OPTIMAL DESIGN OF HYBRID RENEWABLE ENERGY SYSTEMS FOR LIBYA ECONOMIC AREA CASE STUDY IN MISURATA FREE ZONE

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MASTER THESIS
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Master Thesis

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November 2020

I certify that in my opinion the thesis submitted by Musaeb ALGADI titled "OPTIMAL DESIGN OF HYBRID RENEWABLE ENERGY SYSTEMS FOR LIBYA ECONOMIC AREA CASE STUDY IN MISURATA FREE ZONE" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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Musaeb M. ALDAWAINI ALGADI

ABSTRACT

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This study aims to verify the usage of various renewable energy sources as an alternative approach to feed a commercial area in Libya, where the Homer software was used to design different hybrid energy-source systems to feed an electric load, conduct a simulation of the system in different cases and compare the results. The results showed that relying on a hybrid system with more than one renewable energy source ensures more stability for the system and less cost of producing energy. Besides, it is confirmed that the effectiveness of reliance on renewable energy sources as a viable alternative to producing energy at a cost that competes with the cost of producing energy using traditional sources in Libya.

Keywords : Energy systems, renewable energy, Libya, hybrid energy sources, energy effectiveness.

Science Code : 91441

ÖZET

Yüksek Lisans Tezi

MİSURATA SERBEST BÖLGESİNDE, LİBYA EKONOMİK ALANI İÇİN HİBRİT YENİLENEBİLİR ENERJİ SİSTEMLERİNİN OPTİMAL TASARIMI VE ÖRNEK ÇALIŞMASI

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Bu çalışmada, alternatif bir yaklaşım olarak çeşitli yenilenebilir enerji kaynaklarının Libya sınırları içerisinde ticari bir alan için doğrulanması hedeflenmiştir. Çalışmada, elektrik yüklerinin beslenmesi, farklı durumlarda sistemlerin simülasyonunun yapılması ve sonuçların karşılaştırılması amacıyla çeşitli hibrit enerji kaynaklı sistemlerin tasarımında Homer yazılımı kullanılmıştır. Sonuç olarak, birden fazla yenilenebilir enerji kaynaklı hibrit sistemlere bağlı kalınarak sistemlerin daha stabil olması ve enerji üretiminde daha az maliyet elde edilmiştir. Ayrıca, Libya'daki geleneksel kaynakları kullanarak enerji üretme maliyetiyle rekabet eden bir maliyetle enerji üretmenin uygulanabilir bir alternatifi olarak yenilenebilir enerji kaynaklarına güvenmenin etkinliği doğrulanmıştır.

Anahtar Kelimeler **:** Enerji sistemleri, yenilenebilir enerji, Libya, hibrit enerji kaynakları, enerji verimliliği.

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ABBREVIATIONS

RESs	:	Renewable Energy Sources
WESs	:	Wind Energy Sources
SESs	:	Solar Energy Sources
ESSs	:	Energy Storage Systems
HPSs	:	Hybrid Power Systems
PV	:	Photovoltaic
PHS	:	Pumped Hydro Storage
TES	:	Thermal Energy Storage
CAES	:	Compressed Air Energy Storage
P2G	:	Power to Gas Technology
GECOL	:	General Electric Company for Libya
MFZ	:	Misurata Free Zone
RET	:	Renewable Energy Technology
REAOL	:	Renewable Energy Authority of Libya
CSP	:	Concentrated Solar Power
CoE	:	Cost of Energy
NPC	:	Net Present Cost
OC	:	Operation Cost
HERS	:	Hybrid Renewable Energy System
RCREEE	:	Region Center for Renewable Energy & Energy Efficiency
NEEAP	:	National Energy Efficiency Action Plans
NASA	:	National Aeronautics and Space Administration
IRENA	:	International Renewable Energy Agency
O&M	:	Operation and Maintenance
REN. FRAC	:	Renewable Fraction

PART 1

INTRODUCTION

Libya is one of the large countries that contains many remote and sprawling cities, which negatively affects the stability of the public electricity grid, where the network suffers from instability due to the transfer of electricity to long distances, in addition to environmental problems as a result of the dependence of energy production on the use of fossil fuels, and therefore the need to develop the energy system is very important. Libya is a vital area where renewable energy sources RESs such as solar energy source SESs and wind energy source WESs are available. In order to ensure the stability of energy supplies to remote areas, it is necessary to invest and rely on renewable energy technology like wind turbines and solar cells as an alternative to conventional energy production and assistance in protecting the environment. In this part, renewable energy systems and their key components will be defined.

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1.1. RENEWABLE ENERGY SOURCES

Renewable energy sources are highly capable in contributing to the development of the economic, social and environmental system, where these sources can provide half of the world's energy requiring in the future, and because of the negative effects on the environment resulting from the uses of fossil fuels, which creates a challenge to the need to use and develop renewable energy technology, which should be given immediate priority to the development of this sector in the world. Reliance on renewable energy technologies ensures increased economic development, provides solutions to environmental pollution and energy extensions to remote areas [1,2].

1.1.1. Wind Energy

Wind power is one of the most important sources of renewable energies and the most available in many regions of the world, where wind turbines work to produce energy, by converting the kinetic energy generated by the rotation of the turbine into electric power, the quantity of which depends on the size of the turbine and the speed and intensity of the wind. It is possible to integrate this technology and connect many turbines to produce large amounts of energy, as this technology has witnessed great development and spread in many regions of the world, and can be classified wind turbines into two main parts: vertical axis turbines and horizontal axis turbines, figure 1.1 shows the basic components of wind turbines [2].

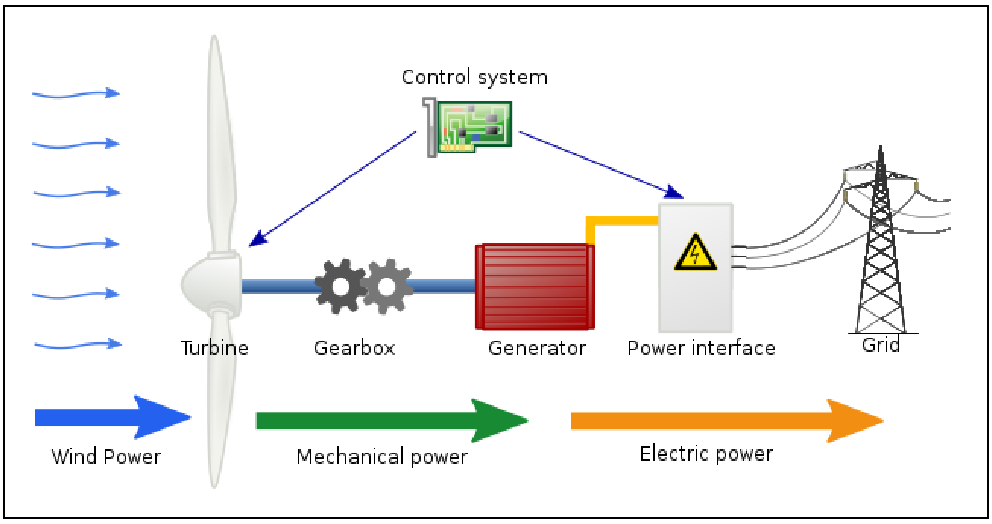


Figure 1.1. Wind turbine [3].

1.1.1.1. Vertical Axis Wind Turbine (VAWT)

In this type of wind turbine, the main spin shaft is vertical, and one of the advantages of this type is the ability to place generators and gearboxes near the ground, and do not require orientation device. Figure 1.2 shows a diagram of VAWT turbine [4].

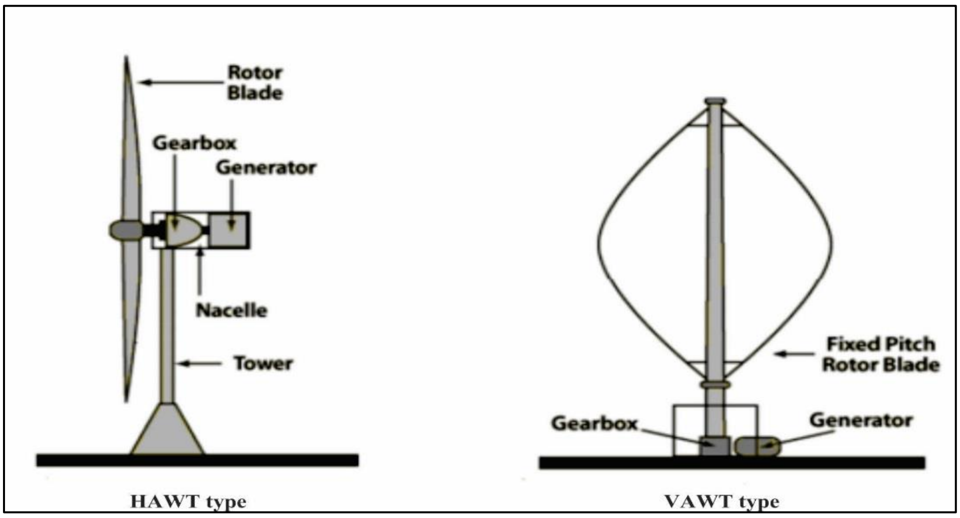


Figure 1.2. Vertical & Horizontal axis wind turbine [4].

1.1.1.2. Horizontal Axis Wind Turbine (HAWT)

This type of wind turbine is known as windmills, in which the main rotor column is parallel to the movement of the wind stream and the surface of the earth, and is more widespread due to high performance compared to other types, where the wind works to move the turbine blades, thus producing an area with lower pressure above the lower feathers, and this difference in pressure between the bottom and the top is called aerodynamic [4]. Wind turbines consist of several sub-components shown in Figure 1.3.

1.1.1.2.1. The Nacelle of Wind Turbine

Located at the top of the tower, this part is connected to the rotor, which is the upper structural body of the turbine and contains many components such as a generator and gearbox, in which kinetic wind energy is converted into electric power [5].

1.1.1.2.2. The Hub of Wind Turbine

This part is connected to all the turbine blades, wherein modern turbines the hub is designed to have the ability to adjust the angle of the blades according to the movement of the surrounding wind to ensure the production of as much energy as possible [5].

1.1.1.2.3. Blades

The turbine blade is the main part that converts wind effects into a regular mechanical movement, where the blade contains the wing that directs the movement of the blades, the wind turbine consists of two or more blades, where the three-blade turbine is more widely used and efficient, and its length varies depending on the design and location of the intended [5].

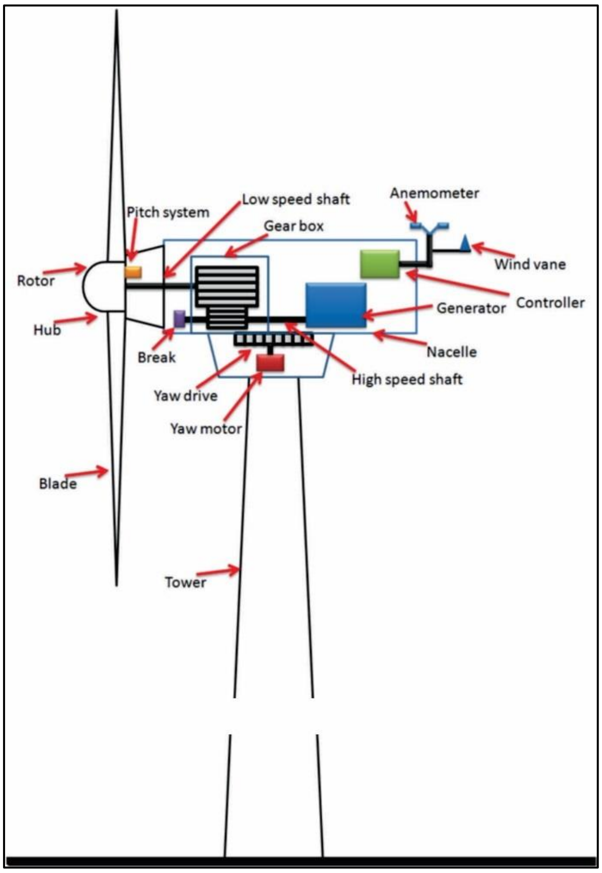


Figure 1.3. Wind turbine components [5].

1.1.1.2.4. Pitch System

This part is available in modern and large-scale turbines, and protects wind turbine parts such as blades and tower from speed and irregular wind direction, adjusting the angle of the feather tilt according to wind movement to ensure maximum energy production and protection of the turbine parts [5,6].

1.1.1.2.5. Main Shaft and Gearbox

This part consists of a slow and main motion shaft which directly connected to the blades, and a fast motion shaft connected to the gearbox, which converts the slow mechanical motion of the blades resulting from wind effects into faster movement connected to the generator [5].

1.1.1.2.6. Generator

The generator is the main electrical part of the turbine, converting the mechanical energy generated by the rotational movement of the blades into electrical energy [6].

1.1.1.2.7. Converter

This part manages the generator, controlling voltage applications by controlling the fixed or rotating part [6].

1.1.1.2.8. Transfomer

This segment adjusts the inner voltage of the turbine, to suit the voltage of the turbine-connected public grid [6].

1.1.1.2.9. Control System of Turbine

This system improves and increases the efficiency and protection of wind turbines, helping to increase energy production and protect the mechanical parts of the turbine. Wind turbines start working at a wind speed of 3-5 m/s, while turbines must stop at a wind speed of 25 m/s, which can cause significant damage to the turbine parts, see Figure 1.4. The system also contains several sensors that control all components of the turbine [5].

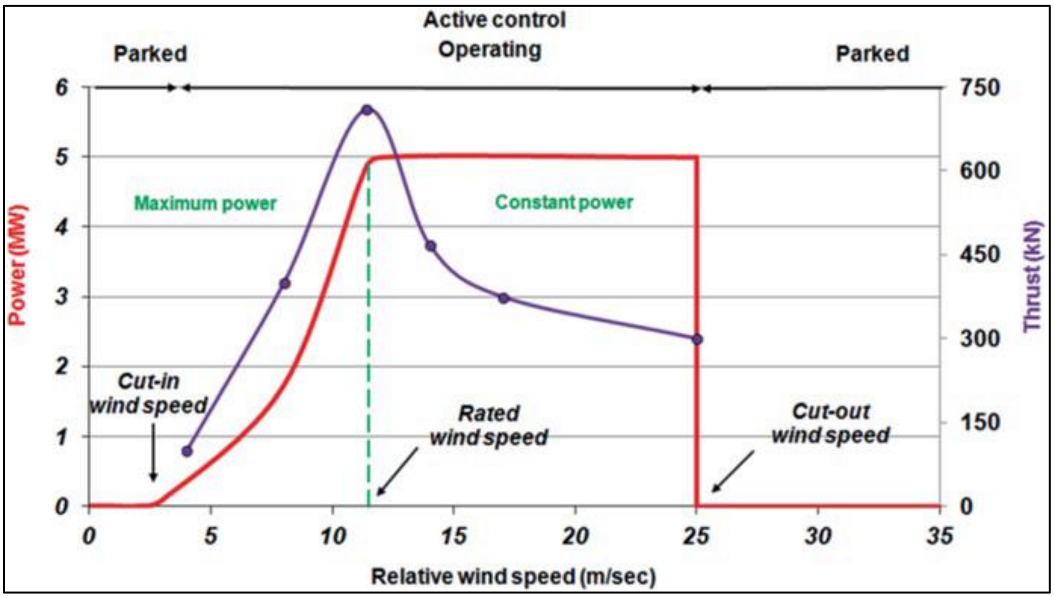


Figure 1.4. The impact of wind speed on the power output of the wind turbine [5].

1.1.1.2.10. Yaw System

This part adjusts the turbine according to the direction of the wind movement, where it continuously adjusts the nacelle-head in the same direction as the incoming wind, in order to avoid mechanical recoils on the turbine parts [5].

1.1.1.2.11. Rotor

This part contains the sum of the blades attached to the center of the rotor and is designed to rotate with or reverse the wind, which is directly connected to the main slow-motion shaft [5].

1.1.1.2.12. Tower

The tower is one of the main parts of the wind turbine, supports all parts of the turbine, and is designed at different heights depending on the desired wind speed so that high turbines can generate more power than others, that the power produced is proportional to the wind speed and height of the turbine tower [5].

1.1.1.2.13. Wind Park

This part is the wind turbine control unit, which is considered as a wind power plant that monitors a range of turbines that are attached to each other, called wind farm, to manage the production of these turbines and connect them to the public grid [6].

1.1.2. Solar Energy

The Sun is the world's largest source of energy, with an estimated 174 petawatts of energy per hour into the universe. About 33% of this energy is reflected in outer space, and this energy can be used by solar cells and thermal systems to convert it into other types of energy [7].

1.1.2.1 Photovoltaic Solar Energy

These cells convert the photovoltaic energy from the sun into electrical energy, where semiconductors release electrons in their cells and thus produce a continuous electrical current. Many of these cells are connected to each other to generate a large amount of energy known as photovoltaic panels Figure 1.5. It has a long shelf life and less need for regular maintenance [8]. Photovoltaic panel are classified into three categories according to the basic materials used in their manufacture [9]:

1. Crystalline Silicon.
2. Thin Film.
3. Concentrated photovoltaic (CPV) and Organic Material.

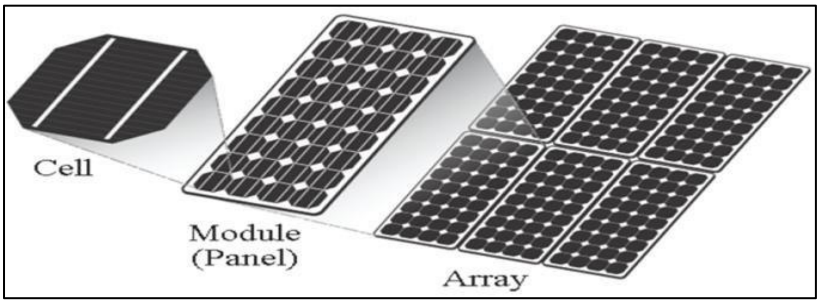


Figure 1.5. PV solar energy system [10].

1.1.2.2.The Principle of the Functioning of PV Cells

These cells convert photon energy into electrical energy directly, where sunlight releases electrons in silicon cells, where type P releases the electron and moves it to type N, thus producing a continuous electrical current DC. This movement of electrons from the positive to a negative pole of all connected cells produces the electrical energy that can be directly utilized or stored in energy storage units [10], photovoltic solar panel shown in figure 1.6. Photovoltaic systems can feed some small loads such as traffic lights and buildings lighting without the need for any other components, but in the case of large electrical loads you may need to add some key components such as regulator or DC/DC converter and inverter or DC/AC converter [11].

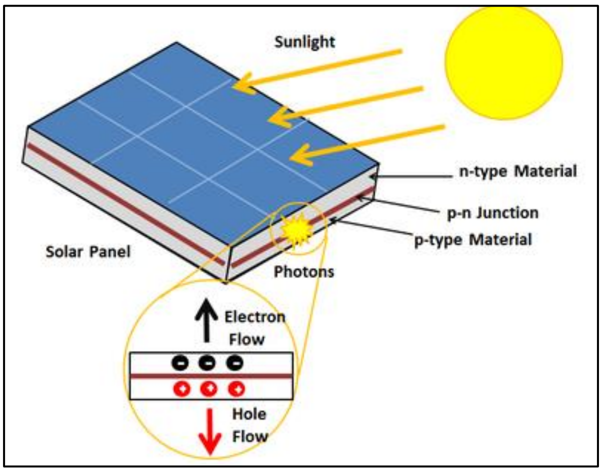


Figure 1.6. Photovoltaic panel diagram [11].

1.1.2.3. Regulator or DC/DC Converter

These devices are one of the most important components of pv energy systems, where they work to modify the value of the voltage resulting from these systems, and ensure the obtaining of the regulated voltage to feed the electrical load connected to this system, where the principle of its work as DC converters [12].

1.1.2.4. Inverter or DC/AC Converter

These devices convert the DC current which generated from PV systems to AC, where the AC can be single or triple-phase and can be at a frequency of 50 or 60 Hz depending on the design of the inverter. These devices are used when connecting accelerators loads directly to photovoltaic systems and without the need for energy storage [13]. In general, the types of power inverter used in PV systems can be classified to [11]:

- Modular UPS.
- Centralized inverters.
- Inverters " String " or " row ".

1.1.3. Solar Thermal Energy

Solar thermal energy is important renewable energy available in many parts of the world, where this technology can be classified by temperature, below 70°C, such as the technology used in solar heating and cooking, and more than 200°C, such as the technology used in solar thermal power generation. This technique is widely used to operate solar water heaters. In addition, its considered to be the most effective energy and the least economic costs [13]. Solar termal technologies can be classified as:

- Low-temperature technologies (working temperature <70°C)—solar space heating, solar pond, solar water heating, and solar crop drying[13].
- Medium-temperature technologies (70°C< working temperature <200°C)—solar distillation, solar cooling, and solar cooking[13].
- High-temperature technologies (working temperature >200°C)—solar thermal power generation technologies such as parabolic trough, solar tower, and parabolic dish [13].

1.1.3.1. Low Temperature Solar Thermal Technology

These techniques are used in areas such as building heating, where these technologies help reduce energy consumption and reduce economic costs and can be a passive system, an active system, or a combination of both [13].

1.1.3.1.1. Passive Space Heating

This technology is based on the design of the system so that it is independent and without the need to add electrical or mechanical equipment to it, so that it does not need maintenance, and can generally be in three categories: direct solar gain, indirect solar gain, and isolated solar gain [13].

Direct Solar Gain Design : this technology is based on the design of the system so that it is independent and without the need to add electrical or mechanical equipment to it, so this technique is based on design, with inlaid windows with tropical sides, so that solar radiation penetrates the entire building, using materials such as concrete, stone slabs with appropriate thermal properties. Indirect Solar Gain Design: this technology uses solar energy indirectly, relying on the use of a glazed heat collector, or the design of buildings with thick walls that have the property of storing sunlight during the day, thus slowly transferring heat to the interior building. Isolated Solar Gain Design: this technology relies on the design of insulated rooms of an extra highly glazed unheated, where buildings are warmer than the outside, ensuring that the loss of the building's income heat is minimized [13].

1.1.3.1.2. Active Space Heating

This technology relies on solar heating of buildings using some electrical and mechanical equipment to support air circulation or water heating. This technique mainly uses heat collectors, storage tanks, heat exchangers and heat emitters [13].

1.1.3.1.3. Hybrid Solar Space Heating

This technique is a mixture of technology, combining both the passive and active systems, as an example of the use of this hybrid technology, a space roof collector, and the addition of fans and ducts for heat distribution [13].

1.1.3.2. Medium Temperature Solar Thermal Technology

This technology is used in medium thermal applications, such as the use of solar energy in cooking, which is widespread in many countries and has an important role in reducing pollution and preserving forests and using them as an alternative to wood and coal. It is also used in solar water distillation applications [13].

1.1.3.3. High Temperature Solar Thermal Technology

This technology is based on the use of thermal power generation systems, by capturing heat from sunlight, where solar radiation is assembled and concentrated to raise its temperature above 200°C, which can be used in steam turbines or Stirling engines to generate electricity. This technique can be classified into the following concepts: solar pond, solar chimney, solar parabolic trough, solar central receiver or solar tower, Solar parabolic dish. As an example of the uses of this technique, using of solar and concentrated thermal energy to operate a steam turbine to generate electricity, as shown in the Figure1.7 [13].

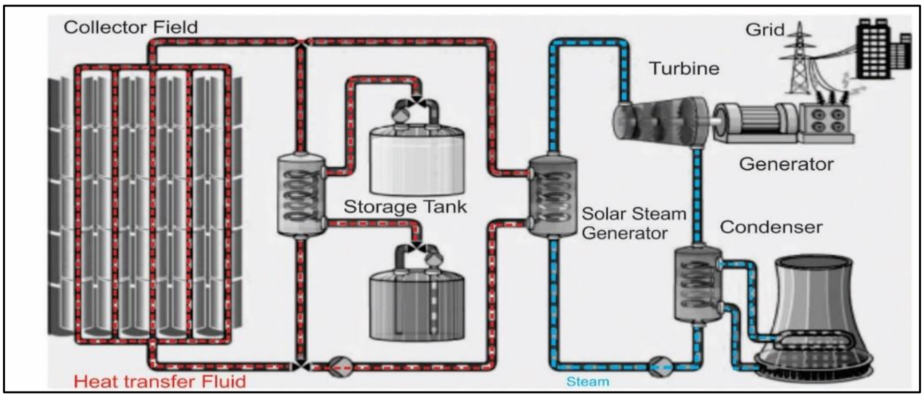


Figure 1.7. High temperature solar thermal technology [13].

1.1.4. Hydro-Power

Hydropower is a renewable energy resource resulting from energy stored in water flowing from above to a lower altitude under the influence of gravity, i.e. this energy is derived from moving water, where it has been used in the past in irrigation and operation of various machines such as windmills, elevators, and cranes. The main source of hydropower is the sun and gravity, where its working principle can be summarized as the overall process of the natural hydrogen cycle of evaporation and condensation in the atmosphere, which redistributes water from low altitudes to higher elevations on earth, this redistribution works to increase the potential energy of water that flows back into rivers and then oceans under the influence of gravity. In addition, hydropower is produced by precipitation and snowfall which causes flows, and the tidal process is considered hydroelectric energies [14]. In modern hydropower projects, which provide very efficient returns of 75-90% compared to conventional power plants, where dams are constructed to reserve water and utilize it for power generation, natural slopes and waterfalls can be utilized [11]. In Figure 1.8, hydropower is converted into kinetic energy to rotate a hydraulic turbine, which is associated with a generator to electricity production [11].

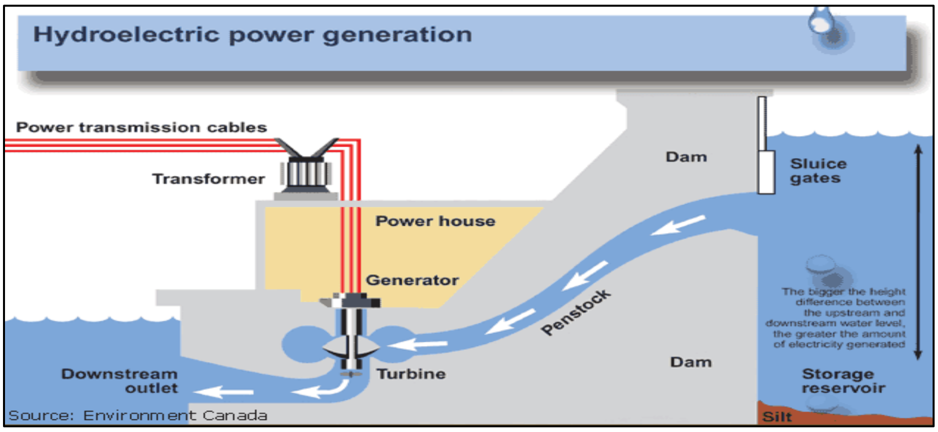


Figure 1.8. Hydraulic energy system [11].

1.1.5. Biomass Energy

Biomass is a source of renewable energy, as this sustainable energy depends mainly on the radioactive energy of the sun, which helps with photosynthesis, solar energy captured by plants. That is plants act as solar storage, which can be utilized as vital energy in the future. In general, the main methods of using plants as an energy producer can be classified in two ways: plant cultivation with a target to be used as an energy source, or the use of plant residues, depending on climate, soil, and geographical location. Biomass is used as an energy source for electricity production or thermal processes, as it is an effective energy resource in many areas [14]. This source of sustainable energy sources needs special attention and more solutions for storage and handling operations [11]. This technology is applied in biomass power plants, as shown in Figure 1.9, where organic fuel is burned inside a boiler and produces steam, which is used to operate generators to produce electricity or engines. The heat produced from this process can be used in heating applications [11].

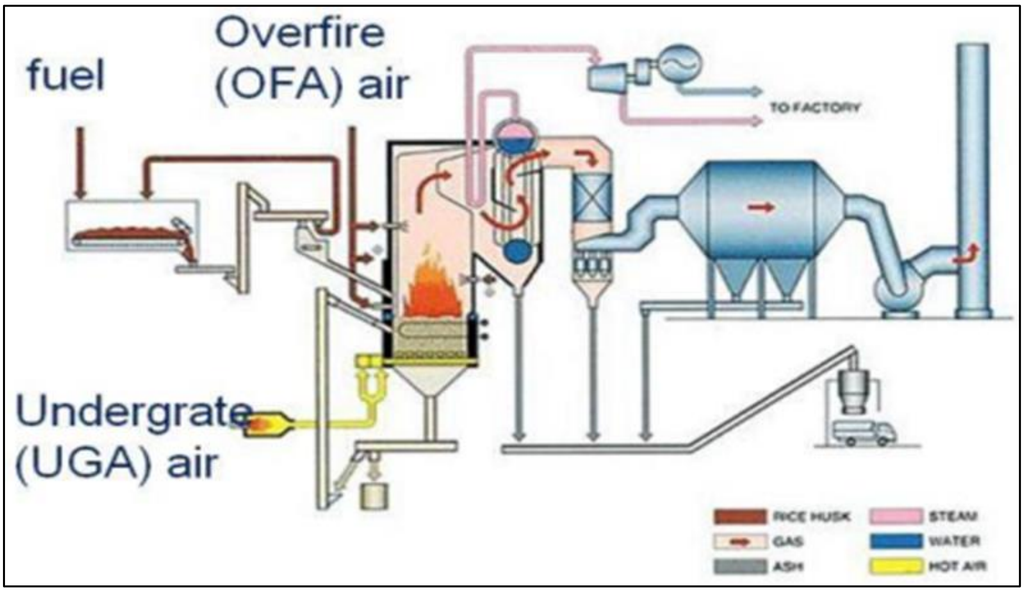


Figure 1.9 Biomass energy system [11].

1.1.6 Geothermal Energy

Geothermal energy is one of the sustainable sources of energy, which is energy derived from the earth's heat. It can be obtained from the ground at a depth of about 4,000 miles where the center of the earth is molten and high temperature in the range of 5000 degrees Celsius. This type of renewable energies is the result of the nature of planets formed from dust and gases and the radioactive degradation of many of the mineral elements in the rocks, which are constantly regenerating. The application of this technique depends on the transfer of heat from the ground to its surface and the use of this heat in many areas. Geothermal energy has a huge potential of more than 50,000 times all the energy that exists as fossil fuels on earth. These resources can be available from natural sources such as volcanoes, hot springs, and hot wells, which have been used in the production of electricity, heating, treatment, and in many different industrial applications. The equivalent of 10,715 MW of geothermal energy has been used in 24 countries since 2010 [14].

1.2. HYBRID RENEWABLE ENERGY SYSTEMS

Hybrid renewable energy systems combine two or more sources of power generation and storage, which are the ideal solution because they ensure high performance at the lowest economic cost [15]. Hybrid power systems (HPSs) provide a high level of energy security by combining different generation systems, often including power storage systems, to ensure maximum reliability of power supply. These techniques can also contain renewable and conventional energy sources, electric and chemical power storage, and fuel cells [11].

The use of renewable energy technologies such as batteries, fuel cells, wind turbines, and solar panels has become common and necessary in many areas, but to create more competitive, operational and environmentally friendly systems by combining these technologies in hybrid power systems, figure 1.10 shown Schema for hybrid renewable energy systems. There are several classifications of hybrid energy systems such as hybrid solar wind, solar-diesel, wind and hydropower, wind, and diesel, whose location depends on several factors, including a geographical location in terms of proximity to major electricity grids and climate [15]. the hybrid systems of renewable energy and widespread in this time [15]:

- Geothermal + solar PV.
- Biomass + Concentrated Solar Power CSP.
- Solar PV + fuel cells.
- Wind + solar PV.
- Biodiesel + wind.

- Gas + Concentrated Solar Power CSP.
- Coal + Concentrated Solar Power CSP.

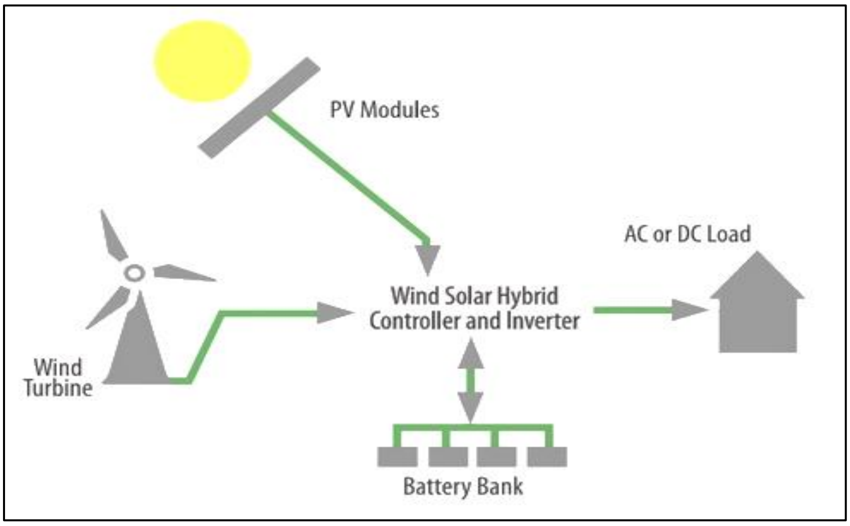


Figure 1.10. Digram for hybrid renewable energy systems [15].

1.2.1. Energy Storage

Energy storage systems are one of the most important components of hybrid energy systems, where they are of special importance and high reliability in electrical systems, where these technologies store energy at store energy in non-peak times, and represent in many applications such as pumping water storage, thermal energy storage, storage of compressed air energy and batteries [11,15].

1.2.1.1. Compressed Air Energy Storage (CAES)

This technology is intended to store the energy and potential energy of compressed air, in which air is pumped into large storage tanks or as normally occurs underground . They are frequently used as a means of processing the resulting shredding in electricity-generating wind turbines. There are two types of compressed air storage systems [15]:

1. Compressed air energy storage (CAES).
2. Advanced adiabatic compressed air energy storage (AA-CAES).

Figure 1.11 shows the use of compressed air technology for energy storage, in times off-peak of energy demand, the air is compressed into the lower underground reservoir (cavem), to be released during peak time to operate the turbine and then to turn on the generator to produce energy [16].

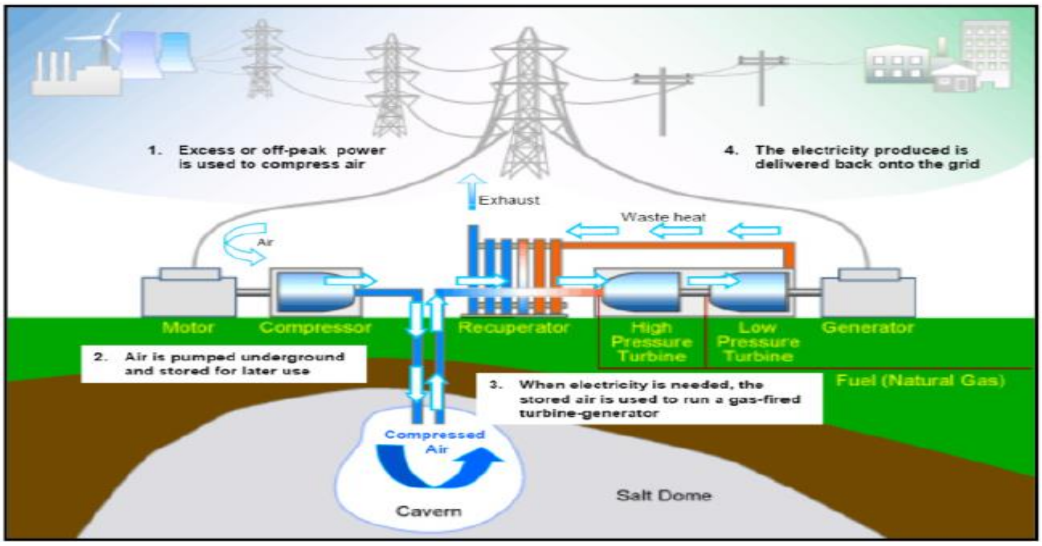


Figure 1.11. Compressed air energy storage system [16].

1.2.1.2. Pumped Hydro Storage (PHS)

The use of PHS technique depends on the establishment of large-scale electric power storage plants, where the facility consists of two water tanks placed at different heights and connected by a waterway, and during the period of peak, which is the time of excess electricity, the pumps pump water to the upper tank, to be discharged in the lower tank during peak times, thus moving the turbines in the system like in conventional power systems [17]. The amount of energy stored depends on the height difference between the two reservoirs and the volume of water in them. There are many PHS stations with a capacity ranging from 1 MW to 3003 MW, and the efficiency of these stations is 70 to 80%. Figure 1.12 shows a scheme for the use of this type of energy storage technique [11].

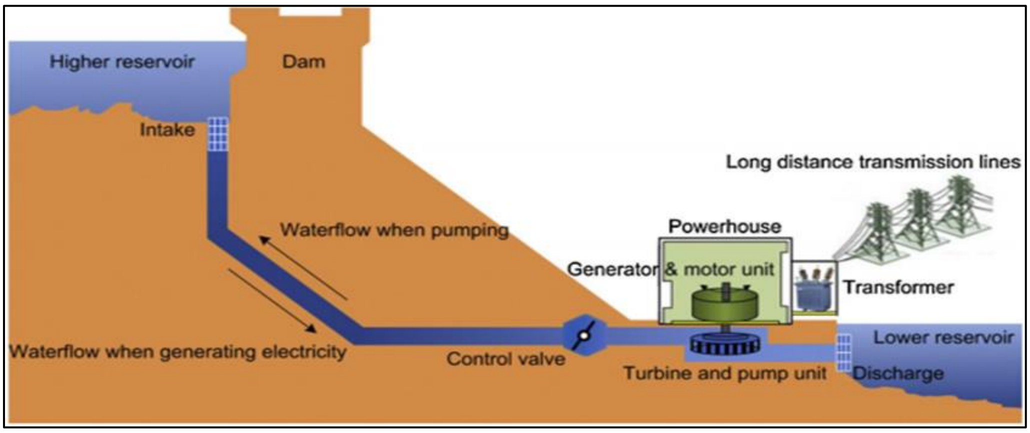


Figure 1.12. Pumped hydro storage system [11].

1.2.1.3. Thermal Energy Storage (TES)

Thermal energy storage TES systems offer environmental and economic benefits by reducing dependence on fossil fuels, the main purpose of using these systems is to prevent the loss of thermal energy by storing excess heat until it is needed to consume it. That the sources of thermal energy are available in all life magazines, solar thermal energy, and geothermal energy are considered one of the largest sources of thermal energy available, as nuclear power plants and heat from industrial processes are sources of thermal energy that can be stored and benefited from in the future [18].

1.2.2. Hydrogen Energy System

Hydrogen is one of the most available elements in the universe, as it can be in the form of water or fossil fuels. Hydrogen is also an environmentally friendly element, and hydrogen is an energy carrier. Hydrogen energy sources can produce hydrogen and store it into another form of energy so that it is sustainable and environmentally friendly. Hydrogen energy systems have extensive uses in renewable energy systems, such as fuel cells, electrolyzer, and hydrogen storage [19].

1.2.2.1 Power to Gas Technology (P2G)

This P2G technology is known for the use of renewable or excess electricity to produce hydrogen through electrolysis of water. This hydrogen can be used directly as the final transporter of energy or converted into methane [20]. This technique can be used in the process of decarbonization during industrial and chemical processes. Given the global climate change crisis, relying on P2G technology in power plants can reduce the resulting emissions. As natural gas technology is less expensive and more efficient than fossil fuels such as coal and petroleum, as the development of P2G technology has become a link between power generation systems and natural gas networks. P2G plants in electric power systems are considered as loads, while in natural gas systems they are producers [20]. P2G connects the electricity grid with the gas grid by converting excess power into gas in two steps:

The production of hydrogen by electrolysis of water, the conversion of hydrogen with carbon oxide products by methylation to methane, known as the natural gas alternative, which can be injected into natural gas distribution networks or gas tanks, and can be used as fuel in some car engines or in natural gas facilities, Figure 1.13 illustrates a blueprint for the basic processes of P2G technologies [22].

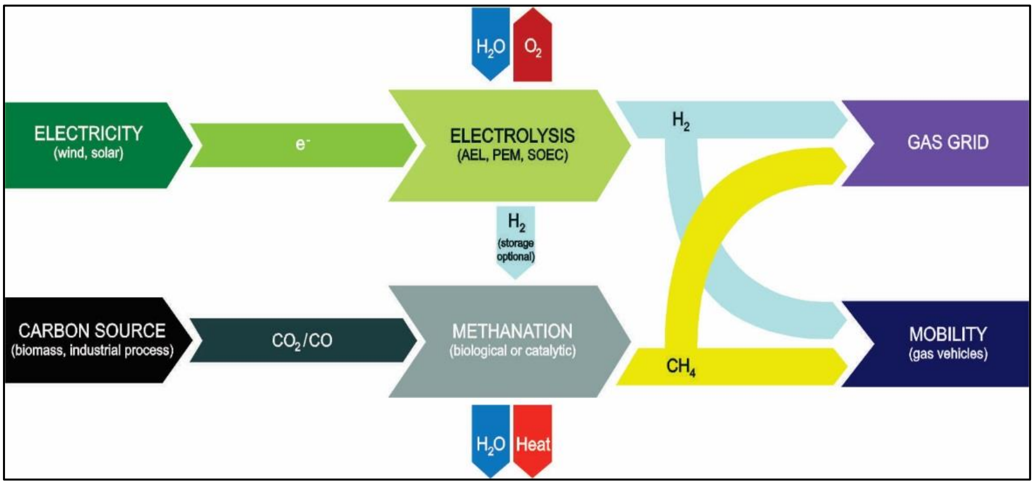


Figure 1.13. P2G technology processes [22].

1.2.2.2. Electrolyzer

Electrolysis of water is a renewable energy source promising to produce hydrogen, where hydrogen can be produced with fossil resources such as coal and natural gas, in addition to the possibility of producing it from biomass, where excess electric power is used to produce hydrogen using electrolysis of water [23]. Electrolysis has three different techniques of interest to P2G systems [22]:

- Alkaline electrolysis (AEL).
- Polymer electrolyte membranes (PEM).
- Solid oxide electrolysis (SOEC).

Figure 1.14 shows a simplified drawing for electrolyzer, in the process of electrolysis of water to produce hydrogen according to next equations (1.1), the chemical reaction when the reduction reaction occurs at the positive pole (Cathode), the oxidative reaction occurs in the negative pole (Anode) [22]:

$$\begin{aligned} &H_2O(l) \rightarrow H_2(g) + 1/2O_2(g) \qquad \Delta H_r^0 = +285.8kj/mol \\ &H_2O + 2e^- \rightarrow H_2 + O^{2-} \\ &O^{2-} \rightarrow \frac{1}{2}O_2 + 2e^- \end{aligned} \tag{1.1}$$

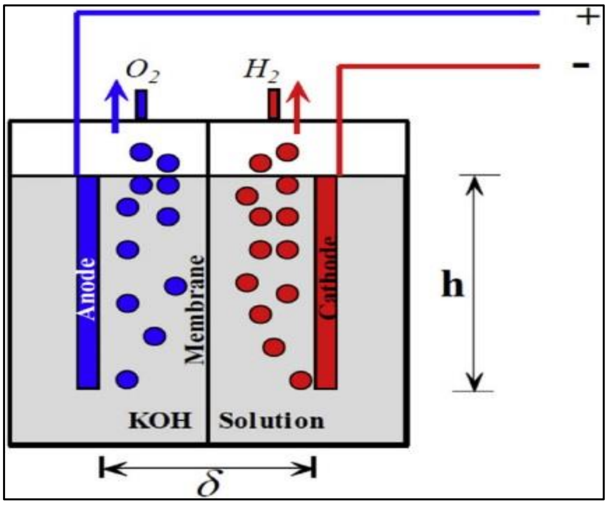


Figure 1.14. Electrolyzer Schematic [24].

1.2.2.3. Fuel Cell

Fuel cells are electrochemical devices that produce direct electric current through the interaction of hydrogen and oxygen as a result of electrolysis, which is widely used with solar energy systems, where it is considered to have high operational efficiency and rapid response to load changes, in addition to not needing to be recharged, unlike conventional batteries. Fuel cells have proven to be useful with PV systems successfully and with network and independent systems applications, as well as other advantages in reusing exhaust heat, ease of installation, and fuel diversity. Fuel cell fuel can be hydrogen or hydrogen compound, where hydrolysis can be used to obtain hydrogen from photovoltaic applications [25]. Fuel cells act as a chemical reaction to the fuel that turns directly into electricity, this process produced some heat and water as its by-product, Figure 1.15 shows a diagram of the fuel cell, where fuel and oxygen are provided continuously in the cell, and when the electrolyte of the cell is acidic, the hydrogen chemical reaction occurs at the pole anode and the oxygen chemical reaction at the cathode [26].

$$H_2 \rightarrow 2H^+ + 2e^- \qquad (Anode) \tag{1.2}$$

$$\frac{1}{2O_2} + 2e^- + H^+ \rightarrow H_2O \quad (cathode)$$

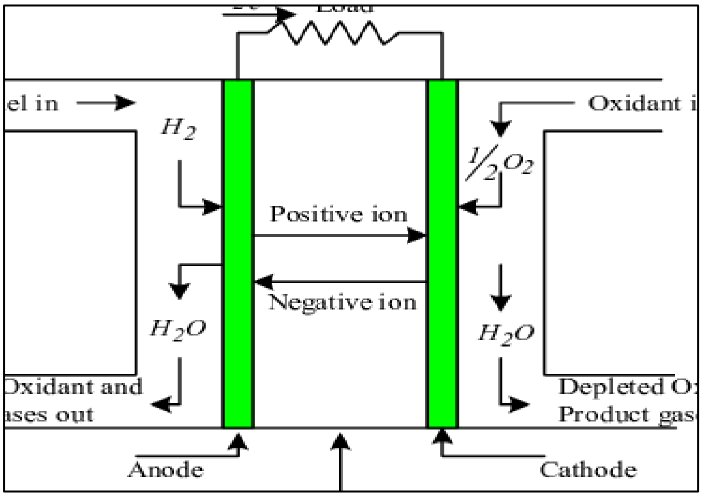


Figure 1.15. Fuel cell diagram [26].

1.3. OBJECTIVE OF THE STUDY

The demand for energy in our daily lives is constantly increasing, as well as the center on energy that is unlimited has grown considerably, public awareness initiatives are required to advertise the advantages of the corridor in providing affordable, sustainable, and secure energy to meet up with rising energy demand. During the last years of our time, roughly 50 % of the extra energy capability has supplied from RET resources [27].

An established obstacle with sustainable energy sources such as instance solar and wind energy is the variability of theirs. Connecting RE components to the grid may, consequently, cause controlling issues in case the electrical energy grid isn't created for handling these kinds of variations. A sizable quantity of research is being carried out on hybrid systems, combining more than one of renewable energy resources, connected with conventional power plants. which is has the advantageous asset that the variability of sustainable resources can be reduced, since the adjustable power output could be leveled out often as a result of a complementary nature involving sustainable energy or perhaps by various other sources of energy which are a lot easier to control, for example, hydropower. It's the situation in certain locations, and it stabilizes the system energy production and compensates the variable caused by solar and wind sources, also, complementing one another and providing a less varying output [28].

Environmental concern is one of the most important issues to consider in Libya, to reduce dependence on fossil energy sources which used to electricity production, also to reduce emissions and air pollution, where during 2008 it recorded CO_2 emissions that formed 62% due to the use of fossil fuels in power plants. The 13 power plants in Libya are distributed on different locations, which are designed with a total capacity of 8,051 MW, and 20% of the power generated depends on steam stations, while 43% are gas stations, while 37% of the power generated depends on combined cycle stations. 20% of the electricity in Libya produced from heavy oil combustion, 40% of light oil combustion, and an estimated 40% of natural gas combustion. During 2012, the amount of electricity produced was 33,980 MWh, which led to an estimated emission of 2.0755E07 tons of CO_2 [29]. On the other hand, the use of electricity in Libya is increasing rapidly, with average annual growth in 2016 to 2018 ranging from 8.7% to 15%, which is expected to reach 8 GW over the next three years. This growth in energy demand is a logical consequence of the economic and population growth in the region, as well as the problems affecting the stability of the electricity grid as a result of the political situation in the country. The Libyan Electricity Company indicated that during 2018 the average load was 6.157 GWh, and the average maximum generation of 5.215 GWh, where the deficit was about 942 MWh of the electric grid [30]. As a result, the GECOL should go to the use of renewable energy technology to generate electricity, by looking for opportunities to integrate clean energy to support existing power plants and to create hybrid power plants, based on the use of solar and wind resources. Which have the most opportunity in Libya, compared to other renewable resources [31].

1.4. STRUCTURE OF THE THESIS

This thesis was organized under the following five parts:

- **Part 1:** It is containing a general introduction to the sources of renewable energies and its various type, and the main problem and the purpose of this study.
- **Part 2:** A literature review study.
- **Part 3:** It describes the current energy systems in Libya, as well as the renewable energy technology currently available in Libya and the opportunities for its development, and describes the assessment of the MFZ site where the study will be conducted.
- **Part 4:** It provides the methodology utilized in this thesis, which includes information on the study area and the sources of its, and the identification of the program used, and also simulation inputs and processing of simulation results.
- **Part 5:** This part presents the results of the study for different hybrid systems cases designed in this study, discusses the results obtained, and conducts a comparison between different cases.
- **Part 6:** It will be the conclusion and recommendation of this thesis.

PART 2

LITERATURE REVIEW

In this part, the researcher will discuss some of the studies that have been conducted with the subject of the current study, to find out the most important topics that are covered, and identify the methods and procedures adopted, and the results reached, and comment on these studies and clarify the extent of their efforts.

Asheibe, et al. have conducted a study on the current situation of energy used to produce electricity in Libya and opportunities for the integration of RET. And they suggested the necessity of introducing renewable energy systems in Libya, and because Libya is characterized by best location to use this technology, and to increase the expected demand for energy during the coming years, the trend to use renewable energy technologies will create a parallel source for the fossil energy sources currently used to produce electricity [32].

Saleh, conducted a study on the existed and expecting renewable energy technology in Libya, where he concluded that Libya has a high chance of exploiting renewable energy sources, where it currently produces approximately 2.5 MW of RET which are which is used to feed electricity to communication systems and water pumping systems and lighting in rural areas, 6000 solar heating systems have been used since 1984, REAOL aimed to increase the use of RET by 10% by the beginning of 2020 [33].

Khalil et al. advised that the Libyan state support and encourage the use of renewable energy technology, attract investors and leading companies in RET and highlight the real opportunities available for renewable energy sources by collecting all data on solar and wind energy, and study its short- and long-term economic returns, and find alternative sources of fossil energy used to produce electricity. they also concluded that the demand for electric power will increase over the next few years. So the exploitation of renewable energy sources will create an opportunity for Libya to be a leader in the investment of renewable energies, by focusing on the construction of wind farms and solar systems, that would make Libya a consumer and exporter of clean energy [34].

Mohamed et al. examined the possibility of using renewable energy technologies to be a major source of energy in Libya, where the Libyan government looks forward to using RET reach 30% by the year 2030, to achieve sustainable economic growth through dependence clean energy, where this study predicts increased demand for energy consumption, which will lead to the necessary need for the construction of power plants to ensure the coverage of continuous growth in demand, thus it is necessary to establish a strategy to introduce RET and reduce pollution and emissions resulting from use of fossil fuel which used for electricity production in Libya [35].

Gawedar et al. discussed the integration of renewable energy technologies, such as wind turbines, and their involvement in electricity supply for an industrial area in the west of Libya, where the results were good and helped the energy generated from wind turbines to help stabilize electricity in the region, and also helped to reduce the emissions of CO_2 [3].

Aljadi et al. studied the efficiency of the use of photovoltaic technology which used in the production of electricity in Libya, where this technology was created since 1976 to feed electricity protection for one of the power plants in Libya. The amount of energy produced from these cells increased from 20 kW to about 1.5 MW in 2005, which was used to feed some rural areas and operate water pumps. The results in this study also found that the use of photovoltaic cells achieved high reliability and low operating cost, which made reliance on this technique acceptable than the use of generators [36].

Alweheshi et al. predict that energy demand will rise soon in Libya, which leads to increasing the consumption of fossil fuel to generate electricity, thereby increasing pollution and CO_2 emissions. This study focused on opportunities to use RET to improve current and future energy conditions, thereby enhancing the reliability, flexibility, and efficiency of Libya's electric grid, and reducing CO_2 emissions. This study concluded the general status of the electric grid and the strategies to be adopted to integrate renewable energy technology and reduce the use of fossil fuels, so that the renewable energy technology is used for street lighting, which can save 20% of general consumption, as well as, save 10% of the reliance on solar heating systems, and the placement of solar cells on the roofs of buildings connected to the electrical grid will save up to 40%, bringing the total amount saved to 60% of the energy generated. Furthermore, the study aimed to explore the policies and conditions of PV applications currently in Libya and to provide an important database for investors and those interested in PV technology [37].

Mohammed et al. focused on studying the prospects for the future of RET in Libya, where it looked at the opportunities available to the energy sector in Libya, and becomes renewable energy technologies to be one of the main sources of energy, where this study indicated that the Libyan government has set a future goal Renewable energy technology accounts for 30% of the main energy by 2030, represented in the wind energy, solar energy (CSP) and photovoltaic (PV). As a result of this plan, Libya will achieve sustainable economic growth by relying on clean energy and ensuring stable energy supplies. On another hand, the study predicted that electricity consumption will increase soon, which requires the construction of power plants to cover the continued growth of energy demand, so solar and wind power is available in Libya, which can It is well invested and planned to cover the continued demand for energy, reduce pollution and reduce carbon emissions [38].

Mohamed et al. aimed to identify the economic and technical challenges and opportunities facing the use of renewable energy resources in Libya, where it focused on the availability of renewable energy resources and practical opportunities for the implementation of these resources and aimed to know the extent to which renewable energy technology can contribute By integrating it into the current energy supply, which contributes to providing alternative sources of energy and reducing emissions, also, to attracting investors to promote renewable energy technology, including wind, solar and tidal energy, Libya has high opportunities to develop it. The study concluded on the importance of the development of renewable energy technology, which is still simple and not in keeping with the global development, which requires the Libyan state to adopt a clear strategy and time plan for the development of this sector [39].

Sayah investigated the opportunities to enjoy RET as one of Libya's major sources of energy, including wind, solar and photovoltaic, to achieve sustainable economic growth through the use of clean energy and ensure the stability of supplies. This paper also aimed to clarify the demand for energy and consumption during the current and future period and to explore the possibility of securing alternative fossil energy resources, by studying the possibility of involving renewable energy sources to ensure stability in the current energy supply and reduce pollution. Resulting from the use of fossil fuels, and keeping pace with the requirements of international organizations that seek around the world to promote the use of clean energy to protect the climate. As a result of this study, the effective reliance on RET will compensate for Libya's current shortage of energy supplies, thereby helping it achieve sustainable development and contribute to climate conservation. Also, the use of renewable energy technology, designed by the Homer program for the study area, demonstrated that Libya has significant renewable energy resources such as wind and solar energy, which should be given priority for implementation, as the results have been shown to get a lower cost of energy through the design of HRES for the study area where the wind energy technology was used where the cost of energy was \$0.151/kWh, which is lower than the solar technology of \$0.335/kWh, and the use of a hybrid system (wind and solar power) was not good cost. The results of this study summarized that renewable energy technology is the best way to achieve sustainable development, which can contribute to solving problems facing energy production and supply problems, and contributing to climate protection that has an effective international return [40].

Nassar et al. aimed at identifying the quantities of dangerous gases emitted from various sources that contribute to air pollution in Libya, to provide decision-makers with information and guidance related to the environmental situation in Libya, this will result in Libya's contribution to reducing global warming working with countries supporting environmental protection. The study showed that the total annual emissions of gases about 61.1 million tons, and the ratio of CO_2 above 96.76%, followed by the ratio of carbon monoxide by 2.13%, which made Libya in the ranking of 41 countries most polluted the proportion of carbon dioxide per capita. Besides, emissions from the use of fossil fuels in electricity production were 33.9% higher than other industrial and service sectors in Libya [29]. This study was a guide and source of pollution and the creation of a strategy and a plan to reduce its sources in Libya, the study recommended that the phenomenon of air pollution in Libya requires a speedy treatment of this problem by relying on clean energy, Including, Libya's try to make use of renewable energy sources and contribute to global warming [41].

Mohamed et al. provided a glimpse of the energy sources currently used in Libya, which make Libya one of the countries suffering from dependence on fossil fuel consumption, which affects the economic situation and environmental issues, and at present is suffering from increased energy demand, which urges Libya On the search for alternative energy sources, Libya is one of the areas where renewable energy resources are available, especially solar and wind energy. The study concluded that there are great opportunities in Libya for the production of solar and wind energy, through the development of strategic plans to attract investors interested in renewable energy technology, to aim at producing energy at a lower cost, which has a role to activate economic growth and reduce emissions resulting from Use fossil fuels to produce electricity, such as using solar cells in street lighting, operating communication systems, supporting the public grid, and relying on photovoltaic energy to operate water heaters. The Libyan government has taken initiatives that will encourage investors with renewable energy technology to invest and enter the Libyan market [42].

Guwaeder et al. indicated that the cost of photovoltaic cells is decreasing and all the international companies specialized in producing this technology are seeking to develop it and reduce their cost, and the study presented the effect of the entry of photovoltaic technology into Libya to support the energy system and its development, moreover, the study was based on the monitoring of the values of solar radiation in four different locations in Libya, where the results showed that the value of solar radiation over the year was very encouraging for those interested in entering photovoltaic technology into Libya, where the daily average for solar radiation value of the different regions ranged from 5.71 to 5.43 kW/m^2, The highest value of solar radiation in the year during June and July was an average of 7.14-7.51 kW/ m^2, while the lowest value of solar radiation during January and December was between 3.2 and 3.93 kW/ m^2. The study demonstrated that solar energy could provide an alternative source of renewable energy for Libya to produce electricity, which will achieve economic growth by reducing fossil fuel consumption, also to covering the growing demand for energy [43].

Panhwar et al. expressed that the specific quantity of fossil fuel, increasing the need for electrical power and worldwide environmental problems for electrical energy development is the primary thing to consider for the exploitation of unlimited energy resources, and given the global interest in greenhouse problems by exploiting renewable energy sources, where the technology of photovoltaic cells and wind turbines has evolved and created competitive opportunities to benefit from RET to generate Electricity. In this study, a hybrid energy system was designed using the Homer software to feed the Institute of Environmental Engineering & Management, MUET Jamshoro Pakistan, and the energy demand and feasibility of the system were calculated in two different cases, the first case of on-grid, and the second as a separate system off-grid. The results showed that NPC in the case of the on-grid system was lower than the off-grid system because the off-grid system needed energy storage batteries that were considered expensive [44].

Alamri et al. presented the design of the hybrid power system for home load feed in Libya using the Homer software in one of the cities of western Libya, where the hybrid system consists of wind turbines, PV panels, and energy storage batteries, where the house was selected in the annual wind speed area more than 4 m/s, the daily solar radiation is about 7.1 kWh/ m^2, where the results showed the lowest COE for a system consisting of 2.8kW PV modules, 3 wind turbine 1.2kW and storage batteries using 56,200Ah units. So, the appropriate COE has been reached and good economic returns can be achieved [45].

Rao et al. outlined that hybrid power systems play an essential role nowadays and are present in all energy applications such as home loads, power supply for industrial and commercial sectors, where hybrid power system consists of two or more energy resources so that it is more reliable than stand-alone power system. This paper used a design of a hybrid energy system based on solar and wind resources so that it was designed by the Homer software to feed a load according to two cases (on-grid and off-grid stand-alone system), where the results indicated that the average energy generated from solar cells is 154,180 kWh/Year, which is 22% of the total energy generated from hybrid systems, the energy generated by wind turbines was in the range of 481,336 kWh/Year, which represents 68% of the total energy produced, and the total energy generated from the grid represented 10%, hence the results confirmed the possibility of good wind and solar power which covered the electrical needs of the system [46].

Hayek discussed the realization of the potential of RE in Jordan, where Jordan crosses from developing countries and fuel resources are very limited, and with increased growth with the increasing demand for energy, which affects the economic situation as a result of dependence on the import of fossil fuels from Outside. It is, so, necessary to look for other energy resources, solar and wind energy, where renewable energies are considered to have high potential and have not yet been exploited. The study collected data on wind energy and solar energy in different regions, collected data on the current load request, and a hybrid system of PV and wind turbines will be designed using Homer software, and conduct a simulation of the system to get reliable results. Economic viability, which in turn will bring economic growth and stability of the electric grid [47].

Halabi et al. presented that when designing hybrid power systems, these systems must be designed with high reliability and ensure operation at the lowest possible cost, and consider the energy and sustainable resource management as an essential element. A hybrid system involving conventional and renewable energy sources was designed using the Homer program, which will be a source of energy for a remote Malaysian village, where system simulations and improvements were made in various cases and key variables of the system, to see the benefits or risks associated with each system. The results suggested that in the case of the standalone system (off-grid), energy storage batteries used to back up the system significantly affected the COE and NPC, The purchase and sell-back of the power are one of the most important factors directly affecting the performance of the system connected to the grid, the prices of diesel used to operate generators in the grid-connected system affect the COE and operation cost of the system, and the number of emissions of CO_2 depends mainly on operational hours of generators, load demands and fuel price. The study concluded that the use of a hybrid, on-grid system achieved more reliable, stable, and less COE, as the standalone system is currently unreliable due to the high cost of batteries [48].

Anwari et al. designed a hybrid power system to feed a small industrial area in Malaysia, with a daily load of 16 MW hours using the Homer program, where the system consisted of PV panel, power converter DC/AC, and connected to the public electric grid, where a simulation of the system was conducted to obtain optimal economic feasibility and was The main goal is to get COE at lowest, reduce CO_2 emissions and reduce global warming. The results showed that the use of photovoltaic cells is beneficial in the long run, despite the high NPC because of PV panels, but the system can achieve the desired economic development, and that renewable energy technologies are recommended to save the world from global warming and the problem of fossil energy depletion [49].

Koussa et al. used Homer analyzed the integration of wind energy with the electric grid in the region of southern Algeria, where the wind is an alternative and environmentally friendly energy resource that has a high chance of use in this region, where an investigation and comparison was carried out between the hybrid system consisting of wind turbines 95 MW connects to the public electricity grid in the first case, operating with the standard electrical grid in the second case, which gave us a view of the economic and environmental impacts after relying on RET, as well as comparing the energy consumed in both cases and the NPC. After a simulation of the system, the results showed that the system consisting of wind power connected to the grid reduced by 19% of the number of emissions, in addition to a lower NPC, and that the COE is equal in both cases at 81% of the total energy consumed. Therefore, it was concluded that the use of wind technology which added to this system had a positive economic and environmental impact [50].

PART 3

CURRENT SITUATION

3.1. THE PRESENT SITUATION OF THE ENERGY SYSTEM OF LIBYA

Libya is located in North Africa and bordered to the north by the Mediterranean Sea, Egypt and Sudan to the east, Niger and Chad to the south, Tunisia, and Algeria to the west. It is an important oil and Natural gas exporting country, so Libya’s economy is heavily dependent on its fossil fuel sector (about 96% of total government revenue). Because of the suffering from high energy usage, substantial standard energy rates as well as environmental problems, mixed with fast need development. where energy production in Libya depends on the use of fossil fuels, Libya contains 13 power plants with a design capacity of 10.3 GW, distributed in different areas shown in Figure 3.1. [41].

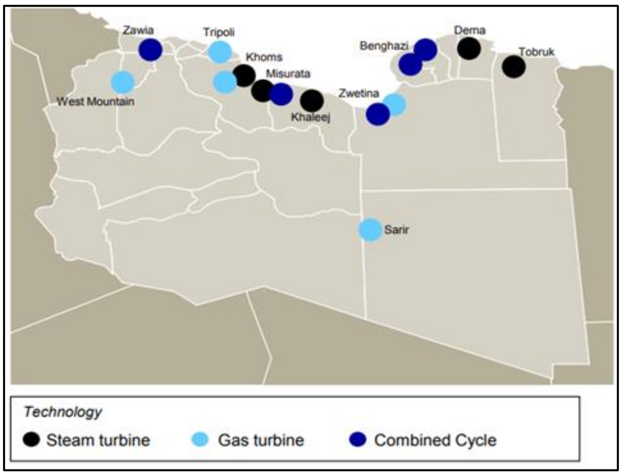


Figure 3.1. Distribution and types of power plants in Libya [30].

Since the Libyan state is working to support energy production, the price of electricity tariff It is lower than the cost of generating, with the sale price of energy ranging from

1.5 U.S. cents/kWh for domestic consumption, and at 5.2 U.S. cents/kWh for public services, although the cost of producing energy ranges from 0.125 to 0.19 $/kWh, and as a result of the instability of energy production in Libya, it is moving to import quantities of energy from neighboring countries such as Egypt and Tunis and the value of the purchase of energy is estimated at 0.11 $/kWh, and Figure 3.2 shows the cost of energy production and the price of selling it to consumers [30, 51].

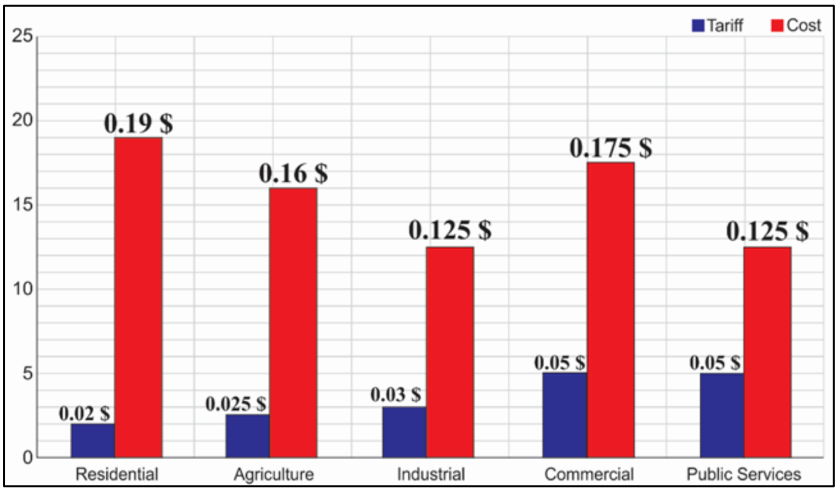


Figure 3.2. Cost and tariff kWh in Libya [51].

The Renewable Energy Authority of Libya (REAOL) has been founded to advertise the improvement of unlimited energy of Libya to boost the utilization of renewable energy, Specially Libya has the rectifiers to do this. Libya is situated on an area of higher solar radiation, and high wind. Its sun radiation reaches 8.1 kWh/m^2/d on a horizontal level along with a coast of about 2000 Km length [54].

Solar radiation, about 88% of Libya’s area considered to be desert areas, where there is a high potential of solar energy which can be used to generate electricity by both of solar energy conversions, photovoltaic, and thermal (the total energy received on horizontal plane reach up to 2500 kWh/m^2 per year) [54].

Wind Potential, Libya has a coast of around 2000 Km length with speed exceeds more than 7 m/s at a height of 40 meters in most of the country's land. This will make the country a good place for wind farms [40].

But, other renewable sources available in Libya like geothermal, and biomass are having less potential in the country [55].

3.2. CURRENT USE OF RENEWABLE ENERGY TECHNOLOGY IN LIBYA

The use of renewable energies has been introduced in a wide application due to its convenient use and being economy effective in many applications, the renewable energy applications used in Libya consists of photovoltaic, solar thermal applications, wind energy, and biomass [32].

3.2.1. Photovoltaic

The use of PV systems started in 1976, and since then many projects have been erected with different sizes and type of applications such as (The project of a PV system to supply a cathodic protection station to protect an oil pipeline connecting Dahra oil field with Sedra Port, Projects in the field of communication where a PV system was used to supply energy to a microwave repeater station and there are many of these stations right now which serve several sectors in Libya Projects in the field of water pumping where PV pumping system was used to pump water for irrigation and the use of PV systems for rural electrification and lighting). The role of PV application is growing in size and type of application [55].

3.2.2. Thermal Conversion

The utilization of a domestic solar heater began in 1980 by adding a pilot project of 35 systems, followed by various other projects. There are approximately 6000 flat plate collectors' solar heaters in Libya. The utilization of evacuated tubes for sun heaters has been started for certain hotels as well as residences and likely to grow up soon [32]. Water heating energy used approximately 12% of total electricity output. The utilization of solar heaters hasn't spread in most places Because there is no orientation for the state or private companies to start constructing these systems and not knowing about the benefits of solar heaters in addition to the relatively low price of electricity in the country [55].

3.2.3. Wind Energy in Libya

Wind turbine technology has not been widely used in Libya, as it has been limited to simple uses such as pumping water in some desert areas, as it requires periodic maintenance. During the last ten years, several studies have been carried out for the implementation of some wind farm projects, where many antennas have been installed in different areas to monitor and record wind speed throughout the year, to determine the technical specifications of wind turbines that suit these areas, and during 2017 was installed 16 turbines with 71m high in Maslata city, which is expected to produce 27 MW of power [32].

3.3. OPPORTUNITIES TO IMPROVE THE ENERGY INDUSTRY IN LIBYA

There are a good opportunity and suitability for using RET to supply electricity to home utilization, communication systems, street lighting, and to connect with the general electricity grid to make it more suitable. The efficient and quick use of unlimited energy must have very good area studies, sufficient funds, and good planning. Solar and wind power resources particularly could be of the great source of power for Libya following natural gas and petroleum. And maybe put together to become a dependable national earning's resource. The electric segment should reform as well as privatized the electricity sector to boost transparency, reduce corruption, and attract private investments [40].

The Libyan government is making efforts to diversify its energy mix and to harness the country’s solar and wind potential. By 2020, Libya aims for 7% of electricity generation to come from renewable energy, followed with 10% by 2025. Libya is also in the process of implementing its NEEAP and a RCREEE member state since 2008 [56].

Although Libya is one of the member countries in the Organization of Petroleum Exporting Countries (OPEC) and it has the largest oil reserves in the world; where oil and natural gas represent 96% of the total government revenue. However, the Libyan government seeks to exploit the potentials of solar energy and wind energy to raise the

Electricity generation in Libya to 7% depending on renewable resources by 2020, rising to 10% by 2025 due to the growing domestic demand for electricity, Which in turn requires an expansion of capacity which leads to increased periods of darkness as a result of reducing loads as one of the solutions offered. Reliance on renewable energy resources in addition to fuel-dependent resources is one of the suggested solutions to overcome this problem [31].

PART 4

METHODOLOGY

4.1. INTRODUCTION

This part presents the methodology of research and data collected and used in the design. Where describing of the methodology used in this study, presentation of the case study methodology and data collection techniques about the study area and used in the practical part, furthermore the methodology that has been relied upon In the design of a hybrid power plant to feed the intended area using Homer software, and how entering the data required for design, simulation, and optimization to get the best results.

4.2. CASE STUDY METHODOLOGY

The case study focuses on the optimal design of a hybrid power system, where a model was designed to simulate a real load existing, where all the data on the electrical load of the MFZ, which is fed by the Libya electricity grid, which suffers from frequent interruptions, instability, and lack of coverage Increased energy demand, as the grid relies on generating energy from conventional sources, which causes a lot of environmental pollution as a result of CO_2 emissions. The main reason for this study was therefore to explore the opportunities that the use of RET could provide in positive support for the main grid economically, technically, and environmentally. The Homer Hybrid System will be designed for MFZ, the simulation of the system and its components, and the optimal position extraction for the lowest NPC, OC, and COE.

4.3. CASE STUDY AREA (MISURATA FREE ZONE) MFZ

The study area was selected in this research, considering the economic importance and interface of attracting investors to Libya, because of its guarantees and tax exemptions for companies wishing to invest. Misurata free zone is located in the middle of the Libyan coast on the Mediterranean Sea between coordinates (15.13) east and 32.22 north, with an area of 3,539 hectares including the seaport divided into two locations. Site A: 539 hectares including Misurata seaport, and Site B: 3,000 hectares 8 km south-east of Site A [52]. Site A and Site B are shown in Figure 4.1.

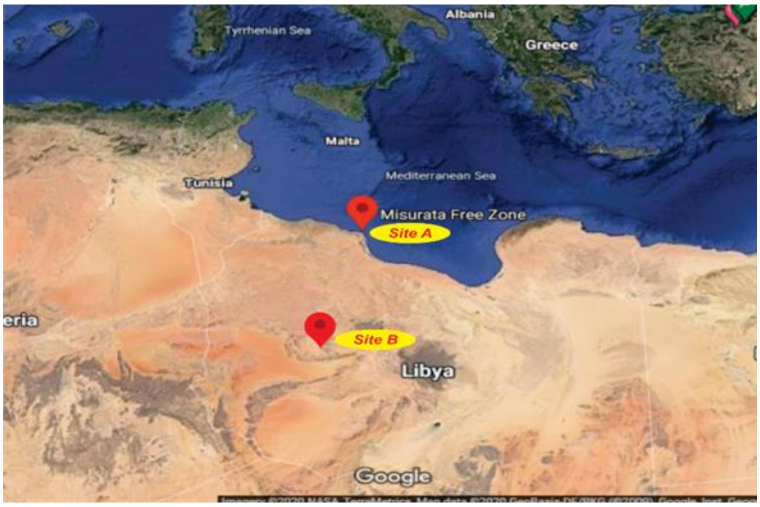


Figure 4.1. MFZ site A, B location [52].

The city is characterized by sunny and dry weather during the summer, wet and rainy season during the winter season. The Free Zone is considered Misurata to be one of the most important economic resources for its active role in trade movements between countries to exempt them from all tax restrictions to encourage investment institutions that lead to a good economic return for all parties and contribute to the establishment of a giant economy and facilitate The global trade movement in a developed investment environment, classified free zones organized by law to host industrial, commercial and service operations that are advertised to all those who wish to invest. In addition to taking advantage of the country's great position and to diversify the base of the national economy, natural resource revenues and expand the performance of the national economy through the effective employment of the potential domestic workforce available to attract foreign capital and investors. It currently has many companies that have started their business, including commercial, industrial, and service. On the other hand, the site of the MFZ is very close to power generation plants and high-voltage distribution lines.

4.4. SELECTION OF HOMER SOFTWARE: HRES

Homer Energy is one of the most important software and tools used to design and evaluate renewable energy technology, whose applications can be used for on-grid and stand-alone systems, and allows for great options for technology, available resources, and components for the system. These advantages thus allow energy systems to be designed more accurately and effectively, as well as contain a resource database for the design of study area coordinates and climate information such as solar radiation data, wind speed data, and temperature data throughout the year. Homer's hybrid system design and analysis software has been used in several previous studies, making the results of Homer's program one of the most used programs compared to other programs [55]. The processes are carried out by Homer based on three main processes: simulation, optimization, and sensitivity analysis. In the first process, the program conducts an 8,760-hour year-long simulation of the intended system, calculating the components of the system to determine the best technical feasibility and calculate the total net costs of the system NPC, which includes the component, operating and maintenance costs. During the second process (optimization), the program identifies the components of the system that are technically optimized and that correspond to NPC. During the third process (sensitivity analysis), Homer software analyzed sensitivity to a large number of assumed variables such as wind speed and fuel costs and sizing the impact of these variables on system components, as well as changes due to the inputs of these variables [53]. Figure 4.2 shows the inputs, outputs, and processes conducted by homer.

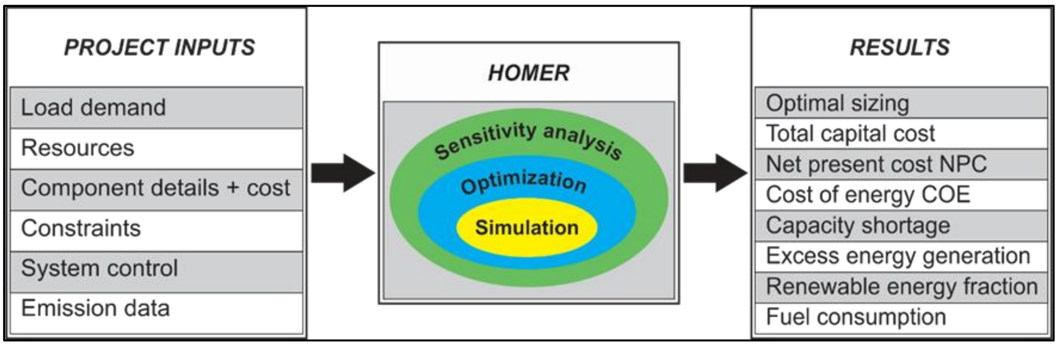


Figure 4.2. Schematic of HOMER inputs and outputs [53].

4.5. MFZ HRES: DESIGNING, SIMULATION, AND OPTIMIZATION

The case study relied on the design and study of four different cases of components of the hybrid power system, which will extend the electric power to the study area (site A for MFZ), where the system in the first case consists of solar technology (PV cells) connected to the grid with the addition of energy storage batteries and electrical converter DC/AC to convert DC electrical current which produced by the PV cells, to AC electric current to feed the main electricity grid. The second case will contain a wind power source (turbine) and connected to the grid, and the third case will contain a solar power source, a wind power source, and a grid-connected. In the last case the system will not connected to the main electric grid (stand-alone system) and it contain PV cells, wind turbine, electric converter, and electric power storage. The economic and technical feasibility for the four cases will be studied and will be compared in terms of net cost NPC, energy cost COE, and what is the best case for system stability on it. On the other hand, this study relied on the conduct of all cases of the system connected to the network, because of one of the objectives of the study is to study the economic and technical feasibility by integrating the technology of renewable energies with the current electric grid, and to find a real opportunity to invest the resources of renewable energies as alternative energy for power generation In Libya. The presence of generators in different study situations has been ruled out, to reduce environmental pollution and reduce the amount of CO_2 emissions from power plants.

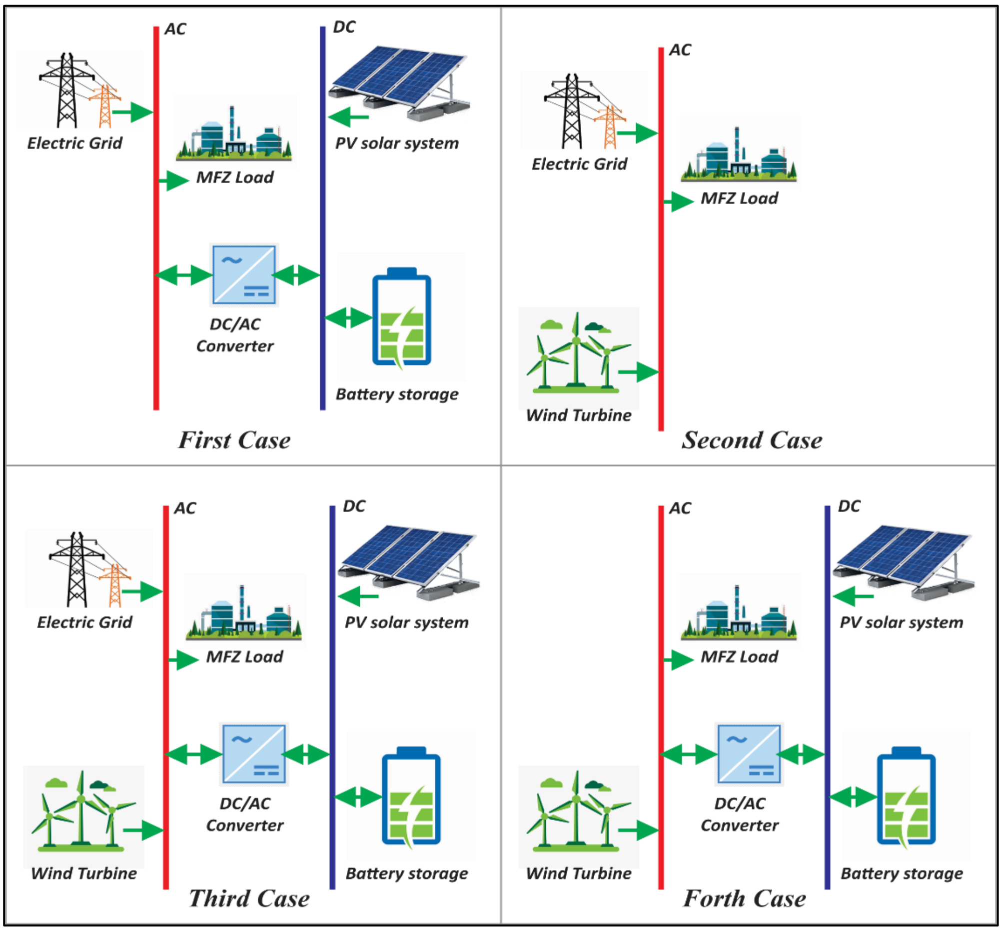


Figure 4.3. Hybrid RET systems to be designed and applied to MFZ using HERS.

4.6. LOAD PROFILE FOR MFZ

MFZ contains a variety of companies, including industrial companies, service companies, commercial companies, and the seaport. This makes the type of electrical load varied. As a result of some of these companies' continuous work throughout the day, the demand for electricity continues unevenly throughout the day. Therefore, for the purpose of designing HERS for the study area, the average electricity demand must be determined within 24 hours, and peak hours for energy demand must be determined, to ensure that the system is designed to provide electrical needs.

Figure 4.4 shows the amount and cost of the MFZ’s monthly energy consumption for 2018, the value of energy consumption as a load for a public service area is calculated at 0.05 $/kWh, although the cost of power generation is in the range of 0.125 $/kWh, and figure 4.5 shows the difference in the value of electricity consumption during 2018 between cost and tariff value [51].

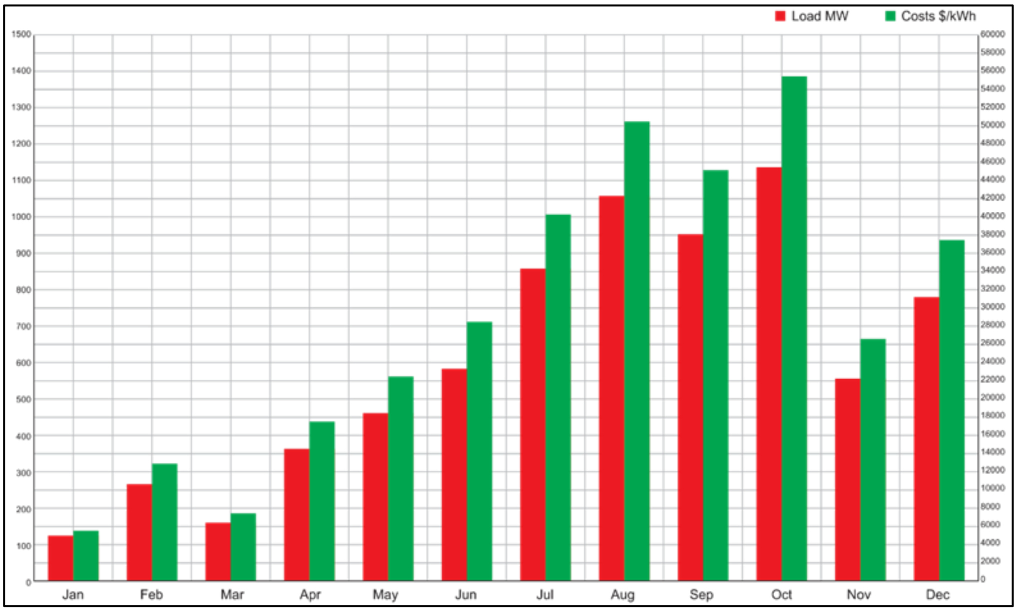


Figure 4.4. Monthly energy consumption amount and cost of the MFZ in 2018.

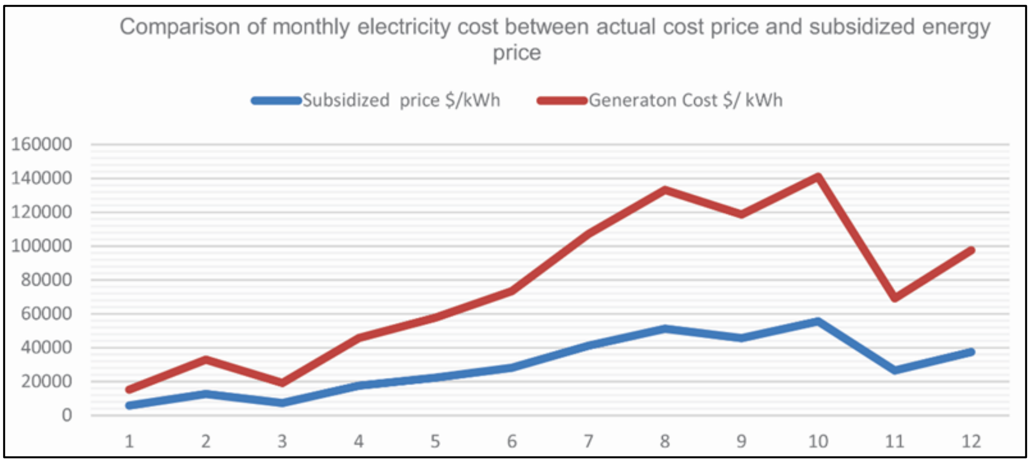


Figure 4.5. Comparison of monthly electricity cost & tariff for MFZ in 2018.

4.6.1. Primary Electric Load For MFZ

In order to determine the peak, and the amount of electricity consumption per month, a graph of the annual load curve of the MFZ was drawn and during the years (2018, 2019) shown in Figure 4.4, where a discrepancy in the amount of electricity consumption was observed during these years, thus the maximum load curve was drawn for these years represented in Figure , and determining maximum amount of monthly loads, and given the monthly load curve, we will find that the monthly peak period starts from July to October. In this context, the calculations in the study of the monthly load curve were taken on the basis of the maximum monthly load during these years, and used it to design HERS for study area.

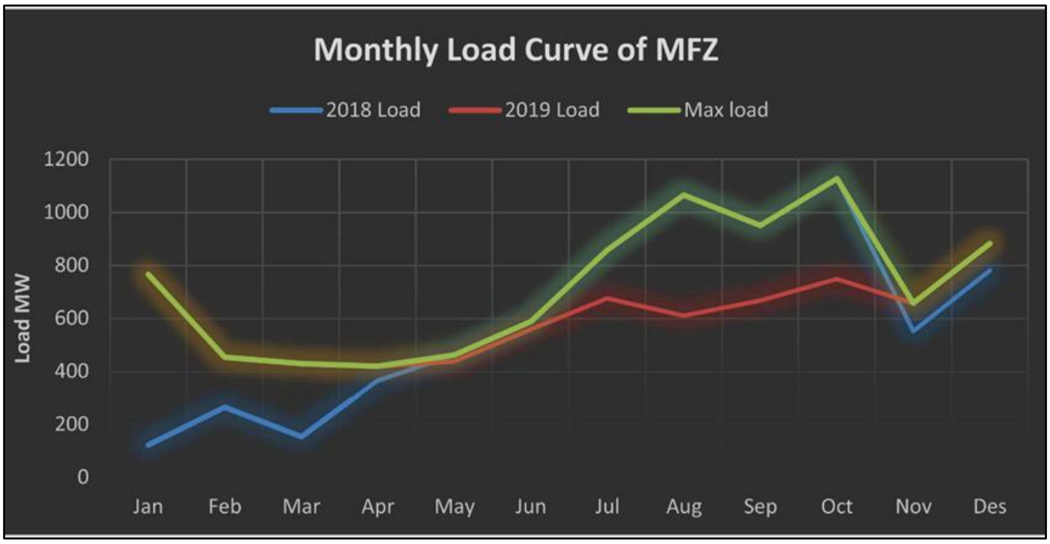


Figure 4.6. Monthly electric load curve for MFZ during 2018, 2019.

The daily load of the system is an important element in the design of the energy system to determine the peak of load throughout the day. As a result of the lack of data on the value of the daily load consumed for the study area, it was calculated as a percentage of the daily load of the Libyan network during July 2018, which was obtained in the database from the Libyan Electricity Company GECOL, and accordingly, the daily load curve of the region was drawn, which shown in Figure 4.5. Furthermore, HERS of MFZ designed using this data.

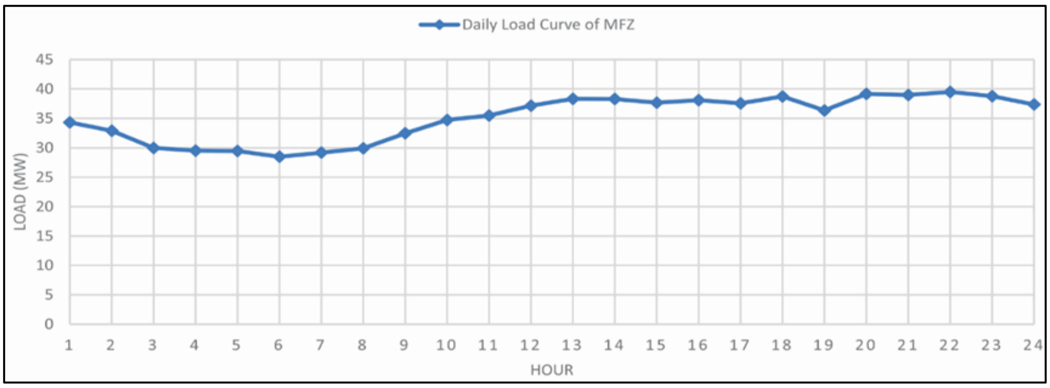


Figure 4.7. Daily load curve for MFZ which determined during July 2018.

4.6.2. Designing Homer System For MFZ

The hybrid power system for the study area was designed using Homer, the required data was entered. The required load was introduced for MFZ, which was calculated according to the daily load curve in Figure 4.6. Loads type in MFZ were AC loads, the system was designed as the basis for the maximum load required throughout the week and weekends because many of the study area facilities continue to work throughout the week. After the entered load data, daily load curves and monthly load curves were calculated by Homer as follows in Figure 4.7 and Figure 4.8.

Figure 4.8. Entered primary electrical load for MFZ in Homer.

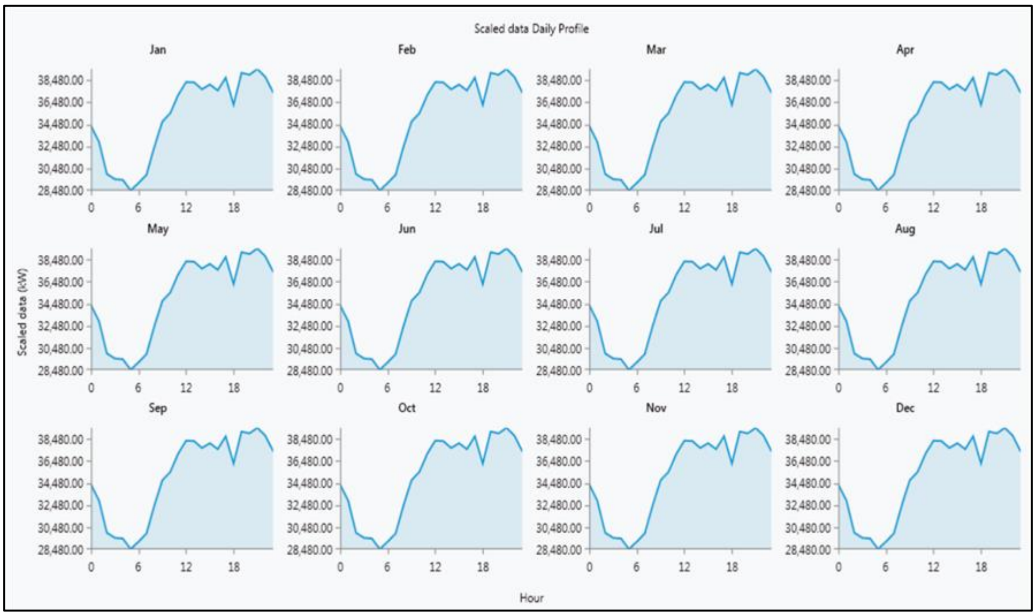


Figure 4.9. Daily load profile for MFZ.

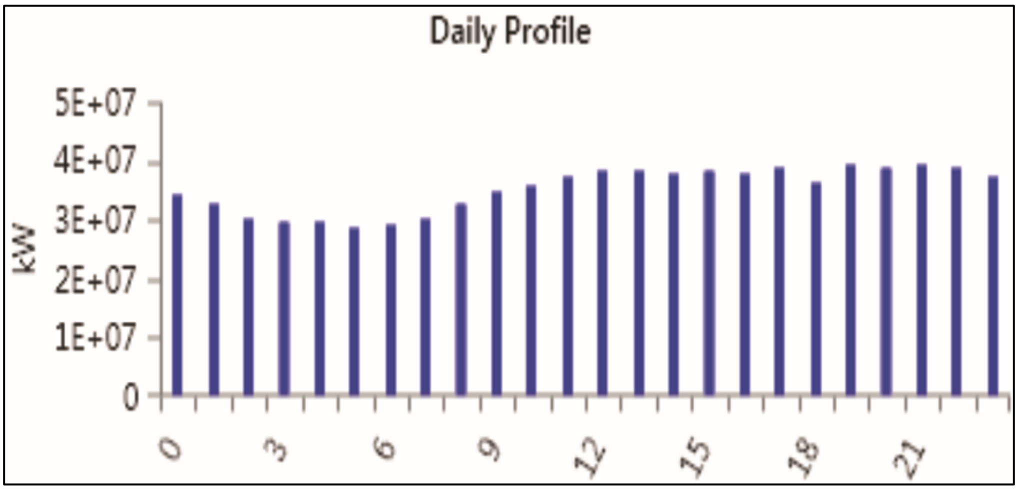


Figure 4.10. Hourly load profile for MFZ.

4.7. ASSESSMENT AND IDENTIFICATION OF RENEWABLE ENERGY SOURCES

It is necessary to evaluate the sources available in the area to be provided for electrical supply (solar source or wind source, etc.), and to choose the most suitable ones. To assess the sources, data on each of these sources must be available. Solar and wind technology will be used in this study, although tidal and hydropower are available in the region, but there is no data on these sources. After identifying the sources from which they will benefit, research, and identification of the most appropriate technological options for these sources are being researched and identified.

4.7.1 Solar Resource

Data of solar resources for the study area is essential and important to calculate and know the amount of solar energy produced by PV panels throughout the year, and solar radiation in the region can be identified by introducing the coordinates of the intended region in the Homer program, which includes an application to import data Solar radiation of the region from NASA database. The figure shows the average daily solar radiation intensity of the MFZ throughout the year. It was noted that during the months of January, February, November, and December, the value of the month is (2.77 to 4) kWh/m^2/d. During the months of March, April, September, and October, between (4.6 and 6.95) kWh/m^2/d. It reaches its peak during May, June, July, and August, ranging from (7.2 to 8) kWh/m^2/d. Thus, the average solar radiation of MFZ is 5.53 kWh/m^2/d throughout the year.

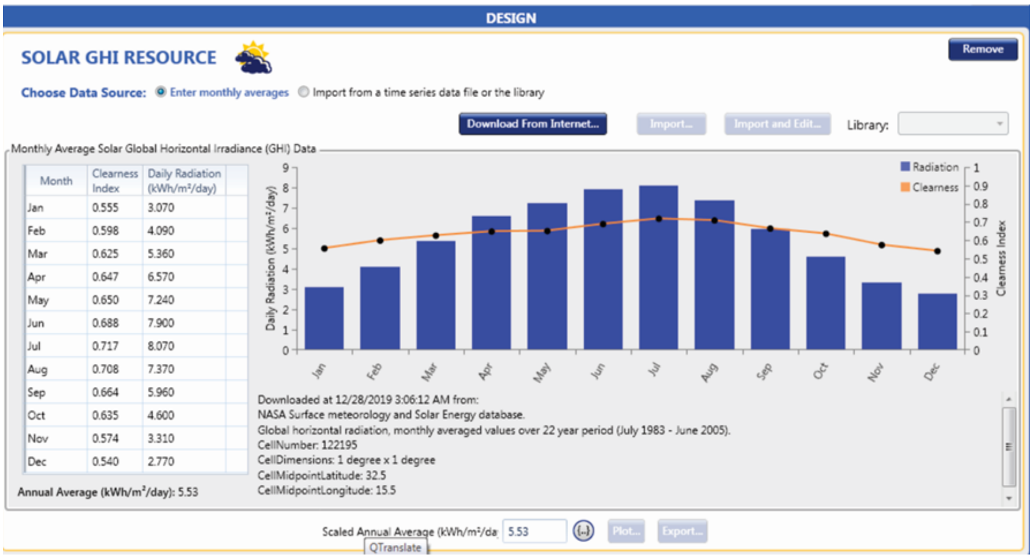


Figure 4.11. Solar resource inputs values for the site of the MFZ HRES.

4.7.2. Wind Resource

Wind resource data for the study area was obtained using the Homer program, in order to determine the production capacity of the wind turbines to be applied in the design. where Homer can show the average wind speed data for the study area, by importing from NASA's database after the Coordinates of the study site. The figure shows the average annual wind speed of the MFZ. The average wind speed is between 4.57 m/s in July and a maximum of 6.20 m/s during February. Thus, the average annual wind speed of the region is about 5.5 m/s.

Figure 4.12. Wind resource inputs values for the site of the MFZ HRES.

4.8. COMPONENT INPUTS AND VARIABLES FOR MFZ HERS

The choice of power system components depends on many characteristics, the most important of which is the cost of capital, the cost of operation and maintenance, the efficiency of the components and their shelf life. These characteristics should be taken into consideration when selecting the components of the power system.

4.8.1 Photovoltaic Panel

PV modules were selected type (Generic flat plate PV) where the capital price assumed 2500 $ for each 1kw, this price includes (shipping and installation costs) IRENA2019 report, where the report assumed the prices of PV decreased by almost 90% from (2009 to 2018), and the operating and maintenance costs of solar units range from 10-19 $/kW [56]. On this basis, in this study, the replacement value was placed in the range of 1500 $/kW and O&M costs 15 $/kW/year. Table 4.1 shows all the data that was introduced by homer program for the properties of PV panels selected for the system, where a solar tracking system was added along the horizontal axis to increase the efficiency of the system, which ensures the production of the largest amount of solar energy, and the ratio of the derating factor was determined by the limit of 90%, This is due to the impact of temperatures and dust on the productivity of PV panels.

Table 4.1. PV panels costs input in MFZ HERS.

Capacity (Kw)	Capital Cost ($)	Replacement Cost ($)	Q&M Cost ($/Year)	Derating Factor (%)	Life Team Year
1	2500	1500	15	90	25

4.8.2. Battery Unit Inputs

The Generic 1kWh Lead Acid battery unit has been selected to add to the system to store power and backup the system. This type of battery is an acid battery, with a nominal voltage of 12 volts, a maximum capacity of 83.4 Ah, an efficiency of 80%, a maximum charge current value of 16.7 A, and a maximum discharge current value of 24.3 A. The following Table 4.2 shows the data battery storage which entered for the MFZ HERS.

Table 4.2. Battery storage costs input in MFZ HERS.

Capacity (Kw)	Capital Cost ($)	Replacement Cost ($)	Q&M Cost ($/Year)	Life Team Year
1	300	300	10	10, 20, 25

4.8.3. Converter

DC/AC power converter type (ABB PSTORE-PCS) has been added in MFZ HERS, with a capacity of 2880 kW, conversion efficiency 96%. The converter is one of the main components of energy systems, in order to convert the energy generated from PV cells (DC) to AC energy to feed the load, and the Table 4.3 shows the data included in the homer for the transformer.

Table 4.3. Converter unit costs input in MFZ HERS.

Capacity (Kw)	Capital Cost ($)	Replacement Cost ($)	Q&M Cost ($/Year)	Inverter & Rectifier Efficiency (%)	Life Time Year
1	300	300	3	96	20

4.8.4. Wind Turbine

Wind turbines are an important component of the hybrid energy system, where wind energy technology is the lowest installation cost compared to solar energy technology, and the price of wind turbines decreased by 35% between 2010 and 2018, and the cost of installation in 2017 decreased from 1600 $ to 1500 in 2018 by 6% [56]. In the design of this system, (Enercon E-101 E2) wind turbine was selected with rated capacity 3.5 MW, It was chosen relative to the characteristics of the power curve shown in figure 4.11, which can generate 400 kW of power at a wind speed of 4-7 m/s. Based on IRENA report 2018 about the cost of onshore wind technology, the cost calculations in this study, which indicated that the cost of wind turbine technology during 2018 is in the range of 1500 $/kW, and the O&M ranges from (0.08 to 0.028) $/kWh. In MFZ HERS the capital cost, replacement cost, and O&M costs considered as data showed in Table 4.4.

Table 4.4. Wind turbine costs input in MFZ HERS.

Capacity (MW)	Capital Cost ($)	Replacement Cost ($)	Q&M Cost ($/Year)	Search Space Unit	Hub Hight (M)	Life Time Year
3.5	4,500,000	3,800,000	70,000	3,6,9	74, 80, 100	20

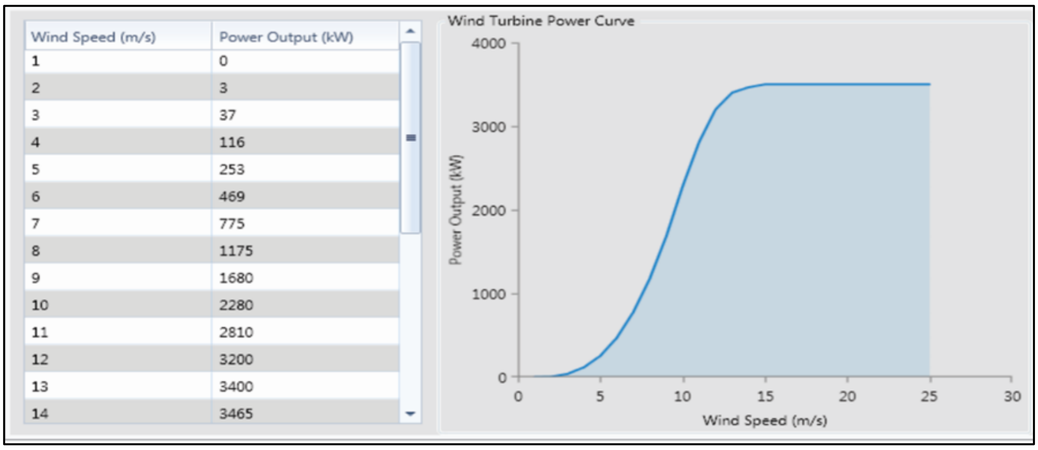


Figure 4.13. (Enercon E-101 E2) Wind Turbine Power Curve which used in MFZ HERS [Homer software].

4.8.5. Grid Inputs

The electrical load of the study area is treated as an public service load, where the value of this type of load on the Libyan electricity grid is calculated as 0.125 $/kWh see figure 3.2. In the design of MFZ HERS, Homer will be designed by using the cost of energy generation in the Libyan grid instead the values of the state-subsidized energy tariff. The purchase value from the electric grid considered 0.125 $/kWh, and the value of sell-back to electric grid was (0.125, 0.16, 0.175, 0.18, 0.19) $/kWh, these different values to look for an economically viable result.

4.8.6 Economic And Variables Inputs For MFZ HERS

Inputs and economic variables control NPC for the project also effected to COE. Homers takes into account these effects, which include the number of components used and their life span, the life of the project, and the total cost. Some values have been introduced for some components of the project, such as the number and length of wind turbines, as well as the life span of some components of the project. The COE is inversely proportional to the increase in the life of the project. on another hand, the production of energy from the sources of renewable energies is considered not achieved 100%, due to the instability of these sources permanently throughout the year, such as the productivity of PV panels on cloudy days, and the production of energy from wind turbines, which change according to wind speed, and therefore homer provides the input of constraints, These changes are included in the calculations within the program, and the following Table 4.5 shown some of the constraints input values that have been adjusted in MFZ HERS.

Table 4.5. The constraints input values for MFZ HERS.

Economic Inputs		**Constraint Inputs**	
Nominal discount rate	8%	Minimum renewable fraction	20%
Expected inflation rate	2%	Solar power output	70%
Project lifetime	25 Years	Wind power output	50%

PART 5

RESULTS AND DISCUSSION

5.1. INTRODUCTION

Homer works to provide the best case for hybrid system design, showing economic feasibility and giving detailed economic reports on the system to be designed, by reducing the total cost (NPC) and operating cost (OC) of the system, by studying input sensitivity and conducting a comprehensive simulation of the system components to achieve the optimal economic feasibility of the system. When simulated and calculated the system by Homer, the program will work on large data calculations through which it will display the desired results. In this study, a specific issue was taken into account in order to compare the different cases designed for the system. The age of the project in each case will be calculated for all its components.

5.2. FIRST CASE: SOLAR PV ON-GRID HRS FOR MFZ

In this case, the system is designed as in Figure 5.1, Solar PV panel sized by Homer optimizer, which rated capacity 205.3 MW, and converter capacity rated 177.7 MW, storage battery with capacity 10M kWh. Sensitive cases for this system are shown in Figure 5.2.

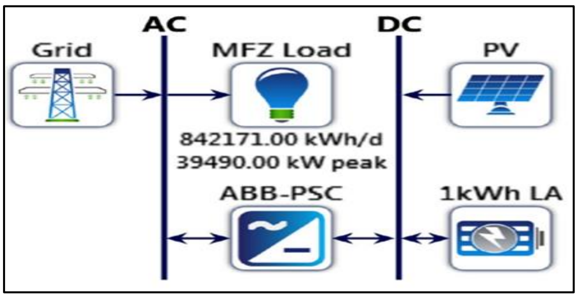


Figure 5.1. Solar PV on-grid MFZ HERS.

Sensitivity	Architecture					Cost				System		PV	
Sellback Rate ($/kWh)	PV (kW)	1kWh LA	Grid (kW)	ABB-PSC (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
0.125	250,000		999,999	177,705	CC	$619M	$0.0780	-$4.58M	$678M	73.1	0	625,000,000	499,014,112
0.160	250,000		999,999	177,705	CC	$480M	$0.0605	-$15.3M	$678M	73.1	0	625,000,000	499,014,112
0.175	250,000		999,999	177,705	CC	$421M	$0.0530	-$19.9M	$678M	73.1	0	625,000,000	499,014,112
0.180	250,000		999,999	177,705	CC	$401M	$0.0505	-$21.4M	$678M	73.1	0	625,000,000	499,014,112
0.190	250,000		999,999	177,705	CC	$362M	$0.0456	-$24.5M	$678M	73.1	0	625,000,000	499,014,112

Figure 5.2. Sensitivity cases for Solar PV on-grid MFZ HERS.

The results of sensitivity variables cases for this design at peak load 39,490 kW, showing decreasing COE and NPC whenever sell-back rate to the electric main grid increasing, Figure 5.3 shows the sensitivity results of changing the value of the sell-back rate compared to the annual emissions of carbon dioxide CO_2 on the one hand, and amount of NPC on the other, the graph curve shows that the amount of CO_2 emissions is not affected by the change in the values of sell-back to the main grid, while the NPC of the system is lowest at 0.19 $/kWh of sell-back rate.

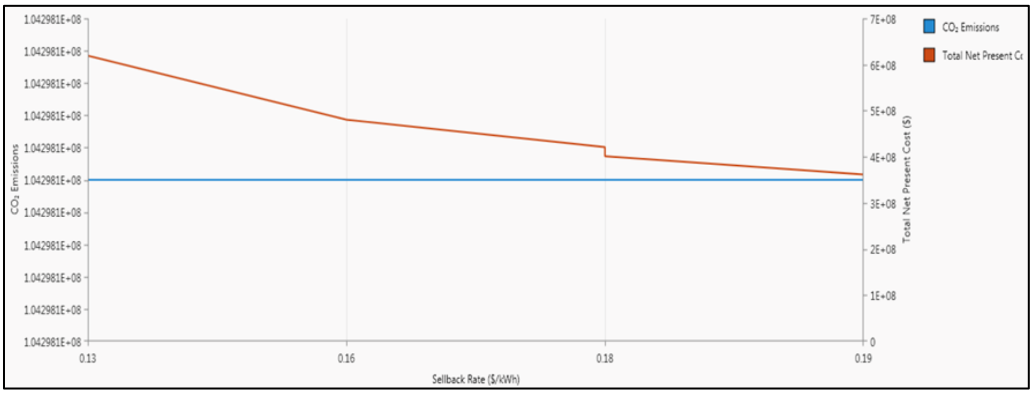


Figure 5.3. The sensitivity results for solar PV on-grid MFZ HERS between sell-back rate, annual emissions CO_2, and NPC.

On other hand, for sensitivity variables cases the change in the value of the sell-back rate to the main electric grid has a significant impact on determining the capacity of PV panels which used in this system, and COE for the system, where Figure 5.4 shows that the value of the sell-back rate at 0.15 $/kWh is achieved to lower capacity of PV panels and COE.

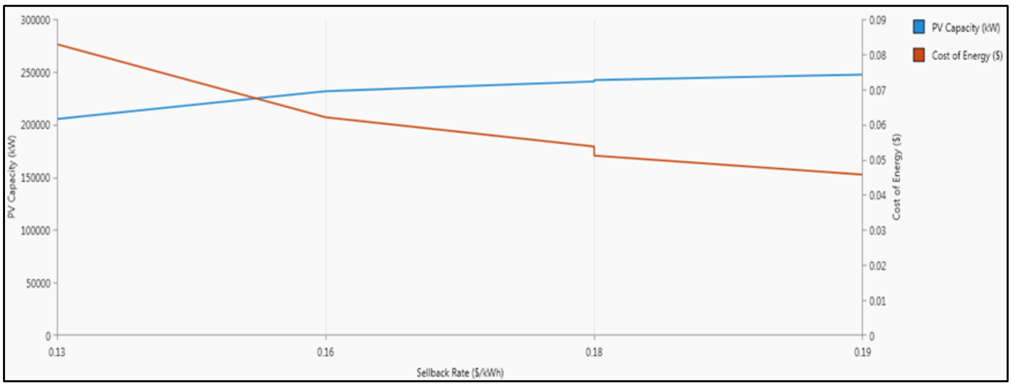


Figure 5.4. Sensitivity variables cases for sell-back rate.

In simulation results for this system, Figure 5.5 showing the monthly productivity of electricity from the system's PV panels relative to the energy purchased from the main grid, Where the productivity of PV panels accounted for 75.1% of the productivity of this system:

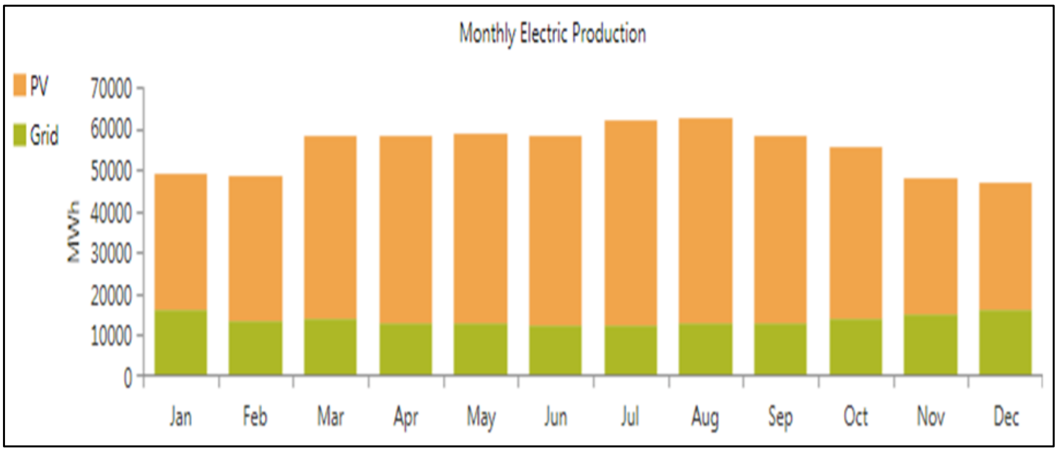
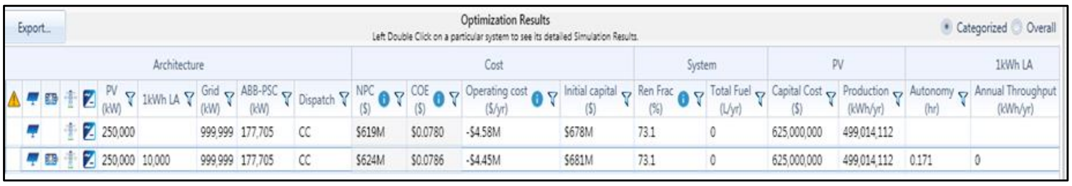


Figure 5.5. Monthly electric production for solar PV on-grid MFZ HERS.

As the results of Homer's optimization for this design, Homer gave two results to this situation, a system without energy storage batteries, and a system that contains energy storage batteries, where in the case of a system that contains energy storage batteries, These results show that Homer does not rely on storage batteries of relatively large size, so NPC, COE and renewable fraction are similar. Figure 5.6 shows the optimization results for PV panel on-grid MFZ HERS.



Export... Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

Categorized Overall

Architecture					Cost				System		PV		1kWh LA	
PV (kW)	1kWh LA	Grid (kW)	ABB-PSC (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	Autonomy (hr)	Annual Throughput (kWh/yr)
250,000		999,999	177,705	CC	$619M	$0.0780	-$4.58M	$678M	73.1	0	625,000,000	499,014,112		
250,000	10,000	999,999	177,705	CC	$624M	$0.0786	-$4.45M	$681M	73.1	0	625,000,000	499,014,112	0.171	0

Figure 5.6. Optimization results for PV panel on-grid MFZ HERS.

The following Table 5.1 and Table 5.2 shows the most important results for this system, that will be used to compare different systems in terms of energy productivity, NPC, COE, and CO_2 emissions from the system.

Table 5.1. Summary of optimization results for PV solar on-grid system for MFZ HERS.

Components	Name	Size (kW)	Total Cost ($)	Production (kWh/yr)
PV solar cell	Generic flat plate PV	250,000	673,000,000	499,014,125
Storage unit	Generic 1kWh Lead Acid	10,000	4,710,000	10,008
System converter	ABB PSTORE-PCS	177,705	67,600,000	448,897,528
Main Grid	-	-	-122,000,000	165,028,672
		NPC ($)	**623,816,300**	
		Levelized COE ($/kWh)	**0.0768**	
		Sellback Rate ($/kWh)	**0.125**	
		CO_2 Emissions (kg/yr)	**104,298,121**	
Annual energy purchased from grid (kWh)	165,028,672	Annual energy sold to grid (kWh)	306,533,758	

5.3. SECOND CASE: WIND TURBINE ON-GRID HRS FOR MFZ

In this case, the system is designed as in Figure 5.7, wind turbine sized by Homer optimizer, which rated quantity 30 turbine with total capacity rated 105 MW, sensitivity variables cases for wind turbine height were entered to the software basis of three possibilities (74, 85, 100) m.

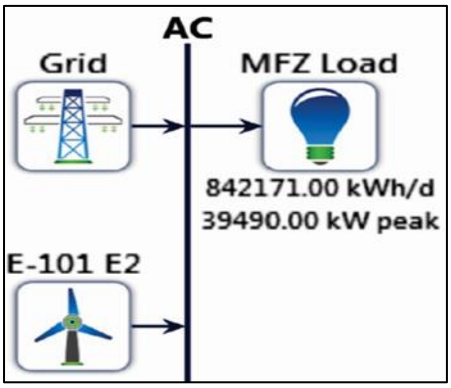


Figure 5.7. Wind turbine on-grid MFZ HERS.

The sensitivity cases for this design, indicate that more productive wind power can be achieved for turbines with a height of 100 meters, and therefore will achieve the greatest value of energy sold to the main electric grid, on the other hand, will be less valuable for NCP and COE at the variable value sell-back rate at 0.19 $/kWh. Sensitive cases for this system shown in Figure 5.8.

Sensitivity		Architecture						Cost				System		E-101 E2			Grid
Sellback Rate ($/kWh)	E-101 E2 Hub Height (m)				E-101 E2	Grid (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	O&M Cost ($)	Energy Purchased (kWh)
0.125	100				30	999,999	CC	$454M	$0.0940	$24.7M	$135M	54.3	0	135,000,000	202,979,584	1,950,000	170,501,408
0.125	74.0				30	999,999	CC	$483M	$0.102	$26.9M	$135M	51.4	0	135,000,000	187,876,480	1,950,000	177,298,336
0.125	85.0				30	999,999	CC	$469M	$0.0984	$25.9M	$135M	52.8	0	135,000,000	194,808,128	1,950,000	174,137,744
0.160	100				30	999,999	CC	$424M	$0.0878	$22.3M	$135M	54.3	0	135,000,000	202,979,584	1,950,000	170,501,408
0.160	74.0				30	999,999	CC	$456M	$0.0967	$24.9M	$135M	51.4	0	135,000,000	187,876,480	1,950,000	177,298,336
0.160	85.0				30	999,999	CC	$441M	$0.0926	$23.7M	$135M	52.8	0	135,000,000	194,808,128	1,950,000	174,137,744
0.175	100				30	999,999	CC	$411M	$0.0851	$21.4M	$135M	54.3	0	135,000,000	202,979,584	1,950,000	170,501,408
0.175	74.0				30	999,999	CC	$445M	$0.0943	$24.0M	$135M	51.4	0	135,000,000	187,876,480	1,950,000	177,298,336
0.175	85.0				30	999,999	CC	$430M	$0.0901	$22.8M	$135M	52.8	0	135,000,000	194,808,128	1,950,000	174,137,744
0.180	100				30	999,999	CC	$407M	$0.0842	$21.0M	$135M	54.3	0	135,000,000	202,979,584	1,950,000	170,501,408
0.180	74.0				30	999,999	CC	$441M	$0.0935	$23.7M	$135M	51.4	0	135,000,000	187,876,480	1,950,000	177,298,336
0.180	85.0				30	999,999	CC	$426M	$0.0892	$22.5M	$135M	52.8	0	135,000,000	194,808,128	1,950,000	174,137,744
0.190	100				30	999,999	CC	$398M	$0.0825	$20.4M	$135M	54.3	0	135,000,000	202,979,584	1,950,000	170,501,408
0.190	74.0				30	999,999	CC	$434M	$0.0919	$23.1M	$135M	51.4	0	135,000,000	187,876,480	1,950,000	177,298,336
0.190	85.0				30	999,999	CC	$418M	$0.0876	$21.9M	$135M	52.8	0	135,000,000	194,808,128	1,950,000	174,137,744

Figure 5.8. Sensitivity cases for wind turbine on-grid MFZ HERS.

Figure 5.9 shows optimum system type plot, the COE produced from the system is inversely proportional to the value of sell-back rate to the main grid, and on the other hand, the COE of the energy produced is directly proportional to the height of the turbines used in the design of the system.

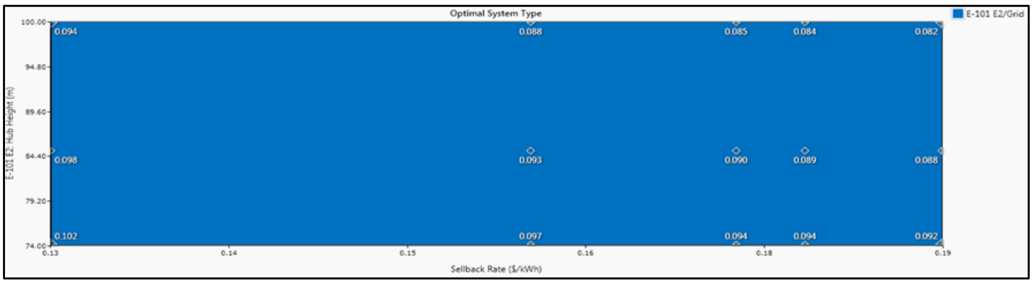


Figure 5.9. COE optimal system for wind turbine on-grid MFZ HERS.

In the simulation result for this system, Figure 5.10 shown the monthly productivity of electricity from the system's wind turbines relative to the energy purchased from the main grid, where the productivity of wind turbines accounted for 54.3% of the productivity of this system:

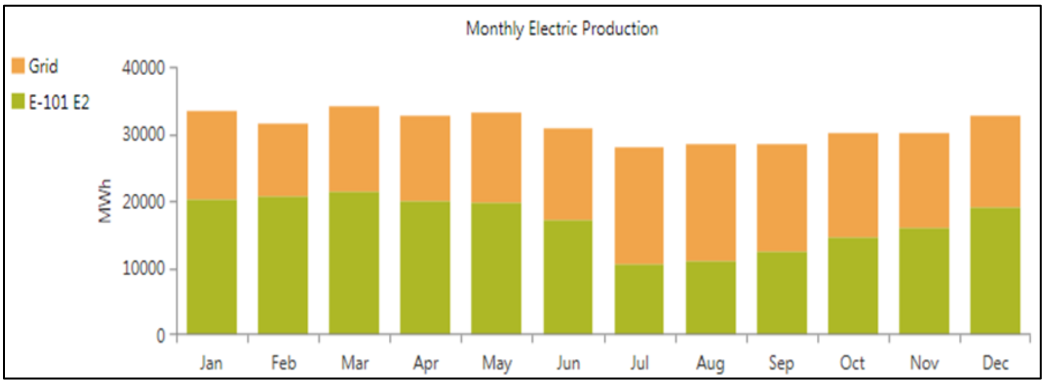


Figure 5.10. Monthly electric production for wind turbine on-grid MFZ HERS.

The chart of the sensitivity results of the system shown in Figure 5.11, where shows that the value of NPC increases as the value of sell-back rate decreases, and that the amount of CO_2 emissions generated from the system is not affected by the change in the value of sell-back energy to the main grid, because the amount of electricity produced from the system does not change by changing the value sell-back rate, where the figure indicates that it is the lowest value of NPC for the system can be obtained at sell-back rate 0.19 $/kWh. The following Table 5.2 shows summary results for wind turbine MFZ HERS,

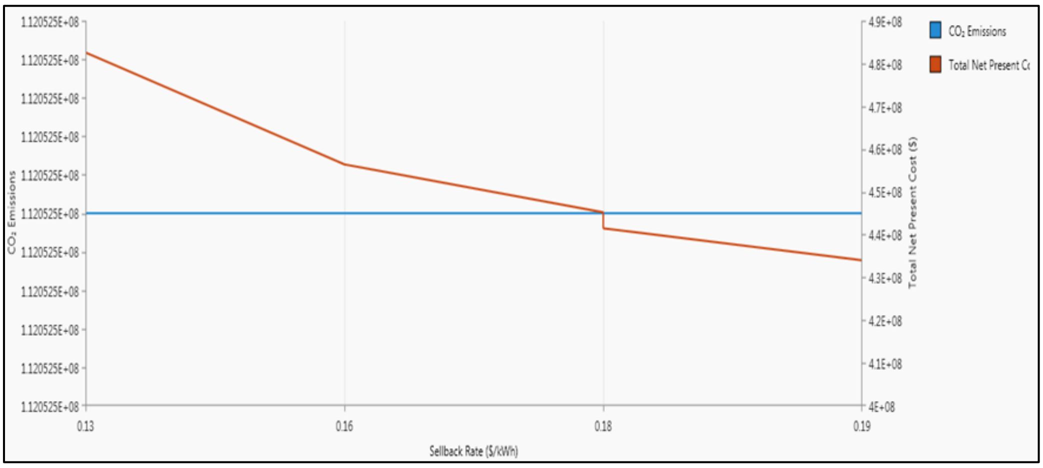


Figure 5.11. The sensitivity results for wind turbine on-grid MFZ HERS between sell-back rate, annual emissions CO_2 and NPC.

Table 5.2. Summary of the optimization results for wind turbine on-grid for MFZ HERS.

<table>
<tr><th>Components</th><th>Name</th><th>Unit</th><th>Size (kW)</th><th>Total Cost ($)</th><th>Production (kWh/yr)</th></tr>
<tr><td>Wind turbine</td><td>Enercon E-101 E2 -3.5MW</td><td>30</td><td>105,000</td><td>175,000,000</td><td>202,979,578</td></tr>
<tr><td>Main Grid</td><td colspan="2">-</td><td>-</td><td>279,000,000</td><td>170,501,401</td></tr>
<tr><td colspan="4">NPC ($)</td><td colspan="2">453,751,100</td></tr>
<tr><td colspan="4">Levelized COE ($/kWh)</td><td colspan="2">0.0940</td></tr>
<tr><td colspan="4">Sellback Rate ($/kWh)</td><td colspan="2">0.125</td></tr>
<tr><td colspan="4">CO₂ Emissions (kg/yr)</td><td colspan="2">107,756,886</td></tr>
<tr><td>Annual energy purchased from grid (kWh)</td><td colspan="2">170,501,401</td><td colspan="2">Annual energy sold to grid (kWh)</td><td>66,088,564</td></tr>
</table>

5.4. THIRD CASE: PV PANELS AND WIND TURBINE ON-GRID HRS FOR MFZ

In this case, the system is designed as in Figure 5.12, the components which designed in the system sizing by Homer optimizer to achieved best feasibility, PV panels capacity rated at 250 MW, converter capacity rated at 177.7 MW, wind turbine rated at 30 unit with total capacity 105 MW, variables for wind turbine height were entered to the software basis of three possibilities (74, 85, 100) m, and Storage battery rated at

1512 unit with total capacity 1.5 MW. The battery size of the system has been reduced by Homer optimizer, in order to reduce the NPC, also because of the system contains a variety of sources of energy, which ensure more stability of the system.

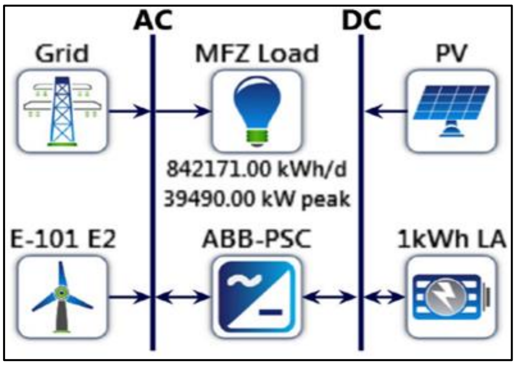


Figure 5.12. PV panels and wind turbine MFZ HERS.

The results of the sensitivity cases in this design, indicate that more productive wind power can be achieved for turbines with a height of 100 meters, and the lowest NPC of the system can be obtained when the sell-back price to grid increases, and the amount of power production of the system is not affected by the change of sell-back rate to the grid, on the other hand, the system can achieve the lowest value of COE when increasing the sell-back price to the grid. Sensitive cases for this system shown in Figure 5.13.

Sensitivity		Architecture						Cost				System		PV
Sellback Rate ($/kWh)	E-101 E2 Hub Height (m)	PV (kW)	E-101 E2	1kWh LA	Grid (kW)	ABB-PSC (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)
0.125	100	250,000	30		999,999	177,705	CC	$426M	$0.0436	-$29.9M	$813M	86.3	0	625,000,000
0.125	74.0	250,000	30		999,999	177,705	CC	$453M	$0.0471	-$27.9M	$813M	85.6	0	625,000,000
0.125	85.0	250,000	30		999,999	177,705	CC	$441M	$0.0455	-$28.8M	$813M	85.9	0	625,000,000
0.160	100	250,000	30		999,999	177,705	CC	$223M	$0.0229	-$45.6M	$813M	86.3	0	625,000,000
0.160	74.0	250,000	30		999,999	177,705	CC	$255M	$0.0266	-$43.2M	$813M	85.6	0	625,000,000
0.160	85.0	250,000	30		999,999	177,705	CC	$241M	$0.0249	-$44.3M	$813M	85.9	0	625,000,000
0.175	100	250,000	30		999,999	177,705	CC	$137M	$0.0140	-$52.3M	$813M	86.3	0	625,000,000
0.175	74.0	250,000	30		999,999	177,705	CC	$171M	$0.0178	-$49.7M	$813M	85.6	0	625,000,000
0.175	85.0	250,000	30		999,999	177,705	CC	$155M	$0.0160	-$50.9M	$813M	85.9	0	625,000,000
0.180	100	250,000	30		999,999	177,705	CC	$108M	$0.0110	-$54.6M	$813M	86.3	0	625,000,000
0.180	74.0	250,000	30		999,999	177,705	CC	$143M	$0.0148	-$51.9M	$813M	85.6	0	625,000,000
0.180	85.0	250,000	30		999,999	177,705	CC	$127M	$0.0131	-$53.1M	$813M	85.9	0	625,000,000
0.190	100	250,000	30		999,999	177,705	CC	$49.7M	$0.00509	-$59.1M	$813M	86.3	0	625,000,000
0.190	74.0	250,000	30		999,999	177,705	CC	$86.1M	$0.00896	-$56.3M	$813M	85.6	0	625,000,000
0.190	85.0	250,000	30		999,999	177,705	CC	$69.4M	$0.00717	-$57.5M	$813M	85.9	0	625,000,000

Figure 5.13. Sensitivity cases for solar PV and wind turbine MFZ HERS.

In the simulation results for this system, the monthly production of the system shown in Figure 5.14, indicates that the energy produced through PV panels represents 61.9% of the total electricity production of the system, while the productivity of energy through wind turbines represents 25.2%, and the electricity imported from the public grid represents 12.9% of the total energy produced in the system.

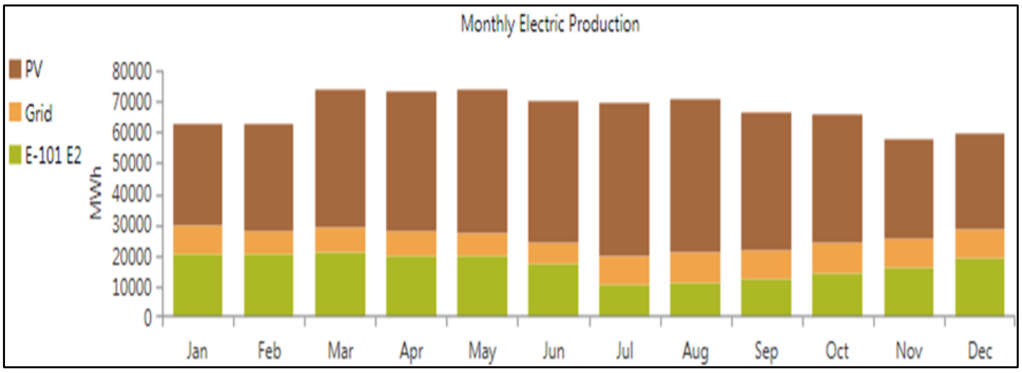


Figure 5.14. Monthly electric production for PV panels and wind turbine for MFZ HERS.

Figure 5.15 shown the surface plot for sensitivity variables (sell-back rate and turbines hub height), Which shows the relationship between these variables and their impact on both the NPC value and COE of the system, where the chart indicates that the lowest value of NPC and the lowest value of COE can be obtained when using turbines hub height at 100 m, and at the value of sell-back to the grid at 0.19 $/kWh.

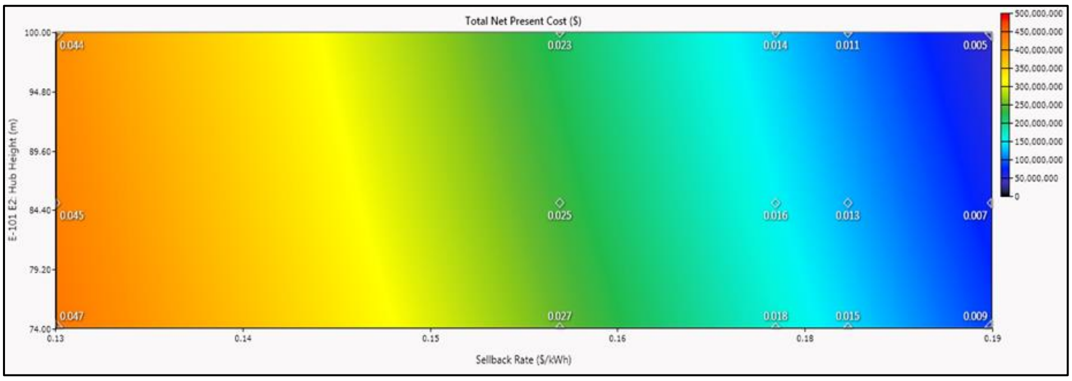


Figure 5.15. Surface plot for some sensitivity variables of third case.

According to Figure 5.15 show a chart of the sensitivity variables, it indicated that the amount of carbon dioxide emissions from the system is not significantly affected by the change in the value of these variables, this is due to the existence of two different sources of renewable energy in the system, which ensure the production of the energy required for the system rather than imported from the public grid.

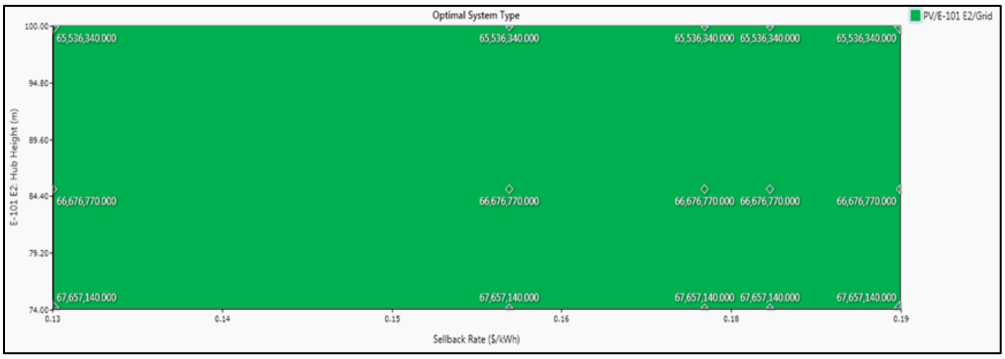


Figure 5.16. Optimal system type plot for some sensitivity variables of third case.

Figure 5.17 shows the relationship of NPC and COE with the sensitivity variables of the system (wind turbine hub height), where the values are noted does not affect significantly, and that the best case of the system which achieves lowest NPC and the lowest COE at the value of sell-back rate at 0.19 $/kWh and turbine hub height at 100 m.

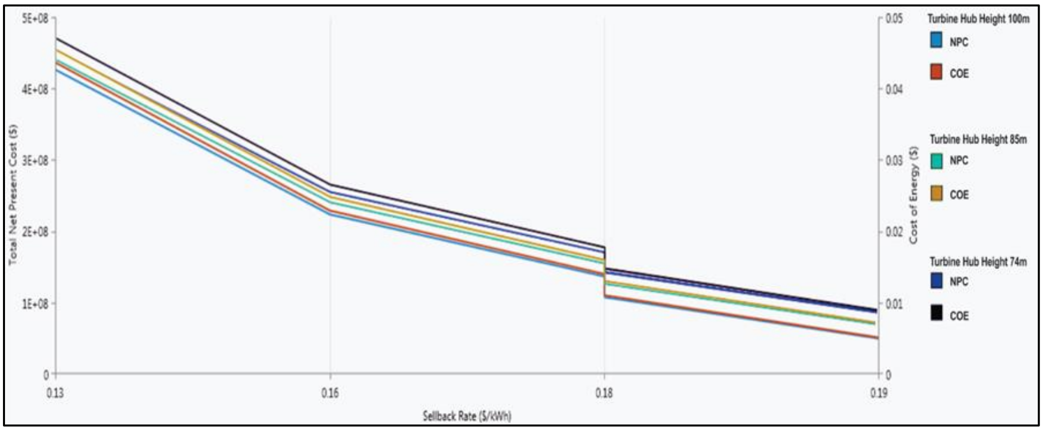


Figure 5.17. The sensitivity results for solar wind on-grid MFZ HERS between NPC and COE.

In the optimization results for this system shown in Figure 5.18, It shows that NPC of the system in the case of the addition of storage batteries increases by 428 M$ by 1753 unit and COE in the range of 0.0437 $/kWh, while the NPC of the system without adding storage batteries is in the range of 426 M$ and the COE in the range of 0.0436 $/kWh. This indicates that in this system Homer optimization chose not to add energy storage batteries, due to the availability of two renewable energy sources that ensure the stability of the system and meet the demand for energy.

Architecture						Cost				System		PV		E-10
PV (kW)	E-101 E2	1kWh LA	Grid (kW)	ABB-PSC (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	Capital Cost ($)
250,000	30		999,999	177,705	CC	$426M	$0.0436	-$29.9M	$813M	86.3	0	625,000,000	499,014,112	135,000,000
250,560	30	1,753	999,999	177,705	CC	$428M	$0.0437	-$30.0M	$815M	86.3	0	626,399,360	500,131,392	135,000,000
	30		999,999		CC	$454M	$0.0940	$24.7M	$135M	54.3	0			135,000,000
	30	1,826	999,999	77.1	CC	$455M	$0.0942	$24.7M	$136M	54.3	0			135,000,000

Figure 5.18. Optimization results for PV panel and wind turbine MFZ HERS.

The following Table 5.3 shows summary results for PV panel and wind MFZ HERS, the table contains a summary of the results from the simulation of this system, where it is clear that NPC is equal to 427.6 M$, and the decrease in the cost, in this case, is due to the fact that the system sells a large amount of electricity produced to the main grid, which was in the range of 491 M$, and therefore this value will reduce NPC cost of the system where Homer calculates NPC as equal to the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime.

Table 5.3. Summary of optimization results for solar wind on-grid for MFZ HERS.

<table>
<tr><th>Components</th><th>Name</th><th>Size (kW)</th><th>Total Cost ($)</th><th>Production (kWh/yr)</th></tr>
<tr><td>PV Solar Cell</td><td>Generic flat plate PV</td><td>250,560</td><td>675,000,000</td><td>500,131,407</td></tr>
<tr><td>System Converter</td><td>ABB PSTORE-PCS</td><td>177,705</td><td>67,600,000</td><td>443,425,767</td></tr>
<tr><td>Storage</td><td>Generic 1kWh</td><td>1,753</td><td>825,693</td><td>908</td></tr>
<tr><td>Wind Turbine</td><td>E-101 E2 - 3.5MW (30 unit)</td><td>105,000</td><td>175,000,000</td><td>202,979,578</td></tr>
<tr><td>Main Grid</td><td>-</td><td>-</td><td>-491,000,000</td><td>103,681,461</td></tr>
<tr><td colspan="3">NPC ($)</td><td colspan="2">427,625,000</td></tr>
<tr><td colspan="3">Levelized COE ($/kWh)</td><td colspan="2">0.0437</td></tr>
<tr><td colspan="3">Sellback Rate ($/kWh)</td><td colspan="2">0.125</td></tr>
<tr><td colspan="3">CO_2 Emissions (kg/yr)</td><td colspan="2">65,526,683</td></tr>
<tr><td>Annual energy purchased from grid (kWh)</td><td>103,681,461</td><td>Annual energy sold to grid (kWh)</td><td colspan="2">448,770,672</td></tr>
</table>

5.5. FOURTH CASE: SOLAR PV AND WIND TURBINE OFF-GRID HRS FOR MFZ

This system is designed to be independent and not connected to the public electricity grid and is known as a stand-alone system, where the size of each of the solar PV cells was determined by the Homer optimizer with a capacity of 166.9 MW, a converter with a capacity of 154.1 MW, and the power storage with 1.57 million batteries connected in parallel at a capacity of 1 kWh per battery, and the wind turbines in this design were 50 turbines. The components designed in the system sizing by Homer optimizer to achieved best feasibility, solar PV capacity rated at 245 MW, converter. The system in this case is designed as Figure 5.19.

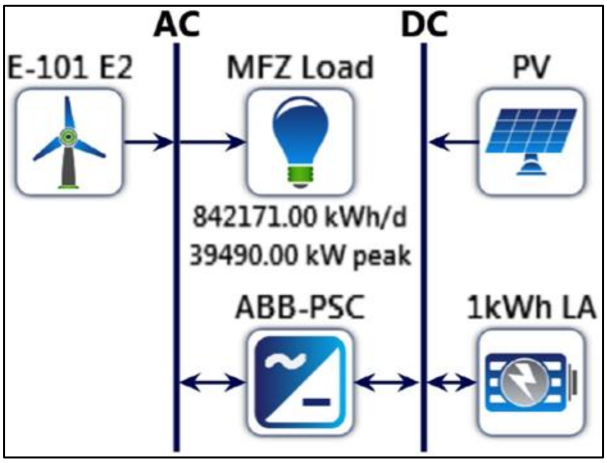


Figure 5.19. Stand-alone system for MFZ HERS.

Sensitivity cases for this design, shown in Figure 5.20, where it is noted that the lowest NPC and less value for COE can be obtained when using turbines with 100m hub height since when using these turbines, it is possible to use fewer energy storage batteries, also might be decrease capacity using solar PV cells and power converter, which allowed to achieve minimally NPC.

Sensitivity	Architecture					Cost				System		PV		E-
E-101 E2 Hub Height (m)	PV (kW)	E-101 E2	1kWh LA	ABB-PSC (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	Capital Cost ($)
100	166,980	50	1,579,599	54,113	CC	$1.69B	$0.426	$43.4M	$1.13B	100	0	417,450,432	333,301,856	225,000,000
74.0	151,164	50	1,879,534	91,738	CC	$1.78B	$0.447	$45.0M	$1.19B	100	0	377,910,560	301,732,320	225,000,000
85.0	166,119	50	1,661,274	47,068	CC	$1.72B	$0.433	$43.9M	$1.15B	100	0	415,296,832	331,582,368	225,000,000

Figure 5.20. Sensitivity cases for stand-alone MFZ HERS.

Through the results of the model of the system, and because of the monthly electricity productivity Figure 5.21, electricity productivity from renewable energy sources was almost equal, energy productivity by wind turbines accounting for 50.4% of the total monthly electricity production by the system, while the productivity of solar cells accounted for 49.6% of monthly electricity productivity.

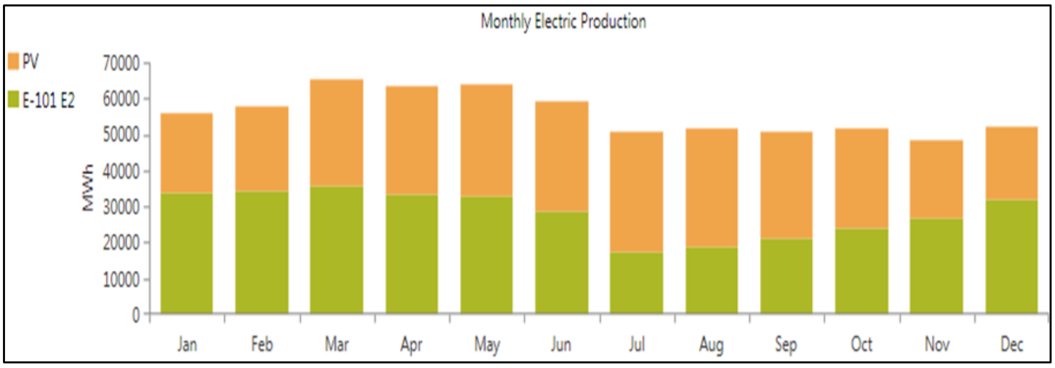


Figure 5.21. Monthly electric production for stand-alone MFZ HERS.

Table 5.4 shows the summary of optimization results for the system, where it is clear that the cost of energy storage batteries is relatively high compared to the cost of other components of the system, this is because the energy storage batteries are still considered expensive compared to the components of other power systems, and their life span is low, wherein this system, Homer considered the life span of the batteries about 12 years, and because they operate at full capacity most of the time as described in Figure 5.22, and therefore since the design life of the system 25 years, these batteries need to be replaced after the passage of 12 years from the first operation, Figure 5.23 shows a chart of the cash flow for system components during the project's life.

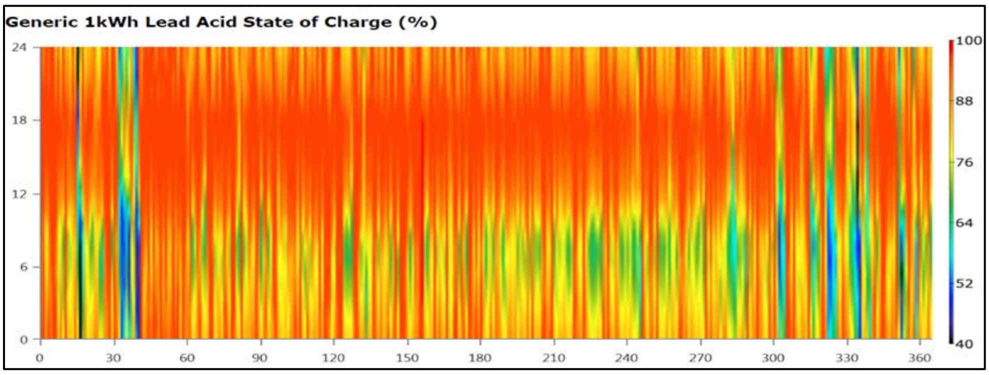


Figure 5.22. Hourly charging status of energy storage batteries throughout the year for stand-alone MFZ HERS.

Table 5.4. Summary of the optimization results for stand-alone MFZ HERS.

Components	Name	Size (kW)	Total Cost ($)	Production (kWh/yr)
PV Solar Cell	Generic flat plate PV	166,980	450,000,000	333,301,856
System Converter	ABB PSTORE-PCS	54,113	20,600,000	443,425,767
Storage	Generic 1kWh	1,579,599	932,000,000	908
Wind Turbine	E-101 E2 - 3.5MW (50 unit)	175,000	291,000,000	202,979,578
NPC ($)			**1,693,415,000**	
Levelized COE ($/kWh)			**0.426**	
CO_2 Emissions (kg/yr)			**Neglected value**	
Annual energy purchased from grid (kWh)	-	Annual energy sold to grid (kWh)	-	

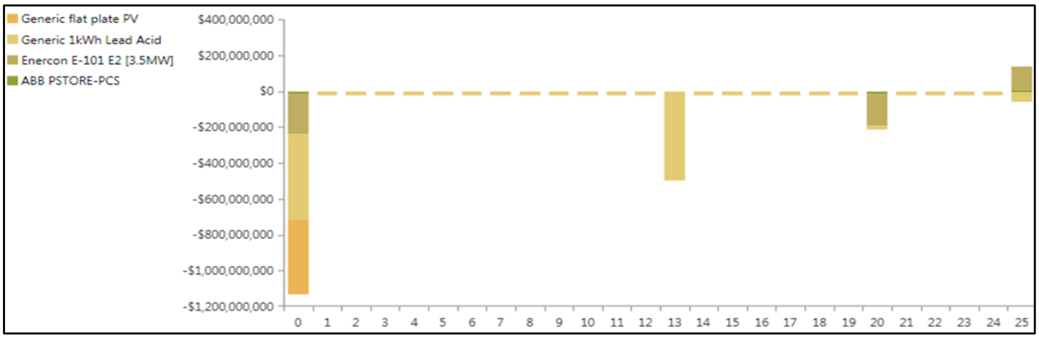


Figure 5.23. Cash flow chart for system components for stand-alone MFZ HERS.

PART 6

CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

This study aimed to look at the economic feasibility of investing renewable energy technology in Libya, where solar and wind energy are widely available in this region, and since Libya is one of the countries that are mainly dependent on the use of traditional energy to produce electricity, which negatively affects economic development and environmental protection. In this study, different-source renewable energy systems were designed to feed the study area by Homer software, where simulation results showed that when relying on a hybrid multi-source renewable energy system (solar and wind) connected to the electric grid, it ensures more stability of the systems, less value for the cost of energy production 0.0437 $/kWh and fewer carbon emissions.

The results obtained from the simulation of the system show that the cost of producing energy from renewable energy systems can compete with the prices of the cost of actual energy production in Libya generated from traditional energy sources, which have negative effects on the environment.

6.2. RECOMMENDATIONS

Based on the results obtained in this study, which shows that reliance on renewable energy sources for power generation in Libya provides a real opportunity to develop the electric grid and increase its stability, we recommend that such a study be conducted in other parts of the country, and the use of larger loads and other renewable energy sources such as tidal power, hydropower, and biomass energy, which are available in the region.

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RESUME

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