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Somia BECHLAGHEM

MODELING, SIMULATION AND SIZING OF A MICROGRID IN THE UNIVERSITY CAMPUS

Defended on 08/11/2020 ***Before the Following Committee:***

Chair	Prof.	Mohammed Osman Sid Ahmed	SUST, Khartoum, Sudan
Supervisor	Prof.	Zahera DIB	University of Tlemcen
External Examiner	Prof.	Leila GHOMRI	University of Mostaganem
Internal Examiner	Prof.	Souhila BENSMAINE	University of Tlemcen

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ENERGY SCIENCES (INCLUDING CLIMATE CHANGE)

ENERGY ENGIGNEERING
MASTER THESIS DRAFT PLAN

TOPIC:

MODELING, SIMULATION AND SIZING OF A MICROGRID IN THE UNIVERSITY CAMPUS

CASE STUDY: CHETOUANE, TLEMCEN, ALGERIA
NORTH AFRICA

SUPERVISOR: PROF. Zahera DIB

PREPARED BY: Somia BECHLAGHEM

SUPERVISOR	STUDENT

STATEMENT OF THE AUTHOR

I Somia BECHLAGHEM, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

STUDENT

Somia BECHLAGHEM
Academic Unit: Energy (Engineering Track)
PAU Institute: PAUWES
Date: 11 /2020

SIGNATURE

SUPERVISOR

Dr. Zahera DIB
University of Tlemcen

SIGNATURE

DEDICATION

To my parents,

who have always stood by my side

To my sister and brothers,

for their love and support

To all my friends,

for all the motivation and help that they had given me

I dedicate this work.

ACKNOWLEDGEMENT

I would like to express my gratitude and appreciation to all those who have given me the opportunity to complete this work. I would like to take this opportunity to express my deepest gratitude to the African Union Commission for giving me to be part of the Pan African family. I would like to thank those who have provided help and support during the preparation of this work. I am grateful to my supervisor Madam Zahera DIB, who has devoted a lot of effort and assistance during this whole journey. Special thanks go to Mr. N. ZERHOUNI and Mrs. L. CHIALI for their valuable efforts, support, and guidance.

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ABSTRACT

The current power grid is one of the most complex engineering systems in the world. Electricity generation in the traditional power grid is very centralized, where energy is delivered unidirectionally from power plants to end-users via a transmission network.

With a worldwide increase in population and thus in electricity demand, the technical problems as well as the environmental concerns associated with fossil fuel combustion have stimulated research to develop new technologies for more sustainable, reliable, and efficient energy systems. With the emergence of Distributed Energy Resources as Solar, wind, biomass, etc., smart microgrids are gradually being recognized as a solution for various problems in the current power system especially for remote regions and well-defined loads as university or military campuses. Using renewable energy sources along with the traditional power generators, also energy storage, and controlling the energy usage are some of the novel aspects of smart microgrids.

The purpose of this study is to propose a modeled and simulated design of a DC microgrid for a localized area in the “university campus of Chetouane”. The system is grid-connected and can provide energy autonomously using solar panels, with a backup supply of batteries and a diesel generator.

The research results will be valuable to the energy management sector and related decision-makers in developing better tools for sustainable and cost-effective energy. This study focuses on the adoption of a decentralized hybrid electricity system in Algerian universities and goes hand in hand with the government's objective to diversify its energy mix as well as going towards achieving SDG's and global targets.

Keywords:* *DC Microgrid, renewable energies, distributed energy, PV, energy storage system, Diesel generator, Simulink MATLAB, PVsyst, energy management system, grid connected mode, island mode

RÉSUMÉ

Le réseau électrique actuel est l'un des systèmes d'ingénierie les plus complexes au monde. La production d'électricité dans le réseau électrique traditionnel est très centralisée, l'énergie étant acheminée de manière unidirectionnelle des centrales électriques aux utilisateurs finaux via un réseau de transmission.

Avec l'augmentation de la population mondiale et donc de la demande d'électricité, les problèmes techniques ainsi que les préoccupations environnementales liés à la combustion des combustibles fossiles ont stimulé la recherche pour développer de nouvelles technologies pour des systèmes énergétiques plus durables, plus fiables et plus efficaces. Avec l'émergence des ressources énergétiques distribuées comme le solaire, l'éolien, la biomasse, etc., les micro-réseaux intelligents sont progressivement reconnus comme une solution à divers problèmes du système électrique actuel, en particulier pour les régions éloignées et les charges bien définies comme les campus universitaires ou militaires. L'utilisation de sources d'énergie renouvelables en plus des générateurs d'électricité traditionnels, le stockage de l'énergie et le contrôle de l'utilisation de l'énergie sont quelques-uns des nouveaux aspects des micro-réseaux intelligents.

L'objectif de cette étude est de proposer une conception modélisée et simulée d'un micro-réseau à courant continu pour une zone localisée dans le "campus universitaire de Chetouane". Le système est connecté au réseau et peut fournir de l'énergie de manière autonome à l'aide de panneaux solaires, avec une alimentation de secours par batteries et un générateur diesel.

Les résultats de la recherche seront précieux pour le secteur de la gestion de l'énergie et les décideurs concernés, car ils permettront de mettre au point de meilleurs outils pour une énergie durable et rentable. Cette étude se concentre sur l'adoption d'un système électrique hybride décentralisé dans les universités algériennes et va de pair avec l'objectif du gouvernement de diversifier son bouquet énergétique ainsi que d'atteindre les objectifs de la SDG et les objectifs mondiaux.

Mots-clés : Micro-réseau DC, énergies renouvelables, énergie distribuée, PV, système de stockage d'énergie, générateur diesel, Simulink MATLAB, PVsyst, système de gestion de l'énergie, mode connecté au réseau, mode îlot.

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LIST OF ABBREVIATIONS

SDG	Sustainable Development Goals
MENA	Middle east and North Africa
DC	Direct Current
AC	Alternative Current
PV	Photovoltaic
GDP	Gross Domestic Product
DER	Distributed Energy Resources
DG	Distributed Generation
ES	Energy Storage
ESS	Energy Storage Systems
CHP	Combined Heat and Power
DES	Distributed Energy Sources
CCHP	Combined Cooling and Heating Power
DR	Distributed Resources
MPPT	Maximum Power Point Tracking
CAES	Compressed Air Energy Storage
SMES	Super-conducting Magnetic Energy Storage
PQ	Power Quality
SG	Smart Grids
HEMS	Home Energy Management System
BEMS	Building Energy Management System
AMI	Advanced Metering Infrastructure
IoT	Internet of Things
O&M	Operation and Maintenance
LCOE	Levelized Course of Energy

CHAPTER 1.
INTRODUCTION

1.1 Background of the research project

A series of profound inequalities characterize the world of energy. According to the Energy Access Outlook 2019 [1], nearly one billion people worldwide (13% of the global population) continue to be left in the dark with no or limited access to electricity. More than two-thirds represent people living in sub-Saharan Africa, mainly in rural and remote areas, while affording efficient and cost-effective electricity for all is one of the most SDG’s priorities. Also, the disparity between the expectations of a rapid renewable energy drive transition and the reality of today’s energy system relying obstinately on fossil fuels. It is worth mentioning the existence of another gap between the latest scientific evidence underlining the need to reduce global greenhouse gas emissions faster than ever before and the data showing that today energy-related emissions have hit a record high (40% higher than emissions in 1990) [2].

The international community is increasingly recognizing the major environmental problems caused by human activities. The World Energy Council is an international organization that supports the development of accessible and sustainable energy worldwide. It stresses the importance of taking into account energy security, energy equity, and environmental sustainability. Thus, the energy transition involves a radical change in energy policy [3].

In 2000, 817 million Africans made up just over 13 % of the world's population; by 2018, that percentage had risen to about 17 %, bringing Africa's population to nearly 1.3 billion, more than double the global growth rate [1].

With such growth, access to modern energy is a central pillar to reduce poverty and sustain Africa's economic growth. That can be achieved through expanding energy production capacity (on-grid and off-grid) and energy sources diversification switching to more sustainable and green energy. Regardless of the abundant renewable energy sources, Africa holds from solar to wind, biomass, and hydro to geothermal energy. These sources have not been exploited due to the limited policies and lack of investment financing.

Algeria is holding the first place in Africa in terms of surface size, with a desert covering 80% of its area. Its geographic location represents an excellent potential for renewable energy sources, especially solar energy. The significant economic transformations that have been witnessed in recent years globally have made it necessary for Algeria to undertake structural changes to gradually adapt to these changes, particularly in the energy sector. By promoting the use of renewable energy technologies for power generation, and targeting a share of 27% of renewables in the energy mix by 2030 [4], Algeria is aiming to reduce its reliance on fossil fuels.

The modern electrical grid is one of the most complex engineering systems. In the traditional power grid, power generation is highly centralized, with energy moving unidirectionally from generators to end users via a transmission/distribution network. However, conventional power utilities' technological and environmental problems have boosted research and development of new technologies for energy systems. With the emergence of distributed energy resources, e.g., wind, photovoltaics, batteries, fuel cells, etc., microgrid technologies as an effective way to integrate renewable distributed generation into power systems have attracted increasing attention [5]. Microgrids can control distributed generation efficiently, flexibly, and smartly [6]. Therefore, it can best improve reliability, costs reduction, and enhance the efficiency of the electrical system [3].

1.2 Problem Statement

Recently, the electric power system is facing a radical transformation worldwide. With the population growth and the pressure on the national power grids, energy production is moving towards centralized power stations by adopting microgrids.

Microgrid deployments are expanding in the world’s power systems, and they are very interesting solutions to supply autonomous power to particular loads such as university campuses, hospitals, or military bases. University campuses were among the early adopters of microgrids for many reasons, specifically for their large and well-defined loads.

In Algeria, providing free education and accommodations, university campuses and dormitories are supplied with electricity from the primary centralized grid. However, demographic rhythms impose severe limits and weigh heavily on existing grids.

According to Eco MENA [7], based on its geographical location, Algeria contains an enormous solar energy potential in the world with an estimation of 13.9 TWh per year. The annual sunshine exposure in Algeria is equivalent to 2,500 KWh/m2. Daily solar energy potential varies from 4.66 kWh/m2 in the north to 7.26 kWh/m2 in the south.

With such potential, the government is seeking to harness by launching an ambitious renewable energy and energy efficiency program.

The program aims to produce 22,000 MW of energy using renewable energy resources between in a period between 2011 and 2030, with more than 12,000 MW destined for domestic consumption while the rest for export. The program focuses on the development and increased use of renewable resources such as solar, wind, biomass, geothermal, and hydropower to diversify reliable energy sources and promote sustainable development of the country [7].

In order to achieve these targets, and tackle the environmental and economic problems related to the reliance on fossil fuels, adopting microgrids in remote areas and public construction and buildings can best meet these requirements.

1.3 Aim and Objectives

This study aims to propose a modeled and simulated design of a DC microgrid for a localized area in the “University Campus of Chetouane” which is the PAUWES building. An off/on-grid hybrid system that will rely on PV power generation with a backup of diesel generator and batteries.

The objective is therefore to design, study, analyze and develop a direct current (DC) microgrid that integrates photovoltaic (PV) sources, which are the most common renewable energy sources for urban and rural areas. This system should be capable of extracting the maximum power from the photovoltaic panels and manage the transfer of energy to the load while taking into account the connection to the public grid, available storage units and other back-up source represented by a diesel generator. The ultimate goal is to achieve, through intelligent control, an optimized local production-consumption of electricity, in secure mode, with a controlled injection of power while taking into account the fluctuations in metrological parameters.

Our study will target the following question:
How can the challenges related to the operation and control of the microgrid system be addressed and what are the proposed solutions?

This research results will be valuable to the energy management sector and related decision-makers in developing better tools and projects for sustainable and cost-effective energy. This study is about adopting hybrid decentralized power system in Algerian universities and goes along with the government's aim to diversify its energy mix to reach the energy target plan 2030.

1.4 Methodology

To achieve our objective, our research has proceeded through the following steps:

- *Step 01:* Demand-side management by evaluating the campus' existing energy infrastructure. Because of the COVID-19 pandemic, it was impossible to perform a walkthrough energy audit; therefore, for collecting data regarding the energy performance of the building and forecasting the load profile, our estimation was based on a previous valid audit performed by a group of students in 2019.
- *Step 02:* Supply-side management, the first thing to be done in this stage was to collect the metrological data as solar radiation and temperature, in addition to reviewing and studying the operation of microgrid system. And finally, sizing the system using PVsyst, by assessing the geographical position, implementation surface, and Market choices/prices.
- *Step 03:* Simulation and control Using Simulink MATLAB, the system is simulated and modeled in different scenarios and with several conditions and cases.
- *Step 04:* at the end, Financial, Environmental, Analysis were conducted to see how effective the system is and its impact on both energy savings and environmental protection.

1.5 Justification

Our hybrid system, composed of PV panels with batteries and a diesel generator, is a reliable university campus solution that reduces energy reliance on the primary grid. This solution can be extended to other well-defined load constructions and especially in remote areas. This study is very relevant for improving access to electricity in African rural regions.

Moreover, this work is of significant importance for Algeria as It will help reduce the high dependence on conventional energy sources (primarily gas) and contribute to strengthening low-cost and environmentally friendly energy supply.

1.6 Scope and Limitations

Not all the complex characteristics of the hybrid microgrids can be studied in a single research project; hence this master thesis focuses only on a specific target case study: sizing, modeling, and simulation of a DC microgrid within the particular building of the university campus of Chetouane.

Because solar energy is abundant at the location where the case study is being undertaken, Photovoltaic power was selected in preference to wind power. Besides, many recent projects and investments are being carried out in the field of solar energy worldwide.

Diesel generators are the best-known conventional power generators used in remote sites. Yet, using a fossil fuel generator limits the switch to more clean energies.

Furthermore, adding an energy storage system makes the power generated hard to be a price competitive to the grid power, giving the fact that batteries are the most expensive part of the system.

1.7 Conclusion

This chapter provided an overview about the problem statement and the targeted objectives of the current study. Given the short history of microgrid and being a relatively new research domain, many technologies are still under test. With researches on this area going deeper, the subsequent chapter explores the literature providing an overview about our topic.

CHAPTER 2.
LITERATURE REVIEW

2.1 Introduction

This chapter provides the key insights from the history of related projects and works conducted in the research topic. Also, it includes an overview about Algeria where our case study occurs, followed by a deep dive into the different aspects of microgrids and electrical networks.

2.2 Related works

A microgrid, as a concept, was originated in The United States [6]. Today, microgrids are very often proposed in energy distribution networks, and this increased use can undoubtedly change the traditional topology of the system. DC micro-grids are expected to provide energy efficiency. There is a lot of research on different aspects of microgrids; those studies vary from one application to another. On the other hand, the main research issues in the field of microgrids are related to energy quality and management, operational safety, communication, control, and economics. However, system control, protection, and energy management seem to be the most important ones [3].

In 2001, Professor R.H. Lasseter from the University of Wisconsin-Madison first proposed a "micro-network" concept. In the meantime, the Consortium for Electric Reliability Technology Solutions (CERTS) and the Micro-Grid project of the European Commission also provided their definitions of a micro-grid.

In 2002, the National Technical University of Athens (NTUA) set up a small laboratory microgrid project known as the NTUA Power System Laboratory Facility for tests on distributed resource and load monitoring with multi-agent technology.

Since 2003, numerous pilot projects have been undertaken worldwide, including the 7.2 kV microgrid at Mad River Park in Vermont USA, the 400 V microgrid on the Kythnos Islands in Greece, and the Aichi, Kyotango, and Hachinohe projects in Japan.

Nowadays, many universities, research institutes, and large companies carry out studies on the microgrid and have set up demonstration projects [6].

Authors in [8] investigated microgrid structures and reviewed campuses’ case studies in different universities in the world. Starting from USA universities, The University of California, San Diego (UCSD) with 42 MW microgrid; Illinois Institute of Technology, Chicago, with 20 % of the load supplied by the microgrid; New York University, New York with 13.5 MW microgrid capacity and other universities. The article moves to Europe, presenting The University of Central Lancashire, the UK with 300 kW capacity, The University of Genoa, Italy with 250 kW of electricity auto-generation, the Technical University of Denmark with 36 kW power capacity. Furthermore, the authors reviewed other case studies in both Thailand, China, and Turkey universities.

Marina Elenkova*et al.* presented in [9] a simulation platform for smart microgrid configuration in the Democritus University of Thrace (DUTH) in Greece. The micro-grid cited includes photovoltaic, energy storage units, and load management schemes by analyzing the actual power consumption.

In [10], a control strategy for energy management is proposed by a scheduling algorithm for the optimal operation of a microgrid and its real-time application. The results show the benefits of the suggested programming to make optimal and harmonious use of the adopted microgrid, even in varying transitions between grid-connected and island modes.

A microgrid based on wind and solar energy sources was also proposed in [11], where the authors discuss issues related to the system's functioning, control, and stability. Thanks to Matlab/Simulink, the system was modeled and simulated to identify relevant technical problems associated with microgrid operation based on renewable energy production units.

In [12] Chanaka Keerthisinghe and al. evaluated a microgrid planned to be installed by Snohomish PUD in Arlington, WA, using a real-time digital simulation on an OPAL-RT real-time digital simulator. This model allows the study of different operating conditions before deploying the microgrid at field by the end of 2021. Once the microgrid is operational, the authors will compare the actual simulations with real measured data.

Considering that our research work is carried out in Algeria, and according to the bibliographical survey taking Algeria as a case-study, a lack of investigations related to our subject also underlines our research's importance and significance.

Three main relevant works were reviewed, starting from [13], where the researchers proposed a first conception of a microgrid in the Sahara area, which includes diesel, wind, and solar energy. Thanks to MEGASIM of the RT-LAB platform, the model was applied in real-time simulation. The obtained results facilitate the understanding of microgrid's operation in terms of power flow and default responses.

In Algeria’s same region, the authors in [14] presented a DC microgrid for agricultural farms in Adrar zone. The microgrid modules were illustrated using the distributed energy resources and power converters' mathematical and equivalent circuits. The DC microgrid was then evaluated using MATLAB Simulink and ETAP software to study both the transition and the steady-state parameters.

A very relevant case study for our research was conducted in [15], where the analyses presented an estimation of photovoltaic energy potential in the USTO campus located in Oran city. In addition to that,[16] provides a comparison between the output of photovoltaic and energy consumption in the university of USTO. The solar photovoltaic energy produced is analyzed taking into account economic aspects such as the cost of investment and the annual cash flow from energy production. The installed capacity of the photovoltaic system has been calculated, and the energy produced is estimated. The feasibility analysis shows an internal rate of 5% return, a payback period of 10.3 years, and a profitability index of 1.78.

2.3 Algeria Overview

Algeria, a large North African country of nearly 2.4 million km^2[17]. From the Mediterranean coast, where the majority of its population lives, Algeria stretches southwards into the heart of the Sahara, a hostile desert where the highest surface temperatures on the planet have been recorded and which makes up more than four-fifths of the country's surface area (more than two million km^2). The Sahara and its extreme climate dominate the country.

Algeria is bordered to the east by Tunisia and Libya; to the South by Niger, Mali, and Mauritania; to the west by Morocco and Western Sahara; and to the North by the Mediterranean Sea. It is a vast country - the largest in Africa and the Arab world and the 10th largest in the world [18] between the 38°-35° of latitude north and 8°-12° longitude east. The northernmost region, generally known as Tell, is subject to the Mediterranean's moderating influences and consists mainly of the Atlas Mountains, which separate the coastal plains from the second region to the South. This southern region, which is almost entirely desert, makes up most of the country's territory and is located in the Sahara's western part, which stretches across North Africa. On the other hand, its 1,200 km of coastline gives it a strategic continental position in the Maghreb heart.

Four factors clearly outline Algeria's future potential: the country's geographical qualities, its demographic composition, its oil wealth, and its modern and experienced security sector. Algeria is also a demographic power with 43.8 million (in May 2020) [17]. Its capital, the most populous city, is Algiers, located in the North of the country. Administratively, Algeria is divided into 48 provinces called Wilayas.

Algeria is one of the largest energy-producing and exporting countries in the world. This has been achieved by implementing strategies and policies to promote energy resources' economic, social, and environmental use.

Figure 2.1. Algeria's map [19]

Figure 2.2. Algeria's Localisation [20]

2.3.1. Economy vs. Energy in Algeria

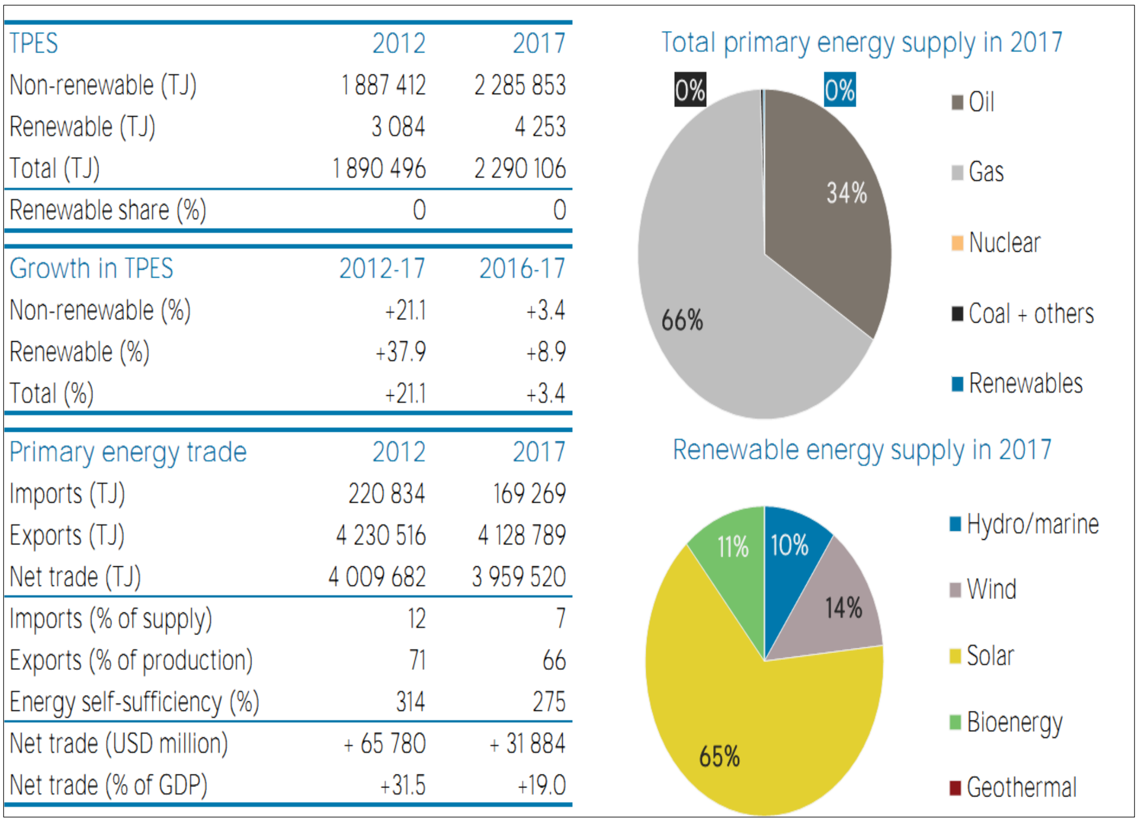
Algeria, the third most important economy in the MENA region and a leader in the Maghreb, is one of the many countries that have achieved a 20 percent reduction in poverty over the past two decades. Indeed, the Algerian government has taken significant steps to improve its people's well-being by implementing social policies in line with the UN Sustainable Development Goals.

The Algerian economy is highly dependent on hydrocarbons and world oil and gas prices. GDP growth reached 1.5% in 2018, compared with 1.4% the previous year, and remained at 1.5% in the first quarter of 2019. Growth in the hydrocarbon sector was slow, with economic activity contracting by 6.5% in 2018 and 7.7% in the first quarter of 2019, partially offsetting the slight increase in non-hydrocarbon growth of 3.4% 3.9%, respectively [21].

The government's 2016-2019 economic plan reduces its exposure to crude oil price volatility by diversifying its exports (hydrocarbons represent more than 90% of total exports in 2016) and reducing the growth of its domestic energy consumption (of which hydrocarbons are the primary source of fuel) to 3% in 2030 [22].

2.3.2. Energy production

Algeria's energy production is dependent on conventional (oil and gas) and renewable energy sources. Algeria's energy production has increased over the past few decades to meet household, industrial and transport demands.



TPES	2012	2017
Non-renewable (TJ)	1 887 412	2 285 853
Renewable (TJ)	3 084	4 253
Total (TJ)	1 890 496	2 290 106
Renewable share (%)	0	0
Growth in TPES	2012-17	2016-17
Non-renewable (%)	+21.1	+3.4
Renewable (%)	+37.9	+8.9
Total (%)	+21.1	+3.4
Primary energy trade	2012	2017
Imports (TJ)	220 834	169 269
Exports (TJ)	4 230 516	4 128 789
Net trade (TJ)	4 009 682	3 959 520
Imports (% of supply)	12	7
Exports (% of production)	71	66
Energy self-sufficiency (%)	314	275
Net trade (USD million)	+ 65 780	+ 31 884
Net trade (% of GDP)	+31.5	+19.0

Total primary energy supply in 2017

Renewable energy supply in 2017

Figure 2.3. Total primary energy supply [23]

2.3.3. Energy consumption

According to the latest estimates provided by the BP 2018 Statistical Review of World Energy, Algeria's domestic energy consumption was about 2.11 quadrillion British thermal units in 2017. Algeria mainly uses oil or oil products and natural gas to meet domestic demand. Only a small fraction of domestic consumption comes from coal, hydroelectricity, and renewable energies. Algeria does not have significant nuclear, hydroelectric, coal, or renewable energy capacity [24].

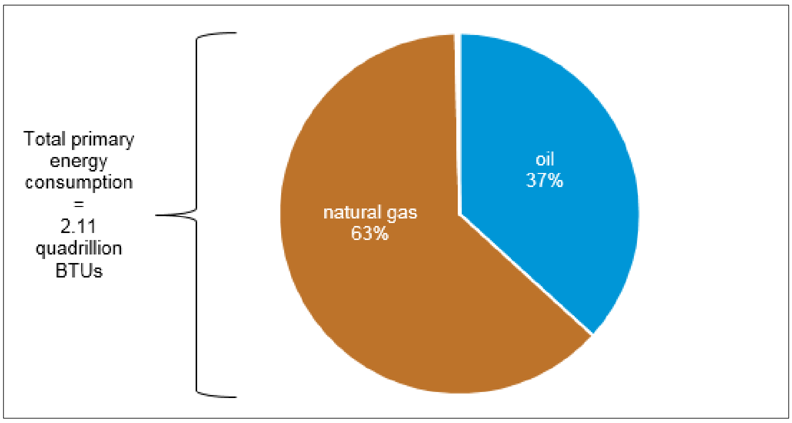
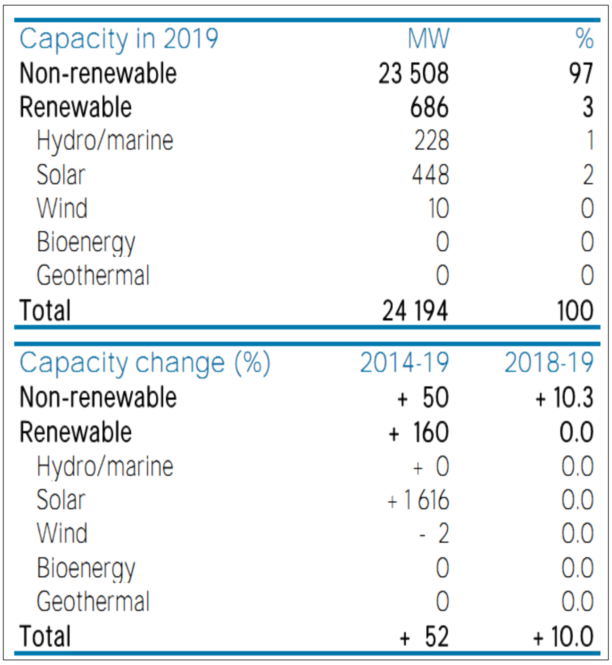


Figure 2.4. Algeria's Energy Consumption by Fuel Source, 2017 [24]

2.3.4. Electricity

Algeria's electricity production capacity reached around 19 gigawatts (GW) in 2016. Electricity consumption was about 56 billion kilowatt-hours (kWh) in Algeria in 2016, double what it was ten years ago. Most of the production capacity comes from natural gas power plants and combined cycle power plants. The share of renewable energies in the Algerian production park is increasing but remains limited.

According to the World Bank Group's latest estimates, 99% of the Algerian population has access to electricity, with around 100% in urban areas, and 98% in rural areas. Although extensive and serving almost the entire population, Algeria's transport and distribution systems have experienced relatively high losses, 15.9% in 2016 [24].



Capacity in 2019	MW	%
Non-renewable	23 508	97
Renewable	686	3
Hydro/marine	228	1
Solar	448	2
Wind	10	0
Bioenergy	0	0
Geothermal	0	0
Total	24 194	100

Capacity change (%)	2014-19	2018-19
Non-renewable	+ 50	+ 10.3
Renewable	+ 160	0.0
Hydro/marine	+ 0	0.0
Solar	+ 1 616	0.0
Wind	- 2	0.0
Bioenergy	0	0.0
Geothermal	0	0.0
Total	+ 52	+ 10.0

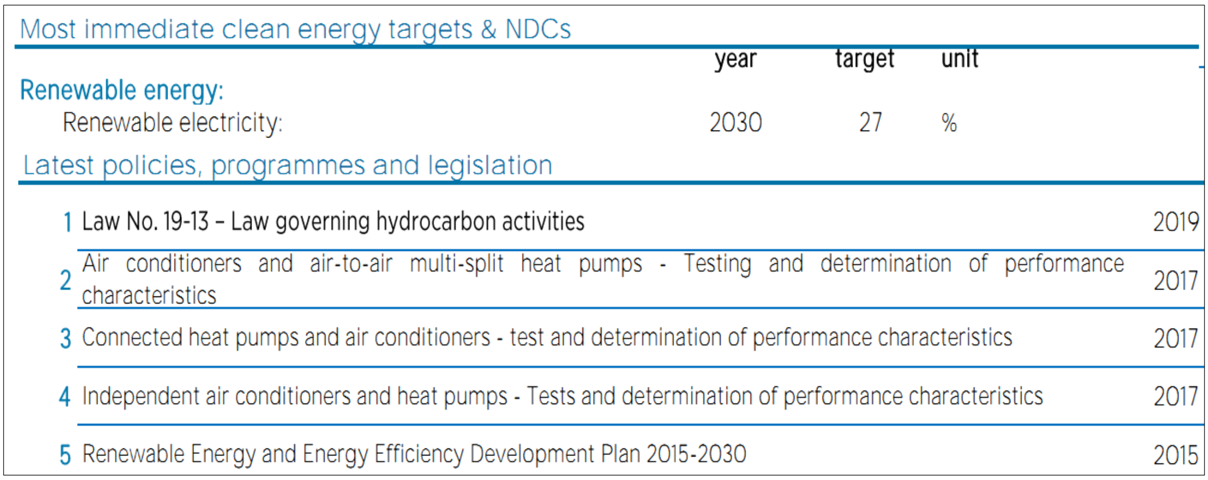
Table 2.1. Algeria's Electricity generation [23]

2.3.5. Renewable Energy

In recent years, political support for renewable energy has grown steadily, both nationally and internationally. Most scientists now agree that the Middle East and North Africa are well placed to play a leading role in the future's lucrative solar and wind energy industries. Algeria plays a vital role in world energy markets, both as a significant producer and exporter of hydrocarbons and a critical player in the renewable energy market. Because of its geographical situation, Algeria has been considered one of the best countries for exploiting solar energy. Algeria benefits from a relatively high level of sunshine, moderate solar radiation, and wind speed, as well as biomass energy resources.

2.3.6. Policy and renewable energy in Algeria

Algeria adopted in 2011 a strategy whose objective is to produce 40% of its electricity from renewable resources by 2030. But it has been reduced to 27% in reality after the revision of the new program in 2015 [27].



Most immediate clean energy targets & NDCs	year	target	unit
Renewable energy:			
Renewable electricity:	2030	27	%

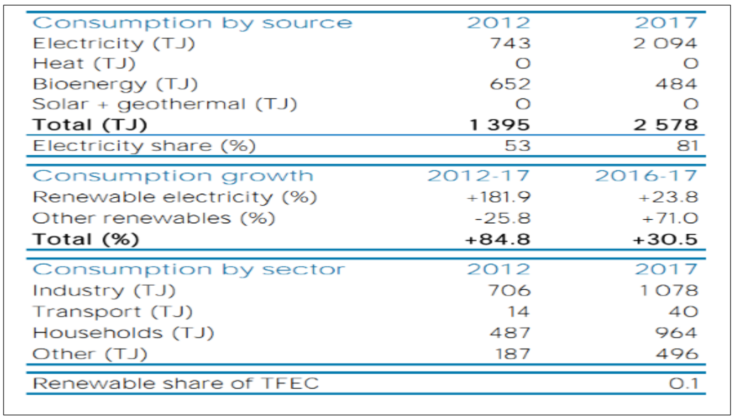
Latest policies, programmes and legislation		
1	Law No. 19-13 – Law governing hydrocarbon activities	2019
2	Air conditioners and air-to-air multi-split heat pumps - Testing and determination of performance characteristics	2017
3	Connected heat pumps and air conditioners - test and determination of performance characteristics	2017
4	Independent air conditioners and heat pumps - Tests and determination of performance characteristics	2017
5	Renewable Energy and Energy Efficiency Development Plan 2015-2030	2015

Table 2.2. Targets, Policies and Measures [24]

When we look at the issue of renewable energies in Algeria, we can see that the country has the technological means, both financial and human, to develop this sector. However, we quickly realize that it lacks the essential: the political will. The least that can be said is that the country has several constraints that rely mainly on oil and gas. Algeria has a window of a few years to put in place a policy of voluntarism based on energy sobriety. Like the developed countries, an audacious strategy must be put in place. An energy mix of 50% renewable energies. Therefore, it is important to set up an energy transition that will enable it to reduce its dependence on fuels by reserving oil for noble uses only, saving energy, and launching the energy plan without delay.

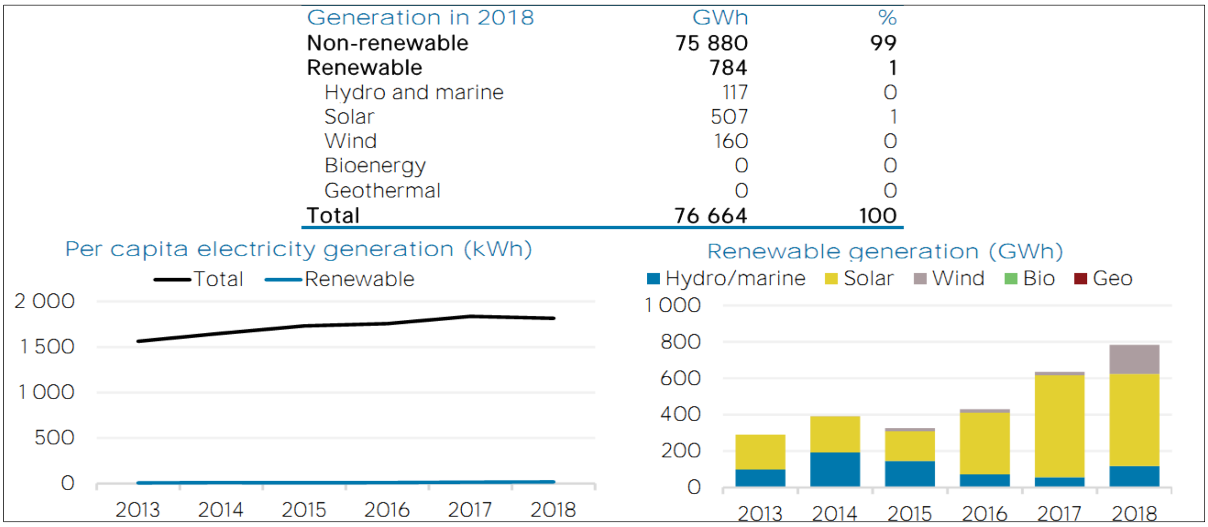
2.3.7. Renewable energy consumption in Algeria

Thanks to its geographical location and its strategic position in the energy sector, all the conditions are in place for Algeria to play a crucial role in the future supply of green electricity, following the Trans-Mediterranean Plan.



Consumption by source	2012	2017
Electricity (TJ)	743	2 094
Heat (TJ)	0	0
Bioenergy (TJ)	652	484
Solar + geothermal (TJ)	0	0
Total (TJ)	**1 395**	**2 578**
Electricity share (%)	53	81
Consumption growth	**2012-17**	**2016-17**
Renewable electricity (%)	+181.9	+23.8
Other renewables (%)	-25.8	+71.0
Total (%)	**+84.8**	**+30.5**
Consumption by sector	**2012**	**2017**
Industry (TJ)	706	1 078
Transport (TJ)	14	40
Households (TJ)	487	964
Other (TJ)	187	496
Renewable share of TFEC		0.1

Table 2.3. Algeria's renewable energy Consumption [24]



Generation in 2018	GWh	%
Non-renewable	75 880	99
Renewable	784	1
Hydro and marine	117	0
Solar	507	1
Wind	160	0
Bioenergy	0	0
Geothermal	0	0
Total	76 664	100

Figure 2.5. Electricity generation in Algeria [24]

2.3.8. Solar Energy

In all the Mediterranean basins, there is a gigantic reservoir of solar energy in North Africa, particularly in Algeria's southern region. With average annual sunshine of 2000 h and evaluated on a territory composed of 86% of the Sahara Desert, its solar energy is estimated at 1700 KWh/m^2/year in the North and 2650 KWh/m^2/year in the South, which corresponds to capacity eight times higher than the country's natural gas reserves and the largest solar fields in the world [25].

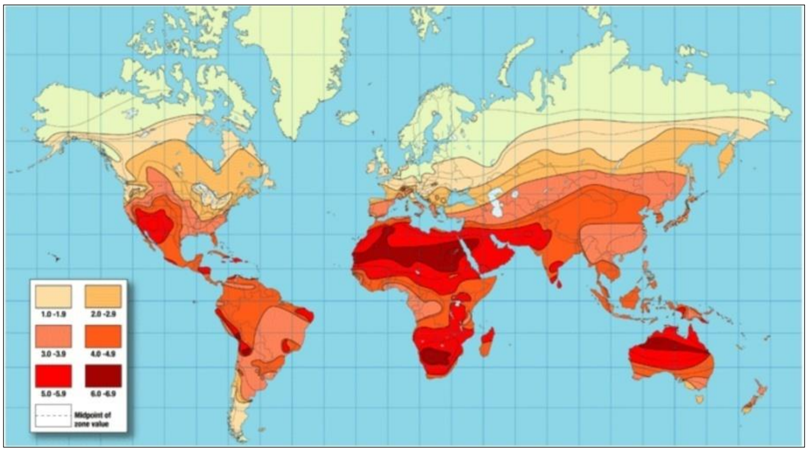


Figure 2.6. Solar insolation Map of the World [25]

The history of the use of solar energy in Algeria goes back to 1954 with the French's solar furnace for the manufacture of ceramics. The insulation time over almost the entire national territory can exceed 2000 hours per year and reach 3900 hours (high plains and Sahara). The daily energy obtained on a horizontal surface of 1 m² is 5 KWh over most of the national territory, i.e., about 1700 KWh/m²/year for the North and 2263 KWh/m²/year for the South of the country (table 00 and figure 00).

Region	**Coastal**	**Highlands**	**Sahara**
Area (%)	4	10	86
Average sun hours per year	2650	3000	3500
Energy received KWh/m²/year	1700	1900	2650

Table 2.4. Data on solar radiation in Algeria [25]

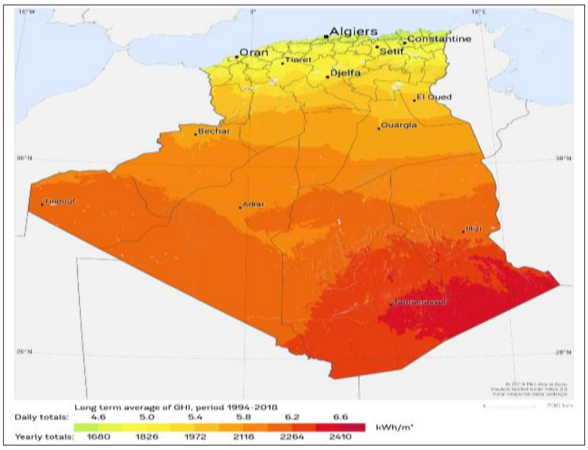


Figure 2.7. Global horizontal irradiation For Algeria [26]

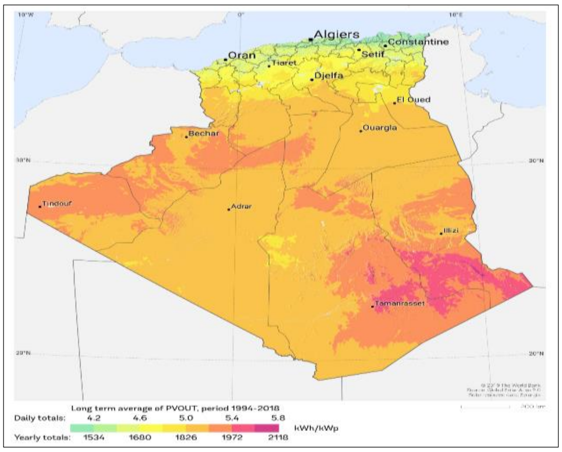


Figure 2.8. PV power potential in Algeria [26]

The amount of solar radiation in Algeria means that it would be possible to consider solar energy as a potential energy source for different applications in the form of individual photovoltaic solar panels or systems. Photovoltaic solar energy is developed in Algeria mainly for six applications: domestic uses, water pumping, refrigeration, village electrification, lighting, and telecommunications. The Ministry of Energy and Mines supports solar power plants' development and is mainly carried out by Sonelgaz and other private installation companies. Solar energy is considered an important research area within the structure of the Sonelgaz Renewable Energy Department. The UDTS/CDTA (Silicon Technology Development

Unit, in collaboration with the Centre for the Development of Advanced Technologies) in Algiers, is working on developing solar cells. With encapsulation, the procedure workshop allows 250 KW/year up to 500 KW/year. A polycrystalline silicon growth furnace with 25 ingots/year capacity, in the first phase, allows the elaboration of silicon ingots. Facilities for cutting silicon ingots and equipment for electrical, optical, and structural evaluation are also available. The manufacture of PV modules at ENIE (National Company of the Electronic Industry) is limited to mono and polycrystalline silicon solar cells, the assembly of PV modules, and the manufacture of the supporting structure. The UDES/CDER (Solar Equipment Development Unit in collaboration with the Centre for the Development of Renewable Energies) ensures the development of solar thermal and photovoltaic equipment (domestic, industrial, and agricultural), electronic, thermal, and mechanical devices and systems involved in the application of solar energy. This means that establishing a silicon production industry is possible in Algeria to supply the local, MENA, and European markets [27].

2.4 Microgrids

2.4.1 The microgrids concept

Traditionally, the power and energy flow in on direction from larger generators through a network of transmission and distribution to the users, making the power generation in the grid highly centralized.

The development and research of new power system is stimulated with the several technical issues related to the traditional electrical utilities and the environment.

Microgrid technologies have attracted attention as a good way for the integration of DER unites to the power systems used for the different distributed energy sreources (DER) such as PV, biomass, battery, fuel cell and micro-turbine [27].

A microgrid is a single, controllable, independent power system comprising distributed generation (DG), load, energy storage (ES), and control devices, in which DG and ES are directly connected to the user side in parallel [6].

The definition of a microgrid from the European Technology Platform of Smart Grids, is an integrity facilitating platform for, energy storage systems ESS, distributed generators (DG), and loads in order a sustainable delivery of power from the grid with a reliable electricity and competitive prices.

Figure (2.9) shows a typical microgrid structure, comprising DGs, such as combined heat and power unit (CHP), micro-turbines, PV systems, wind power systems, fuel cells; distributed energy storage (DES) facility such as battery banks, super-capacitors, flywheels, electric vehicles; flexible loads and control devices [27].

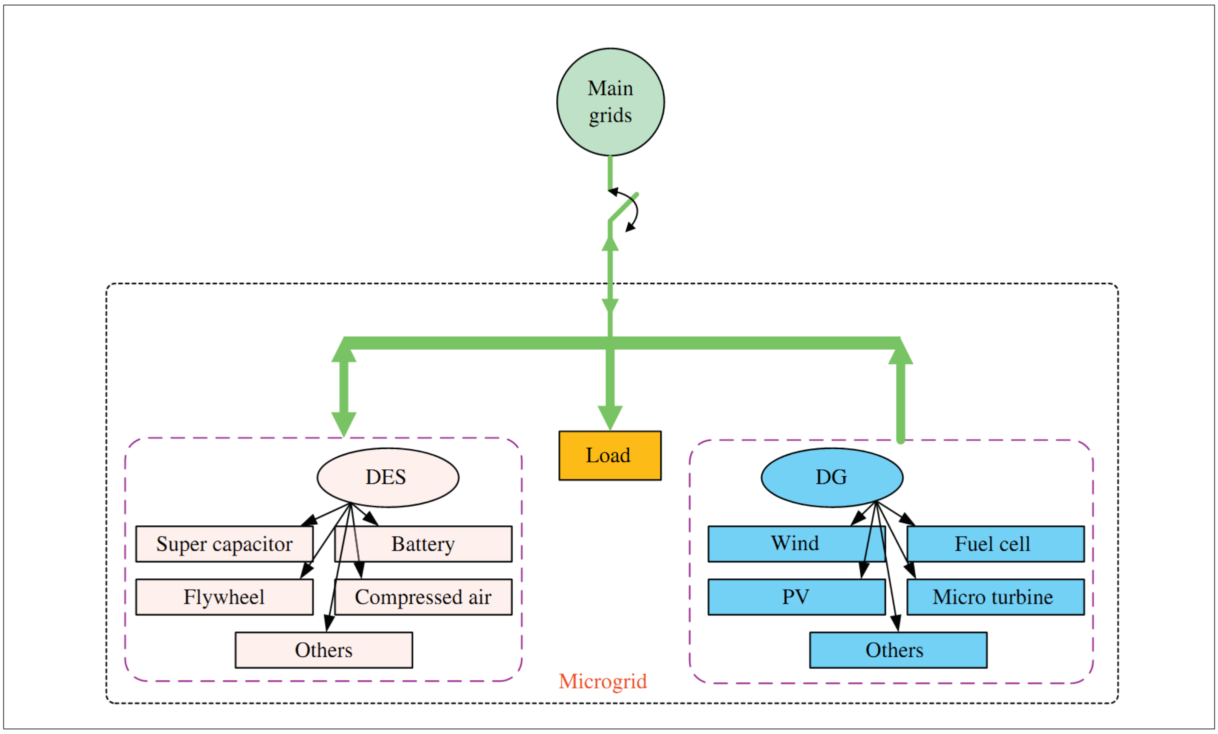


Figure 2.9. Typical structure of a microgrid

2.4.2 Microgrid composition

A microgrid is composed of distributed generation (DG), loads, energy storage (ES), and control devices. It acts as a single entity with respect to the grid, and connects to the grid via a single point of common coupling.

- DG: It can be various types of new energy, such as photovoltaic (PV), wind, and fuel cell; or combined heat and power (CHP) or combined cooling, heat, and power (CCHP), which provides heat for users locally, thereby increasing efficiency and flexibility of DG.
- Loads: It includes common load and critical load.

- ES: It includes physical, chemical, and electromagnetic forms, for storage of renewable energy, load shifting, and black-start of microgrid.
- Control devices: They constitute the control system for DGs, ESs, and transfer between grid-connected mode and islanded mode, facilitating real-time monitoring and energy management [6].

2.4.3 Microgrid classification

Different types of microgrids should be established according to capacity, location, and types of DRs to suit the local situation [6]. Microgrids can be classified as follows according to:

→ **Demand**

The classification of microgrids is done into simple microgrid, multi-DG microgrid, and utility microgrid by function demand.

- **Simple Microgrid**

It contains a single type of distributed generation with a simple design and function with the use of continuous supply or CCHP to loads.

- **Multi-DG microgrid**

It is composed of multiple simple microgrids or multiple types of complementary, coordinated DGs. In comparison with the first type, it costs much more in terms of design, operation and complication. In order to maintain power balance during emergencies to identify some loads.

- **Utility microgrid**

It contains all the distributed generation and other simple microgrids that meet specific technical conditions. The priority is for loads depending on user’s reliability and requirement with the powering of high priority loads in emergency cases.

Microgrids are classified by demand with the definition of the ownership during operation up to operating and managing the simple microgrids by customers, while utility microgrids can be operated via the utilities, and the multi distributed generators to be operated either by utilities or customers.

→ **Capacity**

Microgrids are classified into simple microgrid, corporate microgrid, feeder area microgrid, substation area microgrid, and independent microgrid by capacity, as shown in Table (2.5)

- **Simple microgrid**

A simple microgrid has a capacity below 2 MW and is intended for independent facilities and institutes with multiple types of loads and of a small area, such as a hospital or school.

- **Corporate microgrid**

A corporate microgrid has a capacity of 2–5 MW, and comprises CCHPs of varying sizes and some small household loads, generally no commercial or industrial loads.

- **Feeder area microgrid**

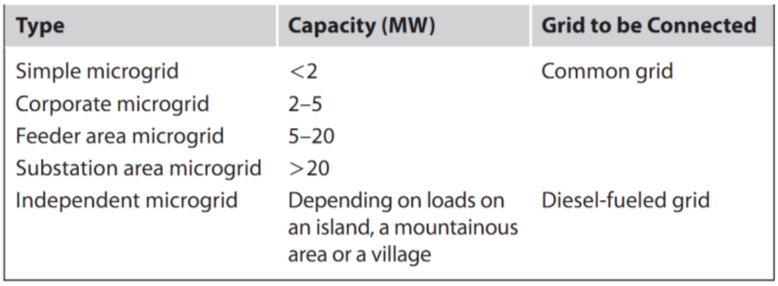
A feeder area microgrid has a capacity of 5–20 MW and comprises CCHPs of varying sizes and some large commercial and industrial loads.

- **Substation area microgrid**

A substation area microgrid has a capacity above 20 MW and generally comprises common CCHPs and all nearby loads (including household, commercial, and industrial loads). These four types of microgrids are connected to common grids, and therefore, are collectively called grid-connected microgrid.

- **Independent microgrid**

An independent microgrid is mainly intended for remote off-grid areas such as an island, a mountainous area, or a village, and the distribution system of the main grid uses a diesel generator or other small units to meet the power demand of such areas.



Type	Capacity (MW)	Grid to be Connected
Simple microgrid	<2	Common grid
Corporate microgrid	2–5	
Feeder area microgrid	5–20	
Substation area microgrid	>20	
Independent microgrid	Depending on loads on an island, a mountainous area or a village	Diesel-fueled grid

Table 2.5. Classification of microgrids by capacity

→ By AC/DC type

Microgrids are classified into DC microgrid, AC microgrid, and AC/DC hybrid microgrid.

- **DC microgrid**

As shown in Figure (2.10), in a DC microgrid, DG, ES, and DC load are connected to a DC bus via a converter and the DC bus is connected to AC loads via an inverter to power both DC and AC loads.

The advantages of the DC microgrid are as follows:

1. As DG control solely depends on DC voltage, it is easier to realize coordinated operation of the DGs.
2. DG and load fluctuations are compensated by ES on the DC side.
3. Compared with an AC microgrid, a DC microgrid is easier to control, does not involve synchronization among DGs, and thus is easier to suppress circulating current. The disadvantage of the DC microgrid is that inverters are required for the power supply to AC loads.

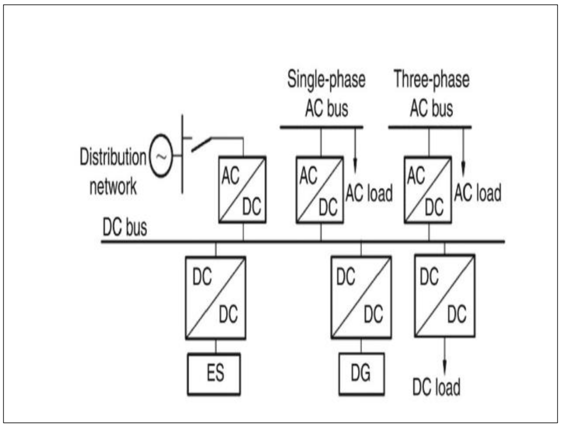


Figure 2.10. Structure of a DC microgrid

- **AC microgrid**

An AC microgrid connects to the distribution network via an AC bus, and the AC bus controls the microgrid’s connection to and disconnection from the distribution network through the circuit breaker at the PCC. Figure (2.11) shows the structure of an AC microgrid, in which DG and ES are connected to the AC bus via inverter. The AC microgrid is a dominant type of microgrid, and the major topic of this book in the following chapters. The advantage of the AC microgrid is that as the microgrid is connected to the grid through an AC bus, no inverter is required for power supply to AC loads. The disadvantage is that control and operation are difficult.

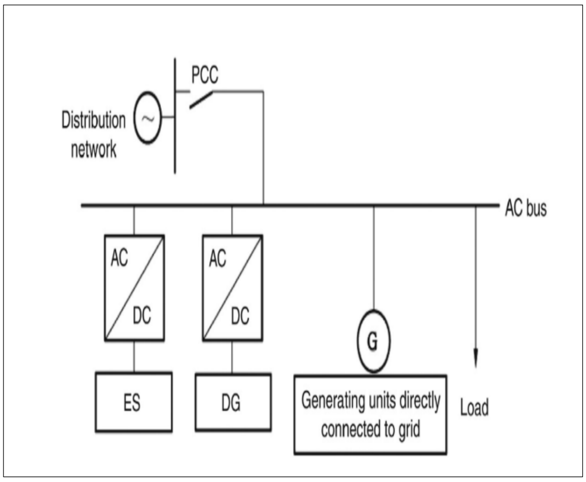


Figure 2.11. Structure of an AC microgrid

- **AC/DC hybrid microgrid**

An AC/DC hybrid microgrid is a microgrid consisting of an AC bus and a DC bus. Figure (2.12) shows the structure of such a microgrid, in which the AC bus and DC bus allow for direct supply to AC loads and DC loads. With special power sources connected to an AC bus, an AC/DC hybrid microgrid is essentially a special AC microgrid on the whole.

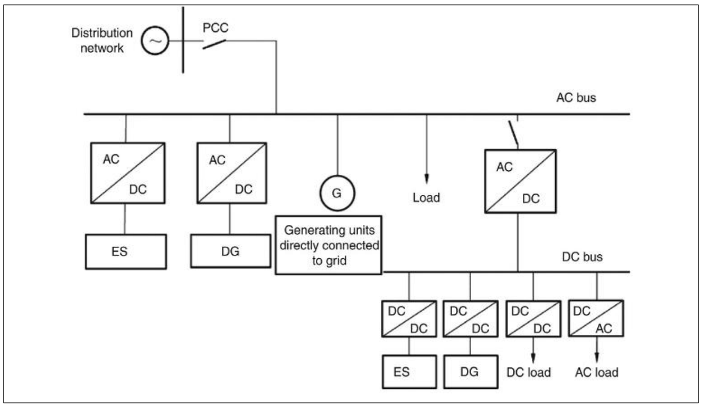


Figure 2.12. Structure of an AC/DC microgrid

2.4.4 Microgrid and distributed generation

2.4.4.1 Characteristics and concepts

Every small electric power system independent of traditional utility grids refers to Distributed generation (DG), located on the side of the user in order to satisfied users demands. This includes internal combustion engine, microturbine, fuel cell, small hydropower system, photovoltaic (PV) generation, wind generation, waste generation, and biomass generation. Distributed resource (DR) refers to a combined DG and energy storage (ES) system, that is, DR = DG + ES. It includes all DG technologies and can store energy in a battery, flywheel, regenerative fuel cell, superconducting magnetic storage device, and other devices.

Distributed energy resources (DER) mean generation of electricity or heat on the user side for local use. It includes all DG and DR technologies, and systems connected to a utility grid with which users can sell surplus power to utilities. As a definition it can refer to the DG as a subset of DR which in its turn a subset of DER [6].

2.4.4.2 PHOTOVOLTAICS

PV is a means of electricity generation by directly converting solar energy to electricity. The solar cell is the core component for light-to-electricity conversion. The worldwide market is dominated by the crystalline silicon solar cell, and other types include amorphous silicon thin film solar cell and compound thin film PV cell. A PV power system may operate independently or in parallel with the grid [6].

- **PV power with independent system**

It is not connected to the traditional electric power system and its generally deployed in remote off0grid areas to fulfill the local requirements. During the daytime the electrification of PV is possible, with the requirement of power during all time. In order to solve the issue, the presence of an independent PV systems is required with ES. Figure (2.13) shows the structure of an independent PV power system, mainly consisting of solar cell array, DC combiner box, controller, battery, off-grid inverter, and AC distribution box. The PV components produce direct current to charge the battery and, after DC to AC conversion by the inverter, serve the AC loads.

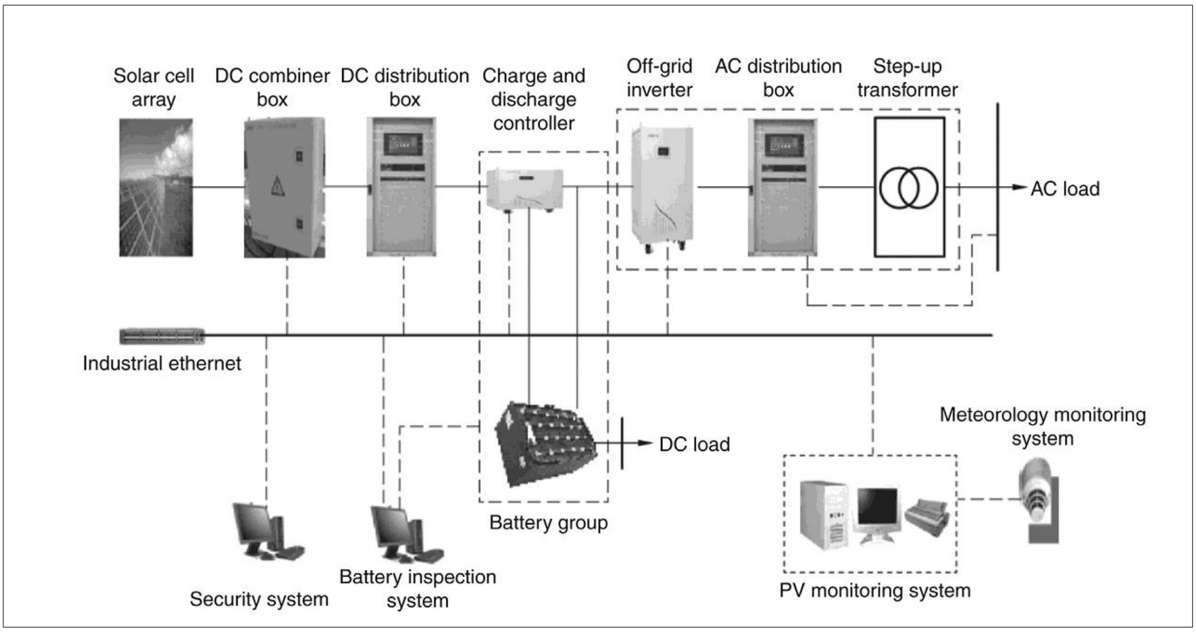


Figure 2.13. Structure of independent PV system

- Solar cell array: it consists of two or more solar cell modules fabricated by encapsulation of solar cells. At present, single crystalline or polycrystalline silicon solar cells are used, which are made of waterproof glass on the front contact and soft material on the back contact. It is the most fundamental component of a PV power system for conversion of solar energy to electricity. DC combiner box: Combines multiple circuits of low-current DC outputs of solar cell array into one or more circuits of high-current outputs. Its output may then be collected to the next-level combiner box or the inverter, and it can protect against and monitor the occurrence of over-current, countercurrent, and lightning strike.
- Controller: Controls the charge and discharge voltage and current of the battery, balances the energy of the system, collects system status information, and controls, protects, and monitors the charge and discharge processes of ESs.
- Battery: Stores the intermittent and uncertain energy produced by solar cells to ensure power supply balance and continuity.
- Off-grid inverter: Inverts direct current to alternating current to serve AC loads.
- AC distribution box: An enclosed or semi enclosed metal box housing
- AC-side switchgear, meters, protections, and other auxiliary equipment for ease of maintenance and management.

Grid-connected PV power system

A grid-connected PV power system is connected to the grid and injects electricity to the grid. It is the mainstream of PV power systems. Grid-connected PV power systems can be further divided into distributed type and centralized type. The former is a type of DG in a microgrid, in which electricity is directly distributed to users and the surplus or deficit is regulated by the grid. The latter is a PV power system that directly injects electricity to the grid for distribution to users. The structures of these two types are essentially the same. Figure (2.14) shows the structure of a grid-connected PV power system, mainly comprising solar cell array, DC combiner box, DC distribution box, grid-tie inverter, and AC distribution box. Their functions are the same as those of an independent PV power system. For the off-grid inverter and grid-tied inverter, the similarity is that they both convert direct current to alternating current, and the difference is that the former is the voltage source for U/f output and the latter the current source for P/Q output. In addition, the grid-tied inverter has the following functions:

(1) maximum power point tracking (MPPT), that is, it always produces the maximum power when the output voltage and current vary with the cell temperature and solar irradiance;

(2) output of current for harmonics suppression to ensure power quality of the grid;

(3) automatic tracking of voltage and frequency of the grid in the case of excess power output.

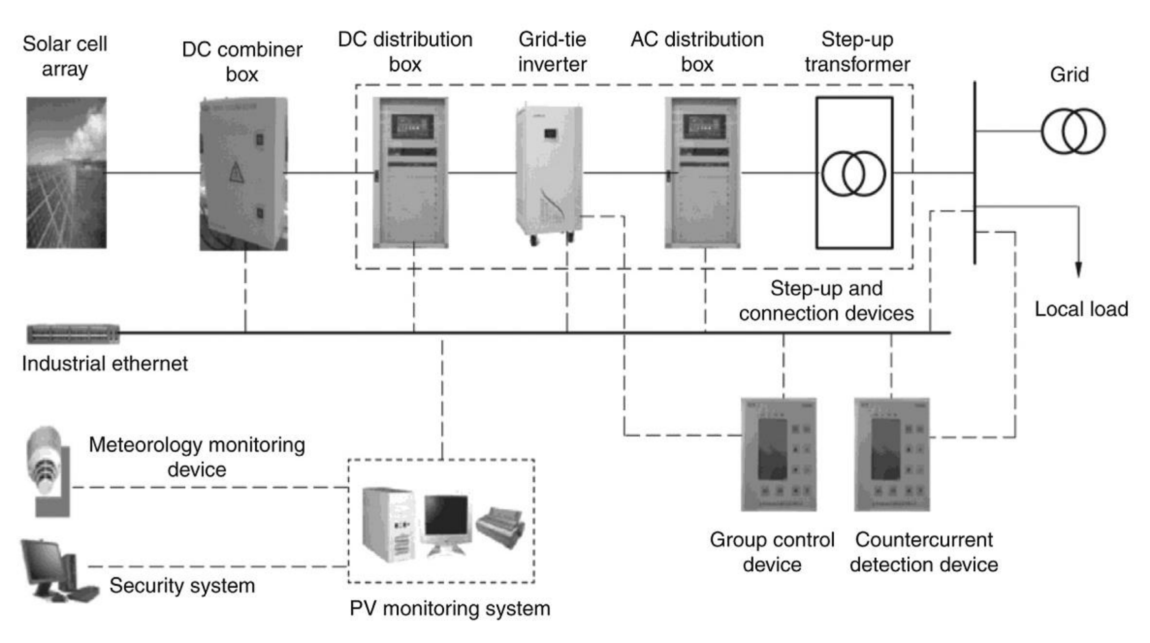


Figure 2.14. Structure of grid-connected PV power

2.4.4.3 Diesel Generator

Concerning the traditional sources seen as backup power, for small-scale microgrids the diesel generator is the most used because of the low initial cost and simplicity. The difference between load consumption and renewable generation causes actuations in the microgrid bus voltage.

Thus, for off-grid operating mode or limited public grid availability a power balance is performed by adjusting the diesel generator power and storage for voltage stabilization. Although the diesel generator large capacity backup power can provide long-term support for the microgrid operation [3].

A generator is one of the major components of a hybrid power system. It provides energy for the load in the unlikely scenario that supply falls short of demand. In most cases, generators are used to maximize the efficiency of renewable energy, to reinforce the frequent energy deficit when power interruption occurs in renewable sources and the battery is not able to provide the required energy. Generators are machines used to produce electricity by transforming the kinetic energy of the motion of combustion engines into electricity through different energy sources [29]. They are chosen according to their size, range, type, the kind of load to be fed and the type of fuel they use to be operated.

A diesel generator is a diesel engine coupled to an electrical generator called an alternator via a shaft to produce electrical energy. The diesel generator uses the chemical energy available in the fuel and converts it into mechanical energy. The mechanical energy, in turn, drives the engine shaft which is connected to the alternator. Diesel generator sets are mainly used: in places where the electricity grid is not available, as uninterruptible backup power, as well as in various complex applications such as peak shaving, export to the electricity grid and grid support [30].

Diesel generators operate most efficiently when used at full load. Figure (2.15) shows a typical efficiency curve for a generator set. It is clear that the efficiency decreases significantly as the load decreases. In addition, when the load increases from 20 to 80 per cent, the efficiency of the generator doubles. Thus, the fuel consumption per kWh is reduced by two times.

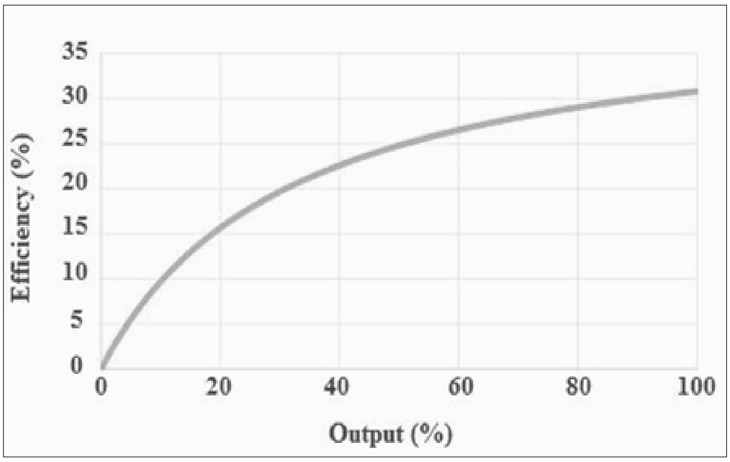


Figure 2.15. Typical genset efficiency curve [31]

2.4.4.4 ENERGY STORAGE

ES technologies solve the imbalance between supply and demand. In distributed generation, they solve the intermittency and uncertainty of output and load shifting. They also enable a number of other functions such as black-start, power quality adjustment and control, and stability [6].

ES technologies include physical, electromagnetic, electrochemical, and phase-change forms. Physical ES technologies include pumped storage, compressed air ES (CAES) and flywheel ES; electromagnetic ES includes superconducting magnetic ES (SMES), supercapacitor, and high-energy density capacitor; electrochemical ES includes various types of batteries such as lead-acid battery, nickel-hydrogen battery, nickel-cadmium battery, lithium-ion battery, sodium sulfur battery, and flow battery; phase-change form includes ice thermal storage [6].

2.4.4.5 Battery

It is a chemical form of storing electricity and it exists in different types such as batteries based on sodium sulfur battery, lead-acid, lithium-ion battery, vanadium redox and nickel-cadmium battery.

1. Sodium sulfur battery: Owing to its high energy density, its size is just 1/5 of a lead-acid battery while the efficiency is up to 80%, contributing to convenient modular design, transportation, and installation. It can be installed by stage according to the intended purpose and capacity, and suits urban substations and special loads. It is a promising ES technology for

DG and the microgrid in improving the system stability, shifting loads, and maintaining power supply in an emergency.

2. Lead-acid battery: Its lifetime will be reduced when working at a high temperature. Similar to a nickel-cadmium battery, it has a low specific energy and specific power, but is advantageous because of its low price and cost, high reliability, and mature technology and has been widely used in electric power systems. However, it has a short lifetime and causes environmental pollution during manufacture. It is mainly used as the power source for closing of circuit breakers during system operation, and an independent power source for relay protection, driver motor, communication, and emergency lighting in the event of failure of power plants or substations.

3. Nickel-cadmium battery: It has a high efficiency and long lifetime, but the capacity decreases as time goes by, and the charge retention needs to be enhanced. Furthermore, it has been restricted by the EU due to heavy metal pollution. It is rarely used in electric power systems.

4. Lithium-ion battery: It has a high specific energy and specific power, little self-discharge, and causes no pollution. However, due to the influence of the process and difference in ambient temperature, the system indices are more often worse than those of a cell, and in particular, the lifetime is several times or even more than 10 times shorter than that of a cell. What is more, integration of a high capacity is very difficult and the cost for manufacture and maintenance very high. In spite of this, the lithium-ion battery is expected to be widely used in DG and the microgrid thanks to advancements of technologies and reduction of costs.

5. Flow battery: Flow battery features slight electrochemical polarization, 100% discharge, long lifetime, and rated power independent of rated capacity. The capacity can be increased by adding electrolyte or increasing the concentration of the electrolyte. The storage form and pattern can be designed according to the location. It is a promising ES technology for DG and the microgrid in improving the system stability, shifting loads, and maintaining power supply in an emergency [6].

2.4.5 Microgrid Monitoring

The monitoring and energy management system of the microgrid serves real-time, extensive monitoring of distributed generation (DG), energy storage (ES), and loads within the microgrid. In grid-connected operation, islanded operation, and during transition between operation modes, it controls and optimizes the DG, ES, and loads, thereby ensuring secure and stable operation of the microgrid at the maximum energy efficiency as seen in Figure (2.16).

The monitoring system coordinates with the local control and protection and remote distribution dispatch, and has the following functions:

1. Real-time monitoring of supervisory control, data acquisition, and DG;

2. Service management: forecast of power flow (including tie line power flow, DG node power flow, and load flow) and DG output; DG output control and power balance control;

3. Smart analysis and decision-making: optimized dispatch of energy. By collecting information of DGs, lines, the distribution network, and loads in real time, the monitoring system monitors the power flow across the microgrid and adjusts the operation of the microgrid in real time based on operation constraints and energy balance constraints. In the monitoring system, energy management is the core that integrates the DG, load, ES, and the point of common coupling [6].

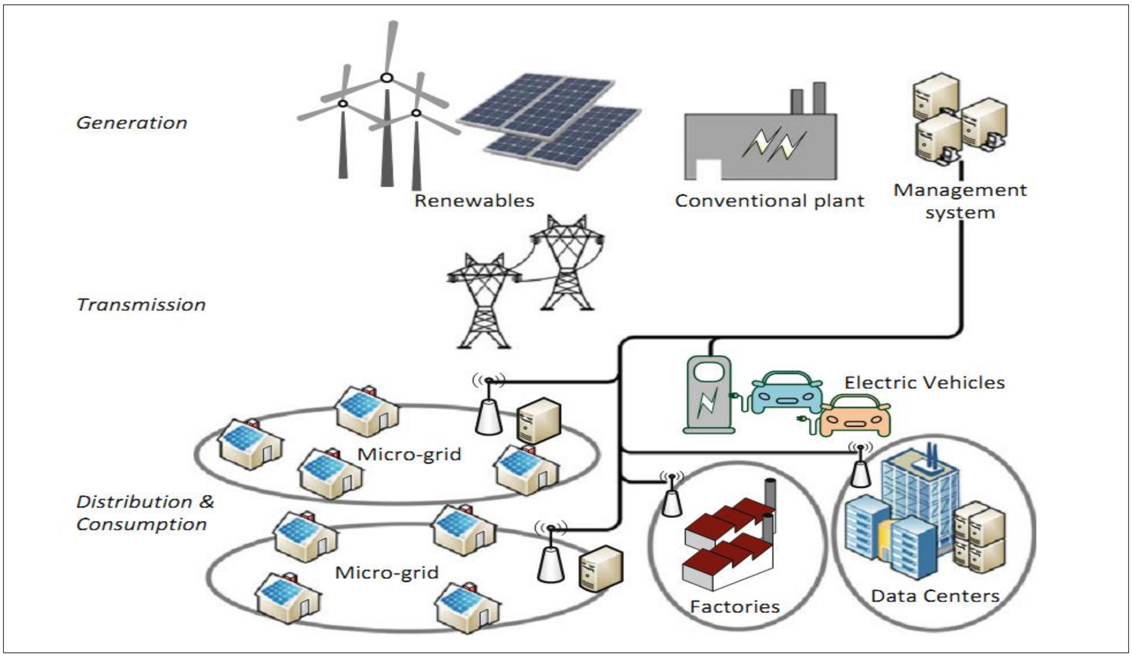


Figure 2.16. The main components of the future smart grid [29]

2.5 Smart grids

Smart grid has numerous definitions and interpretations, which depend on the specific drivers and benefits to each utility, country, and federal goals, and the various industry stakeholders. A preferred view of smart grid is not what it is, but what it does, and how it benefits utilities, consumers, the environment, and the economy.

- The European Technology Platform (comprising European stakeholders and the surrounding research community) defines smart grid as “An electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both, in order to efficiently deliver sustainable, economic and secure electricity supply”.

- According to the U.S. Department of Energy (DOE), “Grid 2030 envisions a fully automated power delivery network that monitors and controls every customer and node, ensuring two-way flow of information and electricity between the power plant and the appliance, and all points in between”.

- The US Electric Power Research Institute (EPRI) defines smart grid as “The modernization of the electricity delivery system so it monitors, protects, and automatically optimizes the operation of its interconnected elements—from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances, and other household devices” .

The U.S. DOE’s National Energy Technology Laboratory (NETL) established seven principal characteristics that define the functions of smart grid as seen in Figure (2.17). Moreover, Table (2.6) summarizes these seven characteristics and contrasts today’s grid with the vision for the smart grid [30].

Today’s Grid	Principal Characteristic	Smart Grid
Consumers do not interact with the grid and are not widely informed and educated on their role in	Enables consumer participation	Full-price information available, choose from many plans, prices, and options to buy and sell

reducing energy demand and costs		
Dominated by central generation, very limited distributed generation and storage	Accommodates all generation and storage options	Many “plug-and-play” DERs complement central generation
Limited wholesale markets, not well integrated	Enables new markets	Mature, well-integrated wholesale markets, growth of new electricity markets
Focus on outages rather than PQ (power quality)	Meets PQ needs	PQ a priority with a variety of quality and price options according to needs
Limited grid intelligence is integrated with asset management processes	Optimizes assets and operates efficiently	Deep integration of grid intelligence with asset management applications
Focus on protection of assets following fault	Self-heals	Prevents grid disruptions, minimizes impact, and restores rapidly
Vulnerable to terrorists and natural disasters	Resists attack	Deters, detects, mitigates, and restores rapidly and efficiently

Table 2.6. DOE Seven characteristics of a Smart Grid

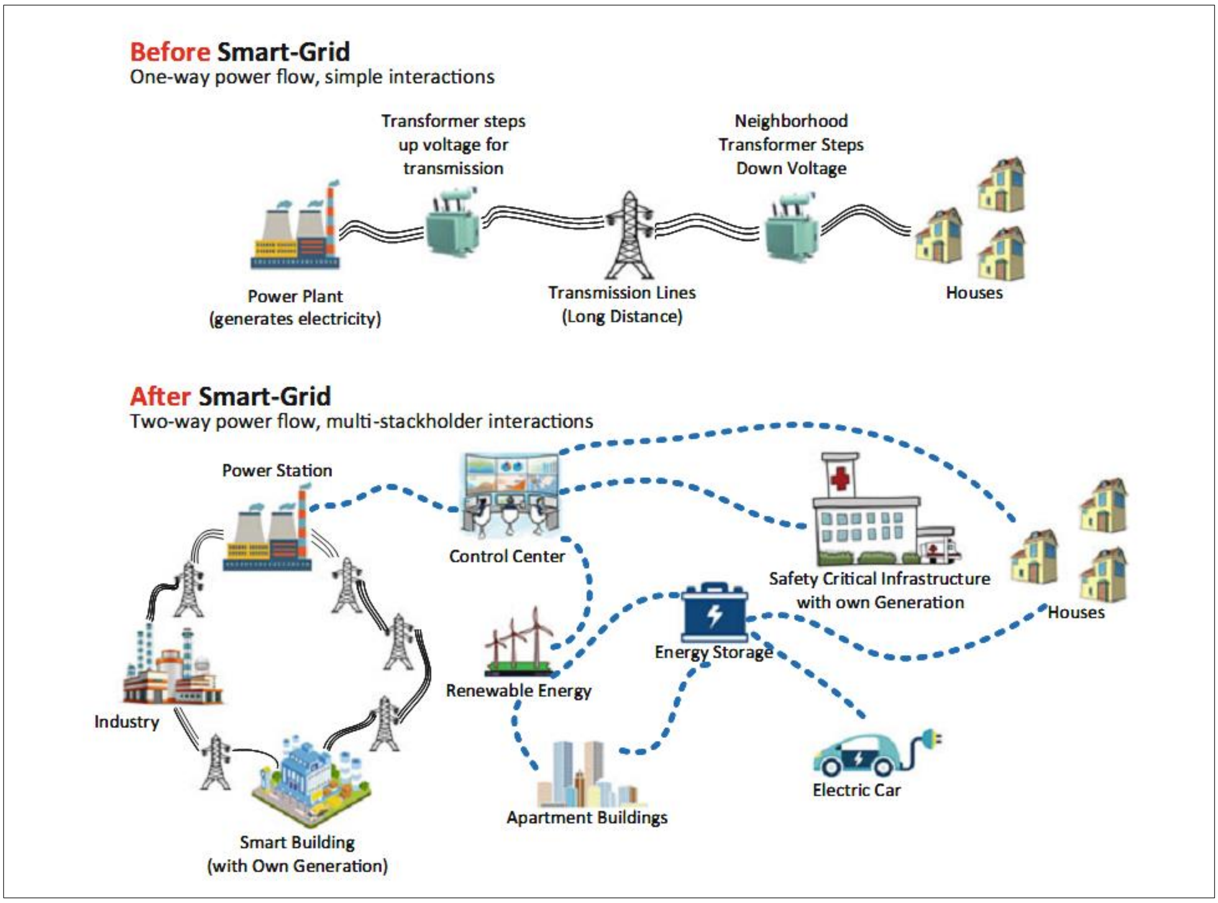


Figure 2.17. Smart grid environment within the broader electricity system [29]

2.5.1 In What Ways Are Smart Grids ‘‘Smarter’’?

SGs are ‘‘smarter’’ in two ways. First, they have the ability to manage the two-way flow of electricity and information to optimize supply and demand. Traditional electric grids have one-way communication between utilities and customers: that is there is a one-way flow of information from customers to the grid (through meters) and a one-way flow of energy from the grid to customers. In contrast, SGs enable two-way flow of information (through a variety of interfaces) and energy (through distributed generation and storage). This is achieved through smart metering technologies and sensors that are installed throughout transmission and distribution grids, and which are linked to integrated communication networks to collect and consolidate data. This ability of two-way communication is fundamental to SG operations. Customers, for example, can proactively monitor and manage their electricity use, and can even sell back to the grid surplus renewable electricity that is produced at home.

SGs are ‘‘smarter’’ also in the sense that they are capable of integrating a wide variety of energy sources and energy customer services—which are now separately managed in traditional power systems—in highly interconnected electricity systems. SGs also integrate a variety of interfaces, including home energy management systems (HEMS), building energy management systems (BEMS), and advanced metering infrastructure (AMI). SGs can coordinate the needs and capabilities of different generators, grid operators, end users, and electricity market stakeholders to operate all parts of the system efficiently as seen in Figure (2.18). All these components require the integration of SGs to achieve scale benefits and cost effectiveness [31].

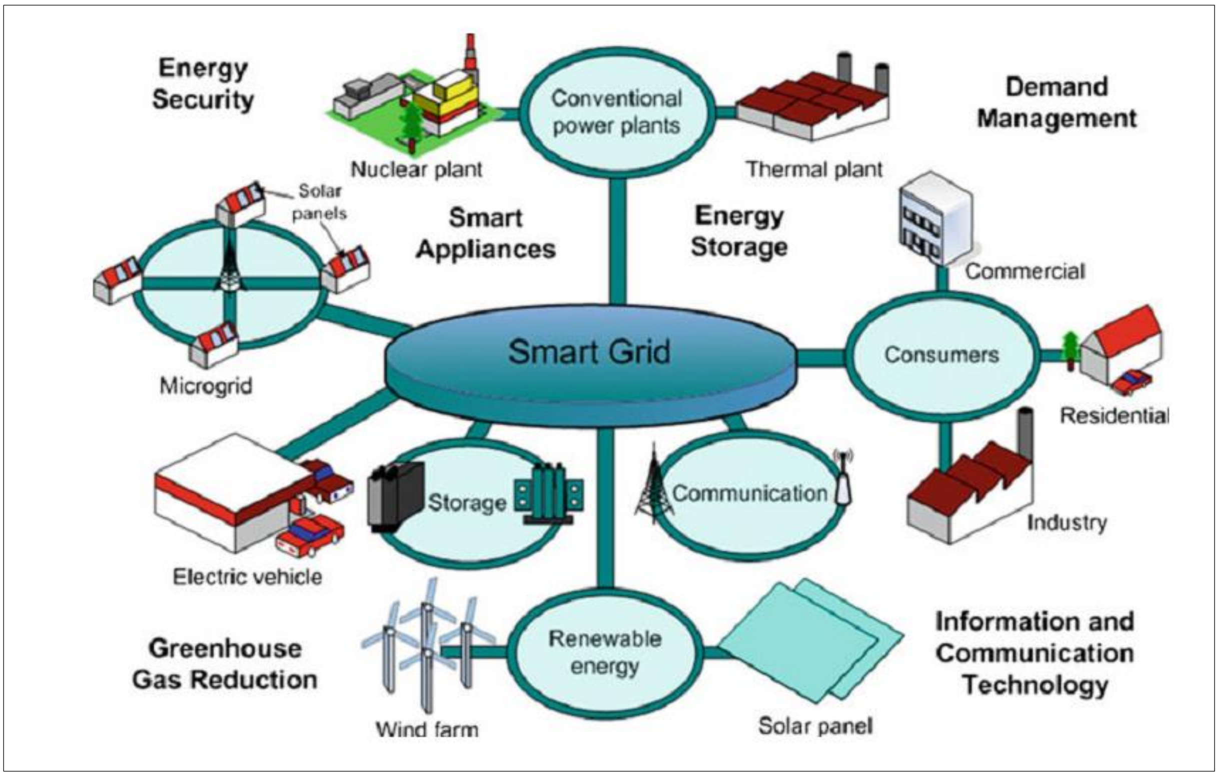


Figure 2.18. The future smart Grid and its application [31]

2.5.2 Sensing and Measurement in Smart Grid

Innovation in sensing and measurement is fundamental for the realization of a more aware and reliable smart grid. This objective can only be achieved by radically upgrading the sensing, measurement, and metering throughout the grid. The smart grid will have real-time measuring devices deployed across the power grid. These sensors will monitor the system and provide data to enable different online and offline applications. The measuring devices installed must be reliable and cost effective also.

These sensors can play an important role in realizing a smart grid by:

- Collecting more information in a given time interval f or analyzing the causes and restructuring the timeline of failure.
- Detecting the potential problems comparatively early thereby helping in the generation of a better corrective action.
- Detection of an external threat.
- Operating the grid in a more efficient way.
- Providing new services to the consumers like demand-side management [32].

2.5.3 Next Generation Smart Communication Subsystems in SGs

The term grid or power grid is used in electricity systems, which mostly refers to the generation, transmission, distribution, and control of electrical power. But smart grid or intelligent power grids are the penetration of communication technologies in the power grid and commonly named as SG (see Figure (2.19)). The prime aim of the SG communication systems is the two-way communication or information flow along with two-way power flow between grid and the consumer. The key requirements and benefits of SG are improvement of the quality and reliability of the power grids, improvement of capacity and efficiency, ability to overcome the disruption automatically, automation of maintenance and operation, handling system disturbance by incorporating self-healing and predictive maintenance, accommodation of different power sources distributed in different geographical areas and enabling smart energy system, smart information system and smart communication system in the grid. In this section, the main focus will be on the communication systems in SG.

Exchange of information efficiently and reliably is the key requirements of future SG communication systems. Some of the key requirements of SG are:

- The communication subsystems in SG must maintain the quality of service (QoS) of the critical data and must be delivered faster and correctly.
- Since large number of different types of devices and communication technologies are used in SG heterogeneous network, the communication subsystems in SG must be reliable.
- It must have high coverage area and in time response to any event in the SG.
- Secure and reliable data communication through SG is also a major concern of SG.

Communication technologies used in SG can be classified as follows:

→ Wired communication technologies for SG.

- Wireless mess network
- Cellular communication
- Cognitive radio
- ZigBee
- Satellite communication
- Free-space optical communication

→ Wired communication technologies for SG.

- Fiber-optic communication
- Power line communication (PLC)

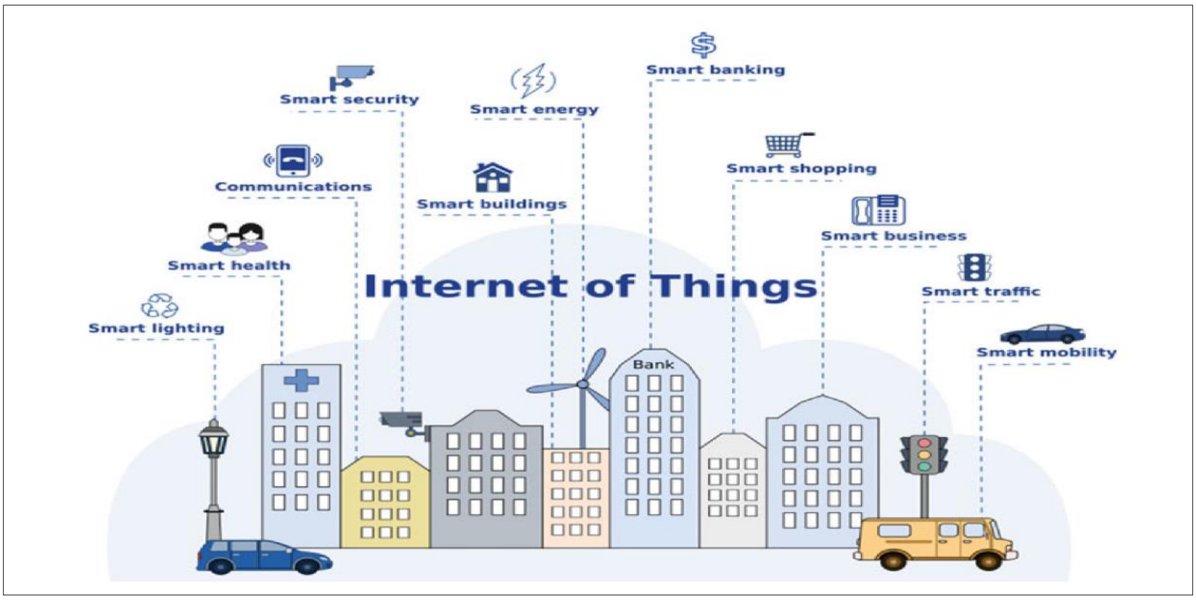


Figure 2.19. Smart cities and IoT

2.6 Conclusion

This chapter has presented updates in literature concerning the research topic, starting with an overview about Algeria, the country of the case study then examining the main elements of smart microgrids.

CHAPTER 3.
METHODS

3.1 Introduction

To attain the proposed objectives of our study, this chapter discusses the appropriate procedures that have been done while conducting the research. It addresses mainly the data collection methods, the techniques and statistical tests used for data analysis. It also explores the software packages utilized for data processing.

3.2 Research Approach Overview

The main objective of our study is to propose a modeled and simulated design of a **simple DC microgrid** for a localized area in the “university campus”.

To achieve this goal, our research has been conducted throughout four steps:

Step 01: Demand-side management;

Step 02: Supply-side management;

Step 03: Simulation and control;

Step 04: Analysis

Before any assessment of the available data, a general brain storming was made to gather all the needed information before being examined. The preliminary overview of the input data and expected output data were summarized in the Table 3.1 and 3.2 respectively.

Input Data			
Load profile	**Weather resources**	**Technical parameters**	**Project costs & Finance**
-Primary consumption	-Radiation -Sunshine duration -Wind speed -Temperature	-Photovoltaic -Wind turbine -Generator -Energy Storage -Converter -Power outage	-Capital -O&M -Fuel -Utility tariff -Feed-in-tariff -Depreciation

Table 3.1. Input data for the research

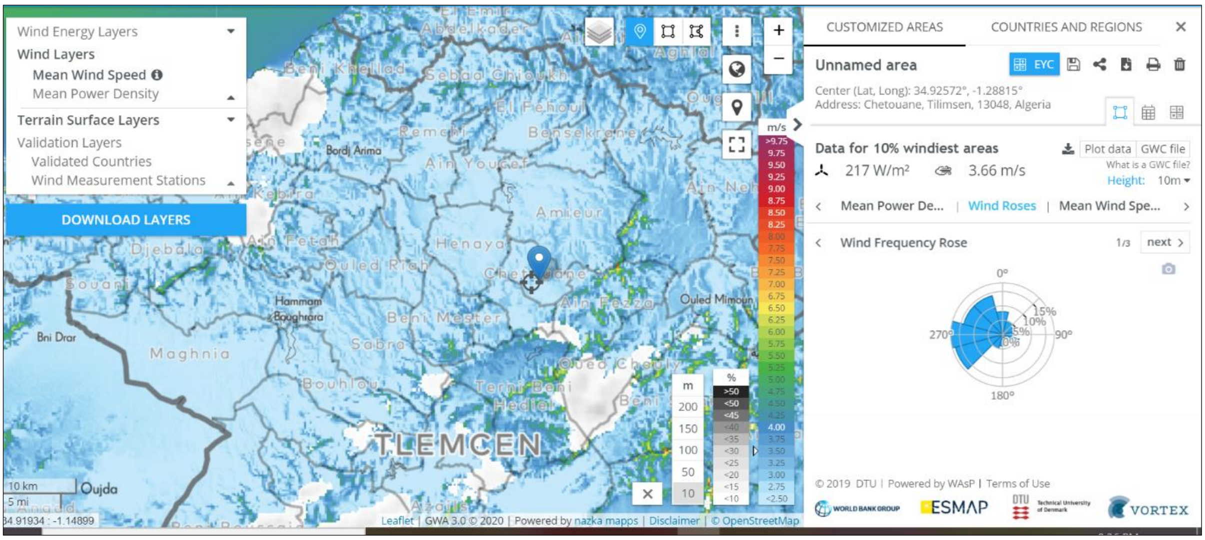
Output Data			
Sizing analysis	**Energy analysis**	**Financial analysis**	**Uncertainty analysis**
-Optimal size of Distributed energy resources and storage system	-Energy production -Efficiency and lifetime -Reliability index -Emissions reduction	-Payback period -Net present value -Internal rate of return -Annual lifecycle saving -Lifecycle cost	-Scenario analysis -Sensitivity analysis

Table 3.2. Output data of the research

3.2.1 Study assumptions

A preliminary natural assessment for Chetouane's potential shows that it has:

- A very low wind potential, with an annual mean wind speed under to 3 m/s [26]
- A very significant solar potential, with almost 1900 kwh/m^2 radiation [26]



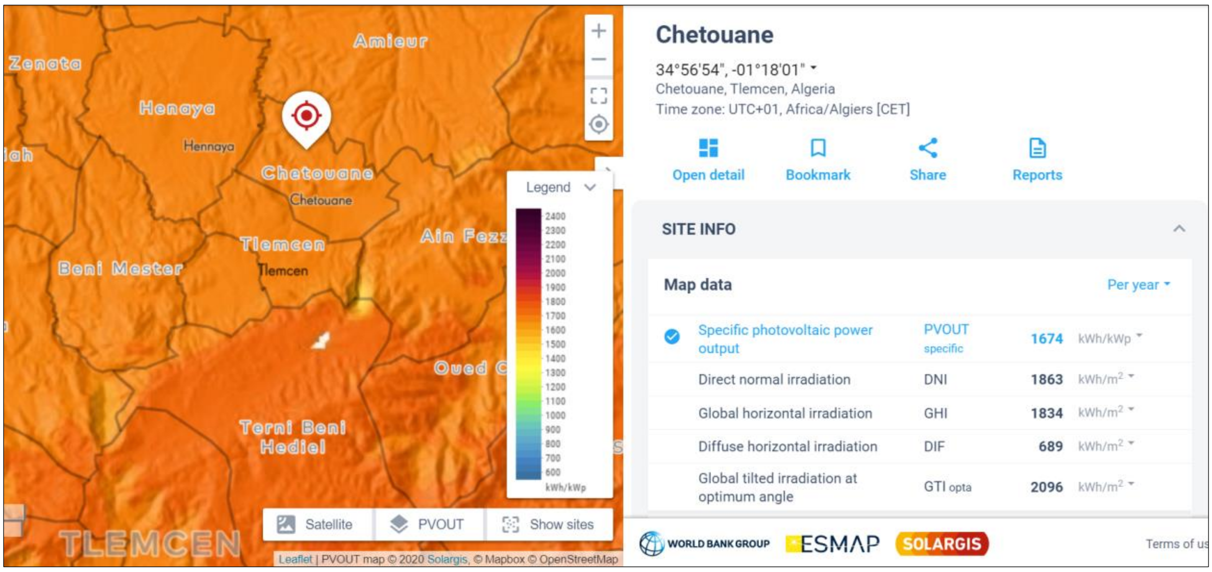
Unnamed area

Center (Lat, Long): 34.92572°, -1.28815°
Address: Chetouane, Tilimsen, 13048, Algeria

Data for 10% windiest areas
217 W/m² 3.66 m/s
Height: 10m

Wind Frequency Rose 1/3

Figure 3.1. Wind potential assessment in Chetouane [26]



Chetouane

34°56'54", -01°18'01"
Chetouane, Tlemcen, Algeria
Time zone: UTC+01, Africa/Algiers [CET]

SITE INFO

Map data — Per year

Specific photovoltaic power output	PVOUT specific	1674	kWh/kWp
Direct normal irradiation	DNI	1863	kWh/m²
Global horizontal irradiation	GHI	1834	kWh/m²
Diffuse horizontal irradiation	DIF	689	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	2096	kWh/m²

Figure 3.2. Solar potential assessment in Chetouane [26]

For that reason, our energy production will be relying on photovoltaic panels with a backup system of batteries and a diesel generator.

3.2.2 Research procedure

Combining all the data needed for the study, and using different technical assessments, the general overview of the research approach is described in the following scheme (Figure 3.3)

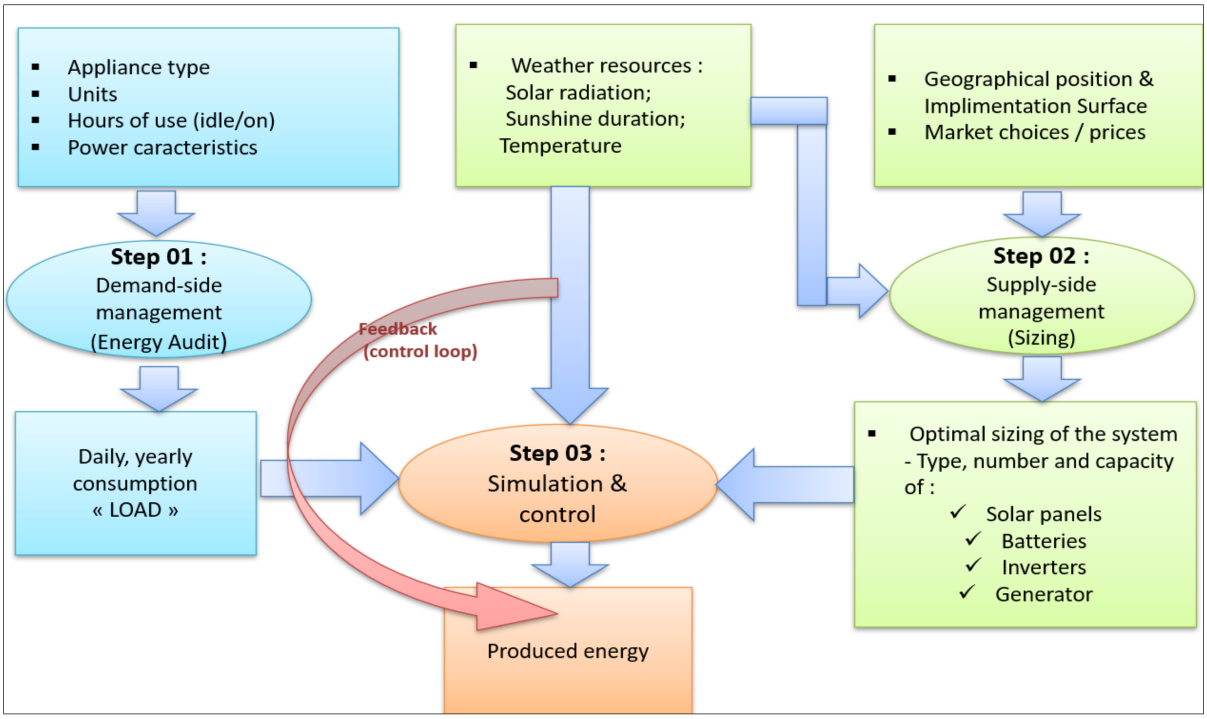


Figure 3.3 Research approach overview

3.2.3 Software Based Approach

Simulation and optimization software are the most common tools for evaluating the performance of renewable energy systems. In computer simulation, the performance and energy production of different system configurations are compared in order to obtain an optimal design. Some of the best-known software packages are: MATLAB, PVsyst, HOMER, HYBRID2, HOGA, HYDROGEMS, etc. PVsyst 7.0 was used in our research for the seizing and analysis of the solar system while the modeling and simulation of the microgrid system was carried out using Simulink MATLAB.

3.3 Step 01: Demand side management

3.3.1 Building description

The study is conducted for PAUWES building situated in Chetouane- Tlemcen city (see Figure 2.2). This building is used as an educational institution, in coordination with the University of Tlemcen. The building was built in 1989, and being used by the Pan African University starting from 2014.

PAUWES building is a two-floor structure made of concrete and steel. Its tinted glass front part faces the northern direction. PAUWES building includes both administration offices and classrooms. The energy end users are 22 Employers and around 120 students.

Figure 3.4. PAUWES building

Figure 3.5. GPS localization of PAUWES
(source: google earth)

3.3.2 Analysis of energy consumption

The energy audit gives visibility on energy consumption and cost. This means it provides us with a comprehensive overview of all the types of energy being used. It also breaks out the energy consumption by users so that we know where and when the energy is being consumed. Furthermore, it describes the energy saving alternatives that could be adopted and provides an energy management plan and easily implemented solutions.

For our case study, the data on energy consumption in the last three years were not provided. Due to Covid-19, even a walkthrough could not be conducted. Thanks to an audit report done by a group of students - in October, 10th, 2019, data on energy consumption were collected. The report was validated by the professor and it was obtained by asking the users and checking the equipment for performance details [36].

For our analysis and using Excel, the building was divided to 25 parts as following:

1. A0
2. A1
3. A2
4. A3
5. A4
6. A5
7. A6
8. A7
9. Interview room
10. Hall 1
11. Toilet Men
12. Stairs
13. Hall 2
14. Toilet Women
15. Students Affaires
16. E-Library
17. Information
18. Coordinators
19. B7 Research.
20. Deputy Director
21. Kitchen
22. Finance
23. Secretariat
24. Director
25. Meeting Room

The Appliances were identified and classified into the following sections:

- Laptops + Desktops + Projectors
- Air Conditioning
- Lighting
- Office Equipment
- Kitchen Appliances
- Others

The consumption of each part was estimated by calculating the usage of each appliance (On/Idle) and thus, the Total power of the load was determined as:

$$P_{total} = \sum_{i=1}^{25} P_i = \sum_{i=1}^{25} [(h_{on} \cdot p_{on})(h_{Idle} \cdot p_{Idle})]_i$$

Where:

P_{total} : Load

P_i : Power consumed per part

h_{on} : Operation time of the appliance

p_{on} : power consumption when the device is ON Mode

h_{Idle} : Idle time of the appliance

p_{on} : power consumption when the device is Idle Mode

The PAUWES building has a number of different uses and includes offices, teaching rooms, halls, laboratories and a kitchen. The energy data were estimated and divided into two cases related to the energy needs during a working day and a weekend/vacation time respectively.

3.4 Step 02: Supply-side management

3.4.1 System configuration

Figure (3.6) illustrates the microgrid considered in our study. It is a grid-connected DC microgrid consisting of a PV module, diesel generator, storage system, inverters, switches and controllable loads. More details of each part are explained and given in the next sections.

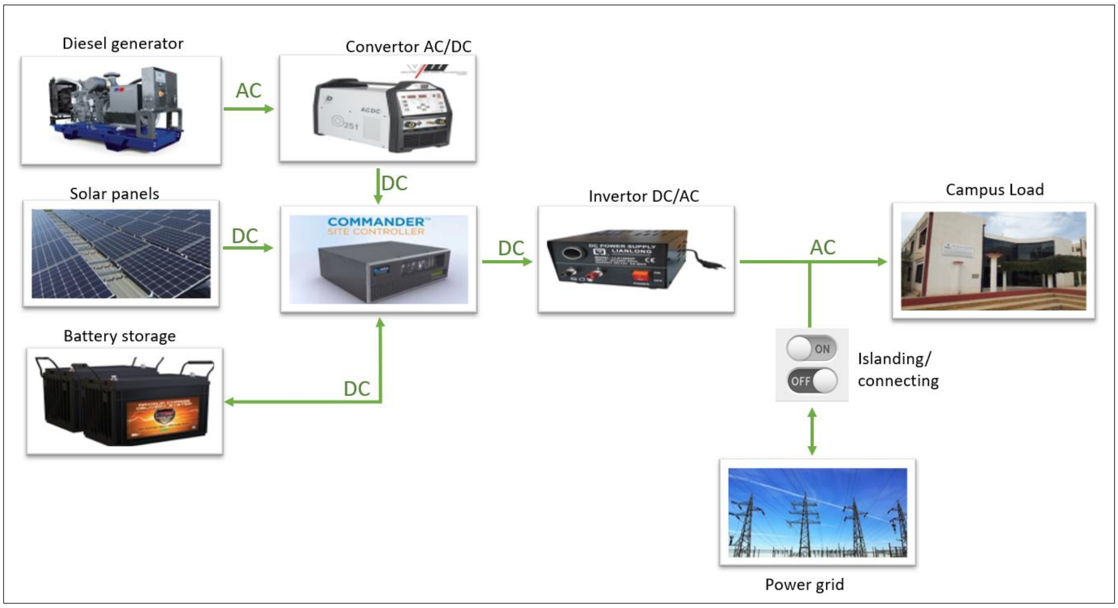


Figure 3.6. System configuration

3.4.2 System sizing

Before starting the dimensioning of our solar system, we had to determine the main constraints of the project and use these constraints as a starting point for the design, among which we can find:

1- Building a system within a target budget;

2- Assessing the appropriate location for the best exposure to the sun;

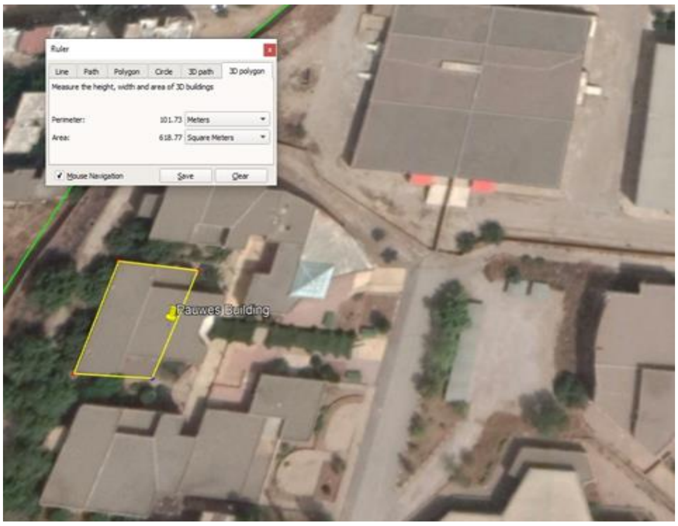
3- Evaluating the effectiveness of products and technologies;

4- Designing a system that compensates for a certain percentage of our energy consumption;

5- Conceiving a system that takes up as little space as possible and susceptible for a future expansion.

It was from 4 and 5 that we approached the dimensioning of the project, using PVsyst software.

The surface available was estimated using google earth software and it had the value of around 600 m^2 and the average daily consumption is 15 kwh



Measure the height, width and area of 3D buildings

Perimeter: 101.73 Meters

Area: 618.77 Square Meters

Figure 3.7. Building's Surface estimate

Solar panels work best when they are oriented directly towards the sun. But this is complicated because the sun moves across the sky throughout the day. It also changes its angle in the sky with the seasons. Trackers automatically adjust the system so that the panels always face the sun, but since trackers are often too expensive, it is better to buy more panels rather than using trackers.

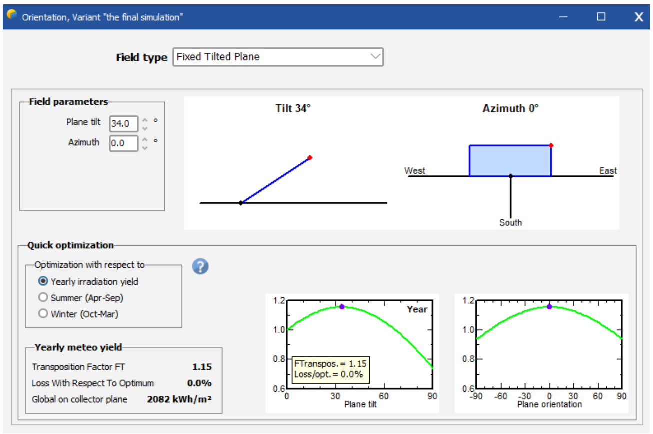
For an optimum orientation, in our location - the Northern Hemisphere-, experts [37] recommend that the panels should:

- Face the south: for the Azimuth angle

- Set them at a tilt angle that is equal to our latitude: 34° shown in Figure (3.8).

We can make some seasonal adjustments to get more power by changing the tilt angle:

In summer, latitude minus 15°. In winter, latitude plus 15°.



Orientation, Variant "the final simulation"

Field type: Fixed Tilted Plane

Field parameters
Plane tilt: 34.0 °
Azimuth: 0.0 °

Quick optimization
Optimization with respect to
● Yearly irradiation yield
○ Summer (Apr-Sep)
○ Winter (Oct-Mar)

Yearly meteo yield
Transposition Factor FT 1.15
Loss With Respect To Optimum 0.0%
Global on collector plane 2082 kWh/m²

FTranspos. = 1.15
Loss/opt. = 0.0%

Figure 3.8. Panels orientation

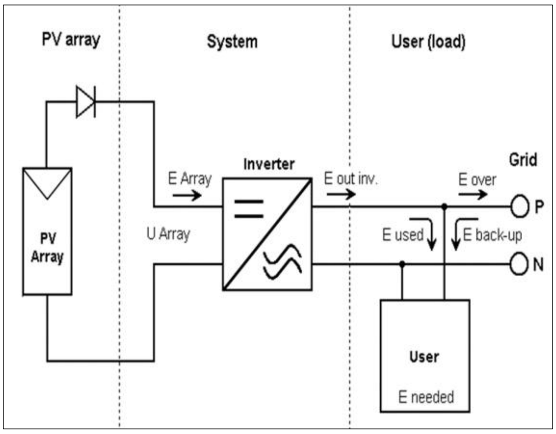


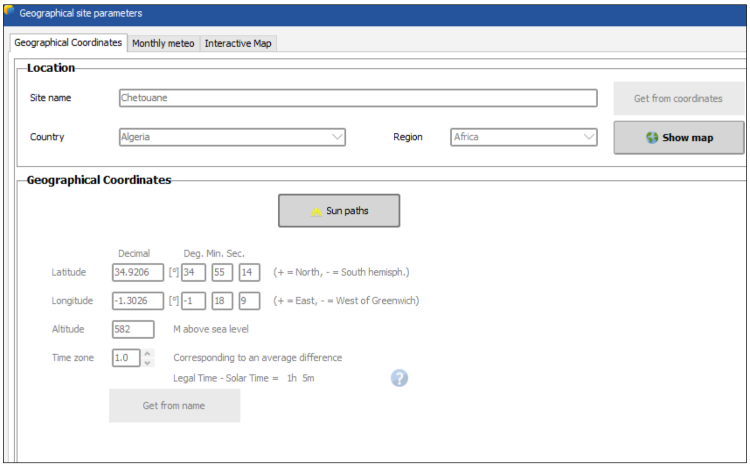
Figure 3.9. System’s simplified sketch

3.4.2.1 Geographical site

By Defining the geographical parameters of our site with PVsyst software, entering the geographical coordinates for our building:

- Latitude: 34.9213°
- Longitude: -1.2951°
- Altitude: 582 m

We get the solar paths graph illustrated in Figure (3.11)



Location

Site name: Chetouane
Country: Algeria
Region: Africa

Geographical Coordinates

	Decimal		Deg.	Min.	Sec.	
Latitude	34.9206	[°]	34	55	14	(+ = North, - = South hemisph.)
Longitude	-1.3026	[°]	-1	18	9	(+ = East, - = West of Greenwich)

Altitude: 582 M above sea level
Time zone: 1.0 Corresponding to an average difference
Legal Time - Solar Time = 1h 5m

Figure 3.10. Defining the site's geographical position

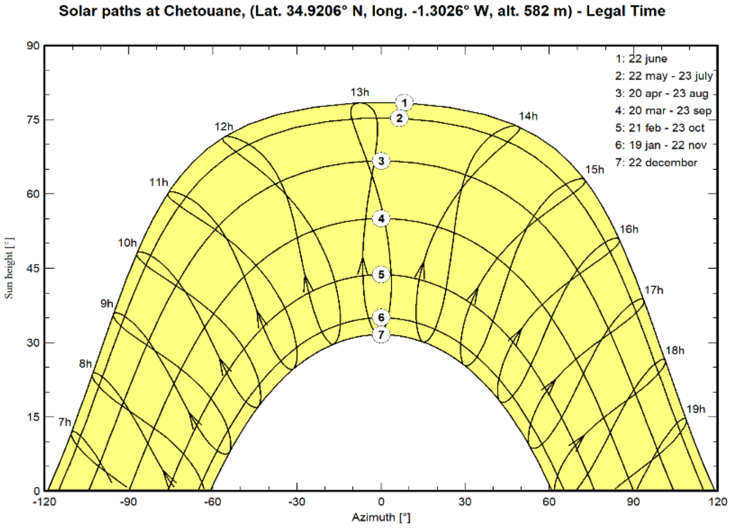
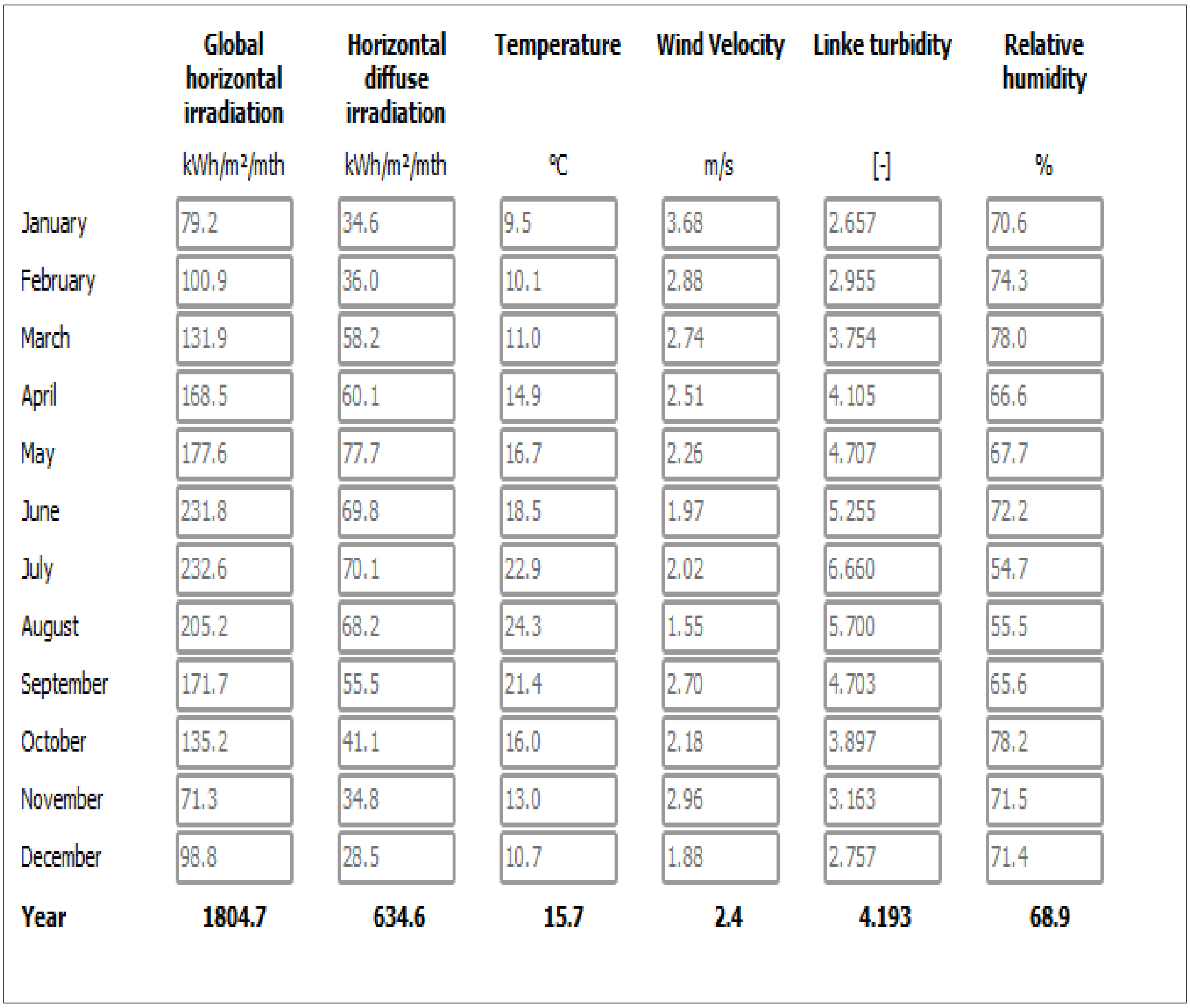


Figure 3.11. Solar paths at Chetouane

3.4.2.2 Natural resources assessment and weather data

In a chosen region, the total radiation, sunshine duration and temperature as measured data are required to generate electricity with a photovoltaic panel.

Therefore, the monthly measurement data in Chetouane - Tlemcen were collected and they are shown in Table (3.3) The table shows that the value of the average monthly radiation measured is 150 kWh/m^2 the value of the average annual temperature is 15.7°C. Thus, it is clear that Tlemcen has a large potential for solar energy.



	Global horizontal irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke turbidity	Relative humidity
	kWh/m²/mth	kWh/m²/mth	°C	m/s	[-]	%
January	79.2	34.6	9.5	3.68	2.657	70.6
February	100.9	36.0	10.1	2.88	2.955	74.3
March	131.9	58.2	11.0	2.74	3.754	78.0
April	168.5	60.1	14.9	2.51	4.105	66.6
May	177.6	77.7	16.7	2.26	4.707	67.7
June	231.8	69.8	18.5	1.97	5.255	72.2
July	232.6	70.1	22.9	2.02	6.660	54.7
August	205.2	68.2	24.3	1.55	5.700	55.5
September	171.7	55.5	21.4	2.70	4.703	65.6
October	135.2	41.1	16.0	2.18	3.897	78.2
November	71.3	34.8	13.0	2.96	3.163	71.5
December	98.8	28.5	10.7	1.88	2.757	71.4
Year	**1804.7**	**634.6**	**15.7**	**2.4**	**4.193**	**68.9**

Table 3.3. Weather data for Chetouane

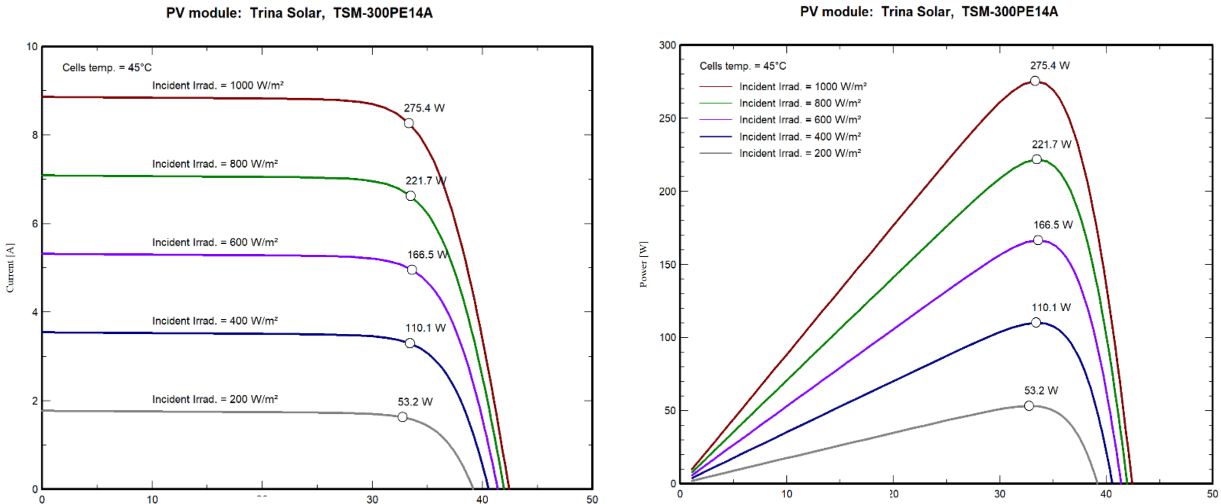
3.4.2.3 Defining Solar system components

- **PV Module**

The characteristics of the selected PV module are summarized in the following tables:

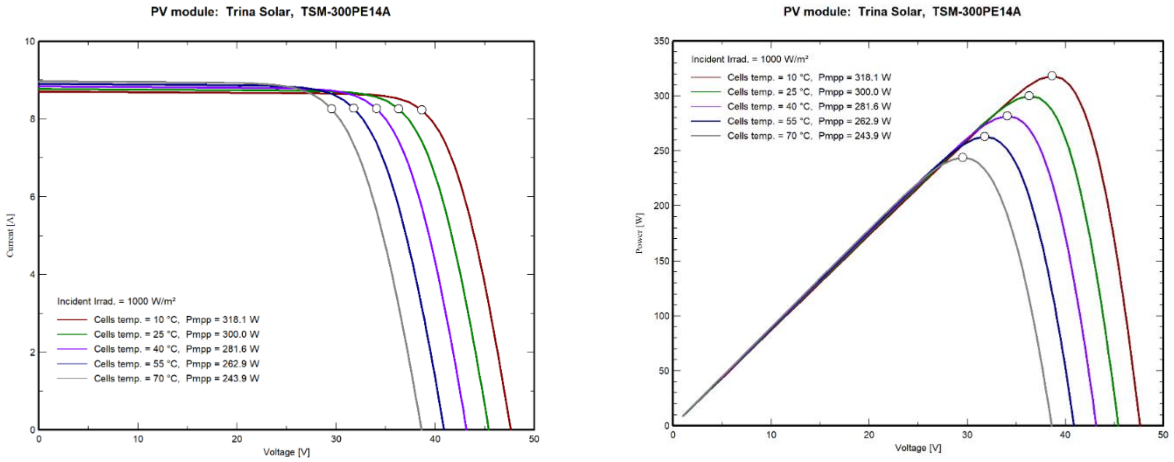
PV module	Si-poly Model TSM-300PE14A 
Manufacturer	Trina Solar Original PVsyst database
Number of PV modules	In series 17 modules, In parallel 3 strings
Total number of PV modules	nb. modules 51
Unit Nom. Power	300 Wp
Array global power Nominal (STC)	15.30 kWp At operating cond. 13.73 kWp (50°C)
Array operating characteristics (50°C)	U mpp 553 V I mpp 25 A
Total area	Module area 99.0 m² Cell area 89.4 m²

Table 3.4. PV System sizing and characteristics



(a) *(b)*

Figure 3.12. Relation of I-V/P-Vo f PV cell at different light intensities.



(a) *(b)*

Figure 3.13. Relation of I-V/P-Vo f PV cell at different Temperatures.

The output voltage and current of the photovoltaic cells vary according to light intensity and temperature. Figure (3.12) shows an example of the relationship between current and voltage (a) and the relationship between power and voltage (b) of PV at different light intensities. Figure (3.13) shows an example of the relationship between current and voltage (a) and between power and voltage (b) of PV cells at different temperatures. At a certain light intensity and temperature, the PV cell can operate at a different voltage, whereas at only a certain voltage, the output power of the PV cell reaches the maximum efficiency. Photovoltaic production uses MPPT voltage control to control the photovoltaic cell operates at the voltage point of maximum output power.

- **Inverters**

To convert DC voltage to AC voltage or vice versa, an inverter must be used. This compensates for power failures and stabilizes the electrical voltage. PVsyst offers several inverter technologies depending on the type of power supply system; there are grid-connected inverters that can connect the DC PV to the AC grid and bidirectional inverters that can connect between the PV generator and/or batteries and the AC load.

In our case, we select an inverter that can be found in the library has the following characteristics:

Inverter Model	Conext TL 10000 E 
Manufacturer	Schneider ElectricOriginal PVsyst database
Unit Nom. Power	10.00 kWac
Oper. Voltage	100-850
Inverter pack Total power	15.0 kWac, Pnom ratio 1.02
Nb. of inverters	3
Total Total power	15 kWac, Pnom ratio 1.02

Table 3.5 Inverter's characteristics

- **Storage system**

For our microgrid, we choose a Li-ion battery with 14V and 100 Ah, a Generic from PVsyst library that has the below mentioned specifications:

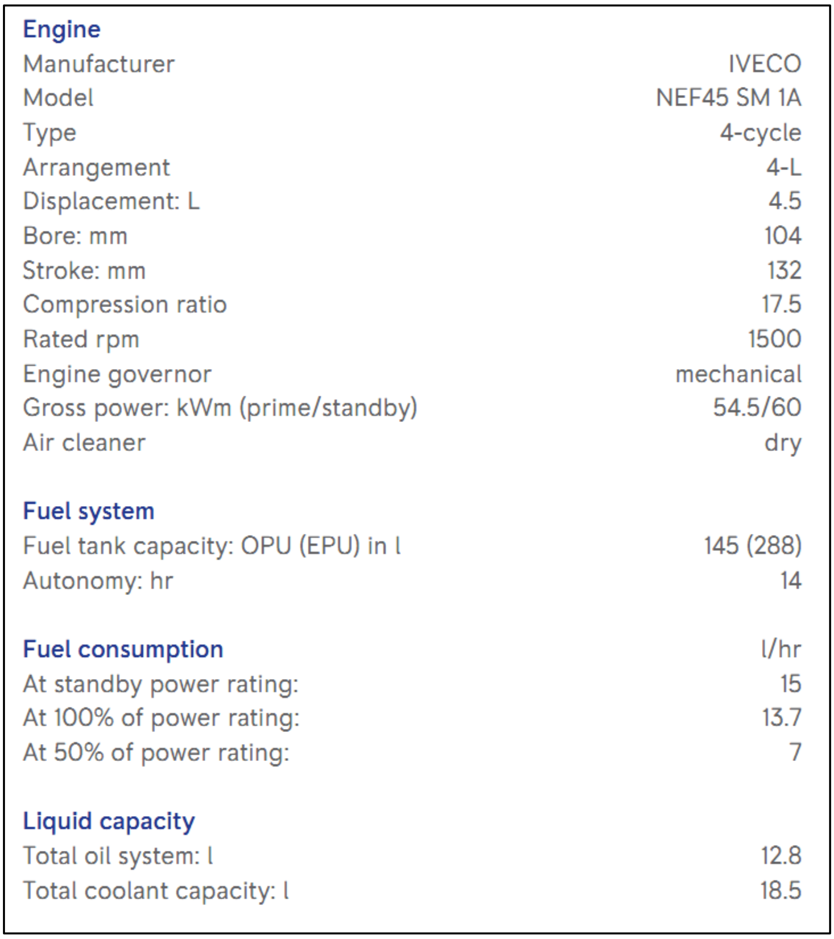
Battery Model	Li-Ion, 14V 100 Ah
Manufacturer	Generic
Nb. of units	5 in series
Voltage	64 V
Nominal Capacity	103 Ah (C10)
Discharging min SOC	20.0%
Stored energy	5.3 kWh
Temperature	Fixed (25°C)

Battery input charger	Model Generic
Max. charging power	3.0 kWdc
Battery to Grid inverter	Model Generic
Max. discharging power	2.0 kWac

Table 3.6 Battery's characteristics

- **Diesel Generator**

The selected one is a *MTU 4R0113 DS63* Diesel Generator Set, produced by EVECO with the benefits of a low fuel consumption, emissions optimizations available, high availability and reliability and long maintenance intervals. The technical characteristics are summarized in the table below [39]:



Engine	
Manufacturer	IVECO
Model	NEF45 SM 1A
Type	4-cycle
Arrangement	4-L
Displacement: L	4.5
Bore: mm	104
Stroke: mm	132
Compression ratio	17.5
Rated rpm	1500
Engine governor	mechanical
Gross power: kWm (prime/standby)	54.5/60
Air cleaner	dry
Fuel system	
Fuel tank capacity: OPU (EPU) in l	145 (288)
Autonomy: hr	14
Fuel consumption	l/hr
At standby power rating:	15
At 100% of power rating:	13.7
At 50% of power rating:	7
Liquid capacity	
Total oil system: l	12.8
Total coolant capacity: l	18.5

Table 3.7 genset's characteristics

3.5 Step 03: Simulation and control

The operation of the various components of the microgrid were analyzed using MATLAB/Simulink. Simulink has an environment called Simscape that can be used to model dynamic systems. The Simscape demonstrates its strength in physical modelling using equation-based representations for solar modules, batteries, converters, diesel generator and a charge controller.

3.5.1 Load profile

In our simulation, we are taking load profile for a working day as it is represented in Figure (3.14)

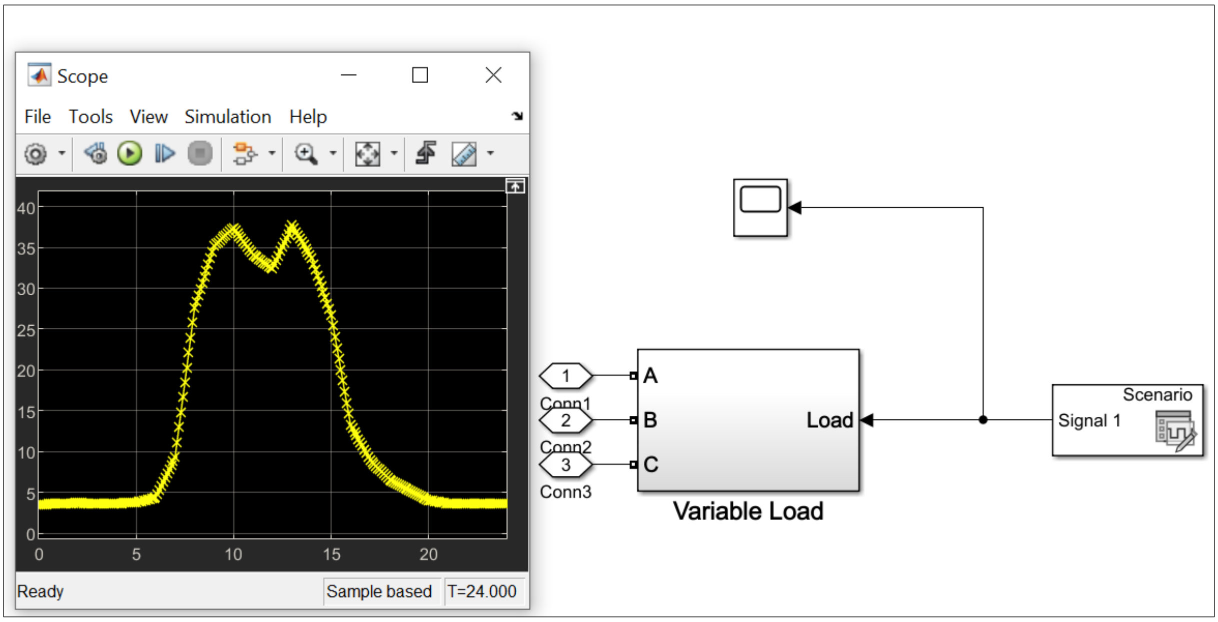


Figure 3.14. Load profile modeling

3.5.2 PV block

The PV model is constructed using Matlab/Simulink to illustrate and verify the non-linear I-V and P-V output characteristics of the PV module.

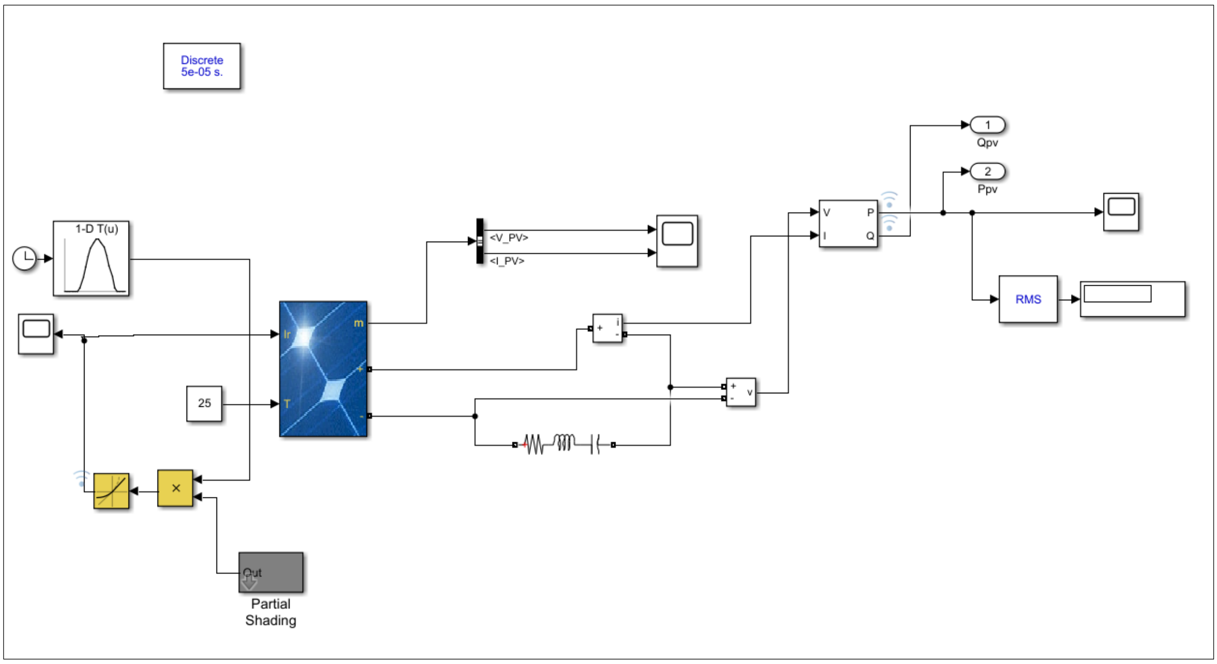


Figure 3.15. PV model block

The example day for simulation was the 11/05/2020 where the input data of irradiation were collected from [40]

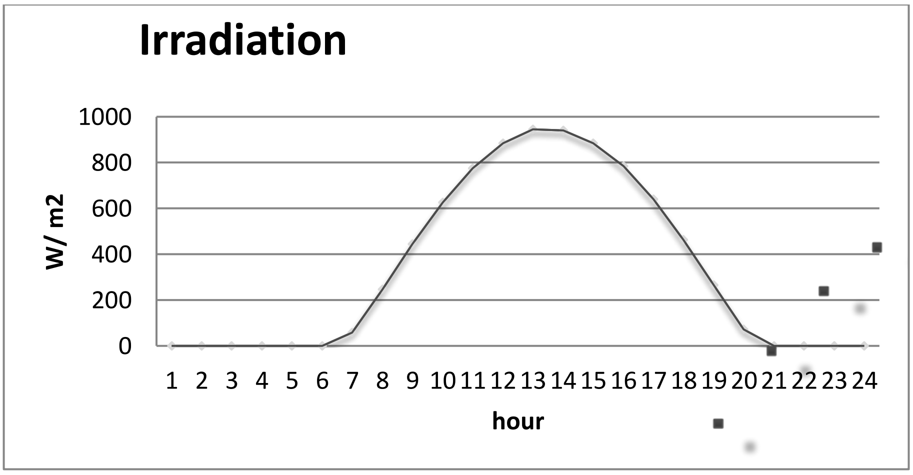


Figure 3.16. Daily irradiation for May,11th 2020

3.5.3 Storage system block

The demand for electricity fluctuates according to the time of day and the time of year. Since the traditional electricity grid is not able to store electricity, the mismatch between supply and demand is more likely to be observed. As the concept of microgrid becomes more and more widespread, energy storage is advantageous in the management of such a system. A desired form of energy storage should provide the electricity to the grid and store enough energy for low electricity consumption.

The short-term storage that is studied and modelled in our case is: batteries storage.

There are several approaches to modelling a battery. In our case, Simulink implements a set of predetermined charging behaviors for four types of batteries: lead-acid, lithium-ion, nickel-cadmium and nickel-metal hydride. Figure (3.17) illustrates a detailed modelling of the charge and discharge battery in MATLAB/Simulink.

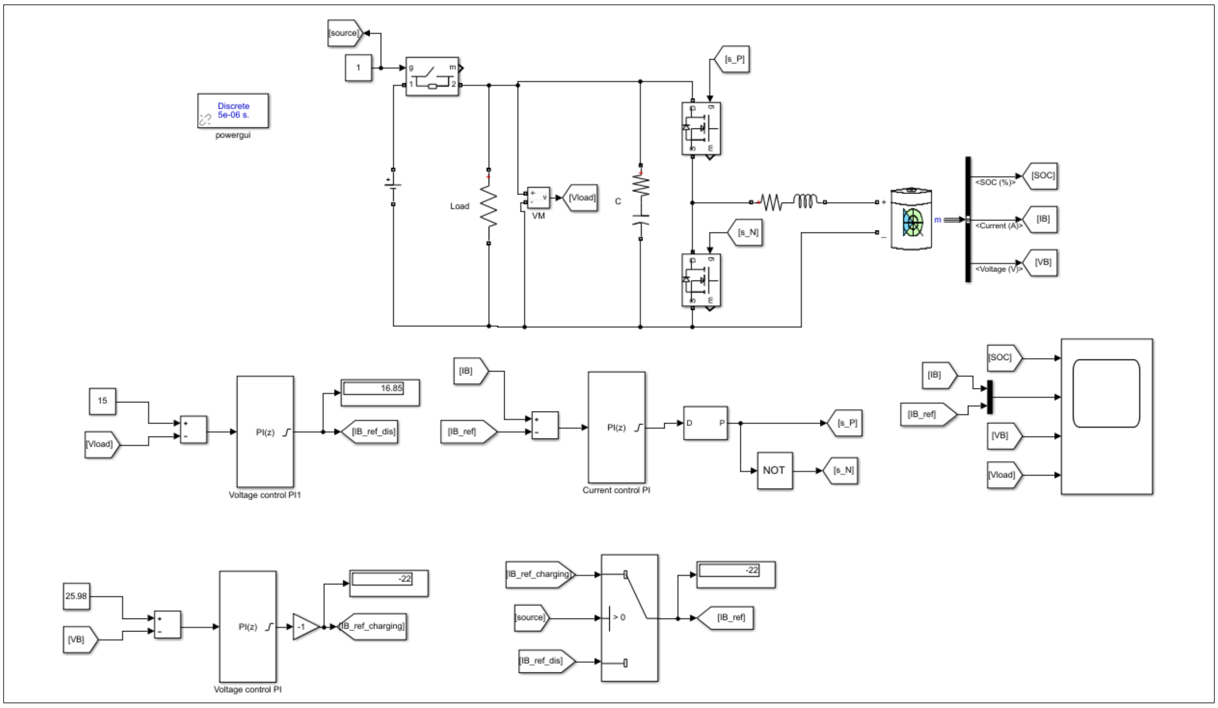


Figure 3.17. Battery model block

3.5.4 Diesel generator block

The diesel engine model provides a description of the fuel consumption rate as a function of the speed and mechanical power output of the engine, and is generally modelled by a simple first-order model relating fuel consumption to the mechanical power of the engine. The output power of the engine and generator varies with load to meet demand.

The governor can be defined as a mechanical or electromechanical device for controlling the speed of an engine by relating the fuel intake, [13]. The task of the governor is to adjust the fuel flow and then regulate the input to the engine and generator, allowing the power required to respond to load variation. There are several types of governors, such as mechanical, electronic, microprocessor-based and others. Figure (3.18) illustrates the diesel engine model in Matlab/Simulink.

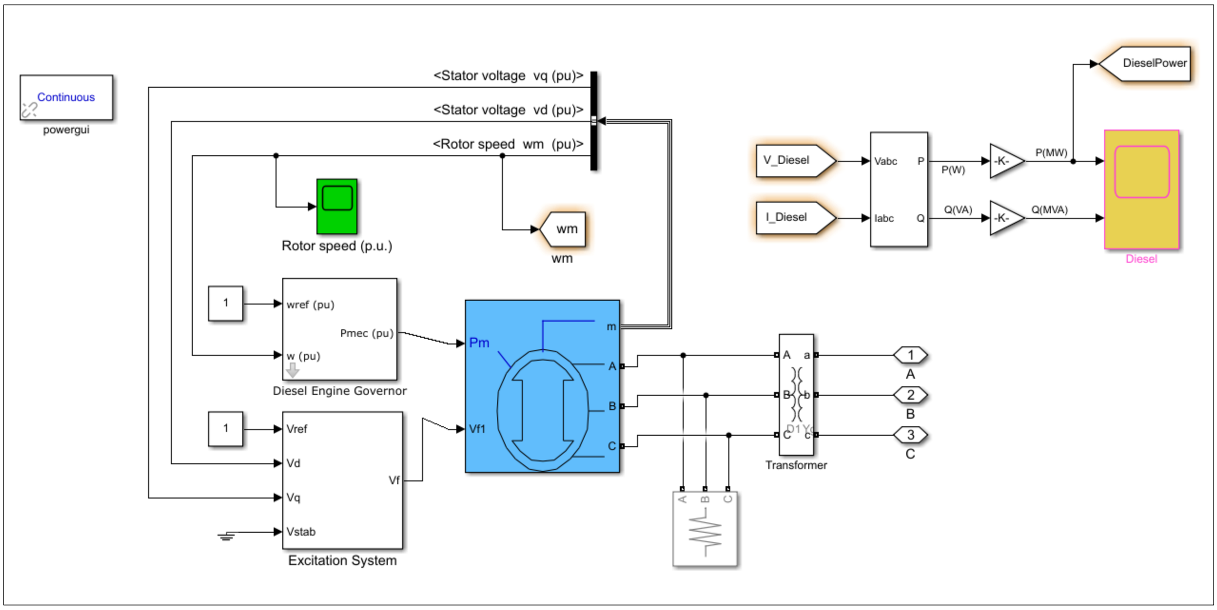


Figure 3.18. Diesel generator model block

3.5.5 Global configuration of the microgrid

After being implemented in Matlab/Simulink, the models are integrated in combination to form a Micro-Grid system (off/on grid) as shown in Figure (3.19)

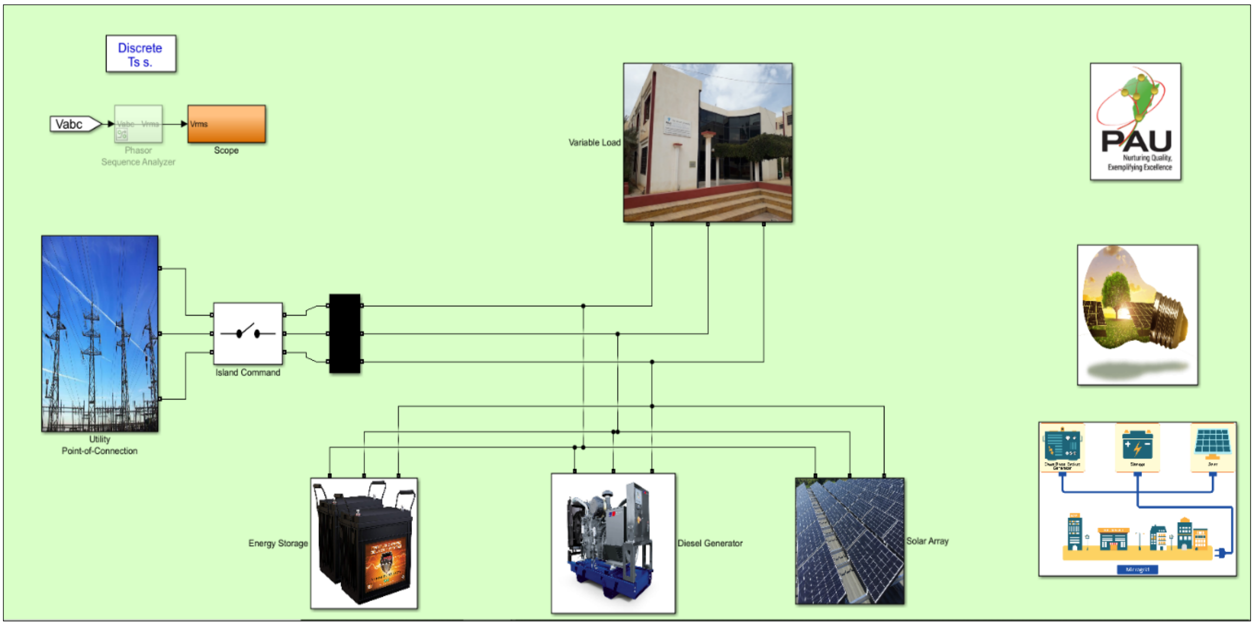


Figure 3.19. General block of the microgrid

The charts presented in the Figure (3.20) and (3.21) propose the control algorithms for the microgrid operation during peak load periods for two cases: sufficient PV power outage and insufficient PV power.

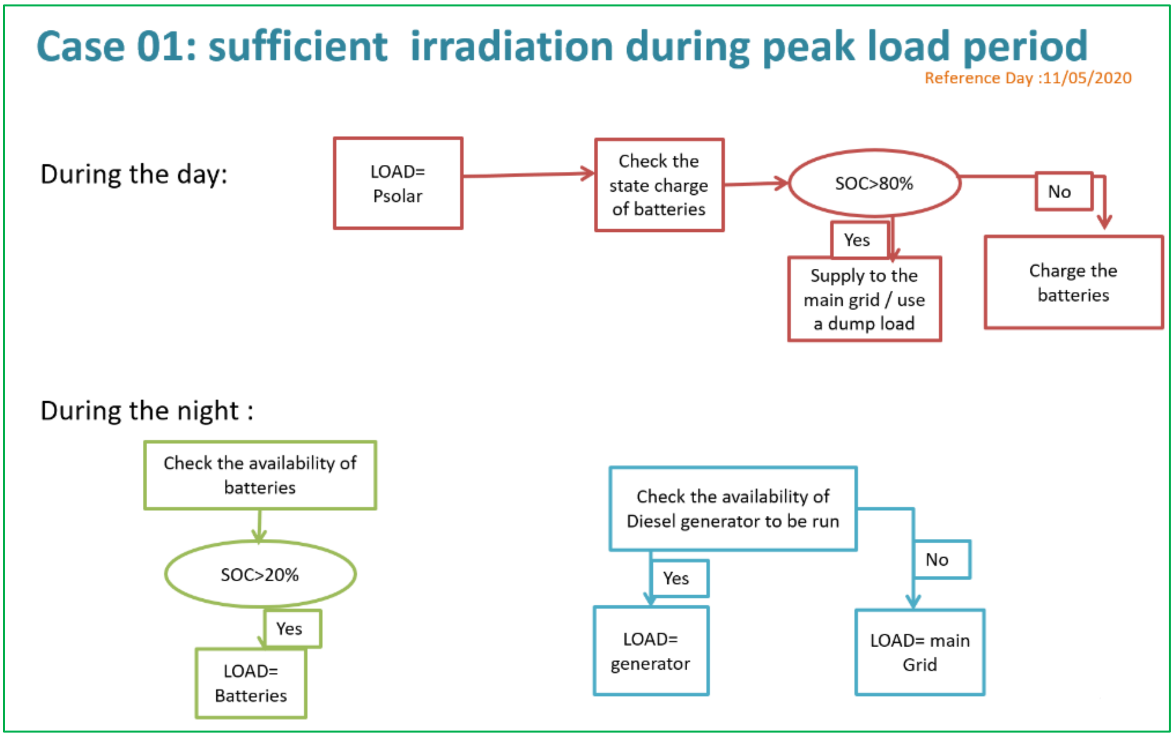


Figure 3.20. Algorithm control in case of PV availability

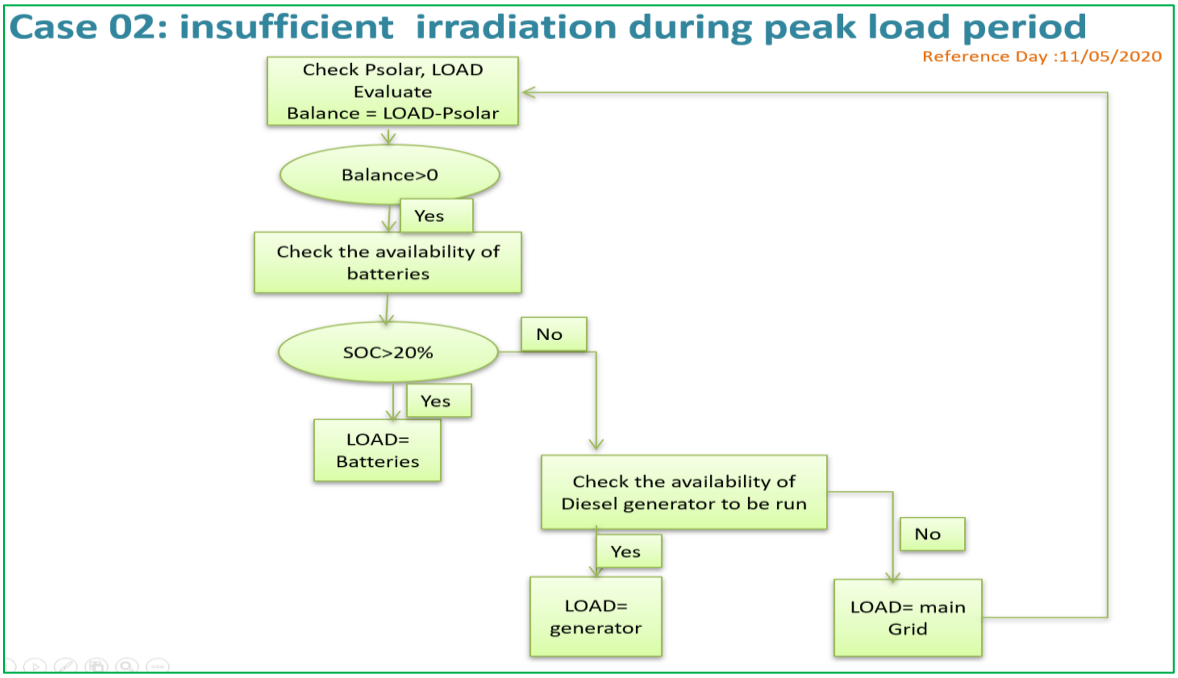


Figure 3.21. Algorithm control in case of PV non availability

3.6 Step 04: Analysis

Using PVsyst an economical and environmental analysis were conducted for the solar system (panels + batteries). The results will be found in the chapter 4.

The Assumptions for the economic study are shown in the Table (3.8) below:

Item	Cost per unit
Panels	300 $
inverter	100 $
Battery	1400 $
Taxes	2%
O&M	320 $
Inflation	0.2 %
Discount rate	0.5 %
Subsidies	1000 $
Project lifetime	25 years

Table 3.8 Economical Data for analysis

3.7 Conclusion

This chapter addressed in details the methods and approaches carried out throughout the research process, from data collection to simulation passing by the sizing and analysis. The results and discussion will be presented in the next chapter.

CHAPTER 4.
RESULTS AND DISCUSSION

4.1 Introduction

Following our research approach, in this section the results and their discussion will be presented in by the following order:

Step 01: Demand-side management;

Step 02: Supply-side management;

Step 03: Simulation and control;

Step 04: Analysis.

4.2 Step 01: Demand-side management

Load profiling and categorization

Once the load details were collected, load profiling is performed to determine the maximum load, the average daily daytime energy demand for both working day and a weekend time, the average yearly energy demand and an analysis for energy consumption per part and appliance.

- The Figure (4.1) shows the daily load curve for a working day and a weekend day.

The peak load of 37 kWh is observed in the beginning of both the morning and afternoon periods, and it can be explained by the activity of both administration and students during those rush hours. From 11 to 13:00 AM, lunch time shows a decrease in the consumption.

For a weekend day the consumption decreases very clearly except for the permanent appliances such as the sever and refrigerators etc.

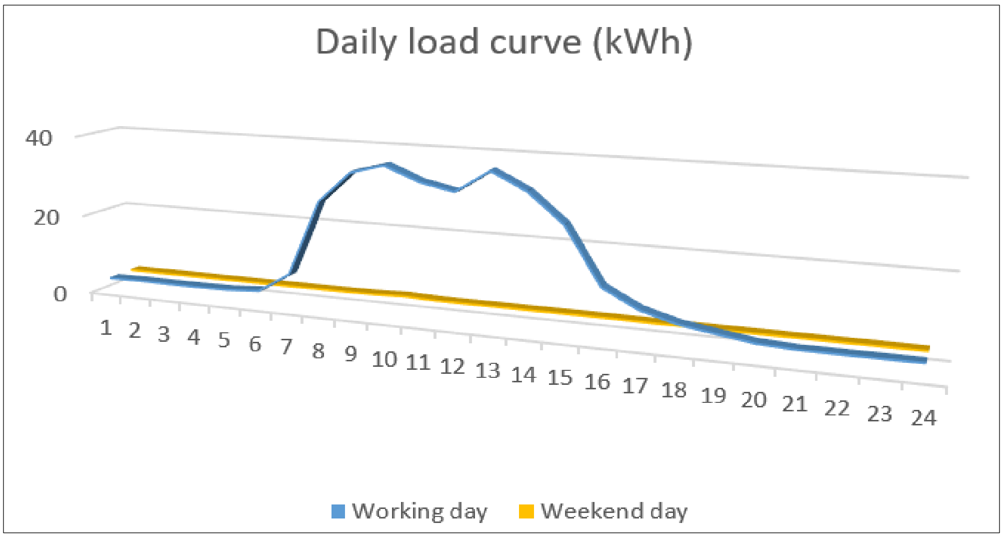


Figure 4.1. Daily load curve for both a working and a weekend day

- The Figures (4.2) and (4.3) represent the electricity daily consumption for the whole building corresponding to its different zones for both a working day and a weekend day respectively. The energy consumption for a working day reaches 350 kWh while it doesn't exceed 88 kWh in a non-working day.
- Figure (4.4) shows the yearly energy consumption of the building which is estimated by almost 82 GWh. It can be seen in the three figures that that Hall 2 has a high consumption compared to the rest of the building. The reason for this is the presence of the server in the area.

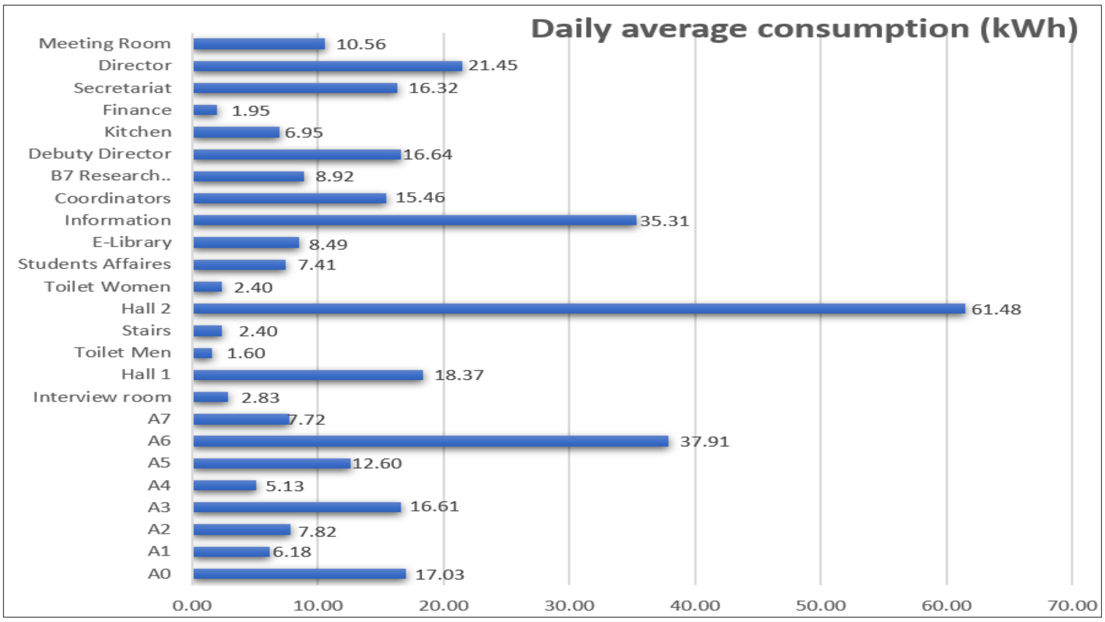


Figure 4.2. Daily average consumption per part for a working day

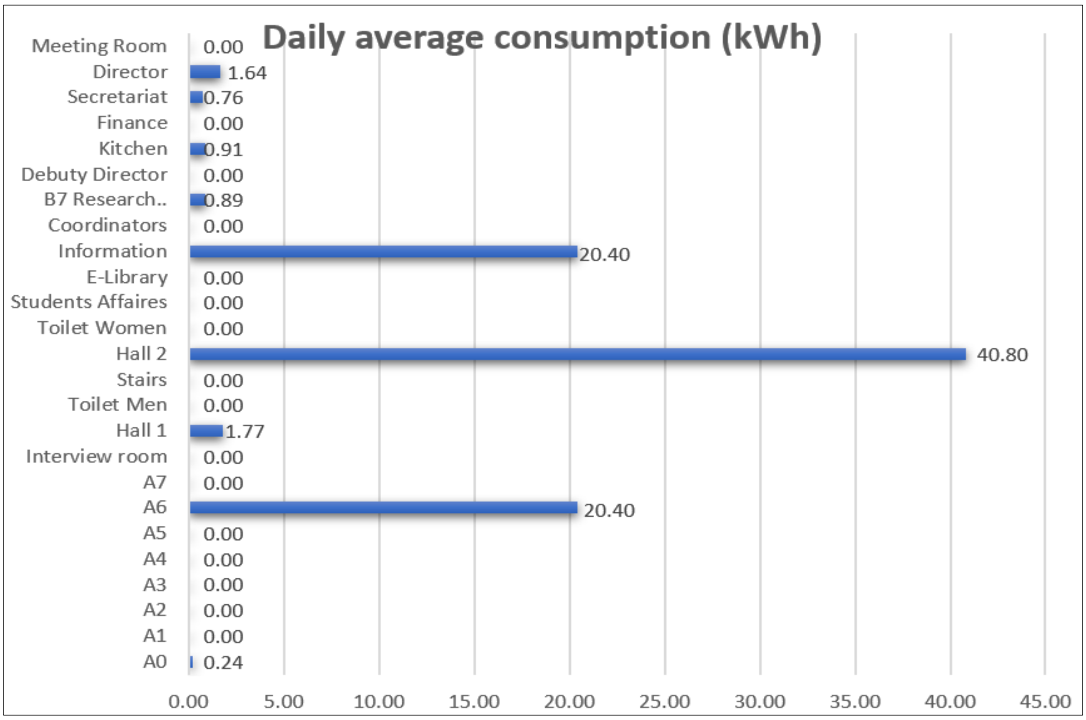


Figure 4.3. Daily average consumption per part for a weekend day

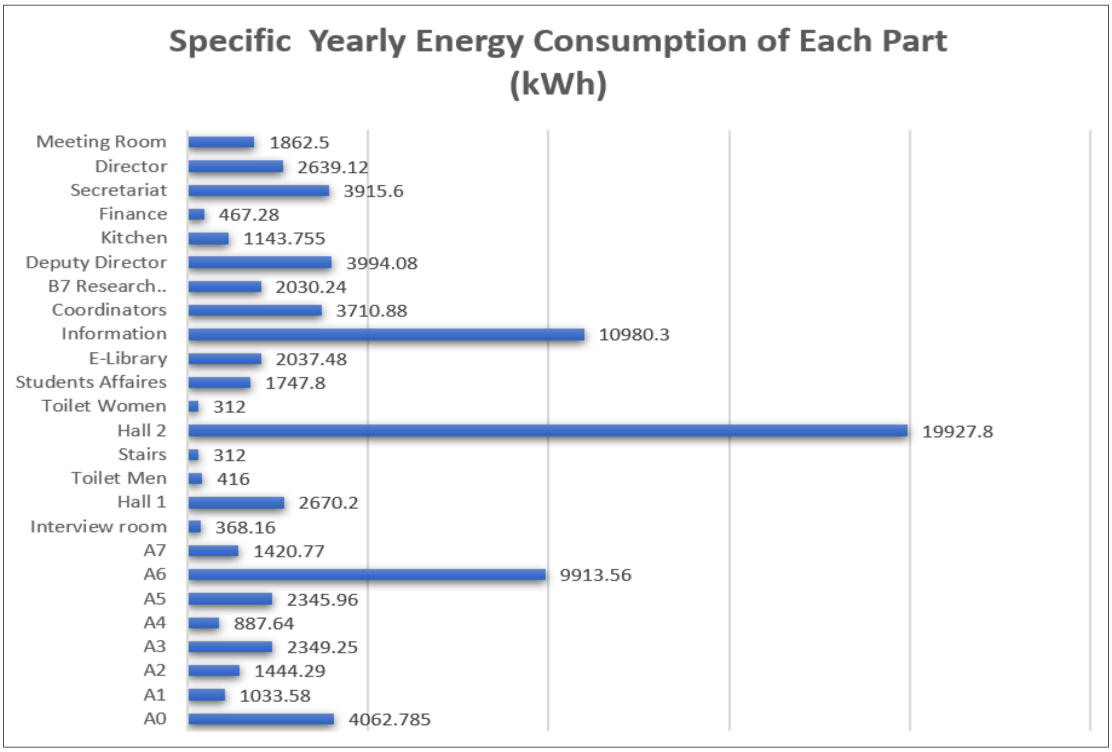


Figure 4.4. Yearly average consumption per part

- The charts in Figures (4.5) and (4.6) display the electricity distribution consumption in the building according to its different uses for both daily and yearly period respectively. It can be seen that office equipment has a significant consumption compared to the rest. Air-conditioning comes in second place with a small difference with the energy consumption related to the use of laptops and related equipment, while lighting comes last in relation to the rest, but its consumption is still very high in general.

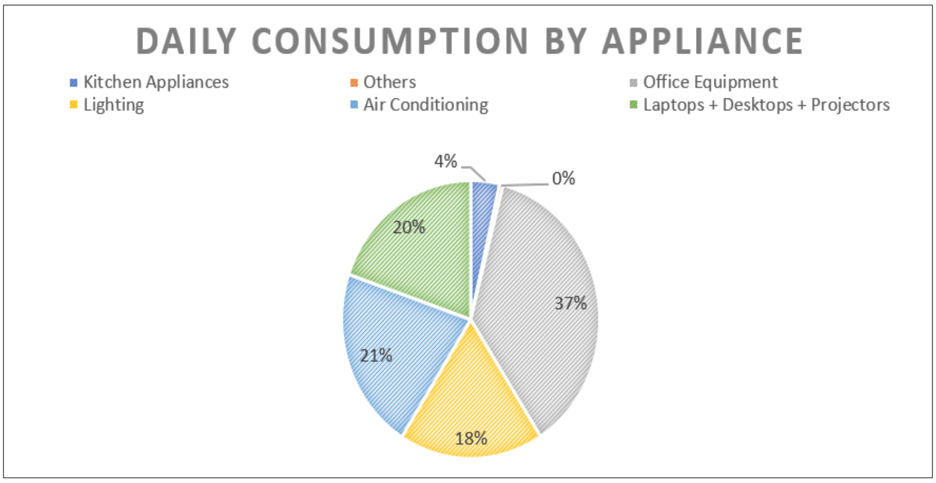


Figure 4.5. Daily consumption by appliance for a working day

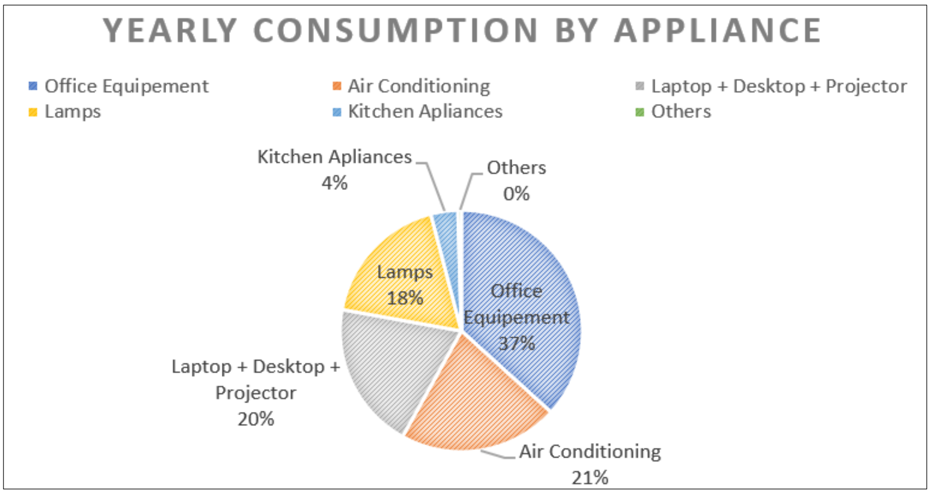


Figure 4.6. Yearly Distribution of consumed energy

4.3 Step 02: Supply-side management

Analyzing the values of the daily measurement of both temperature and irradiation (average radiation measured monthly is 150 kWh/m2, annual average temperature is 15.7°C) shows that Tlemcen has a significant potential for PV.

Our system is composed of 51 Monocrystalline silicon solar panel of 300 W peak power. The data acquisition system and PVsyst software tools used in this study can import meteorological which be used to estimate the amount of energy produced.

The photovoltaic system will be installed on the PAUWES building's flat roof. The inclination of each photovoltaic panel is at 34°, which represents the optimal angle for the whole year, the total covered surface area is approximately 100 m^2.

The output energy of photovoltaic is plotted for each month as shown in Figure (4.7.a) and Figure (4.7.b). The maximum power generation are reached during summer while in winter the electricity generated decreases but remains very important.

The total power installed by this system accounts for 24 MWh yearly which is dispatched to the end user or grid reinjection. In determining total electricity generated of a PV system, it has been taken to consideration all types of losses as PV and module loss, inverter loss, and external transform as illustrated in Figure (4.8).

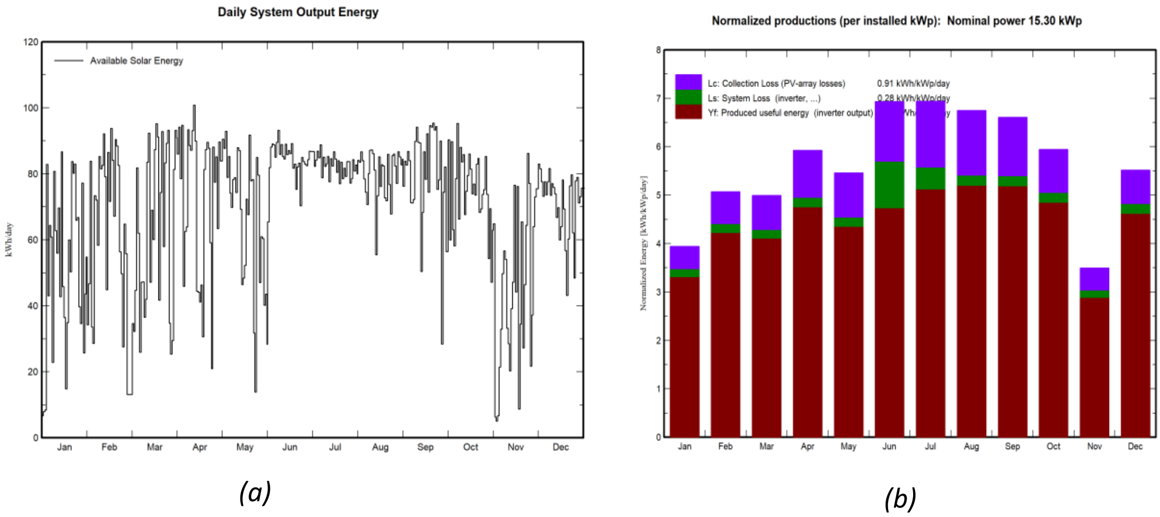


Figure 4.7. Yearly Distribution of produced energy

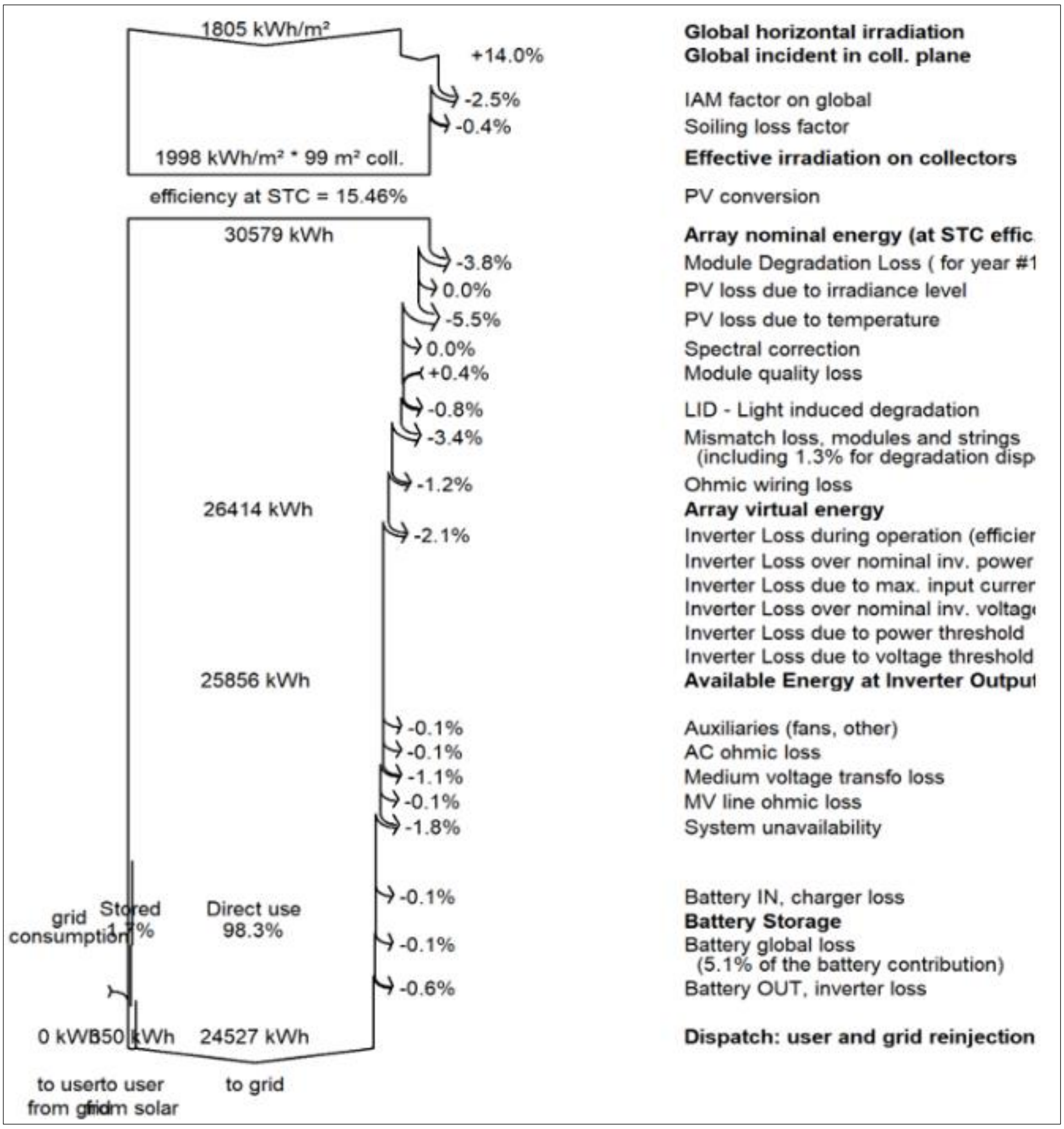
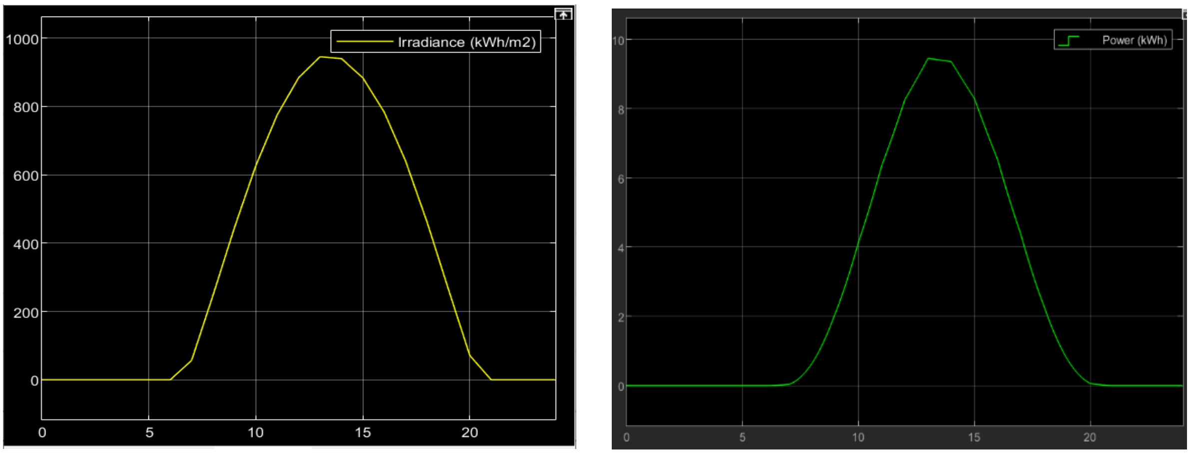


Figure 4.8. Loss diagram

4.4 Step 03: Simulation and control

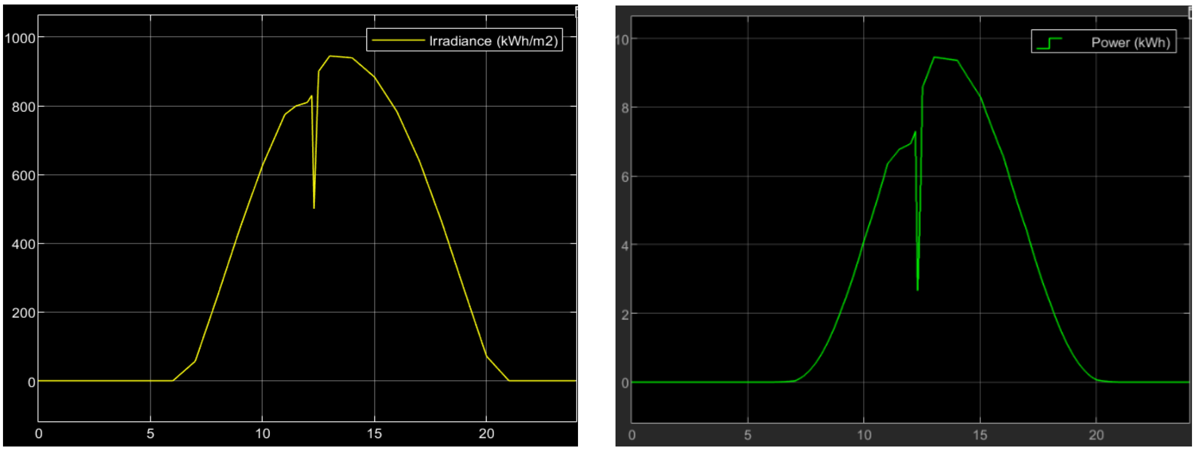
4.4.1 PV

The irradiation curve is given in Figure (4.9.a) while the PV output power is illustrated in Figure (4.9.b), as seen from the figures the energy produced is a function of the irradiance received in a determined time. Thus, as seen from the Figures (4.10.a & b), the irradiance curve also includes cloud effects which affects directly the PV output.



(a) *(b)*

Figure 4.9. Simulation result for PV power in a sunny day



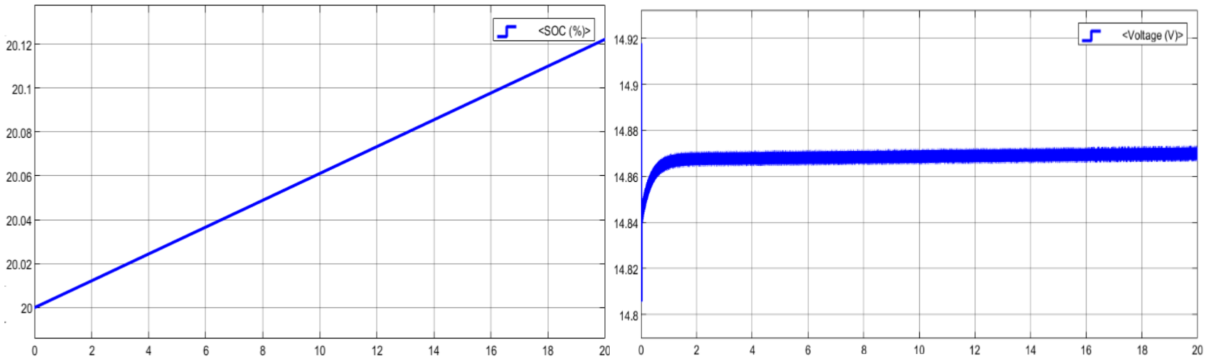
(a) *(b)*

Figure 4.10. Simulation result for PV power in a sunny day with a shading

4.4.2 Battery

- **Charging mode**

When the load is connected to the main grid, and while the solar power is available. The batteries start charging till reaching 90% SOC, that can be seen in the Figure (4.11.a). The voltage output of the battery shown in Figure (4.11.b) is controlled by an PI controller to be working in within the nominal voltage.

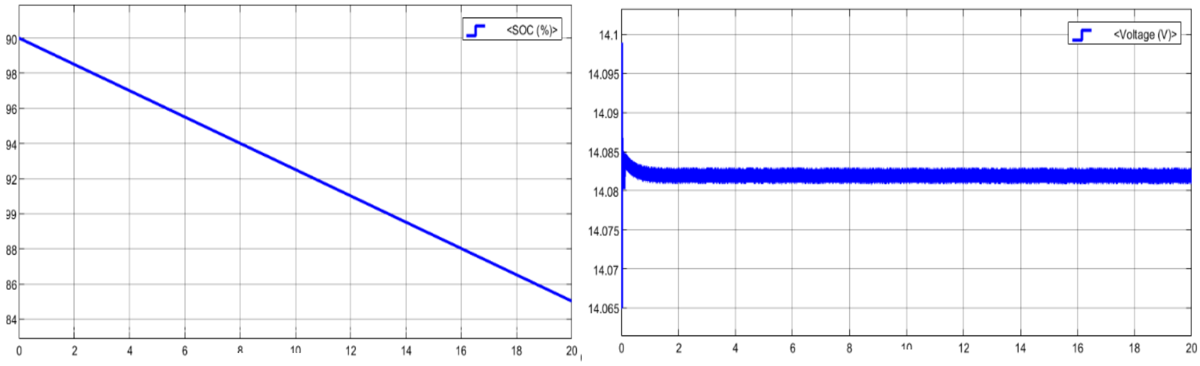


(a) *(b)*

Figure 4.11. Simulation results for batteries charging mode

- **Discharging mode**

Figure (4.12.a) shows that once the system is islanded, the batteries start discharging as soon as power is needed while its voltage remain controlled as illustrated in Figure (4.12.b).



(a) *(b)*

Figure 4.12 Simulation results for batteries discharging mode

4.4.3 Microgrid

We modelled the microgrid components and build them up them into a distributed power system using simscape power system blocks for a desktop simulation.

Subjecting this microgrid to certain dynamic disturbances:

- The first one, involves opening the circuit breaker and isolating this microgrid from the main power grid, which means it will be completely disconnected;
- And then at the second disturbance we see when the load has reached its maximum.

The diesel generator will try to maintain the stability of the whole, it will try to maintain a uniform frequency and voltage, while the solar photovoltaic system will follow the irradiation, so that its energy production will change over time and our energy storage system, in this case, will be charged to be used when the energy is needed.

On the scope illustrated in Figure (4.13), we can see the resulting outputs of the frequency disturbances that have occurred due to the islanding of this micro-grid and then, due to this peak load, we can see how the distributed resources change over time depending on how this microgrid is currently operating.

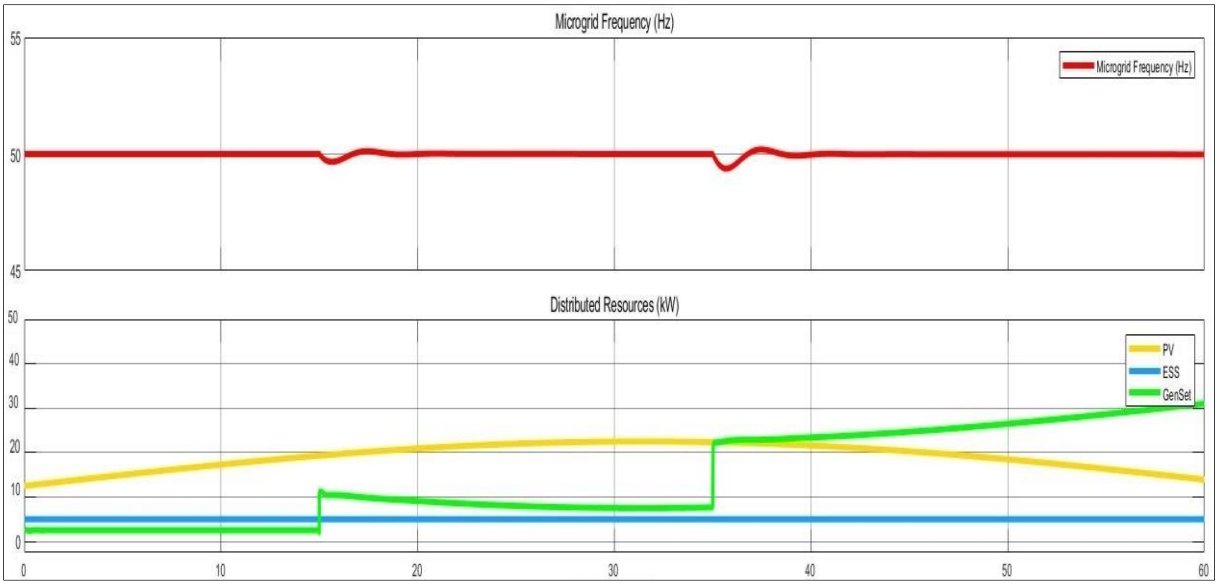


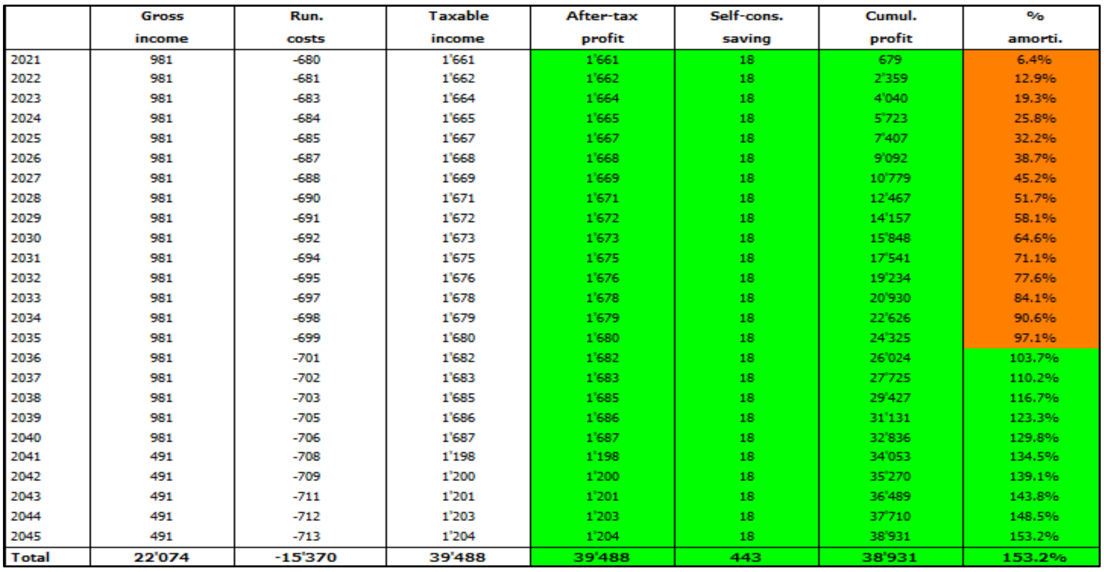
Figure 4.13. Simulation results for the microgrid

4.5 Step 04: Analysis

4.5.1 Economic analysis of PV system

In PVsyst, after defining some economic data before starting the simulation, the results estimated the solar system installation (PV+ batteries) costs by *26 069 USD* with a LCOE of *0.226 USD/kWh* and a payback period of *15.4* years. Table (4.1) shows a detailed economic result and we can see that starting from 2036, the system will start getting net profit.

The economic analysis carried out to assess the profitability shows that the cost of the investment can be recoverable throughout the life cycle. As seen from the Figure (4.12) the income allocation shares 81% of net profit during the project life.



	Gross income	Run. costs	Taxable income	After-tax profit	Self-cons. saving	Cumul. profit	% amorti.
2021	981	-680	1'661	1'661	18	679	6.4%
2022	981	-681	1'662	1'662	18	2'359	12.9%
2023	981	-683	1'664	1'664	18	4'040	19.3%
2024	981	-684	1'665	1'665	18	5'723	25.8%
2025	981	-685	1'667	1'667	18	7'407	32.2%
2026	981	-687	1'668	1'668	18	9'092	38.7%
2027	981	-688	1'669	1'669	18	10'779	45.2%
2028	981	-690	1'671	1'671	18	12'467	51.7%
2029	981	-691	1'672	1'672	18	14'157	58.1%
2030	981	-692	1'673	1'673	18	15'848	64.6%
2031	981	-694	1'675	1'675	18	17'541	71.1%
2032	981	-695	1'676	1'676	18	19'234	77.6%
2033	981	-697	1'678	1'678	18	20'930	84.1%
2034	981	-698	1'679	1'679	18	22'626	90.6%
2035	981	-699	1'680	1'680	18	24'325	97.1%
2036	981	-701	1'682	1'682	18	26'024	103.7%
2037	981	-702	1'683	1'683	18	27'725	110.2%
2038	981	-703	1'685	1'685	18	29'427	116.7%
2039	981	-705	1'686	1'686	18	31'131	123.3%
2040	981	-706	1'687	1'687	18	32'836	129.8%
2041	491	-708	1'198	1'198	18	34'053	134.5%
2042	491	-709	1'200	1'200	18	35'270	139.1%
2043	491	-711	1'201	1'201	18	36'489	143.8%
2044	491	-712	1'203	1'203	18	37'710	148.5%
2045	491	-713	1'204	1'204	18	38'931	153.2%
Total	**22'074**	**-15'370**	**39'488**	**39'488**	**443**	**38'931**	**153.2%**

Table 4.1. Detailed economic results (USD)

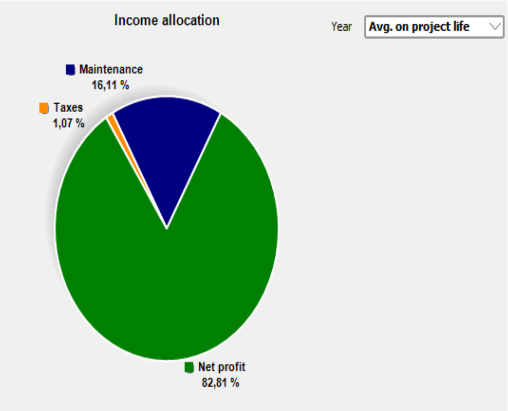


Figure 4.14 Income allocation on the project life

4.5.2 Environmental analysis of PV system

According to the analysis of emissions by PVsyst, the designed solar system will save approximately **242 tCO2** as balance over the lifetime of the project (25 years). As shown in Figure (4.15), the emissions generated by the system, especially during the production and transport of the solar system components, are offset from the seventh year of the project's lifetime to save at the end of the project that important amount of emissions.

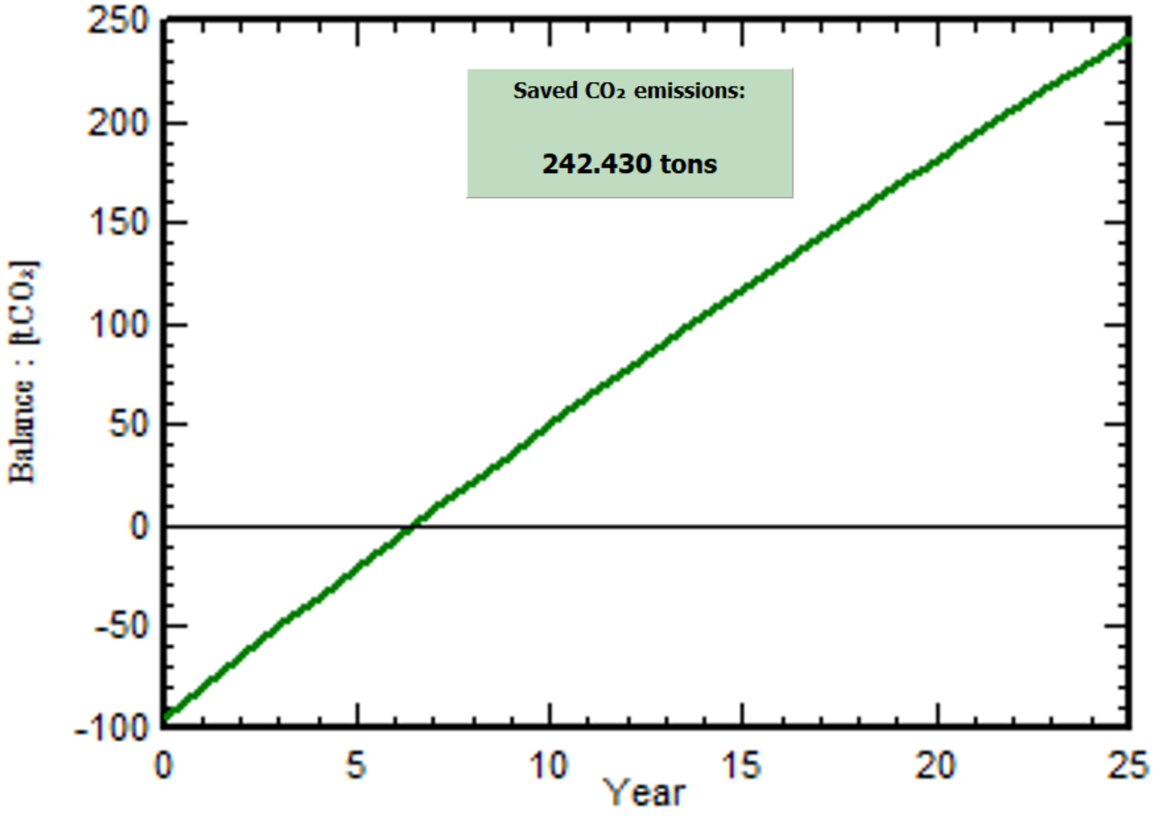


Figure 4.15 Balance of CO2 emissions

4.6 Conclusion

This chapter presented the results obtained during the work’s procedure. It examined the findings with explanations and comments. Further conclusions are addressed in the next chapters.

CHAPTER 5.
SUMMARY, CONCLUSIONS & PERSPECTIVES

The main aim of this study was to propose a microgrid system for the energy supply of the PAUWES building located on the campus of Chetouane University in Tlemcen, Algeria.

The first was a literature review to investigate the potential of energy resources and to identify the possible energy sources that could be used for energy production. As this study focuses on the potential of solar energy, local meteorological data such as annual changes in solar radiation and temperature were required. The hybrid system covered by this study consists of different technologies for energy production, processing and storage. These system components are photovoltaic panels, diesel generators and batteries connected to the main grid. Extensive research has been carried out to determine the optimum size and technical performance using PVsyst software. The hybrid system was then modelled using Simulink MATLAB to evaluate the various energy management strategies. Finally, an economic and environmental analysis of the solar system was carried out in order to examine the benefits of adopting this technology.

During the analysis of the results, the following conclusions could be drawn:

- ✓ Ensuring a sustainable energy system and saving energy relies on balancing both production and consumption. The production side can be conducted through technical assessments while the end user attitudes affect also the consumption therefore awareness among users and small gestures like switching off lights or using automatic shutdown printers are of an important recommendation.
- ✓ Tlemcen region has an important potential for solar energy, and this potential is only exclusive to the northern part of the country, let alone the rest of the country, the Sahara where held the highest irradiation in the word are held.
- ✓ Nowadays, the energy produced by the proposed system isn't cost effective compared to the cheap electricity generated traditionally by burning fossil fuels mainly natural gas. Those prices are heavily subsidized by the government.
- ✓ The system adopted in this research goes along with the Algerian and global energy action plan by implementing renewables into the energy mix.

- ✓ Given the intermittent nature of renewable sources, the main problem associated with stand-alone systems is the continuity of service. This explains why energy storage and conventional sources are required. This energy mix can be a solution in itself while the development of new technologies is still a challenge.

While the focus of this work has covered a variety aspect of microgrid, the thing that made it difficult in the context of a master project to assess each aspect in details from sizing to modeling and from simulation to analysis. This work can serve as a basis for various future works. The latter may focus on different aspects:

- ✓ Other renewable energy sources, such as wind power, would be combined with existing solar energy to ensure that the renewable fraction is maximized and carbon dioxide emissions are emphasized to a minimum.
- ✓ The microgrid can be extended to feed the entire campus, and with further detailed assessments and studies, it can be adopted in reality and implemented in the field.
- ✓ With regard to system energy management and control, other smart monitoring options could be developed and explored for better energy production, conversion and storage.

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