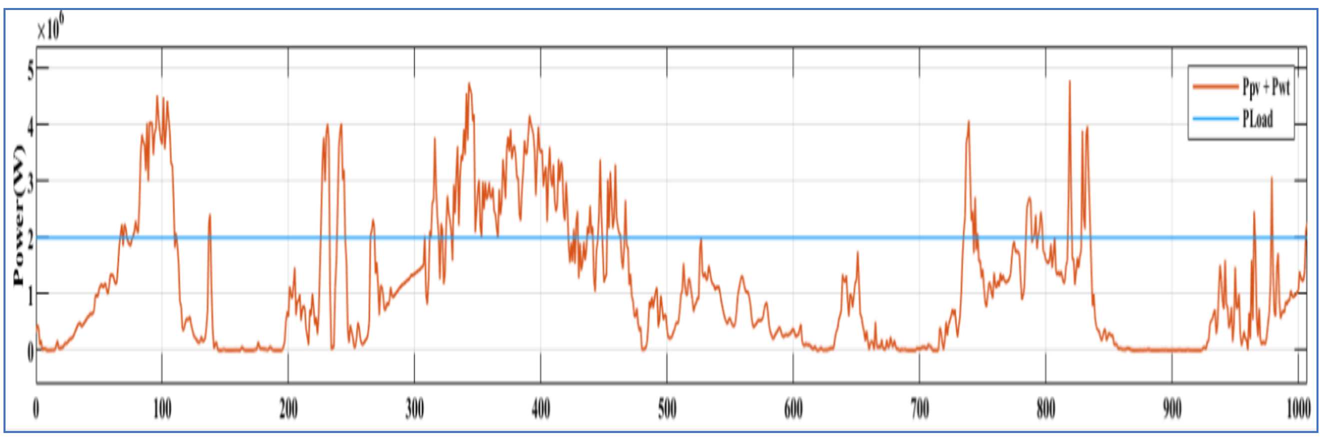

FIGURE IV. 9: POWER SUPPLIED BY THE WIND + PHOTOVOLTAIC SYSTEM AND LOAD

The curve shows us that the power of the load is greater than the power of renewable energy sources. $P_{RE} = P_W + P_{PV} < P_{load}$; and means that the power of the sources is not sufficient to operate the load

IV.6.3.2 Storage system (battery):

Figure (IV.10) shows the temporal rates of the state of charge during six (6) days.

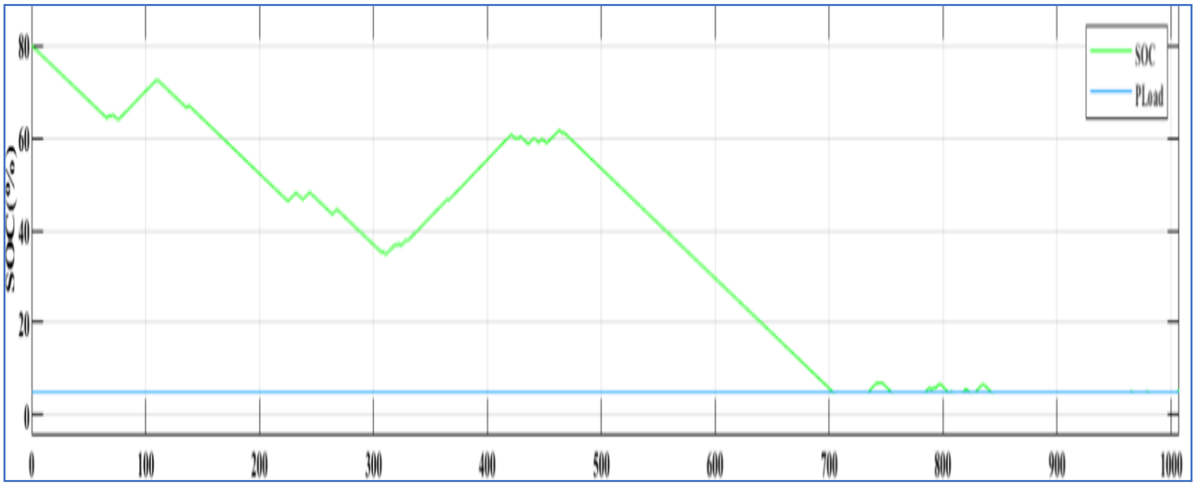

FIGURE IV. 10: THE STATE OF DISCHARGE OF THE BATTERY (%)

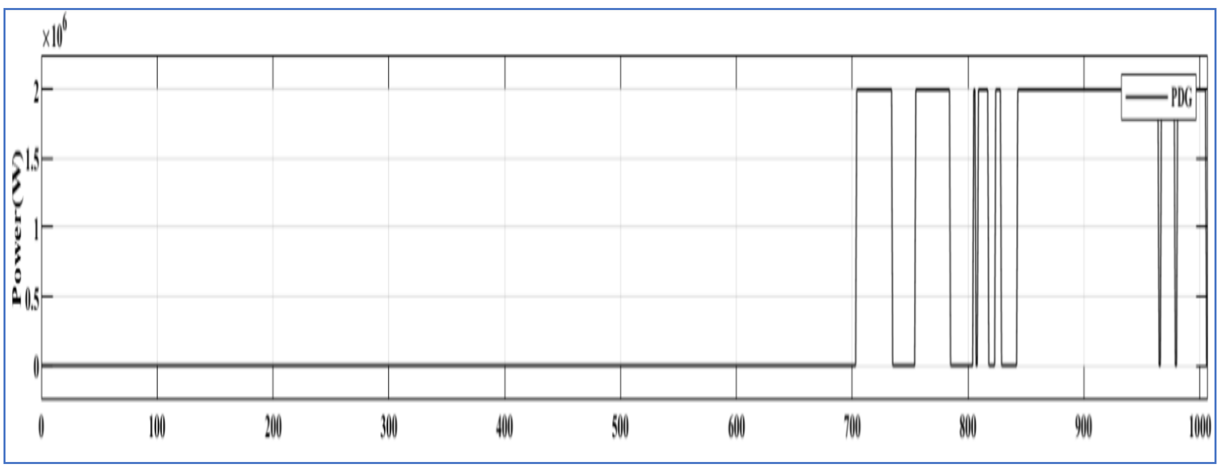

FIGURE IV. 11 DIESEL GENERATOR POWER

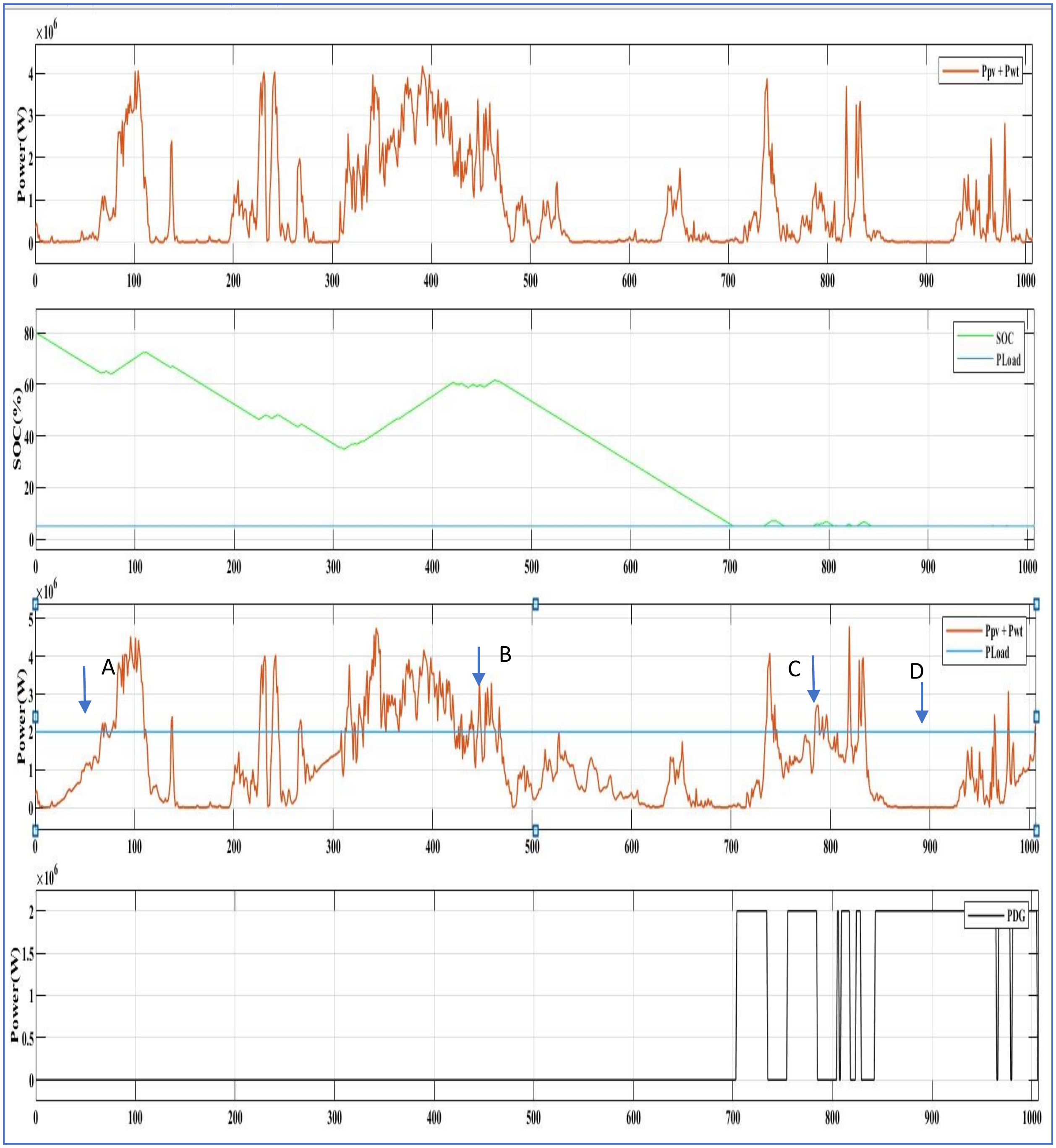

FIGURE IV. 12: THE POWER OF P_{RE} ; P_{LOAD}; $P_{BATTERY}$ AND THE STATE OF CHARGE OF THE SOC% BATTERY.

Scenario A

The curves show us that the power of the load is higher than the power of renewable energy sources P_{RE}. ($P_{RE} = P_W + P_{PV} < P_{load}$); therefore the power of the sources is not sufficient to operate the load; And the battery condition is at its initial value 80% $P_{bat} \geq P_{batmin}$ and the max value is of the battery is 95 % min value is 5%

In this case, the diesel generator is shut down (DG=0).

Scenario B

This shows us that the power of the load is less than the power of renewable energy sources P_{RE}. ($P_{RE} = P_W + P_{PV} > P_{load}$); In this case the power of the sources is sufficient to operate the load. And the state of the battery is discharged, the battery is at 60%; so the surplus will charge the battery and the rest will be relieved; the diesel generator shut down. DG=0

Scenario C

The curves show us that the power of the load is greater than or equal to the power of renewable energy sources P_{RE}. ($P_{RE} = P_W + P_{PV} \leq P_{load}$) ; and means that the power of the sources is not sufficient to operate the load; And the battery status drops $P_{bat} \leq P_{batmin}$ and the min value of the battery is 5 %

In this case, the diesel generator running (DG=1).

Scenario D

The curves show us that the power of the load is less than the power of renewable energy sources P_{RE}. ($P_{RE} = P_W + P_{PV} \geq P_{load}$) ; and means that the power of the sources is more than sufficient to operate the load; And the state of the battery drops or even discharges $P_{bat} \leq P_{batmin}$ so the battery is charging .

So, in this case the diesel generator is shut down (DG=0).

IV.7 Conclusion

In all of the above, we have proceeded to simulate the wind conversion chain associated with storage batteries. The system works with a management system (algorithm) that allows the management of the energy produced, their significant simulation revealed the reliability and efficiency of the system.

General Conclusion

The production of electrical energy is the step towards economic development, security, stability and technological advancement. Thus, in view of the energy and environmental situation around the world, the success of the energy transition in the exploitation of renewable resources is everyone's challenge. As a result, electrical energy production systems based on renewable energies make us the focus of several scientific works in terms of design, dimensioning, modeling, optimization, control, etc.

In recent decades, the world of renewable energies has undergone a major expansion in the world's energy supply. Any sustainable development must be accompanied by installations using renewable energies. The hybrid path among other wind/photovoltaic systems offers several advantages such as the reliability and complementarity of these two natural sources.

The work carried out in this Master's project allowed us to study the wind/ photovoltaic/ battery/GD hybrid system in a remote area. We started in the first chapter by presenting the potential for renewable energy in Algeria, we also presented the different structures of hybrid systems. Finally, a study of the integration of hybrid battery storage was carried out to improve the dynamics of operation. In addition, we have developed a supervision algorithm, whose main objectives are to satisfy the load and manage the energy flows between the different components of the system. In addition, the simulation of the hybrid system illustrates the effectiveness of the proposed energy management algorithm for different operating constraints.

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