Design and Analysis of A DC Stand-Alone Photovoltaic-Battery System for a rural house in Libya

By

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ABSTRACT

This thesis presents a comprehensive study about the design, optimization, and analysis of an isolated Photovoltaic (PV)-battery system for fulfilling the load of a rural house in Libya. A bus voltage of 48 V DC is considered. The annual demand of the house was estimated by completed thermal modeling of the loads in the BEopt program. The assumed design was sized and analyzed using HOMER Pro software and consisted of 12 PV panels, 325 watts each, and 12 lead-acid batteries of 12 V, 219 Ah. The dynamic model of the system is implemented in MATLAB/Simulink software. The results show that the proposed approach can provide a stable 48 V DC for the intended load. It can also be used to meet the electricity needs of houses with low loads or in rural communities with basic electricity needs. A detailed economic analysis was carried out by comparing the proposed PV system with a hybrid PV-DGN-BTT system, an independent Diesel generator. The performed financial analysis reveals that the proposed system is a feasible solution - with a net present cost of $15,070 - that can generate electricity at the cost of $0.333/kWh, indicating that such a system will make economic sense in remote off-grid areas.

DEDICATION

To My Family,

ACKNOWLEDGMENTS

I express sincere appreciation to my supervisor Prof. Dr. M.Tariq Iqbal, for his guidance and insight. He was supportive, motivating, and responsive whenever I needed help or advice throughout the research. I am grateful to my Mother and my siblings for the unceasing encouragement, support, and attention. Thanks also go to my wife; I offer sincere thanks for her continuous support and patience during this period.

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LIST OF ABBREVIATIONS

AWG	American wire gauge
BAT	Battery
COE	Cost of Energy
DGN	Diesel Generator
DOD	Depth of Discharge
ESS	Energy Storage System
ETAP	Electrical Transient Analyzer Program
HOMER	Hybrid Optimization Model for Electric Renewables
FiT	Feed-in Tariff
GECOL	General Electrical Company of Libya
MBD	Model-Based on Design
MPPT	Maximum Power Point Tracking
MW	Megawatt
NPC	Net Present Cost
O&M	Operation & Maintenance
PV	Photovoltaic
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
SOC	State of Charge
CSP	Concentrated solar power

CHAPTER 1

Introduction and Literature Review

1.1 Introduction

For several years Libya heavily has relied on oil and natural gas to produce electric power. However, population growth and economic activities caused a significant increase in the electrical energy demand, which estimates between 6% to 8% per year [1,2]. Recent fluctuations in oil prices lead to pressure on the financial resources of the state. Also, environmental impacts from using conventional energy sources are a paramount concern these days. Libya should seriously consider alternative solutions to face these challenges Figure1.1 shows electricity generation by source in Libya from 1990-2018.

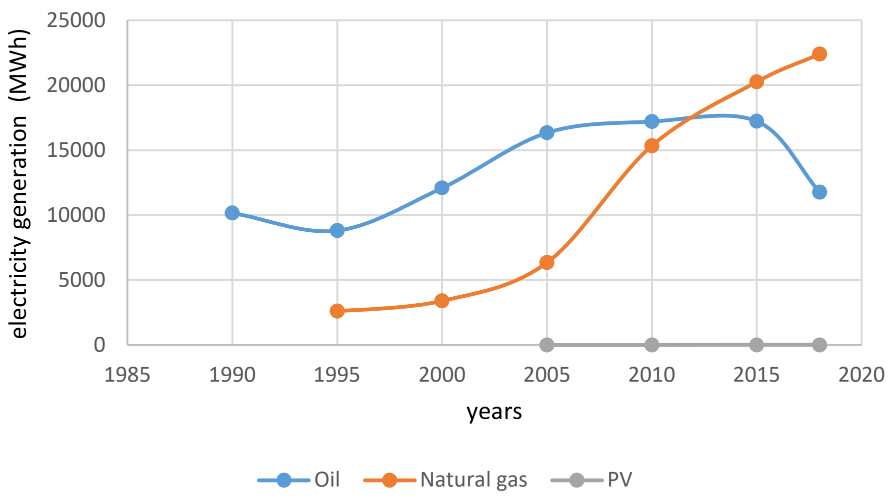


Figure 1.1. Electricity generation by source in Libya [3]

Renewable energy (RE) sources are a promising solution to contribute to minimizing these impacts. Even though Libya is rich in RE sources, it has not utilized (RE) on a large scale [4]. The use of RES to generate electricity has continued to grow, reaching 450 terawatt-hours (TWh) in 2018 [4]. RES involves solar energy, wind, hydropower, which accounted for about 90% of the increase in production growth, in addition to geothermal, marine energies, and biomass. [5]. Table 1.1 demonstrates RES and their utilization.

Table 1.1 Renewable energy sources and their main uses [5,6]

Energy source	Energy conversion and usage options
Hydropower	Power generation
Modern biomass	Heat and power generation, pyrolysis, gasification, digestion
Geothermal	Urban heating, power generation, hydrothermal, hot, dry rock
Solar	The solar home system, solar dryers, solar cookers
Direct solar	Photovoltaic, thermal power generation, water heaters
Wind	Power generation, wind generators, windmills, water pumps
Wave	Numerous designs
Tidal	Barrage, tidal stream

Libya is the second-largest country in North Africa, with about 1,750,000 Km^2 and a 6.93 million population, according to the Bureau of Statistics and Census for 2020. Most of the population is concentrated in the north, and about 10% living in separate areas in the south region [7]. Successive governments have sought to focus on the spatial development of the population by investing in electric power to prevent people from the south and rural areas from moving to the north. The investment in transmission lines, transmission, and generation stations causes excellent costs to the state treasury. The civil war in Libya caused severe damage to the electrical grid, which led to a severe deficit in electrical power, forcing the engineers of the control center to load shedding to keep the system from breakdown. Power load shedding hours in Tripoli reached about 16 hours in summer 2019, and according to the 2018 Multi-Sector Needs Assessment (MSNA), residents of the southwest regions faced frequent power cuts for 6 to 11 hours [8,9]. As a result of this dilemma, several citizens have resorted to diesel generators. However, the growth in diesel fuel demand has led to an increase in its price, making this solution unattainable to many people.

1.2 Literature Review

This section presents an idea of solar energy in Libya and energy consumption in Libya, in addition to a review of previous studies linked to our research field.

1.2.1 Solar Energy in Libya

Libya is located between latitudes 20° N and 32° N and between 10° E and 25° E longitudes. This prime location contains a significant resource of solar energy. The average daily direct radiation between the northern and southern parts of the country is 8.1 kWh / m^2 / day and 7.1 kWh / m^2 / day, with sunshine hours over 3500 per year [10]. Some details are shown in Fig. 1.2.

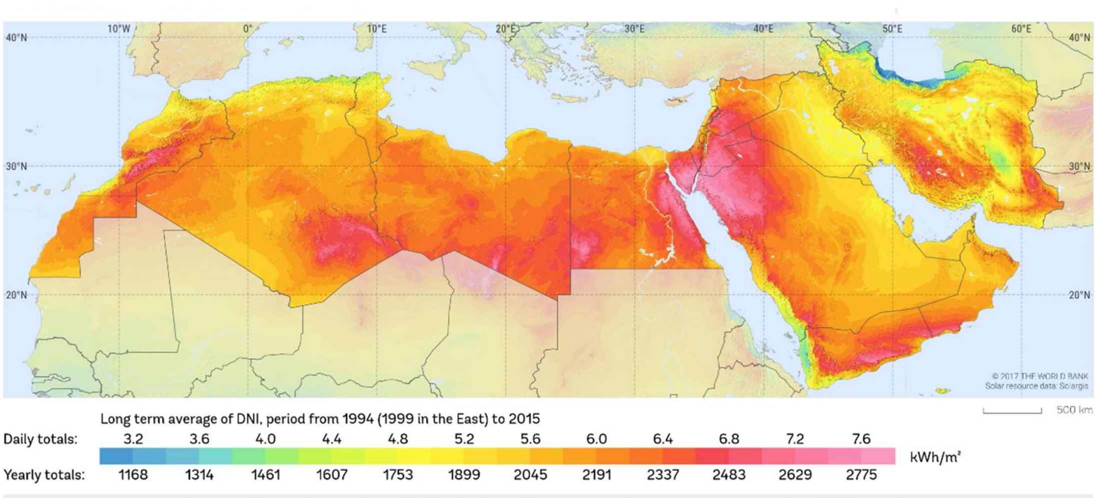


Figure 1.2. Direct average irradiation in the Middle East and North Africa [11]

The Figure indicates a high potential for solar energy in this region, which can be used as alternative energy to cover electricity needs. Two standard techniques are used to benefit from solar energy, either by converting direct solar energy into electrical energy, which is known as photovoltaic technology or from natural sunlight energy into thermal energy identified as solar energy concentration technologies (CSP) [12,13]. A. Asheibe and A. Khalil presented an analysis of the opportunities, challenges, and possibilities of renewable energy in Libya. The study concluded that this is an achievable objective. Given the difficulties with conventional ways of power generation, solar energy technology will play a pivotal role in meeting Libyan's future energy demands. In recent years, there were many research works in Libya to take advantage of the availability of the solar energy to design photovoltaic (PV) systems to meet increasing the demand of energy and to provide energy for remote communities. Aldali and Ahwide investigated the application of a large scale (LS-PV) A 50MW PV-grid connected power. They carried it out by selecting a heterojunction with intrinsic thin layer (HIT) type PV module. A Microsoft Excel-VBA software for the modeling and analysis parameters of this module to determine the efficiency of this system. The results appear that the total energy output is 128.5 GWh/year, and the average module efficiency is 16.6%. Moreover, 85,581 tons of CO_2 pollution would reduce each year. A feasibility study on hybrid PV solar-diesel power system application in Bani Walid in the western part of Libya was presented in [16]. Performance simulation for the system was done by using HOMER VER. 2.68 software. The outcomes showed that a large-scale 76.8 MW PV system with a backup generator and storage batteries could run dependably in that area.

1.2.2 Energy Consumption in Libya

The peak loads in Libya historically occur in the summer. However, low electricity tariffs led to the excessive use of air conditioners in hot weather. Moreover, as a result of the situation in Libya, there are many loads without meters, which leads to a large consumption without control. The General Electrical Company of Libya (GECOL) in 2013 stated that an electric power grid was unable to meet the growing consumption of energy. The household loads consumed about 24% of the total amount of energy consumption [7]. Based on the official annual report of GECOL in 2010, the maximum load reached 5,759 MW in 2010, with a growth rate of 9% over the year 2009. if this pattern continues, the power demand will get about 11 GW by 2030, which means there should be an investment in electricity sources to meet the increase in power demand[17]. Due to the lack of recent data due to the circumstances in Libya, Figure 1.3 shows the expected growth of peak loads according to the latest annual report published by GECOL in 2010.

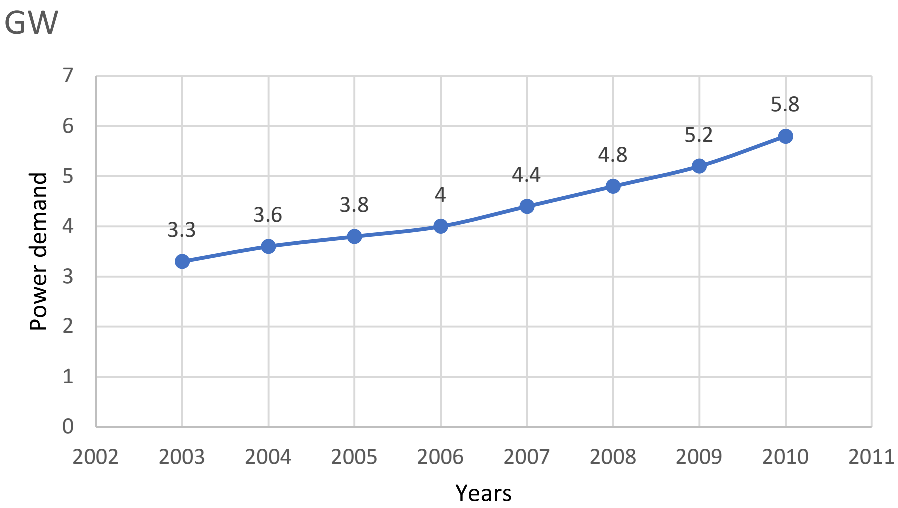


Figure 1.3. Libyan load growth 2003-2010

1.2.3 DC Distribution for Residential Power Networks

This section provides an overview of the development of energy sources utilization and studies related to the use of DC and its advantages compared to the AC sources. In the late 1880s and early 1890s, there was a competition between AC vs. DC to transmit electrical energy, known as the war or the battle of currents. In the end, AC was adopted to carry power over long distances due to the possibility of using high voltages, which means less current and, consequently, fewer losses in transmission lines [18]. As a result of the extensive development in the semiconductor industry, various household gadgets these days run internally on DC power. The AC power from the electrical grid is converted to DC power by internal transformers in devices or adaptors. The PV systems are considered one of the clean energy sources that produce DC power directly. The conversion losses from AC to DC can reach 30%.

Moreover, the lack of need for an inverter reduces the capital cost [18]. In [19], a logarithm was proposed to determine the most efficient design of a solar energy system, including the option of an AC or DC supply system. The results showed economic efficiency in the solar PV system for residential homes with many DC load ratios. The distribution systems for AC and DC power in a residential environment of an average family were compared using a developed mathematical structure, considering the determinants affecting the performance, such as house architecture and the load distribution. The analysis was done by the Electrical Transient Analyzer Program (ETAP). After the comparisons were made on the nominal voltage 220 volts with various DC voltages for typical wire size 4 American wire gauge (AWG), the results showed that 48 V DC is 4% more efficient than 380 V DC and about 9% on AC 220 V. Therefore, for isolated houses, 48V DC is the best solution. It is safe and capable of running most of the house load. DC appliances are commonly available in the market these days [20].

1.2.4 Passive Cooling and Heating of the Building

A passive design strategy is a design that takes advantage of available natural resources such as the sun, airflow, objects shade like trees to create a comfortable residential environment while reducing or eliminating reliance on mechanical and electrical heating and cooling equipment at the same time. Passive design can be achieved by following several procedures, including choosing the house's orientation, the shape of the roof, the insulation of the walls, and the area ratio between the walls and the windows, as a good design contributes to saving up to 40% on cooling and heating energy in some regions [21]. The sun's movement varies with the different seasons of the year, as the sun passes from the upper angle during the summer and a lower one during the winter, as shown in Fg.1.4.

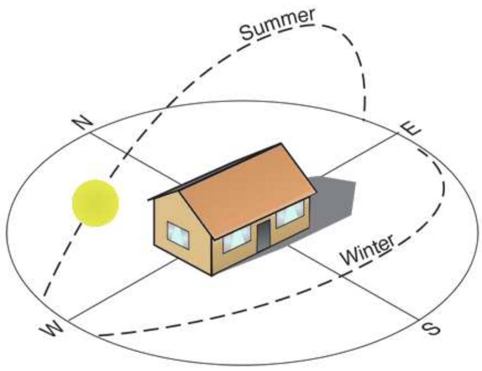


Figure 1.4. Sun movement during summer and winter seasons

This phenomenon can be employed to take advantage of the sun's light for heating during the wintertime by directing the house in the appropriate direction to allow the desired sunlight to pass through the windows. The undesirable sunlight is referred to outside by installing a hanging sheet horizontally and reducing heat exposure during the summer [22,23]. Figure 1.5 illustrates how to employ shading and solar heating. It allows solar energy to benefit from its maximum in the winter; however, choosing the appropriate direction for the building and using simple techniques to control shades contribute to mild temperatures during the summertime.

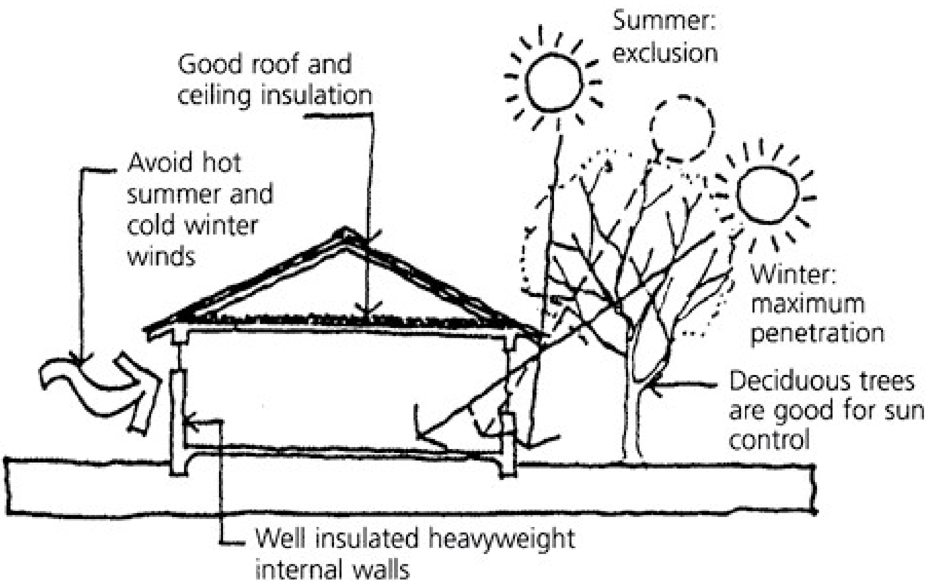


Figure 1.5. Passive design strategy to control the sunlight and airflow [21].

Airflow, evaporative cooling, and thermal mass are all utilized in passive cooling techniques. These methods can be applied to new houses or make some modifications to existing buildings to minimize heat gain by following these steps:

- Select the appropriate orientation of the building.
- Shading windows, roofs, and walls to diminish the direct sunlight during the summertime.
- Using insulation material for walls and roofs and bright colors to reflect the solar radiation.
- Selective and limited use of thermal mass to avert its gain or storage during daytime.
- Choose the optimal place to plant trees and plants to manage airflow and get a cool breeze as shown in Fig. 1.2 [22].

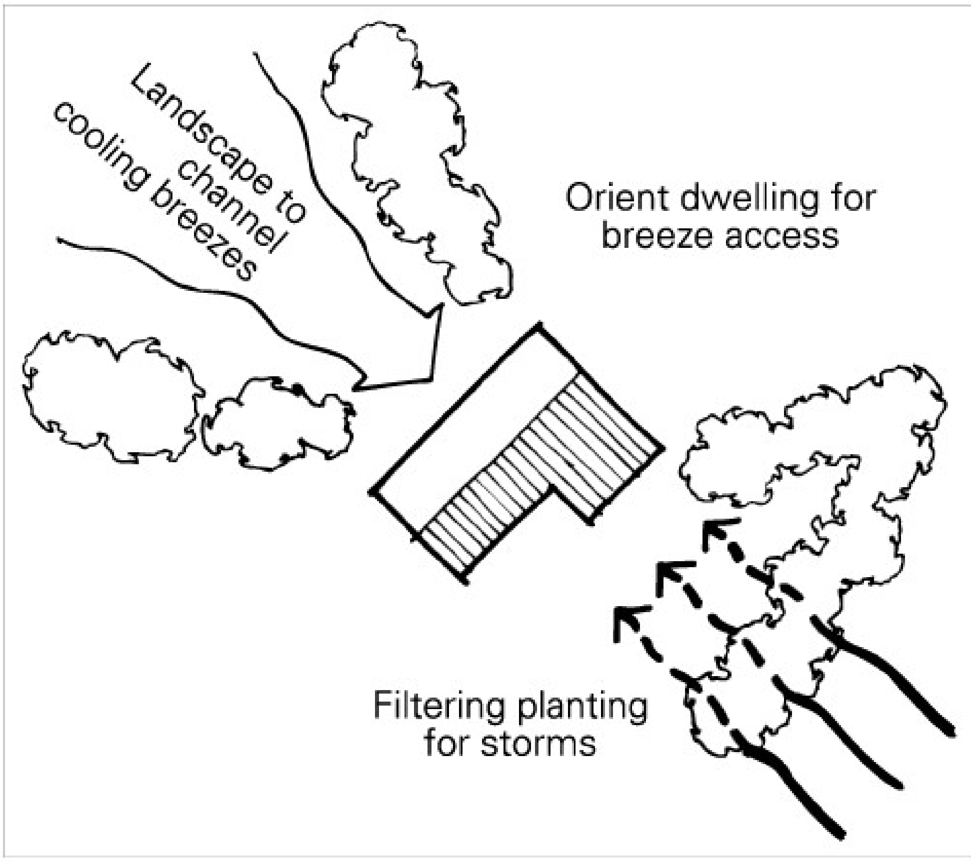


Figure 1.6. Trees and shrubs pattern to drive airflow and get cool breezes[22]

1.3 Conclusion

This Chapter gives an overview of renewable energy resources and their applications. Also, it mentioned the possibility that benefiting from the high potential of solar energy in Libya could meet several challenges related to the increase in energy demand and the damage that occurred in the electrical grid due to the civil war there. Also, this type of power resource contributes to the diminution of the environmental issues caused by the rising level of carbon dioxide due to the excessive utilization of fossil fuels. Looking forward, an alternative energy option is essential in Libya to reduce the period of the outage for residential loads and provide renewable electricity sources to the remote area. A 48 DC was weighted after reviewing the previous studies regarding appropriate voltages for residential loads. HOMER PRO was selected to perform the research study to design, sizing, and economic analysis for a proposed system. It is a widely used program, and its results and outputs are highly reliable.

1.4 Motivation and Research Objectives

Political instability in Libya since 2011 has caused several wars in different regions of the country, which has resulted in significant damage to transmission lines and power stations and delayed the maintenance of some generation plants, which caused a shortage in generation and an increase in the outage hours. This research aims to present a suitable independent electrical generation system for remote area houses, which are among the most affected parties due to the damage caused to the electrical grid in Libya. The research objectives were to:

- Sizing and designing an isolated Photovoltaic (PV)-battery system to fulfill the rural house's load. A home on a farm in Benghazi surroundings in the north of the country was selected as a case study as an excellent example for rustic residential electricity needs. The site was chosen to ensure that if the solar energy system meets the electricity demand of the house in the northern regions, it is a fortiori that can cover the needs of the remote areas in the south, as the amount of solar radiation is more significant there.
- DC 48 volts is used instead of AC 220 volts for voltage bus.
- Present an economic feasibility analysis by using HOMER software to make a comparison between three different systems:
    - i. Stand-alone PV System with battery.
    - ii. Diesel generator which considers the most used independent power source.
    - iii. A hybrid system is comprised of a PV panel, a diesel generator, and a battery.
- Use of MATLAB / Simulink to perform the dynamic analysis and asses the stability of the proposed PV system.

This thesis is structured as follows: chapter 2 illustrates the structure of the house and the estimation of the energy consumption. Chapter 3 demonstrates the design and sizing of the system by using HOMER PRO. Chapter 4 provides a detailed economic analysis by comparing diverse systems. The dynamic modeling, simulation, and results are in Chapter 5. Finally, the conclusion is presented in chapter 6.

CHAPTER 2

Estimation of the Energy Consumption and Thermal Simulation

This Chapter focuses on energy consumption estimation for the proposed building as it is an essential step to design and sizing for the power supply system. BEopt software is implemented for thermal simulation and data analysis. For optimal results, a large-scale e of parameters has been chosen, such as building orientation, walls' thickness, shading, face direction, etc.

2.1 House Structure and Specifications

This study relates to designing a solar energy system that is not connected to the electricity grid for rural residential areas in Libya. A house on the farm in the suburbs of Benghazi was selected to represent the pattern of energy consumption for remote areas. The total area of the case study's house is 59.25 m^2. Figure 2.1. shows the house facade of the case study. The building consists of three rooms, a kitchen, a bathroom, and a small hall. The house windows exist on three facades which led to improving ventilation and lighting in the building. All the room's windows are 1.00 m^2 except the bathroom, which has about 0.5 m^2 area. The kitchen has a door with a window used as an entrance to the backyard. The dimensions of the rooms and their sizes are shown in Fig 2.1.

Figure 2.1. The house facade of the case study

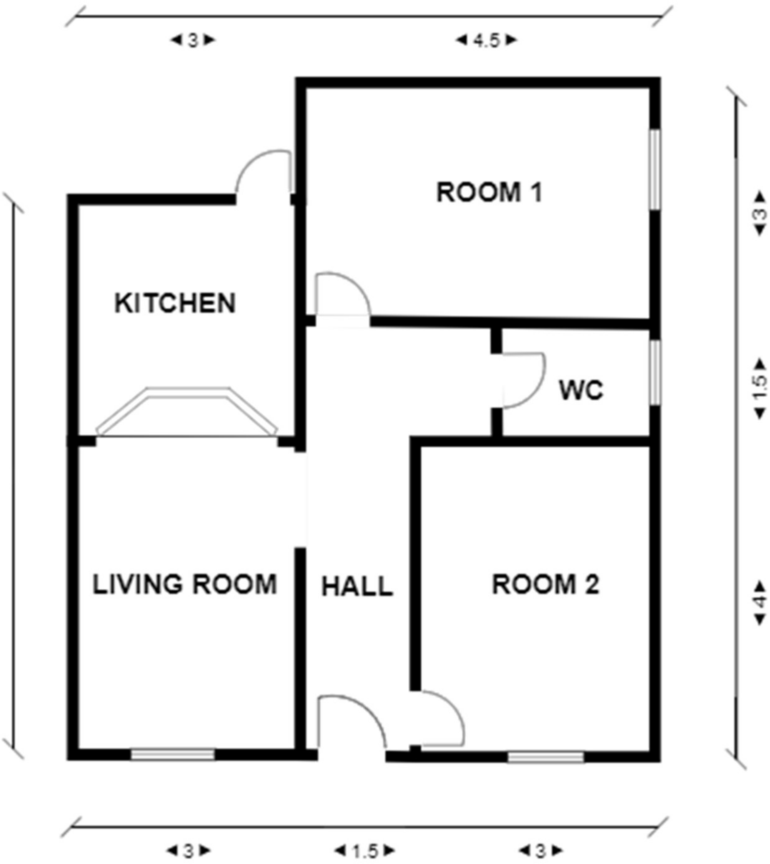


Figure 2.2. Floor Plan of the house

2.2 Load estimate of a rural home in Libya

The load in the rural areas is minimal as it represents the basic needs of electricity of residential people in that region. Table 2.1 exhibits typical appliances in a rustic house such as LED lamps, refrigerators, water pumps, water heating, TV, and Fans. The clothes are dried outside in the open air. Propane is used for cooking and occasionally for heating if needed in the winter. Therefore, such loads are not included in the system design.

Table 2.1 Load estimation of a typical rural house in Libya

#	Items	Number	Power(W)	Total power(W)
1	LED lamp	10	7	70
2	fan	3	20	60
3	water heater	1	450	450
4	fridge	1	100	100
5	TV	1	49	49
6	others	3	100	300

Energy (kWh) is calculated by multiplying power use (in kilowatts) by the number of hours consumed. Operating hours vary according to the type of appliances and the purpose of use. Residential consumption is affected by climatic conditions through seasons of the year. The weather temperatures and variation in the hours of the day and night are critical for some Household gadgets' operation. There are four seasons in Libya, where the climate is moderate during spring and autumn, and it is hot in the summer and rainy and tends to be somewhat cold in winter. Libya extends in an area between the Mediterranean Sea and the Sahara Desert, so there are some differences between the weather between the northern regions, predominantly the Mediterranean climate and the southern areas are hot and dry most of the time [23]. Since the devices at the house cannot work simultaneously, and the loads differ according to the seasons of the year, a reliable method is required to calculate the electrical consumption of the house, which is addressed in the next section.

2.3 Estimating the Residential Load in BEopt Software

Building Energy Optimization Software BEopt is an easy-to-use program to perform simulation on a residential model to identify and evaluate the ideal strategies for cost efficiency and energy saving. It is a free program produced by the United States and can modify existing and new buildings. It is considered among the programs that give reliable results in energy modeling [24]. Using BEopt Software, parameters such as the orientation of the building, thermal mass, walls' thickness, windows' shading, etc. are required to perform the simulation. The weather data for Benghazi, Libya was used. The chosen type of building is shown in Fig 2.3.

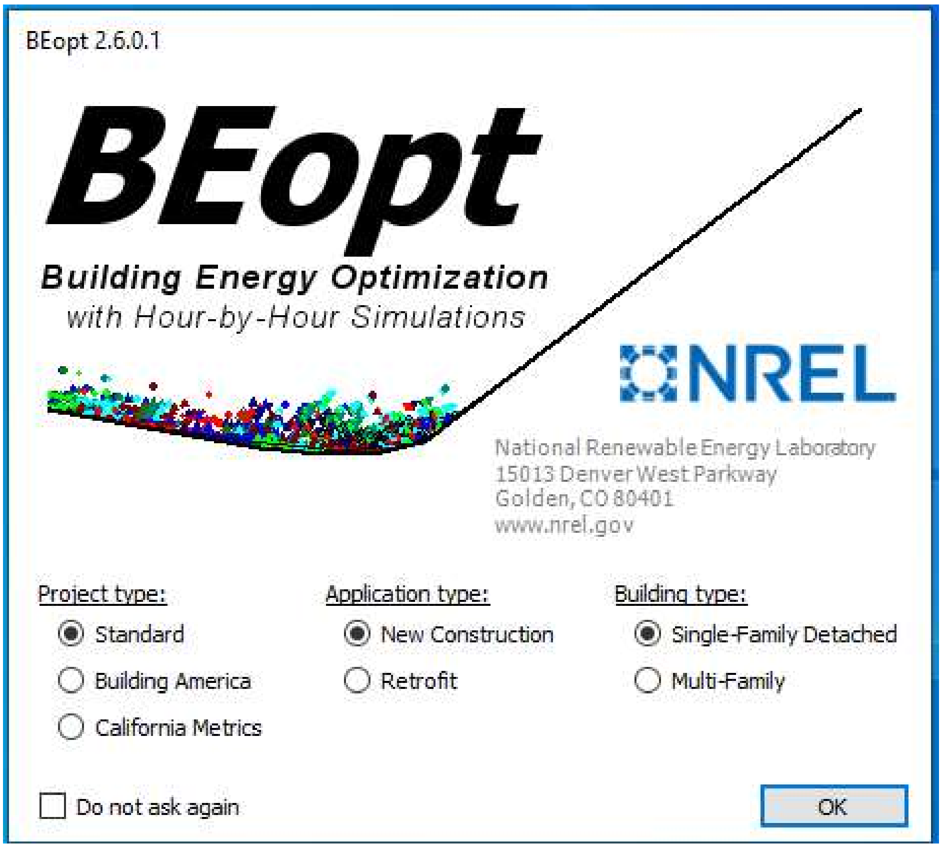


Figure 2.3. The option of building in BEopt software

BEopt program requires many parameters for the study's target building to reach the desired results from this software. These options include the geometry screen for the design of the house, the number of rooms, and the dimensions. The building in this study consists of three rooms, a bathroom, and a kitchen, the total area of the house is 59.25 m^2(637.76f^2), and there is no basement or garage, as shown in figure 2.4. The total windows and door area was entered correctly for a correct thermal analysis.

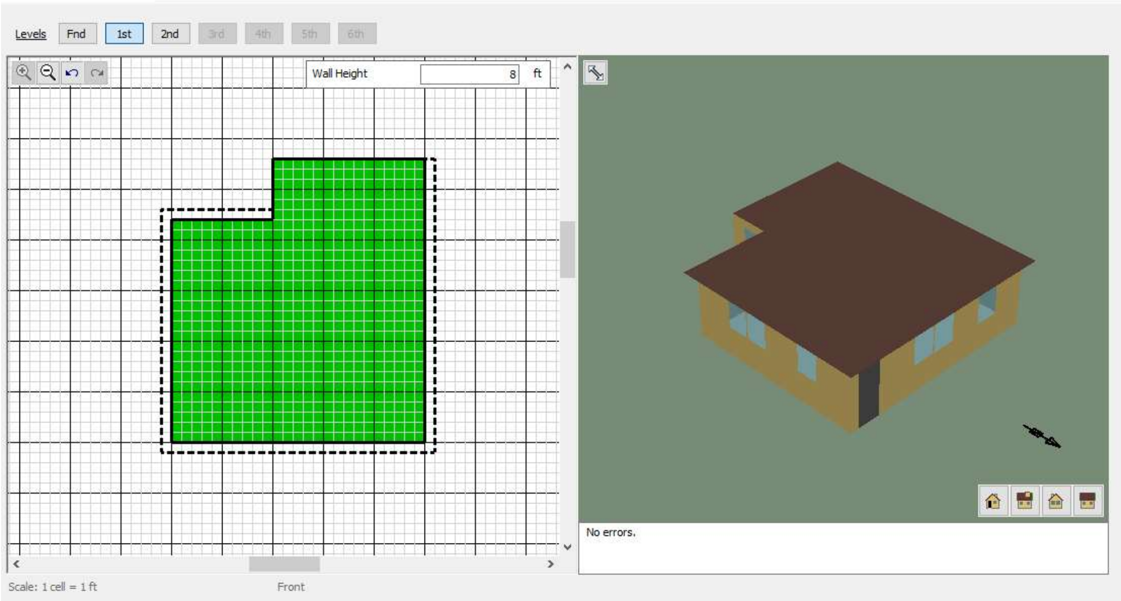


Figure 2.4. The geometry of the house in BEopt software

The screen allows the designer to draw the building according to its dimensions, number of floors, and the type of roof used. After that, the house's specifications are defined by choosing the parameters such as the orientation, the walls, the ceiling, the windows, the doors, the floors, and everything related to the building. Each number in the options screen refers to specific options, as shown in figures 2.5 and 2.6. For instance, the highlighted number in the orientation means that the direction faced by the front of the house is the north, while the same option in the clothes dryer indicates none, which means this appliance does not exist.

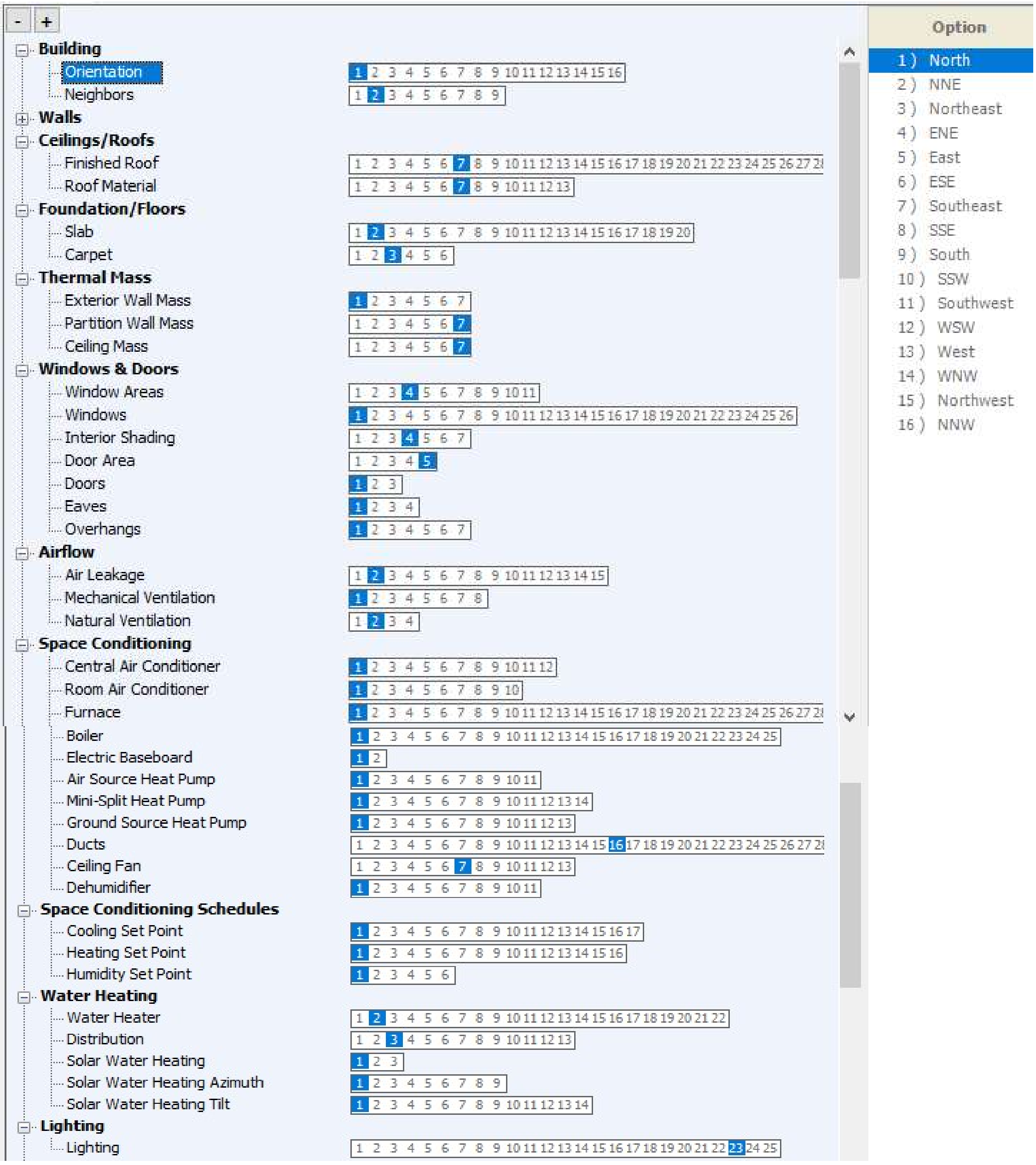


Figure 2.5. The first list of house's parameters option in BEopt software

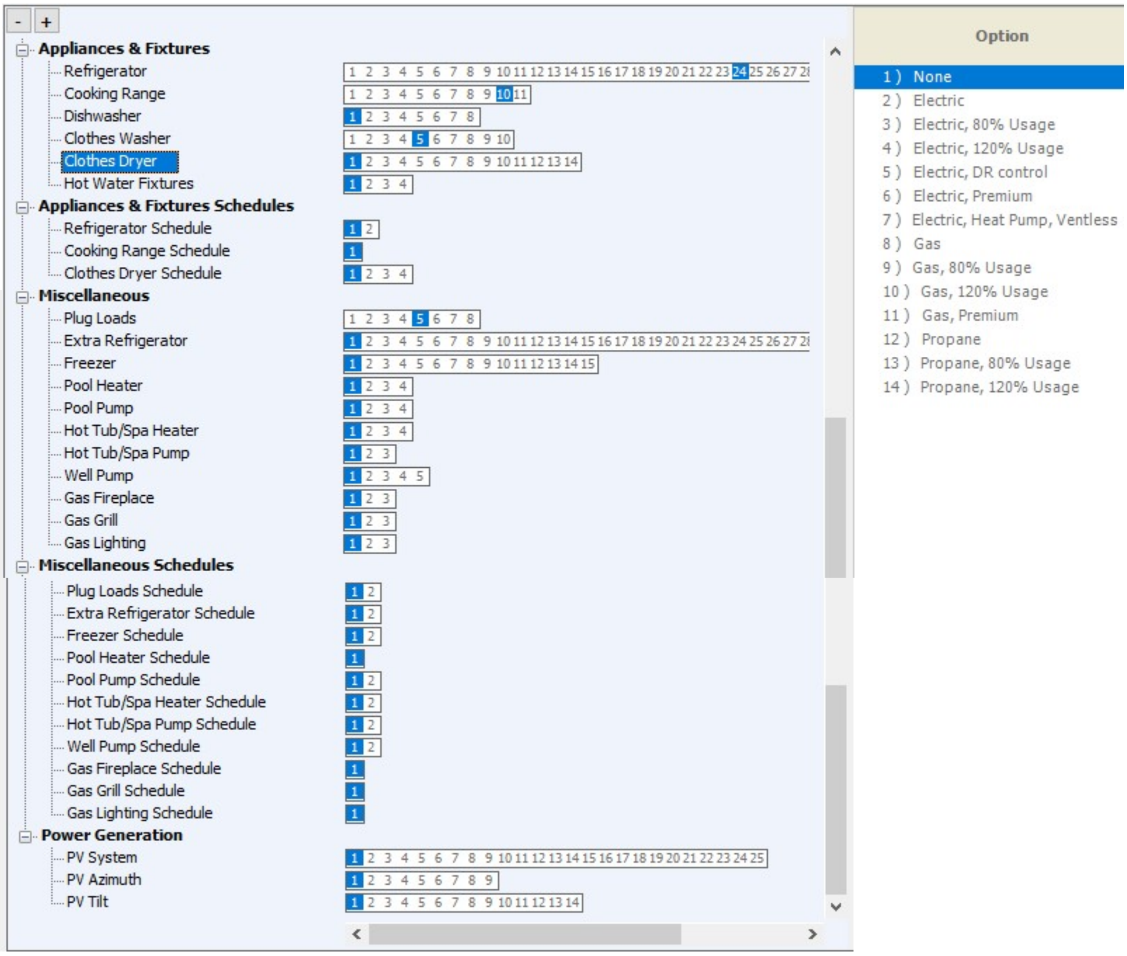


Figure 2.6. The second list of house's parameters option in BEopt software

Figure 2.7 illustrates an hourly load file for a year for the building. That can be noticed; the energy consumption is slightly higher in November, December, January, and February due to the length of the night during the winter, which leads to an increase in the use of lighting and the water heater in cold weather. Moreover, there is no air conditioner in the house, which means less electrical consumption during summertime.

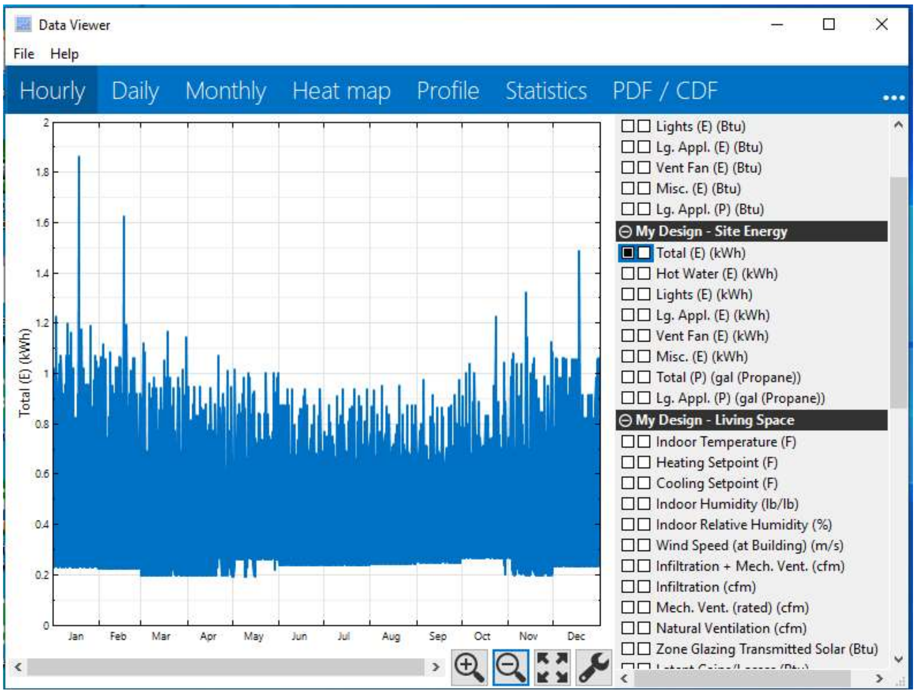


Figure 2.7. The hourly load profile for a year in BEopt

Figure 2.8 shows an hourly load file per month for the house. The peak load is around 20:00 regardless of the selected month because most residential activities are in the evening.

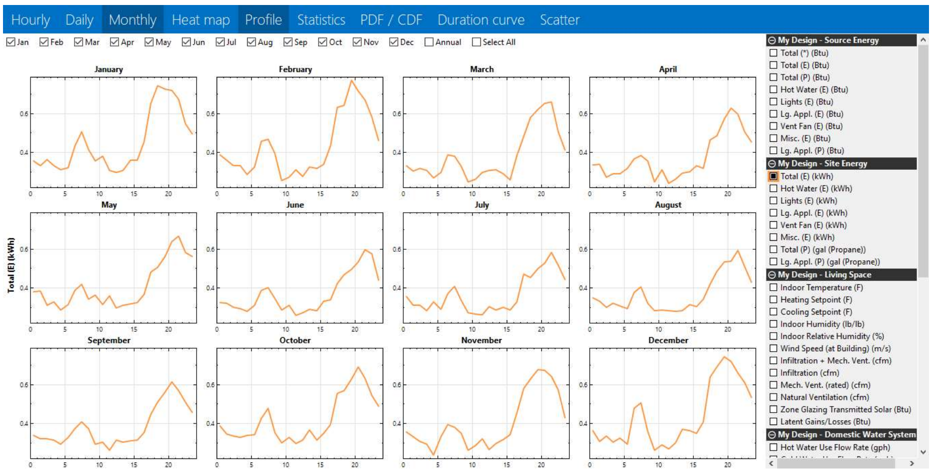


Figure 2.8. The hourly load profile per month in BEopt

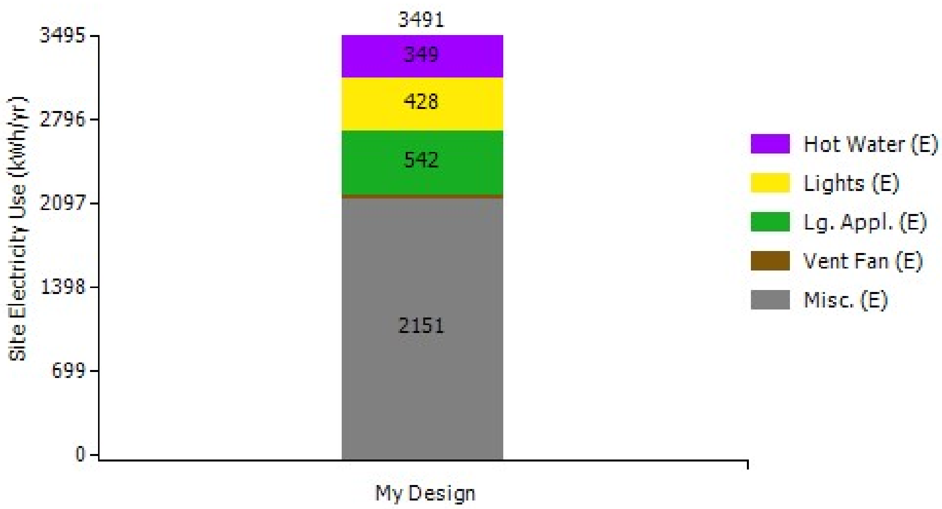


Figure 2.9. The geometry of the house in BEopt software

The annual energy consumption was estimated using thermal modeling for a house in the BEopt program. As shown in Fig 2.9, the miscellaneous load is the highest because it includes others specified in the software's parameters options. According to the simulation outputs, annual energy consumption is 3491 kWh.The energy value is critical for sizing and designing the proposed supply system.

2.4 Conclusion

This Chapter covered many details about the specifications and configurations of the building targeted by this study. The typical rural house load was estimated by using BEopt software. The results of thermal modeling show that the annual energy consumes by the house is 3491kWh/year. In the next Chapter, the estimated load consumption will be used for the sizing design of the PV system for feeding the building.

CHAPTER 3

System Sizing and Analysis in HOMER PRO

The main target in this Chapter is to design a solar energy system that can caver the house load demand. The Hybrid Optimization of Multiple Energy Resources (HOMER) Pro software initially developed at National Renewable Energy Laboratory (NREL) the \USA was approved to sizing and analyze the proposed system. In order to obtain the desired results from using this software, The program should be provided with a set of parameters such as the load to be fed and the location of the proposed system, as well as the specifications of the components of the proposed solar energy system—more detail about that, will be discussed in the following section of this Chapter.

3.1 Site Selection and Electrical Loads

As a case study, a Farmhouse located around Benghazi, Libya, has been considered. Determining the household's energy demand is essential to design the proposed PV- battery system. The annual energy consumption was estimated by performing a thermal model of the house in the BEopte software, as discussed in Chapter 2. Based on the simulation outputs, the energy consumption for one year (365 days) was found to be equal to 3,491 kWh, and the daily energy consumption was calculated to be 9.6 kWh/day. A typical day profile of the residential load is shown in Fig. 3.1.

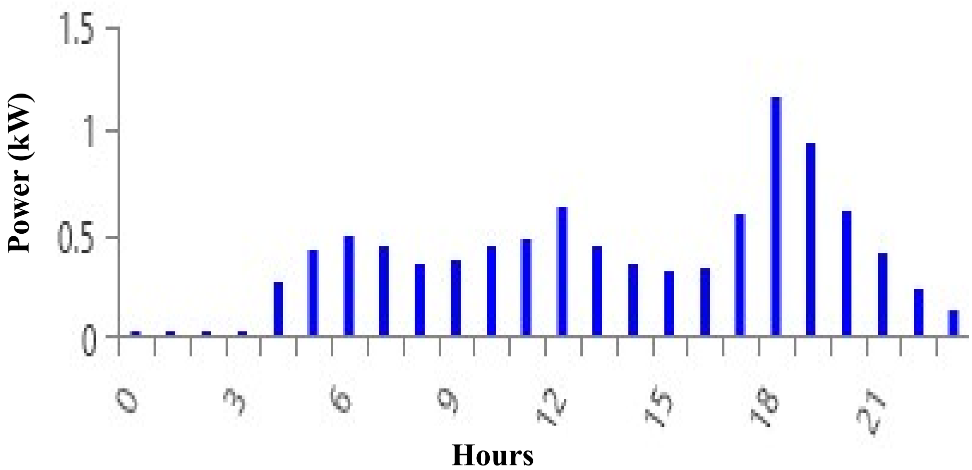


Figure 3.1.A typical day profile of the residential load

The hourly load profile per month and the average load per month of the residential load generated by HOMER PRO are shown in Figures 3.2 and 3.3, respectively.

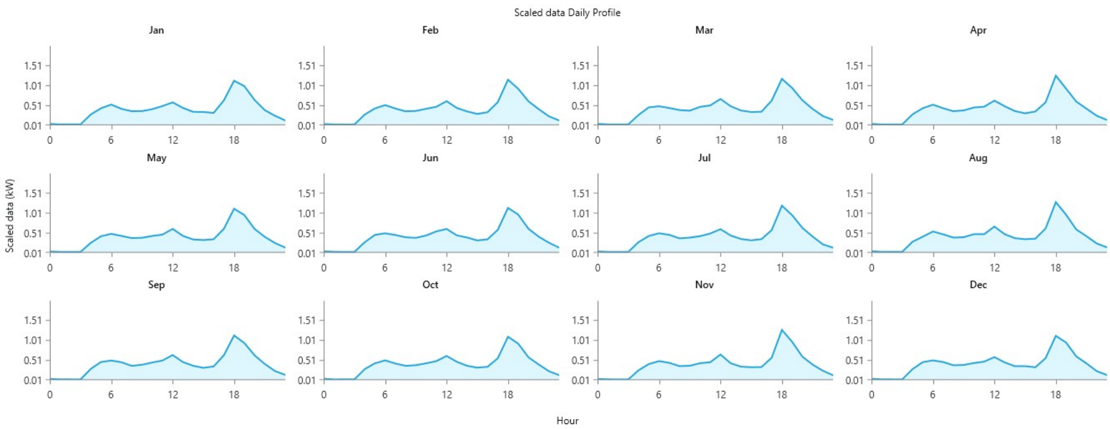


Figure 3.2.The hourly load profile per month of the residential load in HOMER PRO

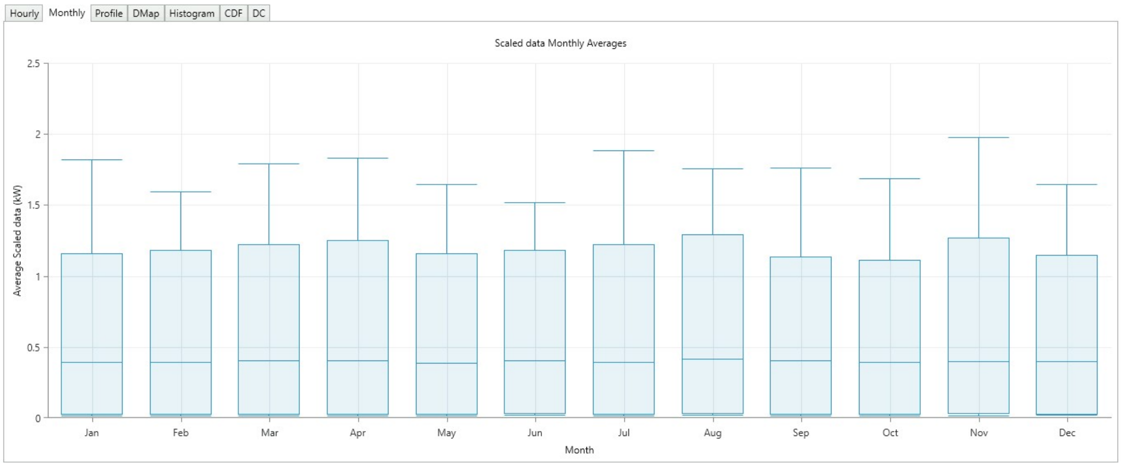


Figure 3.3.The average load per month of the residential load in HOMER PRO

A typical day load profile of a remote area is shown in Figure 3.1. The load demand varies throughout the day, with the peak load occurring between 17:00 and 20:30. Since the type of the investigated load was purely residential, generally, family members will be outside the house in the morning or afternoon. On the other hand, most household activities happen in the evening, increasing the energy demand.

3.2 Solar Irradiation Resources

Libya is among the countries that have excellent potential for solar energy. The proposed PV- battery system will serve the demand load of A house in the vicinity of the city of

Benghazi, which is situated at the longitude of 32°5.5'N latitude and 20°7' E longitude, as shown in Fig.3.4.

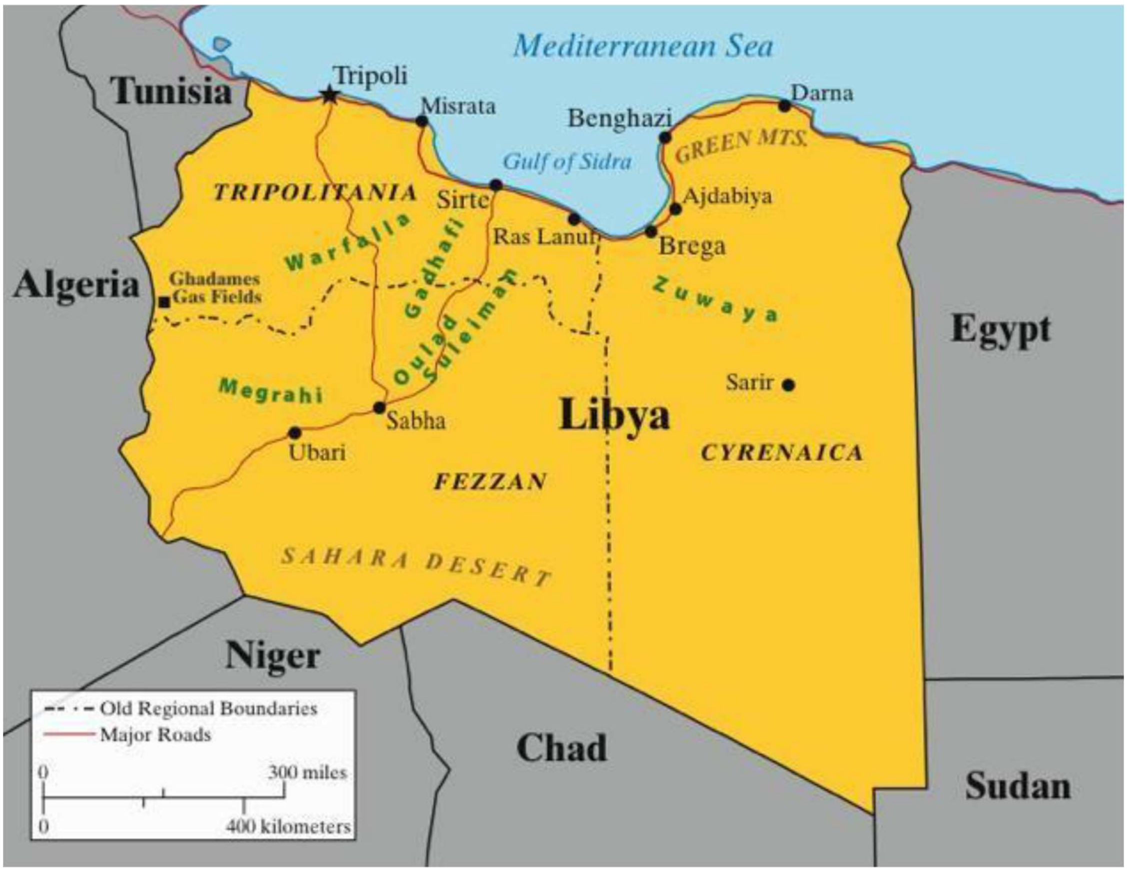


Figure 3.4.The location of Benghazi in Libya[25]

As shown in Figure 3.5, the solar resource has been generated in HOMER Pro software by selecting the proposed system's location. The scaled annual average solar irradiation is 5.44 kWh/m^2/day. Its clearness index varies in the range of 0.509 to 0.705.

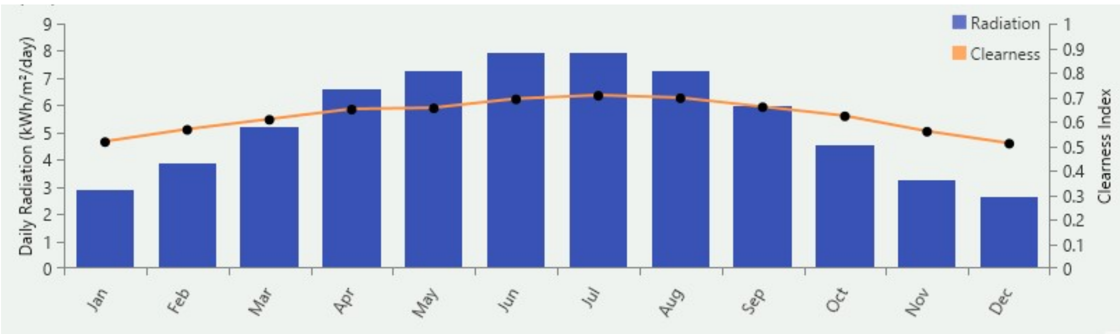


Figure 3.5.The monthly average solar radiation at the selected location in HOMER PRO

3.3 Components of the Proposed PV-Battery System

3.3.1 PV Module

The PV panels consist of a set of solar cells which are made of semiconductor material. The direct sunlight is converted into electrical power by absorbing the light through the semiconductor to increase the energy of the electron in the internal of the cell then pushing this electron's power from the inner of the cell to an external circuit and came backs to the solar cell again [26]. A PV panel (CANADIAN SOLAR MAXPOWER CS6U-325P 325W POLY SOLAR PANEL) [27] was selected for this project; each of them consists of 72 cells. Its efficiency is 16.72% and produces 325W. Specifications of the PV module are presented in Fig 3.6.

ELECTRICAL DATA | STC*

CS6U	315P	320P	325P	330P
Nominal Max. Power (Pmax)	315 W	320 W	325 W	330 W
Opt. Operating Voltage (Vmp)	36.6 V	36.8 V	37.0 V	37.2 V
Opt. Operating Current (Imp)	8.61 A	8.69 A	8.78 A	8.88 A
Open Circuit Voltage (Voc)	45.1 V	45.3 V	45.5 V	45.6 V
Short Circuit Current (Isc)	9.18 A	9.26 A	9.34 A	9.45 A
Module Efficiency	16.20%	16.46%	16.72%	16.97%
Operating Temperature	-40°C ~ +85°C			
Max. System Voltage	1000 V (IEC) or 1000 V (UL)			
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)			
Max. Series Fuse Rating	15 A			
Application Classification	Class A			
Power Tolerance	0 ~ + 5 W			

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

MECHANICAL DATA

Specification	Data
Cell Type	Poly-crystalline, 6 inch
Cell Arrangement	72 (6×12)
Dimensions	1960×992×40 mm (77.2×39.1×1.57 in)
Weight	22.4 kg (49.4 lbs)
Front Cover	3.2 mm tempered glass
Frame Material	Anodized aluminium alloy
J-Box	IP67, 3 diodes
Cable	4 mm² (IEC) or 4 mm² & 12 AWG 1000V (UL), 1160 mm (45.7 in)
Connector	T4 series or PV2 series
Per Pallet	26 pieces, 635 kg (1400 lbs)
Per container (40' HQ)	624 pieces

ELECTRICAL DATA | NOCT*

CS6U	315P	320P	325P	330P
Nominal Max. Power (Pmax)	228 W	232 W	236 W	239 W
Opt. Operating Voltage (Vmp)	33.4 V	33.6 V	33.7 V	33.9 V
Opt. Operating Current (Imp)	6.84 A	6.91 A	6.98 A	7.05 A
Open Circuit Voltage (Voc)	41.5 V	41.6 V	41.8 V	41.9 V
Short Circuit Current (Isc)	7.44 A	7.50 A	7.57 A	7.66 A

* Under Nominal Operating Cell Temperature (NOCT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.41 % / °C
Temperature Coefficient (Voc)	-0.31 % / °C
Temperature Coefficient (Isc)	0.053 % / °C
Nominal Operating Cell Temperature	45±2 °C

Figure 3.6.The Specifications of PV panel [27]

There are many parameters related to the solar panel that should be determined before simulating the system in the HOMER program. As shown in Fig 3.7, the panel capacity is 0.35 kW, as well as the price of each panel, is $184, and the replacement cost is $120. The operation and maintenance expense is estimated at $20 per year for 20 years of the project's lifetime.

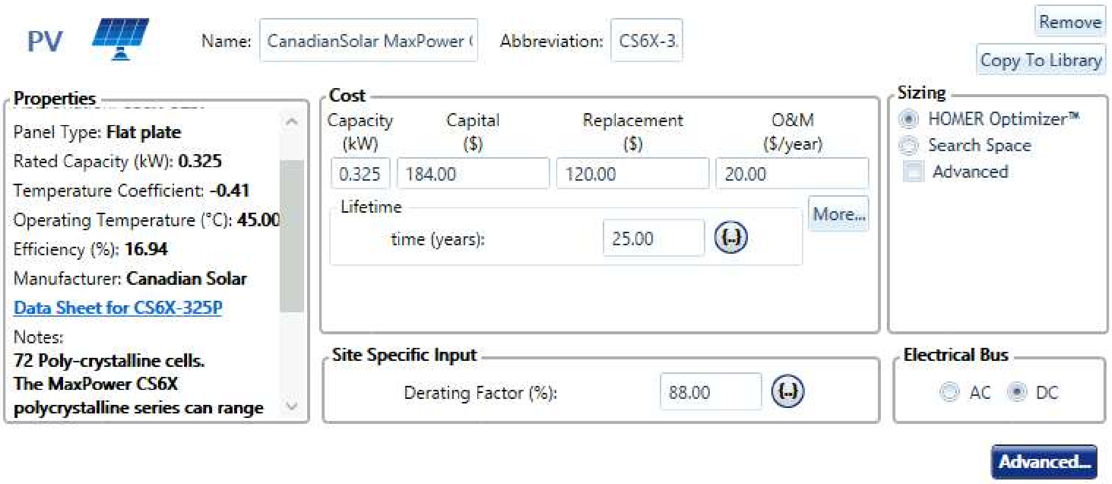


Figure 3.7. The parameters of PV panel in HOMER PRO software

3.3.2 Storage Battery bank

Lead-Acid Battery is one of the energy storage systems coupled with a PV pane solar energy system. Storage technology is fundamental to guaranteeing supply power to load during periods of bad weather and at night in a stand-alone PV system. Even though lead sulfuric acid technology was invented more than 100 years ago still considered one of the reliable storage systems these days, this type of battery is known as a long service life battery. Also, it can be used for an extended period of up to thousands of cycles if appropriate operating conditions are taken into account, which requires:

- Choosing the appropriate number of batteries to fit with the applied load to be charged.
- Avoiding deep discharging so that it does not discharge less than 50% DOD,
- Do not store it or keep it idle while it is in the deep operating mode for a long time,
- Maintain the cell solution replacement within a prepared time plan,
- Avoid overloading and keep it within the capacity of the storage system,

- Create a suitable storage space for the battery system with good ventilation and a range of temperatures between 20 to 40 C^o [28],

Lead-acid trojan battery 12V, 219Ah (SSIG 12205) was selected for this study. Trojan Battery Company is one of the big companies in various types of storage systems. With more than 80 years of experience in this field, it is considered among the most prestigious names in the global market. They cover various applications related to deep cycle systems in different areas around the world. This type of battery is featured by:

- A high level of safety, through the use of a calcium grid, to reduce the emitted gases, in addition to operating pressure in one direction to prevent fires,
- An effective charging where a lower internal resistance contributes to increasing the discharge current,
- A perfect design with excellent performance allows for greater flexibility when using this type of battery,

Figure 3.8.Trojan Lead-acid batter

In addition to the previous menthid features, lead-acid batteries are considered one of widely used as an energy storage component in residential solar power systems. To gain 48 V, DC of the storage system's string size contains four batteries, 12V -219Ah. Figure 3.9 presents the quantity, capital, replacement cost, and operation and maintenance expenses per year. Moreover, the number of strings and the bus voltage are selected in the HOMER PRO simulation interface environment.

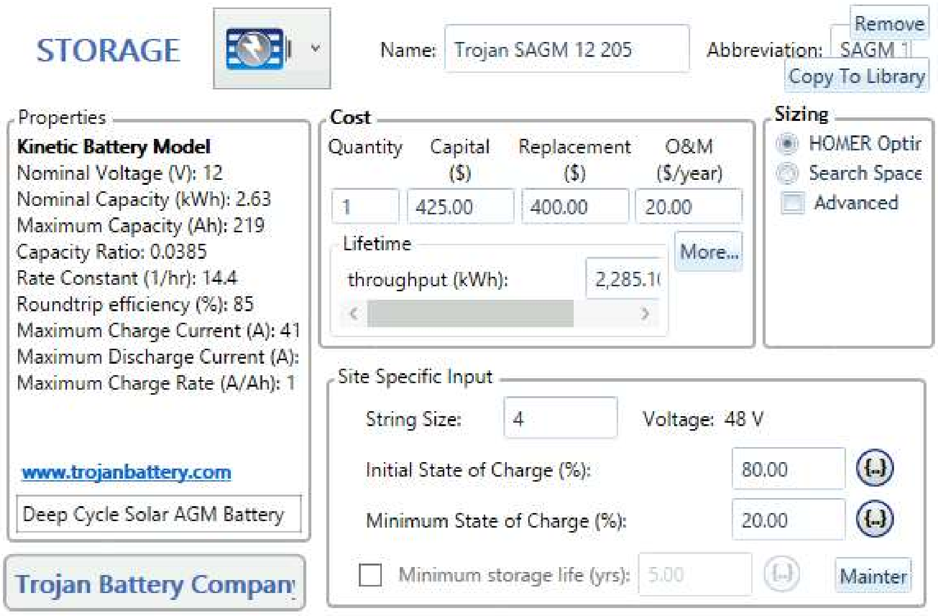


Figure 3.9.The parameters of the battery in HOMER PRO software

HOMER Pro software was used and provided with the proposed system's parameters to analyze and study the feasibility of utilizing PV systems in supplying direct DC loads. A 48 V DC bus was chosen due to its high efficiency among other DC voltage for residential loads. A PV panel 325W each and lead-acid trojan battery 12V, 229Ah were selected. Simulation is done in HOMER Pro software to obtain the optimal size of the PV battery system's components. The diagram of the proposed battery system is shown in Fig. 3.10.

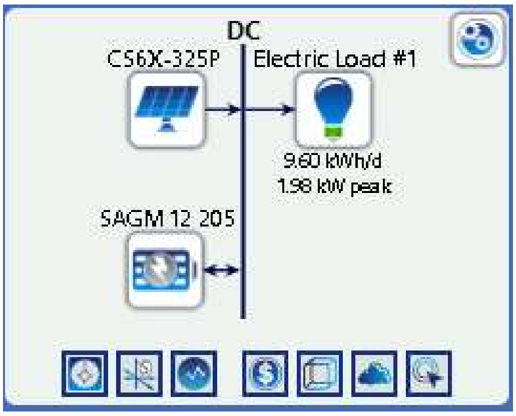


Figure 3.10.Schematic diagram of the proposed PV-battery system

3.4 Simulation and Results from HOMER PRO

HOMER Pro software considers different solar panels and batteries to reach the most cost-effective system that entirely fulfills the load demand in the simulation process. The possible configurations and results have been obtained based on the entered inputs. The most optimal system is chosen-based net present cost (NPC) and cost of energy (COE), and the ability to cover the target design load. The optimization results in HOMER PRO are presented in Fig 3.11.

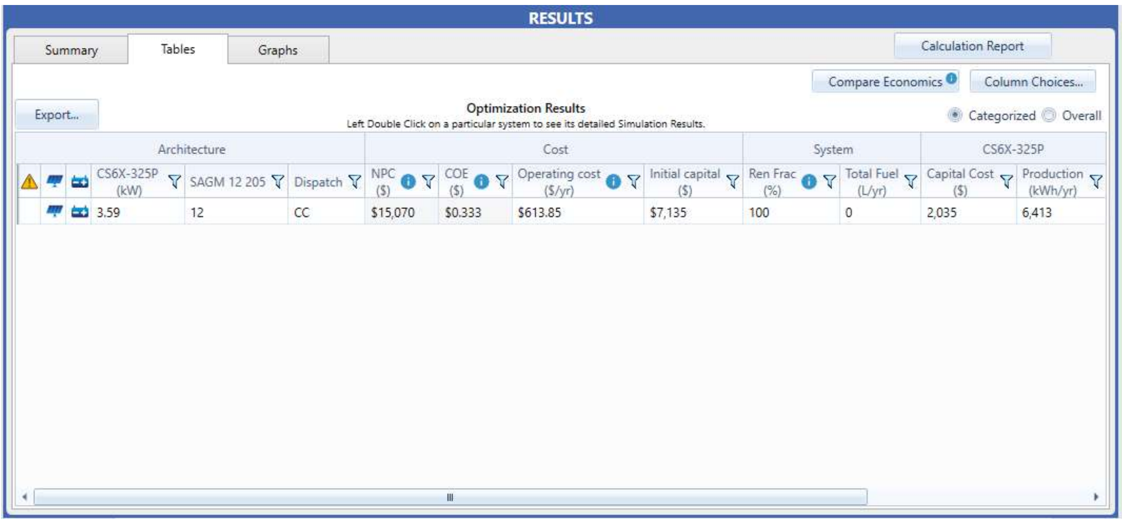


Figure 3.11.Optimization Results in HOMER PRO software

HOMER Pro optimization results clearly show that the desired system components that produce 3.59 KW consist of 12 PV panels 325 W each and 12 lead-acid battery banks making 12 V, 219 Ah to store excess generated electricity and feed the load at night and in bad weather. The simulation results of string size, state of charge, and daily PV power output are shown in Figures 31.2 and 3.13.

Quantity	Value	Units
Batteries	12.0	qty.
String Size	4.00	batteries
Strings in Parallel	3.00	strings
Bus Voltage	48.0	V

Quantity	Value	Units
Autonomy	63.0	hr
Storage Wear Cost	0.190	$/kWh
Nominal Capacity	31.5	kWh
Usable Nominal Capacity	25.2	kWh
Lifetime Throughput	27,421	kWh
Expected Life	13.8	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	2,152	kWh/yr
Energy Out	1,836	kWh/yr
Storage Depletion	8.22	kWh/yr
Losses	323	kWh/yr
Annual Throughput	1,992	kWh/yr

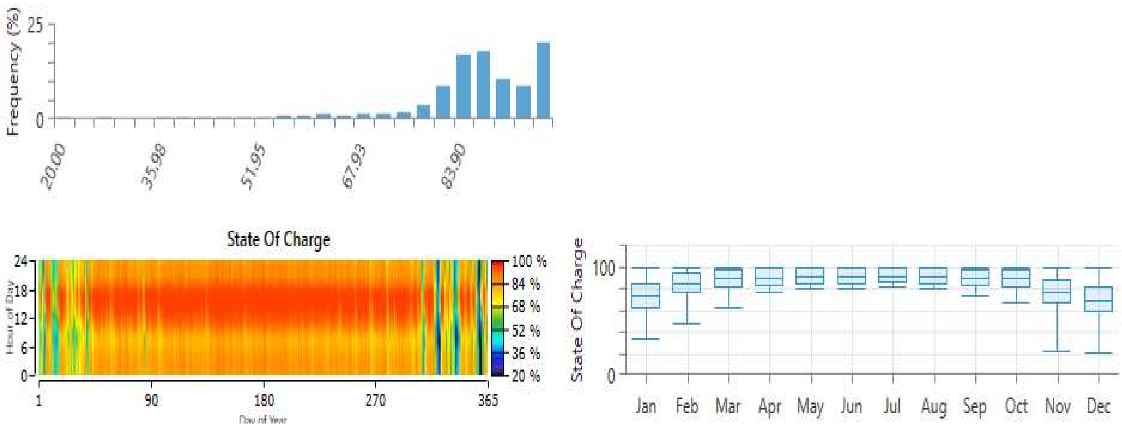
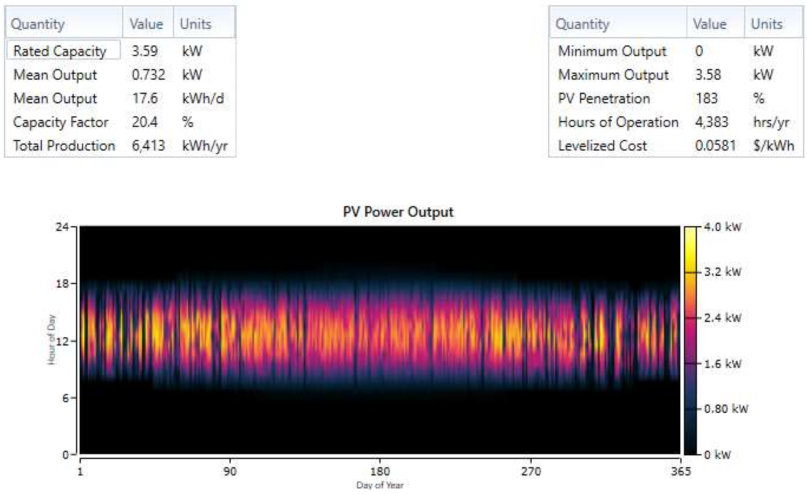


Figure 3.12. Results for the utilized battery bank of the proposed PV-battery system

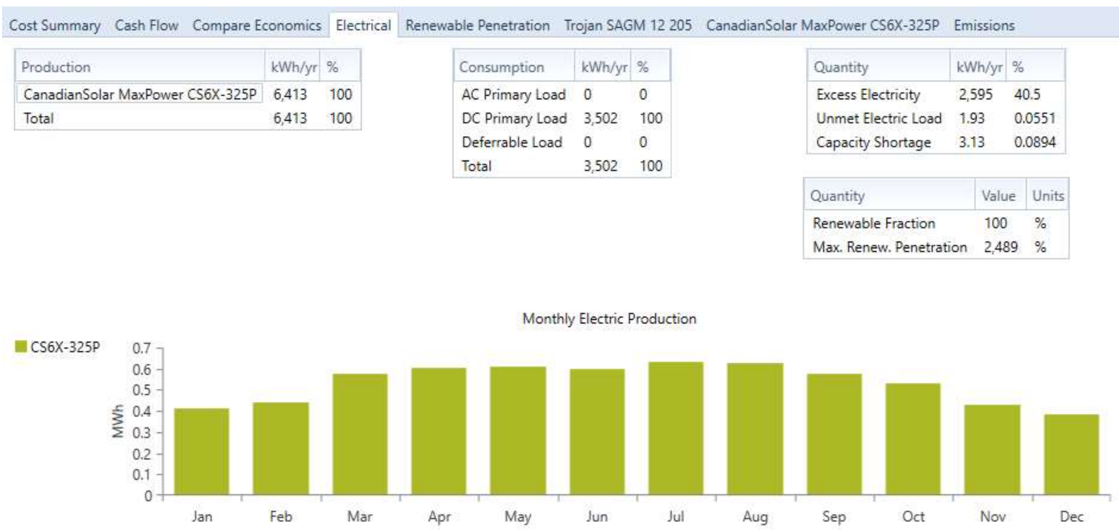


Quantity	Value	Units
Rated Capacity	3.59	kW
Mean Output	0.732	kW
Mean Output	17.6	kWh/d
Capacity Factor	20.4	%
Total Production	6,413	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	3.58	kW
PV Penetration	183	%
Hours of Operation	4,383	hrs/yr
Levelized Cost	0.0581	$/kWh

Figure 3.13.The daily PV power output for a year in HOMER PRO

Figure 3.14 displays the average monthly energy production of the PV panel. Solar radiation has the most potential in the summertime in May, June, July, and August in that region; then, it reduces slightly in the rest of the year. Therefore, the electrical energy produced by the proposed PV system is mainly sufficient to cover the electricity needed for that house. There is 2,595 kWh/yr as excess electricity.



Production	kWh/yr	%
CanadianSolar MaxPower CS6X-325P	6,413	100
Total	6,413	100

Consumption	kWh/yr	%
AC Primary Load	0	0
DC Primary Load	3,502	100
Deferrable Load	0	0
Total	3,502	100

Quantity	kWh/yr	%
Excess Electricity	2,595	40.5
Unmet Electric Load	1.93	0.0551
Capacity Shortage	3.13	0.0894

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	2,489	%

Figure 3.14. Monthly energy production of the proposed PV system

Figure 3.15 illustrates cash flow through 25 years of the system life cycle. $7,143.72 is an initial investment, and then there is $471.16 as an annual operation cost over 25 years of system life. In the 14th year of service, an additional $4,800.00 is required to replace the equipment to keep the system working fine. A salvage value of $882.84 is available for the system at the end of the life cycle.

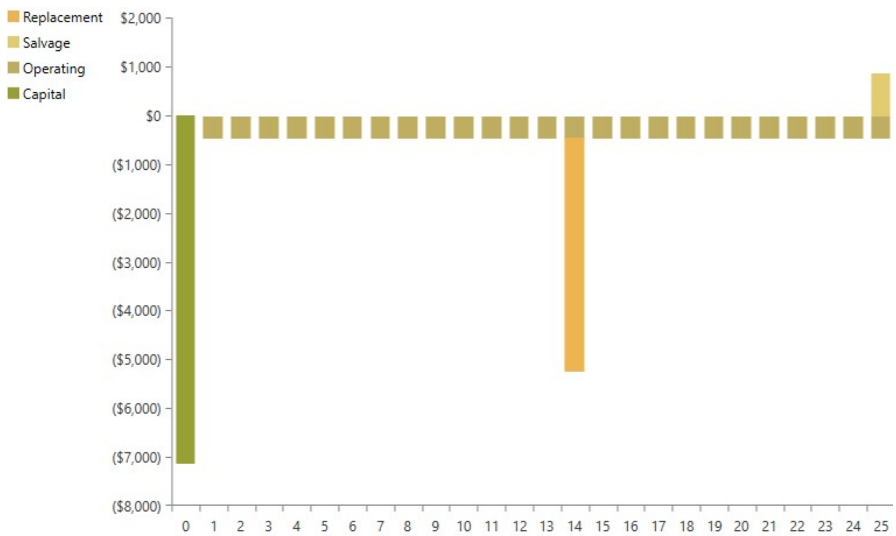


Figure 3.15.Cash Flow for the proposed system in HOMER PRO

The proposed electrical wiring diagram of the PV battery system is shown in figure 3.16. House appliances such as refrigerator, freezer, water pump, and water heating are coupled directly to 48 V DC. A buck converter steps a voltage down to 12 V DC to supply light bulbs and small electronic loads such as TV, fans, etc. Note that DC appliances and light bulbs are commonly used these days.

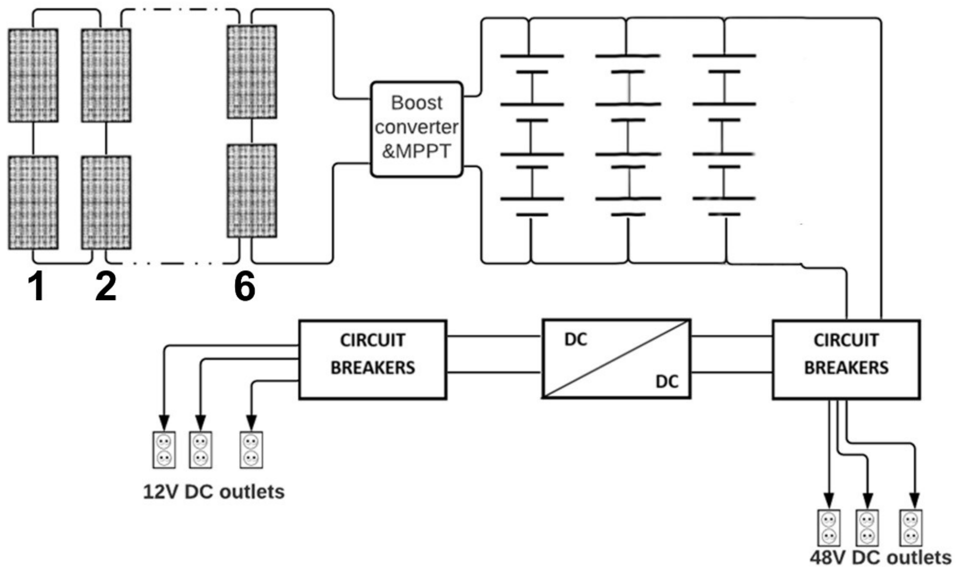


Figure 3.16.The layout of the proposed PV-battery system and the DC distribution in the house

3.5 Conclusion

This Chapter covered location and solar radiation at the selected site of the proposed PV system. Several components of the solar-battery system were evaluated and simulated in the HOMER PRO. The details of the optimal design in terms of performance and cost were presented in this section. Finally, the proposed system's electrical wiring scheme and the cabled household appliances with diverse level voltages are illustrated.

CHAPTER 4

Economic Analysis of the Proposed PV System

4.1 Introduction

The General Electricity Company GECOL is the sole operator of Libya's generation and transmission stations, transmission, and distribution networks. However, the company's work has been dramatically affected by the fragile security situation in the country. Despite the company's technical staff carrying out operations and maintenance within the available conditions and capabilities, the deficit covers the full grid load. Performing major overhauls and upgrading for plants and electrical grid required the help of international contractors partly holding due to the betting conditions. Furthermore, this situation greatly influenced people's lives. It made them resort to alternative solutions, especially in the year's peak periods. Due to the availability of solar energy in excellent quantities in Libya, there are many advantages to employing the independent solar energy system there. In addition to supplying remote areas, it can feed areas with grid instability and frequent interruptions due to damages in stations and transmission lines. Moreover, the excess energy of the PV system could be sold to GECOL under which is known as a Feed-in-Tariff (FiT) policy after upgrading the public grid in the future. This technology contributes to reducing dependence on fossil fuels fuel by using environmentally friendly sources.

4.2 System Components Assessment

To study the economic feasibility of the proposed isolated system, a PV system with a battery bank, a diesel generator, and a hybrid system consisting of both systems have been compared using HOMER PRO software. Figure 4.1 exhibits the schematic diagram of the proposed configuration.

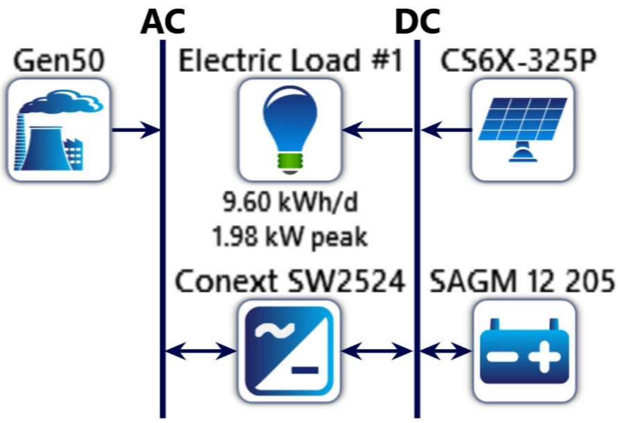


Figure 4.1.Schematic diagram of the hybrid system

A PV panel, battery, diesel generator, and a power converter were specified in HOMER PRO software, converting alternating current (AC) from the generator to direct current (DC) to feed the house's DC load. The diesel fuel price in Libya is about 0.11 $/L which is considered one of the world's cheapest rates [29]. However, subsidized prices are not available because diesel fuel is sold at double prices on the black market. These days, the general mood of decision-makers in Libya goes seriously towards lifting subsidies on oil derivatives and replacing them with financial compensation that directly benefits the citizen. So, the average global diesel fuel price used in this study is 1.04 $/liter, about 1.04 $/liter [30]. Technical specifications and cost details for each of the system's components are listed in Table 4.1.

Table 4.1 Technical and economic characteristics of system's components

Component	Rating	#Of items	Cost /unite	Total
PV	325 W	12	$184	$ 2,208
Battery	12V, 219 Ah	12	$425	$5,100
Convertor	3KW	1	$1500	$1500
Diesel generator	3KW	1	$500	$500

4.3 Results and Discussion

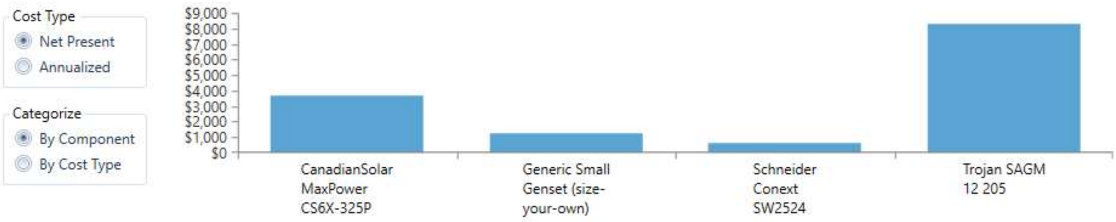
The simulation was completed by comparing the isolated PV System with battery, backup diesel generator, and hybrid PV/diesel generator system with battery. It was carried out based on a project life of 25 years. HOMER Pro software has been utilized to evaluate and analyze various designs. From the total of 1,441 simulations, 1,027 solutions were found feasible. About 414 solutions were omitted due to capacity shortage constraints, minimum battery life, lacking converter, etc. Figure 4.2 shows optimization results in HOMER PRO software for the considered systems. They are arranged so that the most cost-effective and appropriate system to cover the target load is at the top of the list, followed by the least efficient one, and so on.

Architecture					Cost				System		Gen50	
CS6X-325P (kW)	Gen50 (kW)	SAGM 12 205	Conext SW2524 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)
2.71	4.00	8	0.808	LF	$13,895	$0.307	$623.20	$5,838	95.7	60.8	150	150
3.59		12		CC	$15,070	$0.333	$613.85	$7,135	100	0		
	4.00	4	1.57	LF	$32,319	$0.714	$2,269	$2,986	0	1,669	4,094	4,135
6.35	4.00		1.93	CC	$50,040	$1.10	$3,479	$5,063	0	2,561	6,256	6,357
	4.00		1.97	CC	$57,332	$1.27	$4,320	$1,484	0	3,590	8,760	8,916

Figure 4.2.Optimization results for the investigated systems

4.3.1 Hybrid PV-DGN-BAT system

The results from the HOMER simulation show that the Hybrid PV/Diesel System with Battery offers the least NPC and COE with $13,895 and 0.307 $/kWh, respectively. The cost summary of the system Hybrid is summarized in Figure 4.3. shows that the energy storage system ESS partition is the highest, with a total cost equal to $8,268.80. On the other hand, the NPC for the PV module and diesel generator are $3,690.10 and $1,285.10, respectively, as exhibited in Fig 4.3.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CanadianSolar MaxPower CS6X-325P	$1,534.24	$0.00	$2,155.86	$0.00	$0.00	$3,690.10
Generic Small Genset (size-your-own)	$500.00	$0.00	$58.17	$816.76	($89.83)	$1,285.10
Schneider Conext SW2524	$403.87	$285.43	$0.00	$0.00	($38.70)	$650.60
Trojan SAGM 12 205	$3,400.00	$3,013.21	$2,068.40	$0.00	($212.82)	$8,268.80
System	$5,838.11	$3,298.65	$4,282.44	$816.76	($341.36)	$13,894.60

Figure 4.3. Cost summary of hybrid PV-Gen-Batt system

The Figure 4.4. shows the annual electricity produced by the PV-Gen-Batt Hybrid System. It can be observed that solar panels produce most of the electrical energy in the hybrid system. They are considered prime supply to feed the essential loads, and the surplus of their produced energy is employed to charge the battery bank. On the other hand, the battery bank is the prime power resource on cloudy days and night-time. A diesel generator will operate only if both PV and battery cannot cover the load demand. In other words, it will work as a backup power supply, especially in the winter months when the amount of solar radiation decreases in November, December, January, and February. In addition to avoiding deep discharging for the battery system to less than 50%. The daily generator power outputs are shown in Fig 4.5.

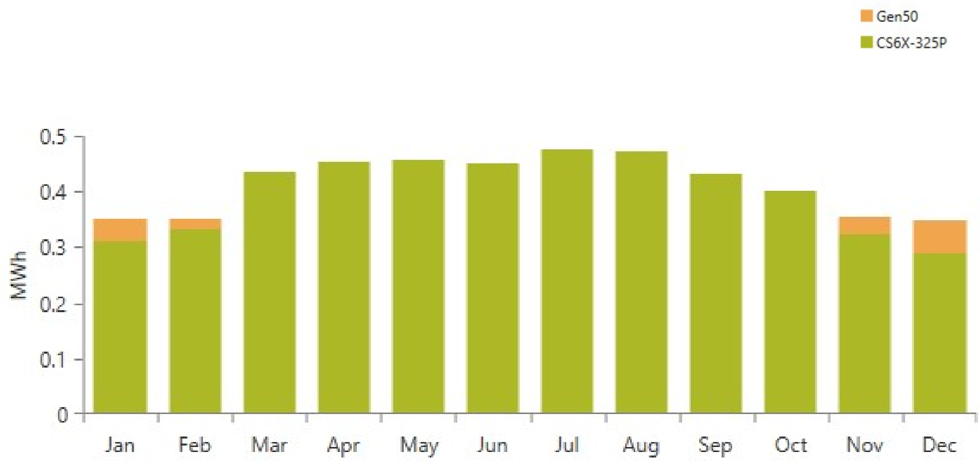


Figure 4.4. Electrical simulation results for the hybrid PV-Gen-Batt system

Figure 4.5. The daily generator power outputs in HOMER PRO

4.3.2 Isolated PV System with Battery

The results reveal that the second optimal solution matches an isolated PV system with a capacity of 3.59 kW and 12 units of lead-acid battery. The solution offers NPC and COE $15,070 and 0.333 $/kWh, respectively. The cost summary of the PV system with battery is summarized in Figure 4.6. It can be noticed that the cost of the system is affected significantly by NPC of the battery bank, which is more than 67% of the total expense. Even though 97% of annual electricity produced in the hybrid system is by solar panels, Homer has not approved it as an optimal configuration due to the initial cost of the battery bank in the solar panel system. However, going deeply into the details, one can see that the difference between the two systems is approximately $1,100, which is not that much for a project that is about 25 years old. In addition, taking the benefit of using a purely renewable system means less reliance on fossil fuels and more conservation of the environment. The cost summary of the PV with battery system is presented in Fig 4.6.

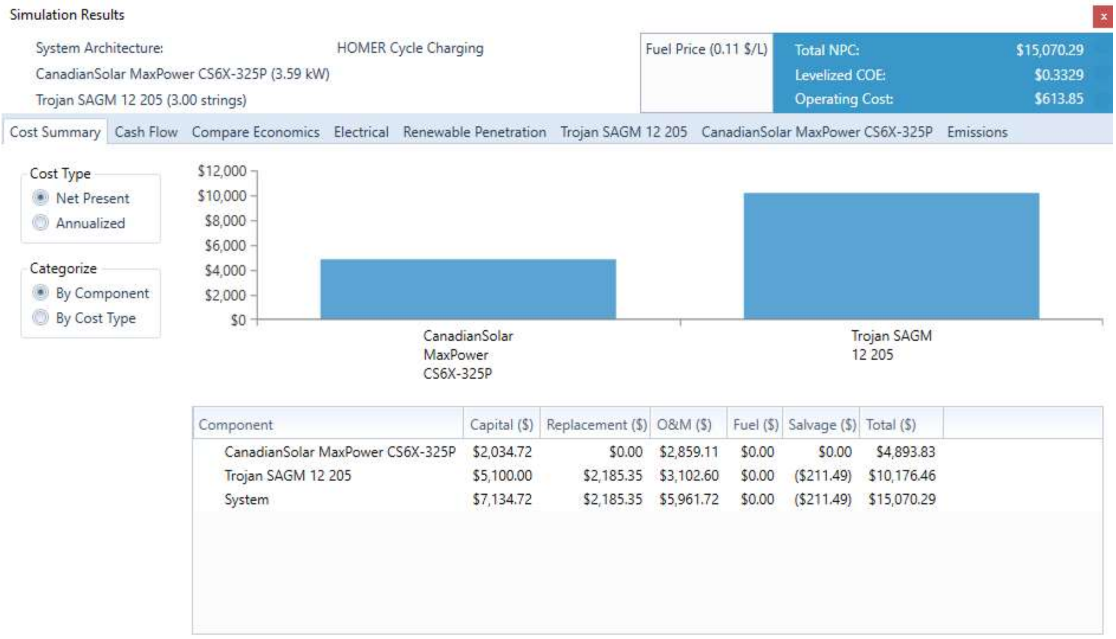
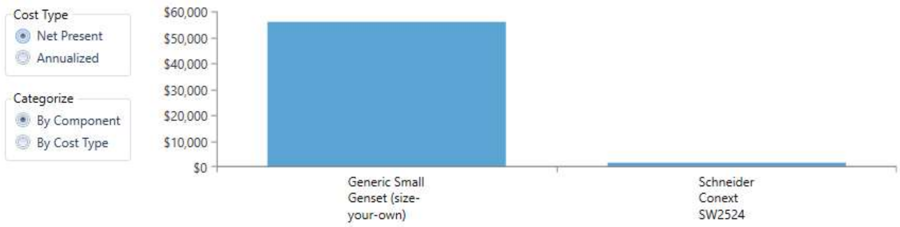


Figure 4.6.Summary of the PV-battery system cost results

4.3.3 Stand-alone diesel generator

The simulation results show that the diesel generator-only is the most expensive solution investigated systems. Its NPC and COE of $57,332 and 1.27 $/kWh, respectively, as shown in Fig 4.7.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic Small Genset (size-your-own)	$500.00	$3,627.34	$3,397.35	$48,269.94	($47.91)	$55,746.72
Schneider Conext SW2524	$984.38	$695.71	$0.00	$0.00	($94.33)	$1,585.76
System	$1,484.38	$4,323.04	$3,397.35	$48,269.94	($142.24)	$57,332.47

Figure 4.7. Cost summary of stand-alone Diesel generator

Although its initial cost is low compared to other systems that compose RE sources with high-cost construction, the diesel generator-only system is poorly economically configuration due to the high expenses associated with fuel, operation, maintenance, and replacement costs. The independent diesel generator's cash flow and power output are exhibited in Figs 4.8 and 4.9, respectively.

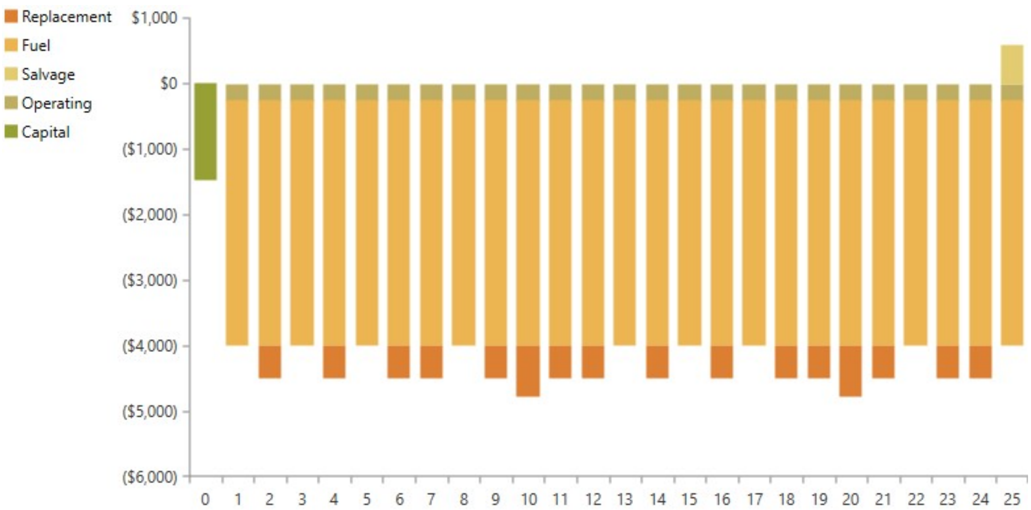


Figure 4.8. Cash flow of stand-alone Diesel generator

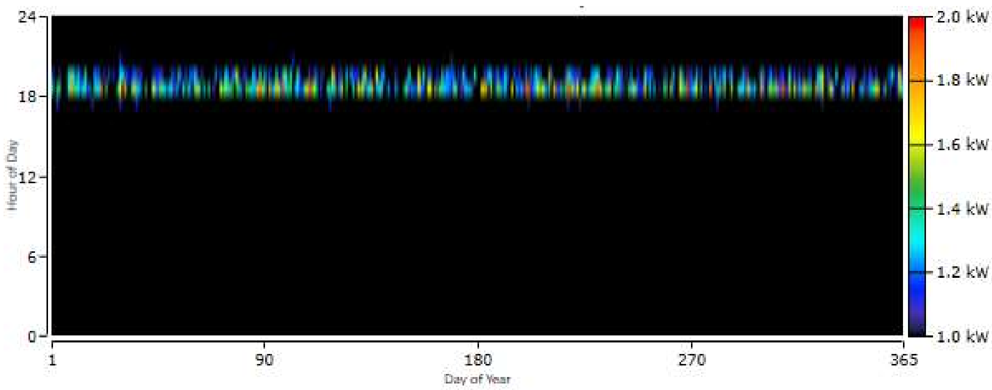


Figure 4.9. Diesel generator power output

In addition to its contribution to raising environmental pollutant emissions, the use of diesel generators only causes an increase in the rate of noise pollution that affects the comfort and health of residents. Since utilizing a stand-alone PV system with a battery does not produce any emissions, a comparison of the gas emissions between a diesel generator system and a hybrid PV/diesel system with a battery is presented in Table 4.2.

Table 4.2 Pollutant's emissions for different systems (kg/yr) in HOMER PRO.

Configuration	Carbon Dioxide	Carbon Monoxide	Unburned Hydrocarbons	Particulate Matter	Sulfur Dioxide	Nitrogen Oxides
hybrid system	159	0.993	0.0437	0.00595	0.389	0.933
DGN only	9,399	58.7	2.59	0.352	23	55.1

4.4 Conclusion

An economic analysis was presented in this Chapter. The investigation was focused on studying different scenarios of independent systems. Besides PV-BAT, DGN-only and hybrid PV-DGN-BAT systems were investigated. The financial comparison between the three solutions was performed in HOMER PRO. The results showed that there is a slight difference in cost in favor of the hybrid system. Still, by looking in-depth at the results in terms of operation cost, prices, availability of diesel fuel, and the emission of pollutants, it became clear that the solar energy system with battery is the most appropriate in the Libyan case.

CHAPTER 5

Dynamic Modeling, Simulation, and Results

5.1 Introduction

Recently, mainly upon on design simulation rather than physical inspection to verify or study a procedure or a recommended design. Model-Based on Design (MBD) is one of these methods. The dynamic model is represented within a simulation program to modify the model. There is no need to conduct the designs tests on the ground, which means a cost reduction and shortening of the completion time. In Model-Based on Design, the system model focuses on a set of procedures, including identifying system requirements, collecting the necessary data, and preparing the designs. The proposed configuration is developed by simulating and testing by a suitable Integrated Development Environment (IDE) to determine whether this design has met the conditions that have been predetermined. An essential benefit of MBD is simplifying design and quickly modifying without using a physical object, decreasing cost and time.

Moreover, it gives us the ability to make comparisons among numbers of models, which assists the designer in making the final design decision. The easy dealing with a graphic interface for designing the systems makes it easy to employ users who are inexpertly dealing with this design approach. Presenting the design in diagrams and charts is considered the preferred way for engineers to comprehend the work [31,32]. In this study, the MATLAB /Simulink environment was used for modeling the proposed PV battery system, as shown in Fig 5.1.

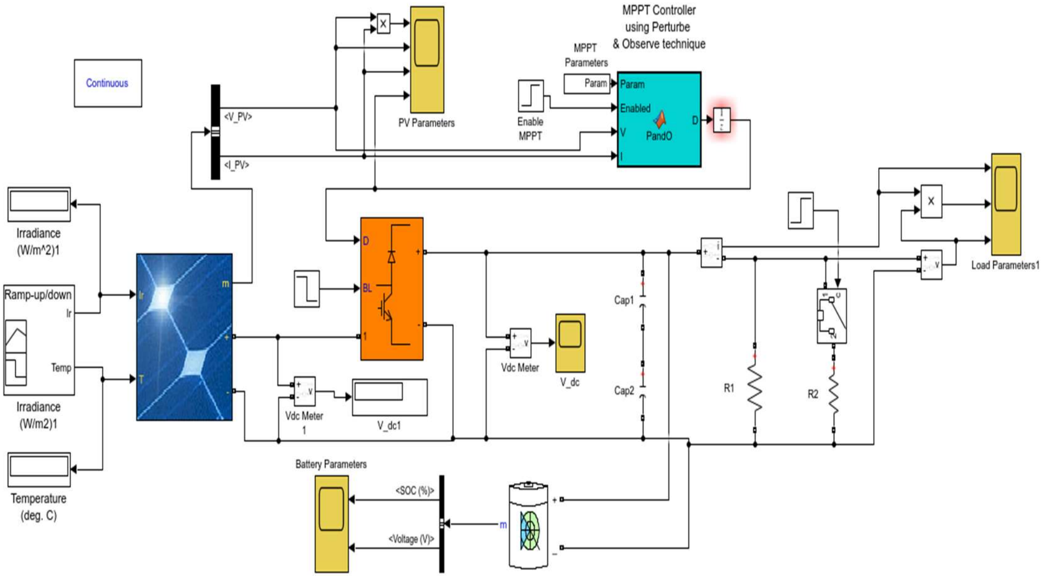


Figure 5.1. MATLAB/Simulink model of the PV-battery system

5.2 The PV array Characteristics

HOMER PRO results proved that the sizing of the proposed system consists of 12 PV panels type CANADIAN SOLAR MAXPOWER CS6U-325P 325W POLY SOLAR PANEL 72 cells. The PV array consists of 6 parallel connections and 2 series string modules. Figure 5.2 shows the PV module configuration and its connection method.

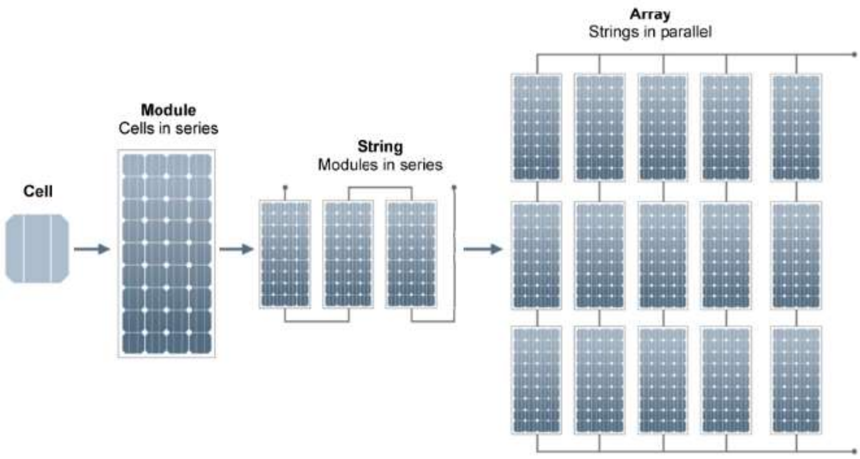


Figure 5.2 PV module configuration and its connection method [33]

The PV array is done in MATLAB by selecting its block from the Simulink library. The block parameter was provided by data as open-circuit voltage, the voltage at the maximum power point, temperature coefficient, etc., were taken from the module datasheet. Figure 5.3 exhibits the block of PV array parameters.

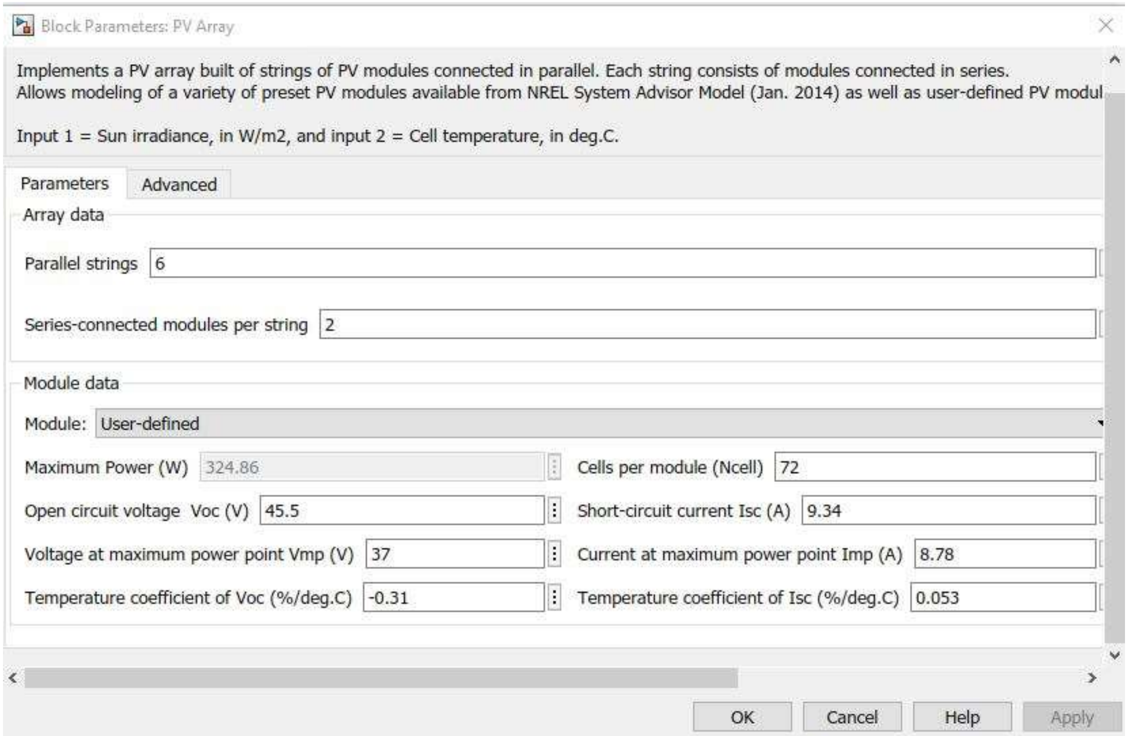


Figure 5.3 PV array parameters of the proposed system

The solar panel's output varies significantly with the difference in solar radiation and the ambient temperature—the PV curves of used panels in various irradiance and temperature are shown in Figs 5.4 and 5.5.

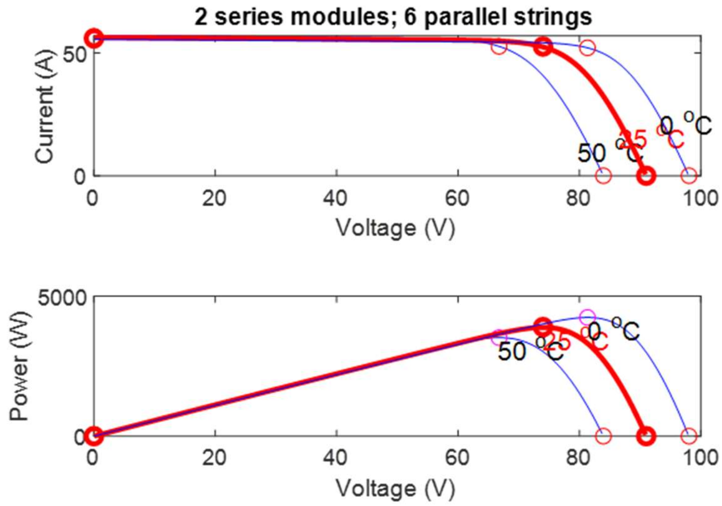


Figure 5.4 PV array characteristic curves with various temperatures in MATLAB/SIMULINK

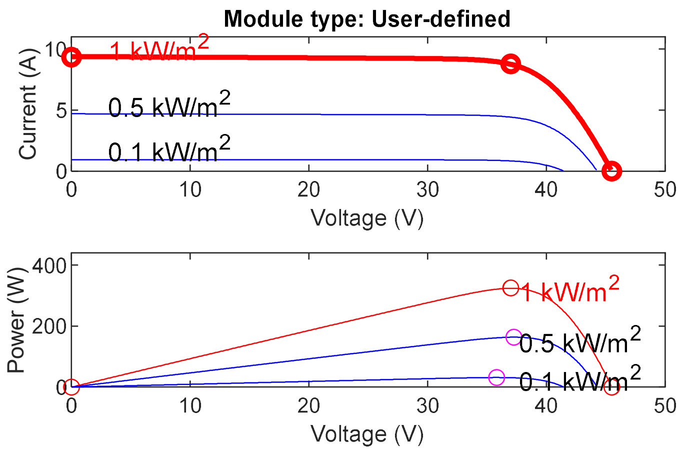


Figure 5.5 PV array characteristic curves with various solar radiation in MATLAB/SIMULINK

5.3 Battery storage system

The battery system contains of 12 batteries, 12 V -219 Ah, string size 4, and string in parallel 3. Figure 5.6 presents the state of charge measured details from the manufacturer for the trojan battery 12V, 229 Ah. Also, the depth of discharge (DOD) in cycle life and self-discharge graphs can be seen in Figs 5.7 and 5.8, respectively [34].

Percentage Charge	Specific Gravity	Cell	12-Volt
100	1.277	2.122	12.73
90	1.258	2.103	12.62
80	1.238	2.083	12.50
70	1.217	2.062	12.37
60	1.195	2.040	12.24
50	1.172	2.017	12.10
40	1.148	1.993	11.96
30	1.124	1.969	11.81
20	1.098	1.943	11.66
10	1.073	1.918	11.51

Figure 5.6. State of charge measure of open-circuit voltage

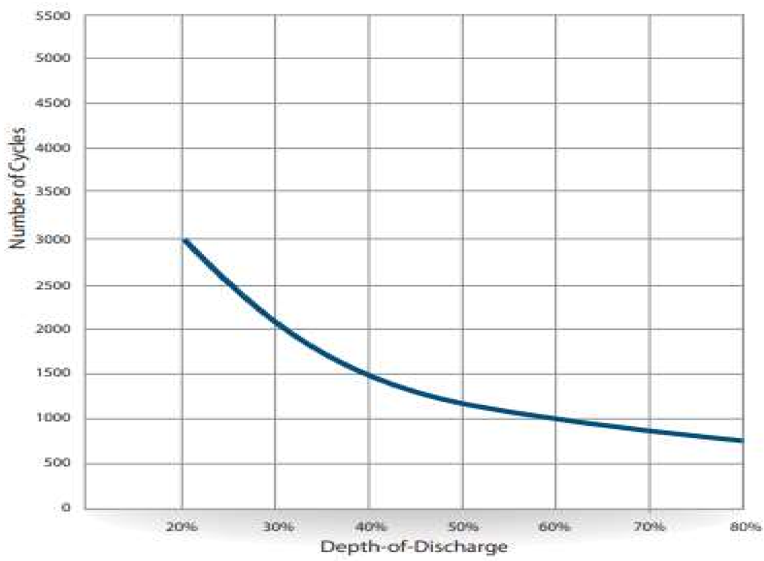


Figure 5.7**.** DOD vs. cycle life in a stationary application

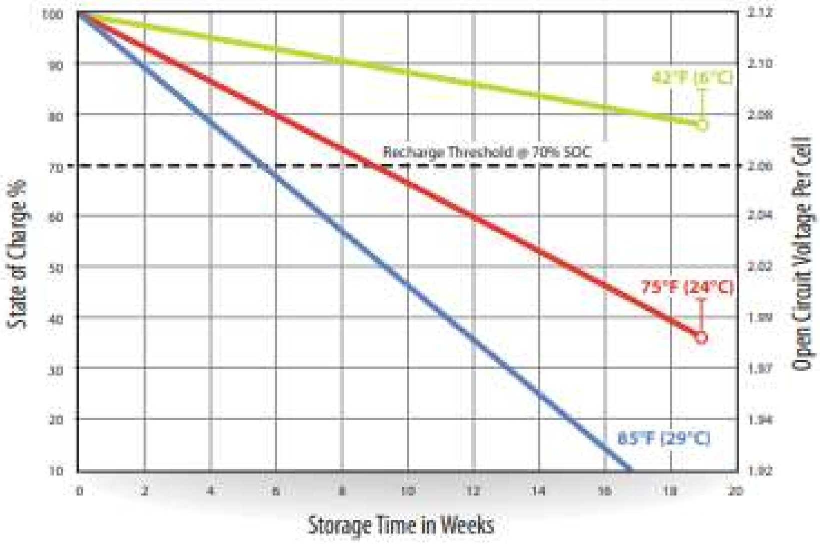


Figure 5.8. Self-discharge vs. time

The battery's block parameters in SIMULINK were provided with data such as the nominal voltage, rated capacity, the initial state of charge, and response time of the proposed battery system, as demonstrated in Fig 5.9.

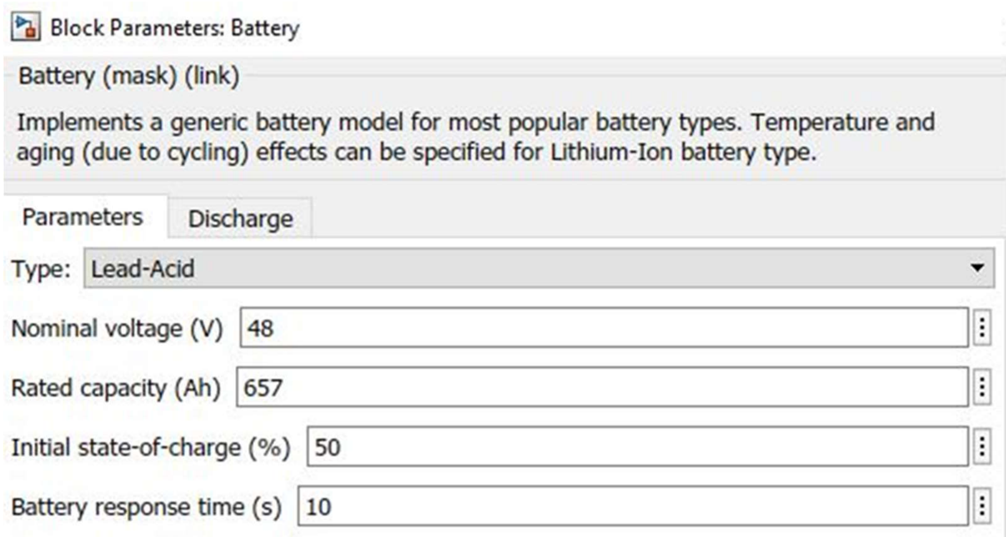


Figure 5.9 Battey bank parameters of the proposed system

5.4 Boost converter and Maximum power point tracking for PV systems

5.4.1 Boost Converter

The DC-DC converter is coupled between a PV module and the load to enhance and maintain non-linear DC voltage generated by the PV panels within the desired limits and charge the battery system. The main parameters in the boost converter are Maximum Power Point Tracking (MPPT), the Pulse-Width Modulation (PWM), the inductor, and the capacitor. Equations (5.1) and (5.2) for the boost converter are utilized to determine the input and output capacitors' values as follows [35,36]:

$$C_{in} \geq \frac{I_{max} \times D_{max}}{0.02 \times [(1-D_{max}) \times V_{in} \times \mathrm{F_{sw}}]} \quad (5.1)$$

$$C_{out} \geq I_{max} \times D_{max} \times \Delta \mathrm{V} \times \mathrm{F_{sw}} \quad (5.2)$$

where, D_{max} is the maximum duty cycle, F_{sw} is the switching frequency, and ΔV is the voltage ripple.

Figure 5.10.presents the boost converter block in SIMULINK.

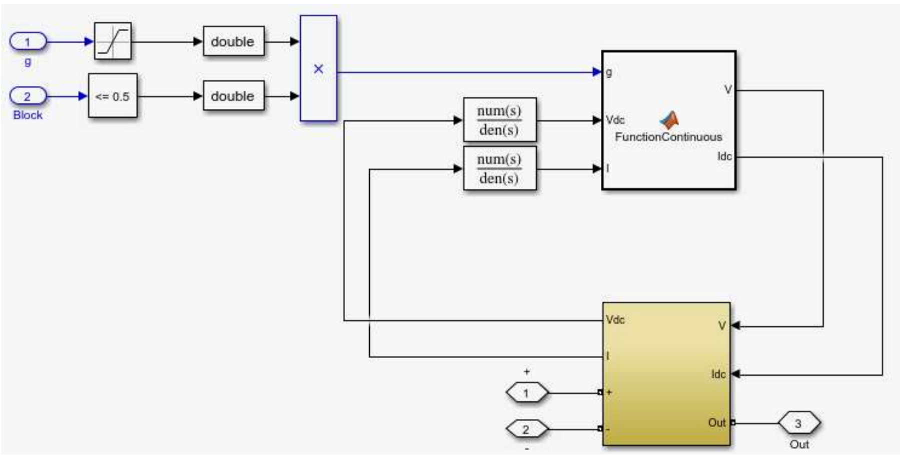


Figure 5.10. Boost converter in MATLAB/SIMULINK

5.4.2 Maximum Power Point Tracking (MPPT)

The control of the Algorithm is an essential stage of an MPPT, which is decisive for the raise or the reduction of the duty ratio that drives MOSFET to ensure the solar panels generate maximum possible power of solar radiations and temperature variations. The perturb and observe method is used for the MPPT technique in this design by controlling the duty cycle of the boost converter. It is one of a widely used methods, while voltage and current are applied to the function that handles the duty cycle value according to the following equation:

$$D = 1 - \frac{V_i}{V_O} \qquad (5.3)$$

where D is the duty cycle, Vi is the input voltage, and Vo is the output voltage

The output voltage is almost constant; the differences in the duty cycle stabilize the variations in the input voltages as this maintains the current. The Algorithm detects the point at that maximum power point can be tracked, hence:

$$P_{max} = I_{max} \times V_{max} \qquad (5.4)$$

The idea of this method is to select a reference voltage and keep changing the output voltage to decrease the power variation. MPPT utilizes the available maximum power output of the PV. The Algorithm is implemented according to the flow diagram, as shown in Fig 5.11.

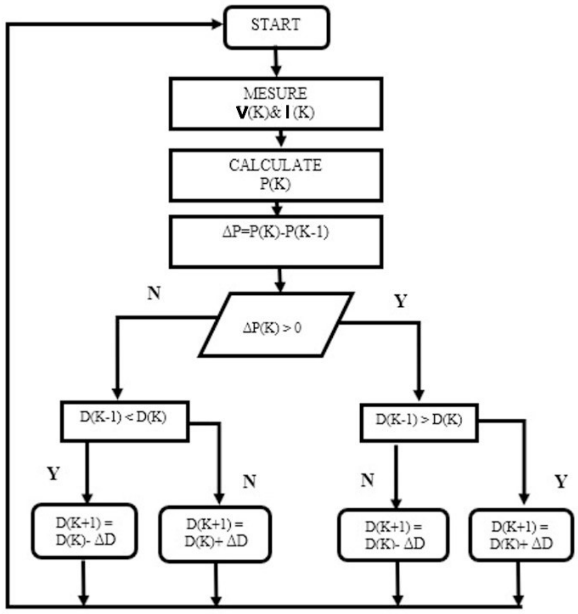


Figure 5.11. Perturb and observe Algorithm

5.5 Result and Discussion

The PV battery system is greatly affected by changes in temperature and radiation, so the system's output has been correlated with a DC/DC boost converter with the Maximum Power Point Tracker (MPPT) controller. The perturbation and control method is implemented in this model to regulate the duty cycle of the Algorithm of MPPT, which controls the output DC voltage to 48 V and supplies it to the load and battery bank. The battery bank will be out of use when the PV array production power meets the house load. Therefore, the battery bank's primary duty is to feed the loads at night and in cloudy weather. The state of charge SOC of the battery bank and the PV array outputs are presented in Figs 5.12 and 5.13, respectively.

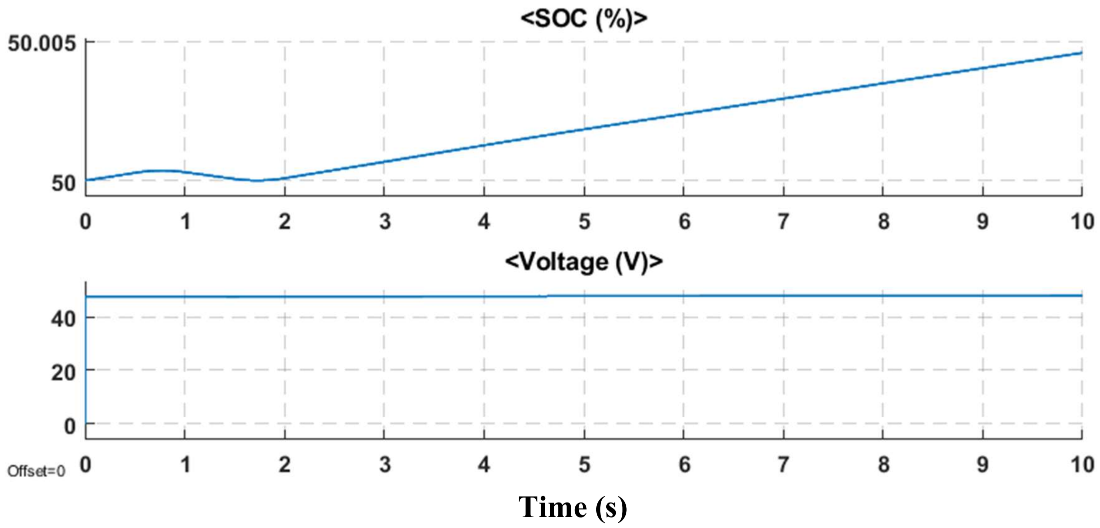


Figure 5.12. Battery state of charge and voltage

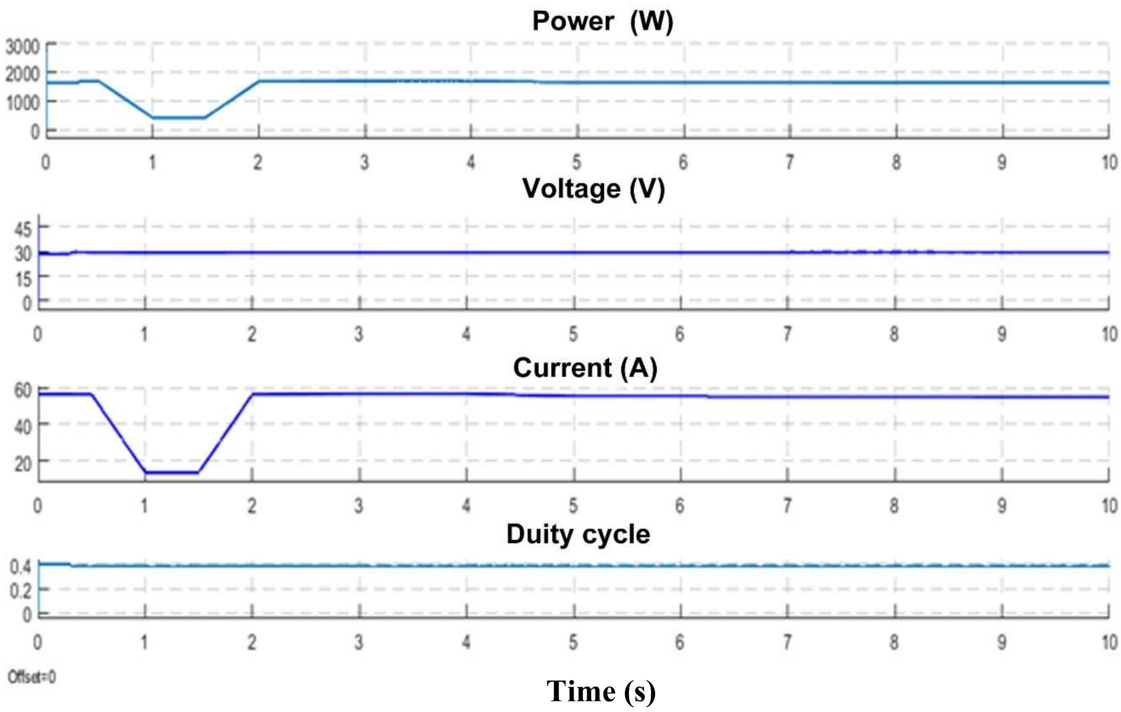


Figure 5.13. PV array power, voltage, and current.

The house's load was divided to apply two scenarios on the proposed system to ensure its stability with various load demands. The PV system was connected with half and with a full load. Despite the difference in loading, the system's final desired output showed to be stable at 48 V DC voltage, as revealed by Figure 5.14.

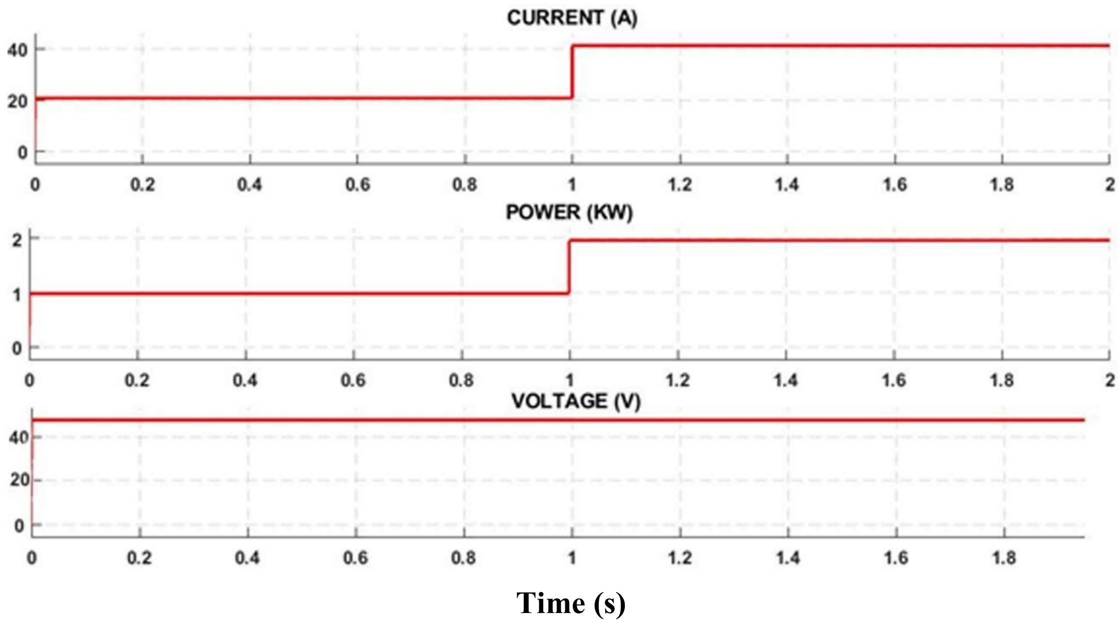


Figure 5.14. The load voltage, current, and power

5.6 Conclusion

In this chapter, the system of the PV array, residential load, Boost Converter, MPPT controller, battery storage, and inverter is presented in this model. The performance of the system was assessed under various solar irradiance. The results showed that the output power of the PV array was increased proportionally to the increase in the solar irradiance and the system's output voltage is almost stable under the variation of the solar irradiance.

CHAPTER 6
CONCLUSION

6.1 Conclusion

This study included an optimal design and analysis of a stand-alone PV system with a battery to supply a rustic house in Libya. A 48 DC volts were chosen as bus voltage after reviewing previous works related to the use of the DC as a power supply. BEopt was utilized to estimate the demand load for a building in Benghazi surroundings. The specifications and configurations of the house were used. The outputs of carrying out thermal modeling of the loads by the BEopt program showed that the annual load of the house is 3491 kWh/year. The third section of the thesis covered the amount of solar radiation at the selected site of the proposed PV system. The HOMER PRO was used to evaluate various components of the solar system. Findings showed that the optimized system consists of 12 PV panels 325 W each and 12 lead-acid batteries 12 V, 219 Ah to store excess generated power and cover the load demand at night-time and cloudy weather. Then a detailed economic analysis was performed. Three scenarios were investigated. The financial comparison between stand-alone PV systems with battery, independent Diesel generator, and hybrid PV-DGN-BAT system solutions was performed in HOMER. Complete modeling, sizing, and optimization for the stand-alone. PV-battery systems with DC load have been presented in this research. The performance of boost converter, MPPT controller, and battery bank charging are evaluated under various—solar irradiance. MPPT controller made significant improvements on PV array outputs, leading to the system's final desired output voltage of 48V DC with a stable operation. The results showed that the proposed stand-alone PV system with a capital cost of $15,070 is stable, and it can fully meet the house load. However, it was not the cheapest solution during the economic analysis where there is only an $1175 disparity in cost in favor of the hybrid system.

In contrast, by looking at operation cost, prices, and diesel fuel availability, diesel fuel is not always available because of the high demand, especially in the southern regions. Moreover, the solar energy system is noise-free and does not produce any emission pollutants; Therefore, it is an effective solution in Libya. Also, there is excess annual energy of 2,595 kWh that can be used in the future for an additional load.

6.2 Research Contribution

The essential contributions from this work are as follow:

- Identification of the optimal design of stand-alone PV system to supply rural house in Libya and thermal analysis.
- Possibility for utilization of DC instead of AC as a power source in Libya due to its efficiency conversion losses and safety.
- A comprehensive economic feasibility analysis by making a comparison between various systems using HOMER software.
- Dynamic modeling of the designed PV system in MATLAB/Simulink to assess the system's performance with different conditions.

Here are some important observations and recommendations to utilize solar energy systems in this study to feed the grid-connected loads with a sustainable energy source:

- The battery bank is a crucial factor impacting the capital cost of isolated PV battery systems. For this reason, it is necessary to decrease its size by reducing the demand load.
- Since heating and cooling loads represent 40% of the total household consumption [21], it is recommended to increase the insulation of homes by changing the construction technology currently used in Libya, which relies on cement bricks without any insulation.
- It is recommended to take advantage of the surplus produced electricity from the independent PV battery system by selling it to the grid if this policy is adopted in the future.

- Giving the state incentives for RE projects - the reduction of their cost should play an essential role in motivating the Libyan population to switch to RE systems.

6.3 Future Work

As part of the future work, the following could be done:

- Adding wind turbines to the designed system and studying its effect in reducing dependence on the battery system and thus reducing the cost.
- Study the effects of dust on the photovoltaic system and dust cleaning methods.
- Add SCADA system to monitor various parameters of the hybrid system.
- Expanding the utilization of the pattern of this study so that a hybrid micro-grid network is designed to supply grid-connected loads for a residential community in Libya. The prime idea will be to classify the loads in the housing units according to their importance to DC and AC loads. In the case of outages and subtracting, the necessary loads are fed by the PV arrays with a battery system installed for each unit. However, the large load will supply when the grid is available. This aims to diminish the cost of establishing RE projects by minimizing the PV system load. Moreover, the ability to sell the excess power generated from the alternate source when the grid and the situation are stable in Libya through preform FiT policy. In addition, it contributes to reducing carbon dioxide emissions.

6.4 Publications

Youssef Dabas, M. Tariq Iqbal, "Sizing and Analysis of a DC Stand-Alone Photovoltaic-Battery System for a House in Libya." Jordan Journal of Electrical Engineering. - Volume 7, Number 2, June 2021

Youssef Dabas, M. Tariq Iqbal, Design and analysis of an isolated PV system for a house in Libya, presented at the 28th Annual IEEE NECEC conference St. John's, November 19th, 2019.

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