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I declare that this Master's thesis does not include any borrowings from the works of other authors without corresponding references.

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Kyiv, 2020

Content

ACRONYMS

ABSTRACT

The use of renewable energy installations in local systems affects the reliability of power supply. At the moment, in order to assess the reliability of power supply in local systems with renewables, there are a large number of indicators that are not directly related to each other.

Reliability is one of the key concepts in electricity. The reliability of the power system is a feature of the continuous supply of electricity to consumers to meet their needs. The concept of reliability includes such features as failure-free, durability and maintainability. But this terminology has not become commonplace, it has not embraced or streamlined many terms for reliability. Thus, many authors use the concepts of structural, mode (functional) and balance reliability. This separation is conditional, first, to simplify the solution of the task of assessing the reliability of complex networks, and secondly, based on quantitative assessments of the components, measures can be taken to improve the level of reliability.

Changes in energy sector related to the implementation of market relations and distributed generation require an update of terminology that can be used to decompose the reliability assessment task. Because assessing the reliability of distribution grids in today's environment is quite a challenge.

The purpose of the article is to analyze the reliability of power supply for local systems with renewables. One of the main issues in this topic, despite the large amount of research work involved, is the uncertainty of the method for calculating the reliability of power supply in Microgrids. The paper assesses the reliability of power supply and proves the need to introduce new indicators for local systems with renewables, since distributed energy sources, including renewables, affects systems reliability. Such indicators will allow assessing the reliability by each factor individually, and will show the impact of each factor on the overall state of the system.

Keywords— reliability; distributed generation; complex assessment; microgrids, local power systems.

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CHAPTER 1

CHAPTER 1: STATE OF MODERN ELECTRICITY GRIDS WITH RENEWABLES

1.1 PRESENT STATE OF RENEWABLE ENERGY RESOURCES

Notions and principle on renewable energies:

Renewable energy means energy from the sun, wind, the heat of the earth, water or even biomass. Unlike fossil fuels, Renewable Energies are unlimited resource energies.

Renewable energies such as wind, solar, biomass and hydropower are promising solutions to compete with mass energy sources such as fossil and nuclear.

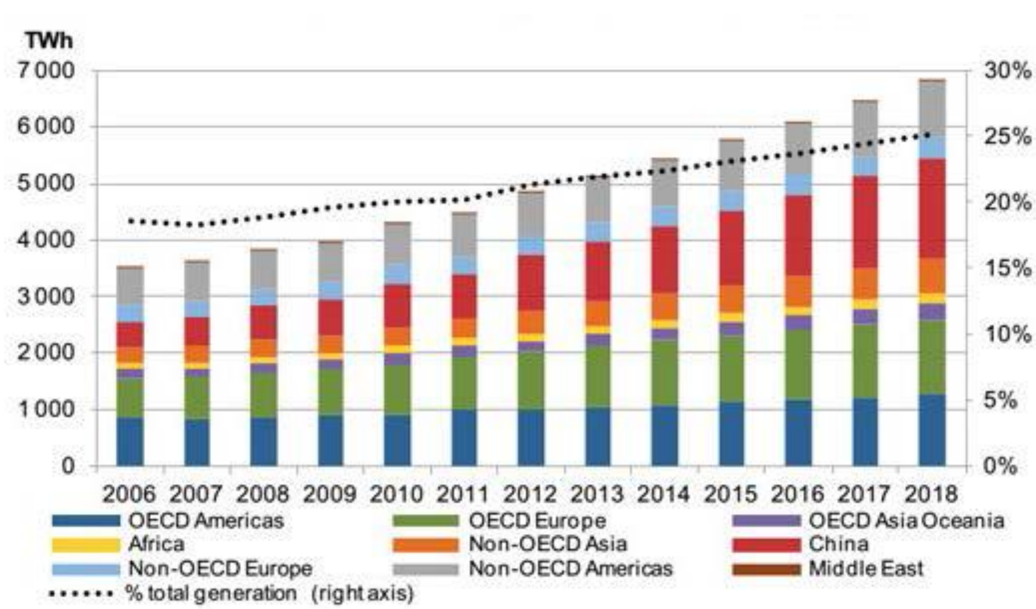


Figure I.1 *Global renewable electricity production by region* [1]

Photovoltaic cell:

The photovoltaic cell or solar cell is an Optoelectric component, composed of a semiconductor material which absorbs light energy and transforms it directly into electrical energy.

The operating principle of this cell uses the properties of solar radiation and those of semiconductors.

The set of photovoltaic cells linked together constitutes the photovoltaic module. Several modules are grouped together to form a photovoltaic system which includes other components such as the regulator, the battery and the inverter for an isolated (autonomous) site.

In the case where the photovoltaic system feeds an electrical distribution network, the battery is no longer involved since it is the network which returns energy in the event of a deficit.

Photovoltaic system connected to the electrical distribution network :

It is possible to use a photovoltaic generator in a non-autonomous way, by connecting it to the public electricity distribution network. In this case, the energy produced is either consumed on site by the site or is sold on the network in the event of excess production. When there is a deficit or during unfavorable moments, the network supplies the site. There is therefore no battery.

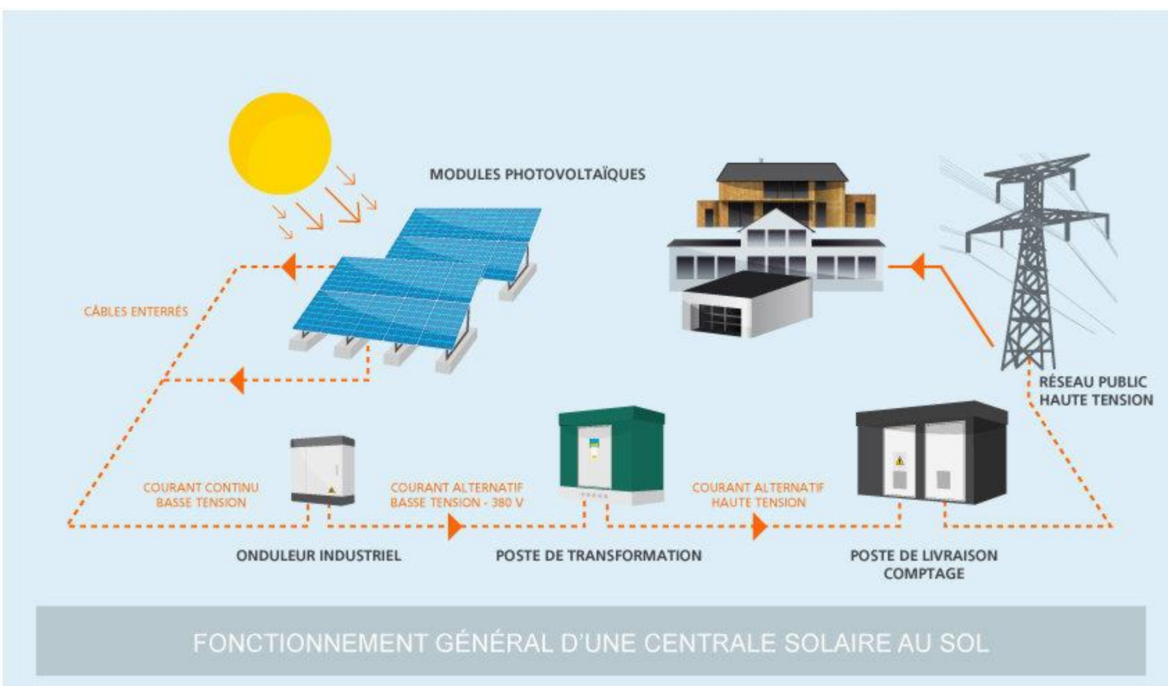


***Figure I.2**: Scheme of a photovoltaic system connected to an electrical network* [2]

Solar radiation:

Definition

The solar radiation is the set of electromagnetic waves emitted by the Sun. It is composed of the whole range of radiation, from far ultraviolet like gamma rays to radio waves and visible light. The solar radiation also contains cosmic rays of particles animated of an extremely high speed and energy.

Radiation on earth:

A small part of the solar radiation reaches the surface of the earth, from HF radio waves to the softest ultraviolet rays, the rest being reflected or absorbed by the atmosphere and the ionosphere.

When it reaches the surface of the earth, depending on the albedo of the surface struck, a more or less significant part of the radiation is reflected1. The other part of this radiation is absorbed by the earth's surface (converted into heat) or by the living beings that live there, in particular plants (photosynthesis). This source of energy, called solar energy, is the basis of life.

The total solar radiation received on earth is the sum of direct radiation and diffuse radiation. On average on the Earth, 61% of the radiation received is direct. Depending on where we are on Earth, this share varies greatly.

Components of solar radiation

The part of the solar radiation exploited by photovoltaic systems is limited to light, but it can itself be broken down into three elements, the proportion of which varies according to place and time:

a) Direct Radiation:

The most powerful, which comes directly from the sun without undergoing obstacles in its path (cloud, buildings ...), it's the one that blinds us when we try to look the sun "right in the eyes" in open weather.

b) Diffuse radiation:

Comes from the multiple diffractions and reflections of direct solar radiation by clouds. It is to it that we owe the "daylight" which allows us to see clearly even when the weather is overcast.

c) The radiation due to Albedo:

Results from the reflection of direct solar radiation from the ground, which is all the more important as the surface is clear and reflective (snow, body of water, etc.). He's the one who can make us sunburn in the mountains or the sea without us feeling them coming.

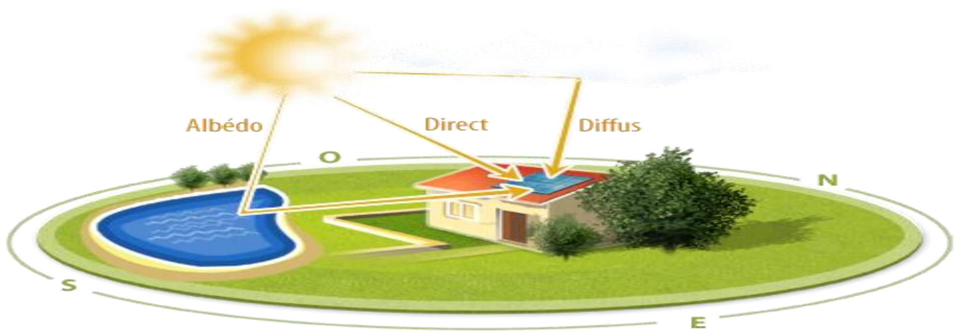


Figure I.3: *Components of solar radiation on the ground* [3]

Spectrum of solar radiation

It is the set of electromagnetic waves emitted by the sun, it is composed of the whole range of radiations (Far Ultraviolet rays, Gamma rays, Cosmic rays).

The emission of electromagnetic waves by the sun is suitably modeled by a black body at 5800 Kelvin's, and can therefore be described by Planck's law. The maximum emission is in the green (504 nm), and the distribution of the radiation is roughly half in visible light, half in infrared, with 1% of ultraviolet.

Arrived at sea level, that is to say having crossed the entire Earth's atmosphere, part of the solar radiation has been absorbed. We can identify in particular on the spectrum opposite the absorption bands of ozone (which absorbs a significant part of the ultraviolet rays), dioxygen, carbon dioxide and water.

• Ultra violet (UV): [200; 400 nm]

• Visible: [400; 800 nm]

• Infrared: [800; 2000 nm]

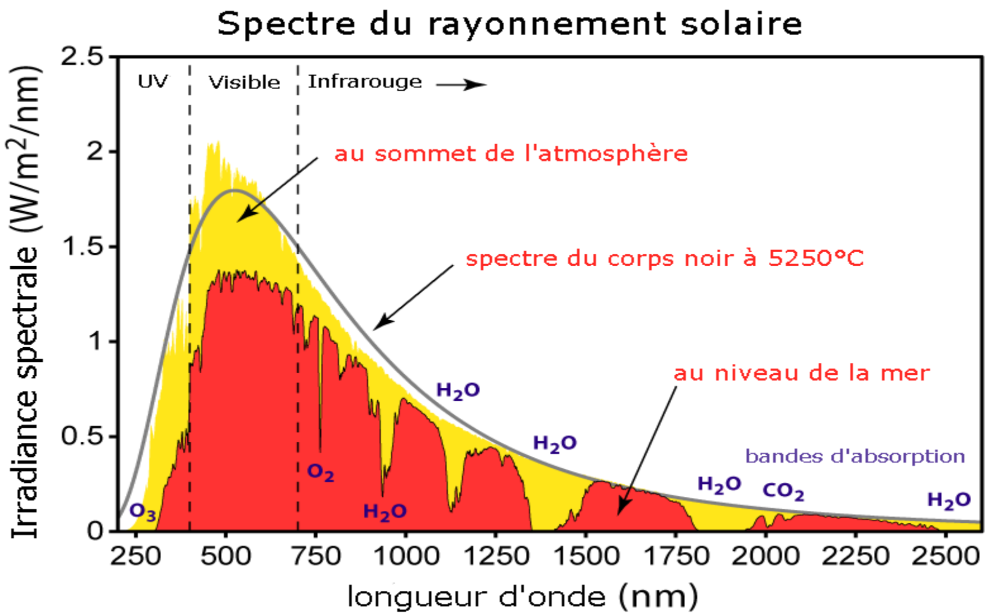


Figure I.4*: The spectra of the Sun, theoretical, on, and under the atmosphere* [4]

Air Mass (AM):

The solar radiation passing through the atmosphere during the day, which means that it depends on the relative position of the sun in the sky, to take account of this position which modifies the thickness of the atmosphere crossed by the light rays, we define a coefficient AM called atmospheric mass or mass number of air. AM0 and AM1.5 represent the current solar spectrum reaching the earth.

Description of the elements of a photovoltaic collection system:

. Historic:

It is important to cite the most important dates in the history of photovoltaics which noted:

- ✓ 1839: The French physicist [Edmond Becquerel] discovers the process of using sunlight to produce electric current in a solid material. It’s the photovoltaic effect.
- ✓ 1875: Werner von Siemens exhibits at the Berlin Academy of Sciences an article on the photovoltaic effect in semiconductors, but until the Second World War, the phenomenon remains a laboratory curiosity.
- ✓ 1954: Three American researchers, Chapin, Pearson and Prince, develop a high-efficiency photovoltaic cell as the emerging space industry searches for new solutions to power its satellites.
- ✓ 1958: A cell with a yield of 9% is developed. The first satellites powered by solar cells are sent into space.
- ✓ 1973: The first house powered by photovoltaic cells is built at the University of Delaware.
- ✓ 1983: The first car powered by photovoltaic energy covers a distance of 4000km in Australia.

Photovoltaic cell

The photovoltaic cells are optoelectronic components that directly transform sunlight into electricity through a process called

"Photovoltaic effect" was discovered by Edmund Becquerel in 1839. They are made using semiconductor materials, that is to say having properties intermediate between conductors and insulators.

It’s the only known way to convert light directly into electricity.

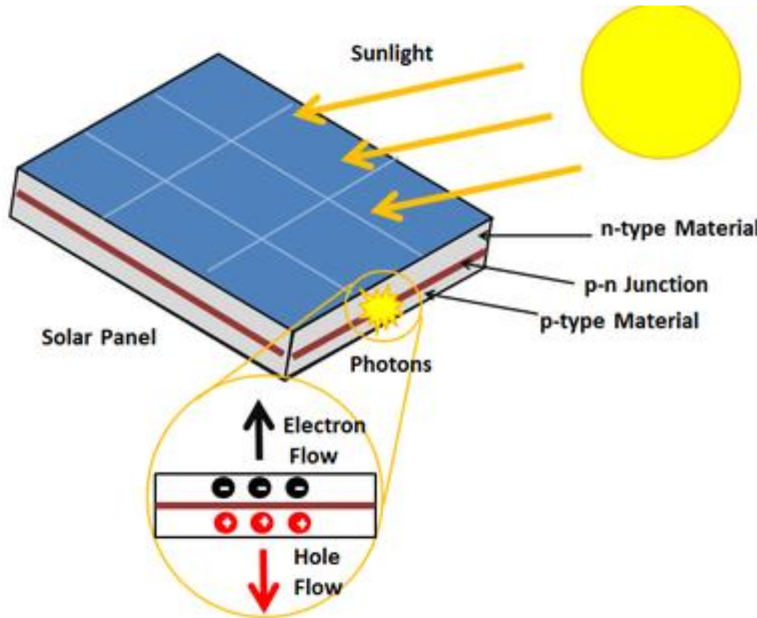


Figure I. 5 *Photovoltaic Cell* [5]

The simplest structure of a photovoltaic cell comprises a junction between two zones doped differently from the same material (homo junction) or between two different materials (hetero-junction). The purpose of the photovoltaic structure is to create an internal electric field.

The photovoltaic cell is made from two layers of silicon (semiconductor material):

- A layer doped with boron which has fewer electrons than silicon, this zone is therefore positively doped (zone P).
- A layer doped with Phosphorus which has more electrons than silicon, this zone is doped negatively (zone N).

. Operating principle of a photovoltaic cell

There are different techniques for direct conversion of sunlight into electricity, the best known of which is the photovoltaic conversion carried out using semiconductor materials such as silicon (Si), germanium (Ge), selenium (Se) or semiconductor compounds such as gallium arsenide (GaAs), cadmium telluride

(CdTe). GaAs type solar cells are very expensive to manufacture, their use today is essentially limited to space applications.

The majority of photovoltaic cells are made from crystalline silicon, because it has the characteristic of being non-toxic unlike cadmium or selenium, in addition, it makes it possible to achieve remarkable conversion efficiencies, it constitutes approximately 28% of the earth's crust in the form of compounds (silicates, silica), which makes it an almost inexhaustible source.

The semiconductor solar cell is a device for delivering an electric current to an external load when it is exposed to light. Its operating principle can be summarized as follows: When the cell is exposed to solar radiation, the energy photons (Eph = hv) entering the solar cell transmits their energy to the atoms of the junction. If this energy is high enough, it can pass electrons from the valence band to the conduction band of the semiconductor material and thus create "electron-hole" pairs. The electrons (N charges) and the holes (P charges) are then kept separated by an electric field which constitutes a potential barrier. If a charge is placed at the terminals of the cell, the electrons of zone N join the holes of zone P via the external connection, giving rise to a potential difference and an electric current circulates (figure I.5).

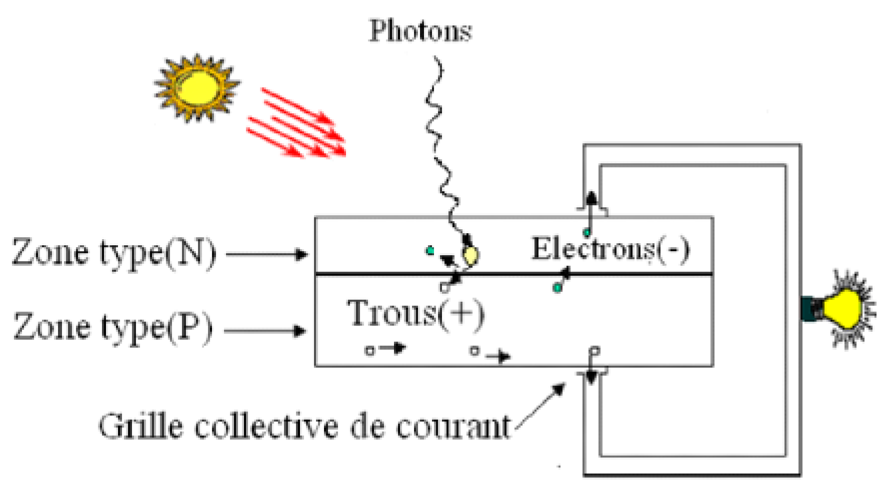


Figure I.6 *Operating principle of a photovoltaic cell* [6]

A photovoltaic cell remains the basic element of any photovoltaic generator whatever the considerable power required.

To predict its performance, it is very important to know your mathematical model. For the purpose of simulation and design, several researchers have studied the photovoltaic cell using different models.

Solar or photovoltaic module:

The electrical characteristics of a single cell are generally insufficient to supply electrical equipment. To produce more power, the photovoltaic cells are assembled to form a module. The series connections of several cells increase the voltage for the same current while the paralleling increases the current while preserving the voltage therefore the power of a solar panel is a function of its surface, i.e. the number of cells photovoltaic.

Solar panel:

The solar panel or the solar field consists of photovoltaic modules interconnected in series and / or in parallel in order to produce the required power. These modules are mounted on a metal frame which supports the solar field with a specific angle of inclination.

Storage system:

The storage of the energy produced by the photovoltaic generator is the action which consists in placing a quantity of energy in a given place to allow its later use. The parameters of the output of this type of generator are the following: surface of panel and level of sunshine (which varies according to regions, seasons, time of day, weather, etc.).

Conversion system:

An energy converter is an equipment that is generally available either between the photovoltaic field and the load (without storage with continuous charge, it will be called DC-DC or DC-DC converter or the Chopper), or between the battery and the charge (It will then be called an inverter or DC-AC converter).

The inverter is generally associated with a rectifier which realizes the transformation of alternating current into direct current and whose role will be to charge the batteries and to supply the continuous circuit of the installation in case of long period without sun, we distinguish two types of converter namely

- The DC-DC converter (Chopper)
- The DC-AC converter, which is used to convert direct current into alternating current. It is known as an inverter.

Advantages and disadvantages of the photovoltaic system:

Advantages:

Photovoltaic systems have several advantages:

- They are non-polluting without emissions or discernible odors.

- They can be autonomous systems which operate reliably, without supervision for long periods.

- They do not need any connection to another energy source or to a fuel supply.

- They can be combined with other energy sources to increase the reliability of the system.

- They can withstand harsh weather conditions such as snow and ice.

- They do not consume any fossil fuel and their fuel is abundant and free.

- High reliability because the installation does not have moving parts, which makes it particularly suitable for isolated regions, hence its use on spacecraft.

- The modular system of photovoltaic panels allows mounting adaptable to various energy needs; systems can be sized for applications ranging from milliwatt to megawatt.

- The photovoltaic technology has ecological qualities because the product is non-polluting, silent, and does not cause any disturbance of the environment.

- They have a long lifespan.

- The costs and risks of transporting fossil fuels are eliminated.

Disadvantages:

- The manufacturing of photovoltaic modules is high technology, which makes the cost very high.

- The real yield of a photovoltaic module and of the order of 10 to 15%,

- They are dependent on weather conditions.

- The energy coming from the photovoltaic generator is continuous and of low voltage (<to 30V) so it must be transformed by the intermediary of an inverter.

- Many devices sold on the market operate on 230 V AC.

Wind energy:

Wind energy has been used for at least two thousand years. In Mesopotamia, around 1700 BC, wind power was used for irrigation and to grind grain.

Mechanical wind pumps were largely used in the 19th century to provide energy for irrigation, drainage, etc. and have marked the landscape of many countries.

Global wind energy production:

The modern use of wind power is today almost exclusively used for the production of electricity. The major discovery of wind power was made with the oil crisis in 1973, when the skyrocketing oil prices went from US $ 12 to US $ 35.

Suddenly, the OECD countries wanted to become more independent of oil imports and turned to the development of wind power, almost exclusively for the production of electricity. Twenty years later, wind turbine technology has matured and wind turbines have grown from 10 kW to over 3,000 kW[7]

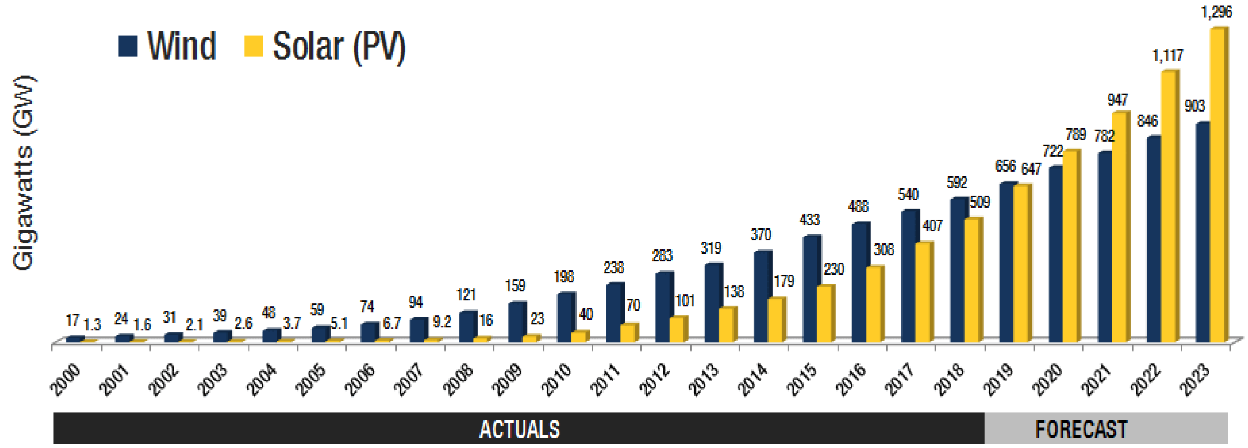


Figure I.7 *the evolution and forecast of wind power and solar PV capacities in the world 2000-2023*[7]

Main components of a wind turbine

- **The mast:**

Generally a steel tube or possibly a wire mesh which supports the nacelle is the rotor of the turbine. It is important that it is high enough (40 to 60 m in height for a 500 kW wind turbine) to exploit the strongest winds at altitude. Inside these is a ladder which allows access to the basket for maintenance.

- **Blades:**

For wind turbines intended for the production of electricity, the number of blades conventionally varies from 1 to 3, the three-bladed rotor (Danish concept) being by far the most widespread because it represents a good compromise between the cost, the vibration behavior, visual pollution and noise

- **The nacelle:**

It brings together all the mechanical elements making it possible to couple the wind rotor to the electric generator: shafts, multiplier, bearing, the disc brake which makes it possible to stop the system in the event of overload, the generator which is generally a synchronous machine or asynchronous, the hydraulic or electric systems for orienting the blades (aerodynamic brake) and the nacelle (necessary to keep the surface swept by the wind generator perpendicular to the direction of the wind).

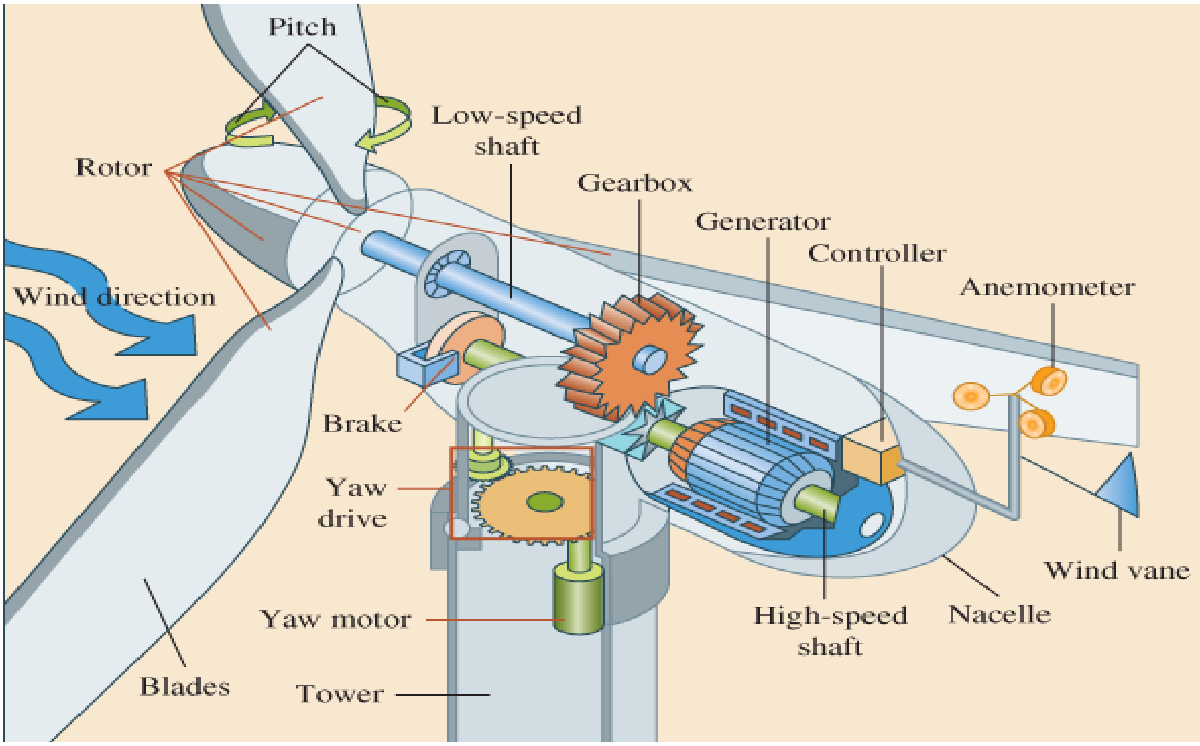


Figure I.8 *Basic components of a wind turbine* [8]

The different types of wind turbines:

There are two main types of wind turbines which essentially differ in their energy-capturing component, the aero-turbine. According to the arrangement of the turbine relative to the ground, we obtain:

- Vertical axis wind turbines.

- Horizontal axis wind turbines

-Wind turbines with vertical axis:

They were the first structures developed to produce electricity. Many technologies have been tested of which only two structures have reached the industrialization stage; the Savonius rotor and the Darrieus rotor. Nowadays, this type of wind turbine is rather marginal and its use is much less widespread.

- Wind turbines with horizontal axis:

Horizontal axis wind turbines are based on the principle of windmills.

They generally have two or three blades propellers, the three blades are a good compromise between the power coefficient, the cost and the speed of rotation of the wind sensor as well as the aesthetic aspect compared to the two blades.

Horizontal axis wind turbines are the most used because their aerodynamic efficiency is higher than that of vertical axis wind turbines, they are less exposed to mechanical stresses and have a lower cost.[9]

Wind energy conversion chain:

To obtain electricity from the wind, the same basic elements are found in the different configurations, namely:

- A turbine which transforms wind energy into mechanical energy.

- Mechanical transmission.

- A generator.

- An electrical connection system.

Depending on the use of the wind turbine, some of these parts are more or less developed; there are two main families of wind turbines:

- Wind turbines connected to the network.

- Autonomous wind turbines.

Wind energy conversion principle:

The wind spins the rotor. In the nacelle, the main tree drives a generator that produces electricity. The speed of rotation of the rotor must be increased by a speed multiplier up to approximately 1500 rpm for a machine with 2 parts of poles, speed necessary for the proper functioning of the generator.

Electronic speed converters necessary for the proper functioning of the generator.

Electronic power converters adjust the frequency of the current produced by the wind turbine to that of the electrical network to which it is connected, while allowing the rotor of the wind turbine to rotate at variable speed depending on the wind.

The voltage of the electricity produced by the generator is then raised through a power transformer, located in the nacelle or inside the mast. This voltage level allows the electricity produced by each of the wind turbines in a wind power plant to be transported to the point of connection to the public electricity grid.

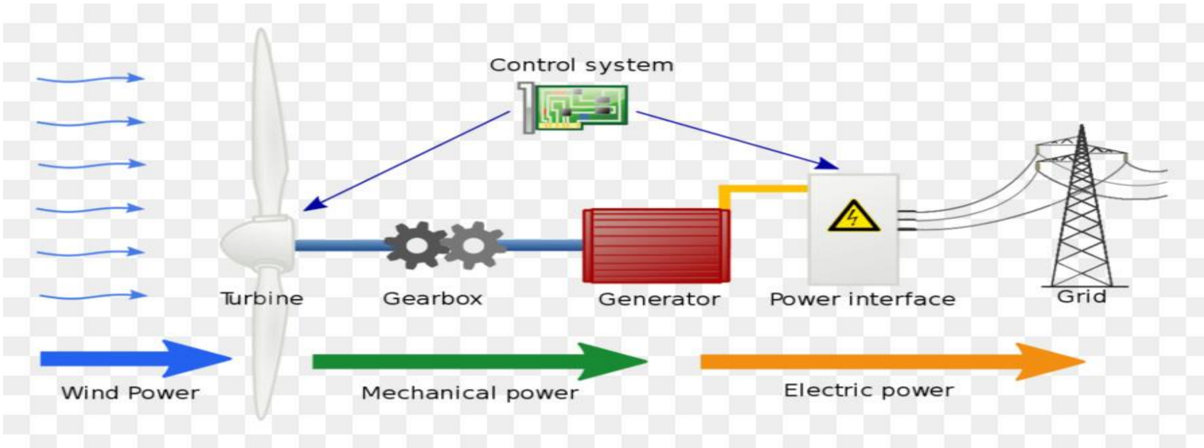


Figure I.9 *Wind energy conversion principle.*

Advantages and disadvantages of wind energy

Advantages:

- Wind energy is renewable energy, that is to say that unlike fossil fuels, future generations will still be able to benefit from it.

- The exploitation of wind energy is not a continuous process since the wind turbines in operation can easily be stopped.

- Wind energy is clean energy.

- The wind farms can be dismantled very easily and leave no trace. Wind energy also has certain economic advantages.

- It is a local energy source that meets local energy needs. Line losses due to long energy transport are therefore minimal.

Disadvantages:

- The stochastic nature of the wind has an influence on the quality of the electric power produced, which represents a constraint for connection to the network.

- The cost of wind energy remains higher compared to other conventional energy sources, especially on less windy sites.

- Noise: the essential source of noise in wind turbines is the multiplier, which begins to disappear after the appearance of direct attack wind turbines. 10

Hydro electric energy

Water, like the Sun, is essential to our life. But unlike our star, which gives off energy in the form of hot and bright rays, water, it does not produce it directly. It's his movement which has energy. There is a lot of water on our planet. And as you probably know, she continues, under different forms, a cycle: water evaporates from the ground and oceans, forms clouds, and returns, in the form of rain, on the continents and in the oceans. The rain enters the soil forms streams, rivers, streams and lakes, before jumping into the sea. Hydraulic power works much like energy wind turbine: the movement of water turns a turbine which produces electricity. The faster the water flows, the more the energy produced is important. Indeed, the quantity energy produced depends on pressure and volume water available. The pressure is itself linked to the height difference between Lake Surface and position of the turbine. This mode of electricity production is one of the most clean and efficient (no waste or CO_2). It draws on a powerful and unlimited resource that has no need to be transformed: the water passes through a central, and comes out intact. [11]

Advantages

- Renewable energy
- Available all year round
- Very long-term installation
- Well-mastered technology
- Very good yield (90%)

Disadvantages

- Impact on the landscape
- Depends on weather conditions
- The installation must adapt to each site
- Not always reconcilable with the ecosystem

Biomass Energy

Biomass is organic material that comes from plants and animals, and includes crops, waste wood, and trees. When biomass is burned, the chemical energy is released as heat and can generate electricity with a steam turbine.

Biomass is often mistakenly described as a clean, renewable fuel and a greener alternative to coal and other fossil fuels for producing electricity. However, recent science shows that many forms of biomass especially from forest produce higher carbon emissions than fossil fuels. There are also negative consequences for biodiversity. Still, some forms of biomass energy could serve as a low-carbon option under the right circumstances. For example, sawdust and chips from sawmills that would otherwise quickly decompose and release carbon can be a low-carbon energy source.[12]

Geothermal Energy

The term geothermal energy is formed from the Greek words Gê (the Earth) and thermos (hot), geothermal energy is the heat that lies beneath the Earth's surface. The origin of this heat is twofold: to a small extent, it comes from the Sun which heats the surface of the Earth. However, it is mainly magma, which is located at the heart of the planet, which heats the earth's crust.[14]

The Thermal gradient

The thermal gradient of each region measures the average temperature rise as a function of the depth. In Europe, the gradient has an average value of 3 ° C for 100 m deep (therefore 30 ° C increase for 1000 m). In volcanic areas, the gradient can be very high. [13]

The principle of geothermal energy

Calories from the subsoil can be captured by geothermal probes consisting of a closed circuit in which a heat transfer fluid circulates. Hot water from the aquifers can also be collected directly, brought to the surface and then reintroduced into the aquifer after heating the surface installations. If the water is very hot, it can spin a turbine and generate electricity. Geothermal energy has been used since ancient times. [13]

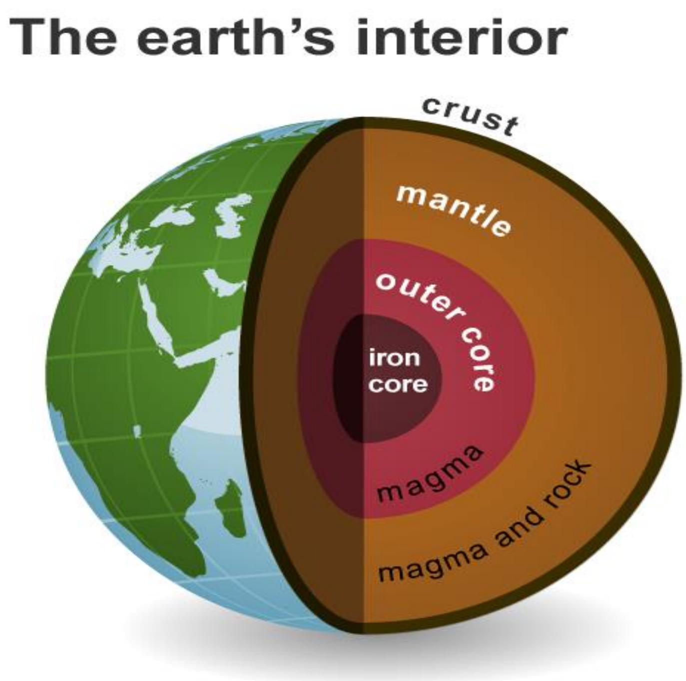


***Figure I.10**: Adapted from a National Energy Education Development Project graphic* [15]

1.2 MICROGRIDS AS AN INSTRUMENT OF IMPLEMENTATION OF RENEWABLE ENERGY SOUCES INTO THE ELECTRICITY GRID

Microgrids

Introduction

A microgrid refers to distributed energy resources and loads that can be operated in a controlled, coordinated way; they can be connected to the main power grid, operate in "islanded" mode or be completely off-grid.

Microgrids are low- or medium-voltage grids located at or near the consumption sites. They can generate power from both renewable and conventional sources and although they are mainly electrical systems, they can also incorporate a thermal energy component, such as combined heat and power.

Microgrids are increasingly being equipped with energy storage systems, as batteries become more cost competitive. The system is controlled through a microgrid controller incorporating demand-response so that demand can be matched to available supply in the safest and most optimized manner. A flywheel or battery-based grid stabilizing system can be included to offer real and reactive power support.

The concept of a microgrid is not new: the earliest electricity networks were essentially microgrids before they were joined into regional and national grids. What is new is their changing and expanding role, in the face of rising power demands, the falling cost of renewable sources, and the increasing need for supply resilience and autonomy both on- and off-grid.[16]

WHY MICROGRIDS

Secure and reliable access to power

Microgrids can be installed quickly and easily, even in remote areas without access to the power grid or where the power grid is weak. Microgrids that are connected to the main power grid can be easily disconnected in case of blackouts and will continue to generate power reliably.

Cost-effective and independent power supply

Microgrids can lower the cost of electricity through self-generation and consumption.

With integration of renewables, they also protect against fossil fuel price volatility.

Sustainable and low carbon

Microgrids that include renewable power generation support sustainability goals through CO_2 reduction.

Local generation

A microgrid presents various types of generation sources that feed electricity, heating, and cooling to user. These sources are divided into two major groups – thermal energy sources (e.g,. natural gas or biogas generators or micro combined heat and power) and renewable generation sources (e.g. wind turbines, solar).

Consumption

In a microgrid, consumption simply refers to elements that consume electricity, heat, and cooling which range from single devices to lighting, heating system of buildings, commercial centers, etc. In the case of controllable loads, the electricity consumption can be modified in demand of the network.

Energy Storage

In microgrid, energy storage is able to perform multiple functions, such as ensuring power quality, including frequency and voltage regulation, smoothing the output of renewable energy sources, providing backup power for the system and playing crucial role in cost optimization. It includes all of chemical, electrical, pressure, gravitational, flywheel, and heat storage technologies. When multiple energy storages with various capacities are available in a microgrid, it is preferred to coordinate their charging and discharging such that smaller energy storage does not discharge faster than those with larger capacities. Likewise, it is preferred a smaller one does not get fully charged before those with larger capacities. This can be achieved under a coordinated control of energy storages based on their state of charge. If multiple energy storage systems (possibly working on different technologies) are used and they are controlled by a unique supervising unit (an Energy Management System - EMS), a hierarchical control based on a master/slaves architecture can ensure best operations, particularly in the islanded mode.[17]

Point of common coupling (PCC)

It is the point in the electric circuit where a microgrid is connected to a main grid. Microgrids that do not have a PCC are called isolated microgrids which are usually presented in the case of remote sites (e.g., remote communities or remote industrial sites) where an interconnection with the main grid is not feasible due to either technical or economic constraints.[17]

Types of Microgrids

There are several types of microgrids for different applications. As markets, technology, and regulation changes, the types of microgrids will continue to evolve.[18]

Military Microgrids

The ability to reliably incorporate solar PV and energy storage into military energy systems is a critical objective for the United States DOD. Reliance on diesel fuel in remote regions in the world is a weak point in military operations, and the results can be costly and deadly due to the challenge of transporting fuel through hostile regions. Additionally, the us DOD recognizes climate change as a driver of increasing instability, resulting in internal and external pressure to reduce emissions.

Campus Microgrids

Campus microgrids could refer to corporate campuses, university campuses, and military campuses. They are often CHP / Combined Heat and Power.

Community Microgrids

Community Microgrids could be considered community solar 2.0. In the developing world, community microgrids can be used to achieve electrification for the first time. In the developed world they are often used to help communities achieve renewable energy targets.

Island Microgrids

Island microgrids are attractive due to the high cost of importing liquid fuels. While traditionally run off diesel, small and large islands around the world are incorporating renewables and energy storage into their energy systems.

Examples of island microgrids.

Remote Microgrids

Remot microgrids create energy access beyond the grid. Like island microgrids, remote microgrids were traditionally dominated by diesel but are rapidly incorporating solar plus storage.

Utility Microgrids are done by incumbent electric utilities.

New Types of Microgrids:

Blockchain Microgrids

Blockchain microgrids allow prosumers to buy and sell electricity without electric utility involvement, and it is now becoming a reality. This democratic type of microgrid is already being deployed in New York, Africa, Europe, and Australia and electric utilities are scrambling to catch up with technology they see as a threat.

DC Microgrids

An influx of DC microgrids and distribution could be inevitable as solar panels, electric vehicles, batteries, LED lights, and DC electronics flood the electric grid, prompting innovators to seek more efficient ways of stringing them all together.

Autonomous EV Microgrids

Autonomous EV microgrids are enabled by driverless electric vehicles that can fetch electricity whenever a home system or microgrid is running low. It can also get signals from wind and solar farms that they are producing too much energy, and can fill up on the cheap.

Desalination Microgrids

Desalination micro grids are in demand for solving water challenges with renewables. Solar desalination can be achieved without energy storage simply by desalting during solar hours and storing the water.[18]

Typical distributed generations of Microgrids

●Renewable

- ✓ PV
- ✓ Wind
- ✓ Small hydro
- ✓ Biomass Plant

●Non Renewable

- ✓ Emergency Generator
- ✓ MicroTurbine
- ✓ Fuel Cell. [18]

Microgrid Operation

Microgrid, which integrates renewable energy sources, is connected to the main grid by relays. When the load is insufficiently powered by one of the sources, the corresponding switch will open, and other sources available will be the main providers for the load, following the scenarios below:

• Case 1: If the wind energy is sufficient to power load, wind turbine relays will be closed, and the connection to the load will be achieved.

• Case 2: Both wind and solar energies produce enough energy at the same time: the wind turbine is connected to the load, and the photovoltaic panels are used for charging the storage battery.

• Case 3: There is no half energy produced by the wind turbine, but solar radiation allows the photovoltaic panel to power the load.

• Case 4: Renewable source productions are insufficient or non-existent; the load is connected to the grid.

The aim of microgrid design

The aim of microgrid design is to study large-scale development, field demonstration and performance evaluation of domain names by:

• The frequency and voltage of control of different methods and technologies, under different microgrid operating modes.

• Switching between grid-connected and island mode.

• High penetration of ADR and its impact on the host network and interaction phenomena between ADRs.

It is important to note that the control strategies and dynamic behavior of a microgrid in autonomous mode of operation may be different from those of a conventional electrical system [19, 20].

Communication used in micro-grid

For reasons of reliability, large amounts of data must be exchanged as much as possible in real time between zones. This will allow the system to react quickly to any changes in network operating parameters.

Micro-grid control and monitoring must be ensured:

• High-speed, highly reliable and redundant communication infrastructure

• Optimal real-time communication, infrastructure

• Reliable and coordinated controls by the system before and after disruptions

• Dedicated communication infrastructure, e.g. fibre-optic cables, for monitoring underground cables

• Local flexibility market platform and algorithm

Tools based on real time synchronized network models for preventive and emergency network management systems and simulation of the behavior of the entire electrical/energy system

Smart Grids

Definition and categories

Smart grids are electricity networks which, thanks to computer technologies, adjust the flow of electricity between suppliers and consumers.

By collecting information on the state of the network, smart grids contribute to a balance between production, distribution and consumption.

It is necessary to differentiate between the smart grid and the smart meter (or “smart meter”), which is the consumer on demand for electricity. "Smart grids" are a general name for all of the "smart" technologies and infrastructure installed. In the home, the communicating meter is a first step in the implementation of smart grids.

Smart grids can be identified according to four characteristics in terms of:

Flexibility: they allow finer management of the balance between production and consumption;

Reliability: they improve the efficiency and security of networks;

Accessibility: they promote the integration of renewable energy sources throughout the network;

Economy: their distribution, thanks to better management of the system, energy savings and lower costs (for production and consumption).[21]

Operation

In the broadest sense, a smart grid combines electrical infrastructure with digital technologies that analyze and transmit the information received. These technologies are used at all levels of the network: production, transport, distribution and consumption.

Real-time flow control: sensors installed throughout the network instantly indicate electrical flows and consumption levels. Network operators can then redirect energy flows according to demand and send price signals to individuals to adapt their consumption (voluntarily or automatically).

Network interoperability: the entire electricity network includes the transmission network and the distribution network. The first connects the electricity production sites to the consumption zones: these are the main axes that crisscross the territory. The distribution network is similar to the secondary axes. It routes electricity to final consumers. Through the instant exchange of information, smart grids promote interoperability between the managers of the transport network and those of the distribution network.

Integration of renewable energies into the grid: smart grids are based on an information system which makes it possible to predict the level of production and consumption in the short and long term. Renewable energies which often operate intermittently and in an unpredictable manner (eg wind power) can thus be better managed.

More responsible management of individual consumption: smart meters are the first application versions of the smart grid. Installed with consumers, they provide information on prices, peak hours of consumption, quality and level of electricity consumption in the home. Consumers can then regulate their consumption themselves during the day. Network operators, on the other hand, can detect faults more quickly.

Energy issues

Electricity networks are currently facing new energy needs, including the development of air conditioning, electronic devices or electric heating. This increase should be amplified by new uses such as the electric car or heat pumps. Smart grids aim to provide an answer to these constraints.

Economic and environmental benefits

Smart grids improve the security of electrical networks. By balancing supply and demand, they avoid over-equipment of the means of production and allow a more suitable use of the means of storing electricity, available in a limited way.

Smart grids also increase overall energy efficiency: they reduce consumption peaks, which reduces the risk of generalized outages.

Finally, they limit the environmental impact of electricity production by reducing losses and better integrating renewable energies.

1.3 THE INFLUENCE OF DIFFERENT TYPES OF DG SOURCES ON THE GRID POWER QUALITY

POWER QUALITY ISSUES

Overview

Power quality has wide range of problems in different phenomena. For improvement of power quality and equipment performance each phenomenon has range of different causes and individual solutions.

Looking forward to the general steps which are associated with investigating many of these problems, especially if the steps can involve

Voltage variations and fluctuations [24], [25]

The voltage variations are variations in the effective value or the peak value amplitude less than 10% of the nominal voltage and voltage fluctuations are a following voltage variations or cyclic or random variations in the envelope of a voltage whose characteristics are the frequency of the variation and the amplitude.

- Causes: Significant variations in loads (welding machines, arc furnaces, etc.).
- Consequences: Fluctuation of the luminosity of the lamps (flicker).

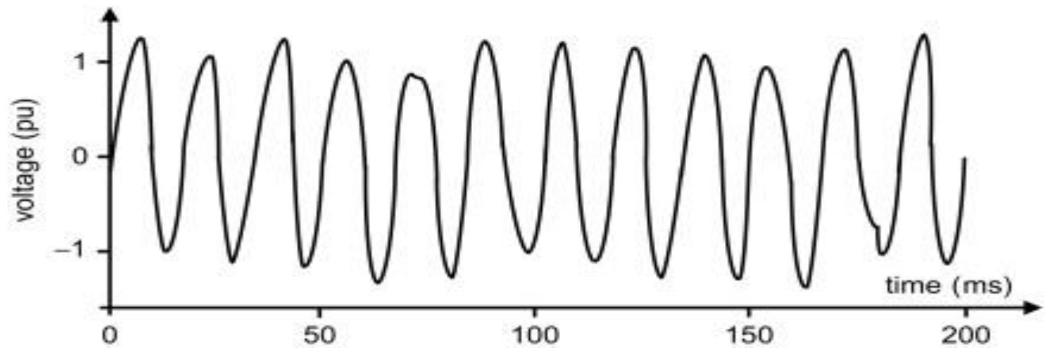


Figure I.11 Voltage flicker caused by arc furnace operation.[22]

Voltage dip

A voltage dip is a sudden drop in voltage at a point in a network of electrical energy, at a value between 90% and 10% of a reference voltage followed by a restoration of tension after a short period of time between the half fundamental period of the network (10 ms at 50 Hz) and one minute. The reference voltage is generally the nominal voltage for LV networks and the declared voltage for Medium Voltage and High Voltage networks.

- **Causes:** short circuit, switching of high power loads (starting engine…).
- **Consequences:** disturbance or termination of the process: loss of data, data incorrect, contactor opening, variable speed drive locking, slowing down or stalling of motors, switching off discharge lamps.

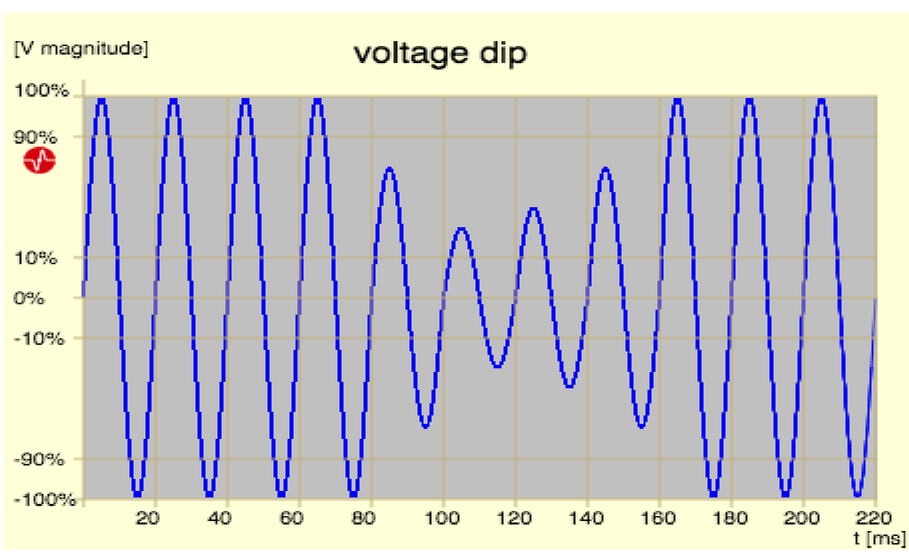


Figure I.12 voltage dip[25]

Very short interruptions

Total interruption of electrical supply for duration greater than 1 to 2 seconds

- **Causes:** Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines orpoles, fire, human error, bad coordination or failure of protection devices.
- **Consequences:** Stoppage of all equipment.

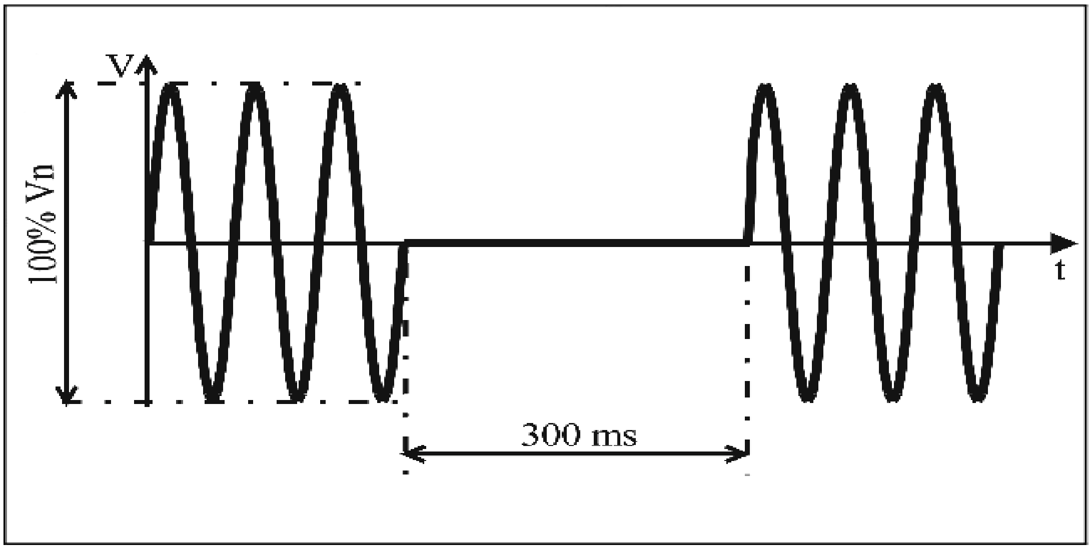


Figure I.13 Short interruption.[26]

Long interruptions

Description: Total interruption of electrical supply for duration greater than 1 to 2 seconds

- **Causes:** Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines orpoles, fire, human error, bad coordination or failure of protection devices.
- **Consequences:** Stoppage of all equipment.

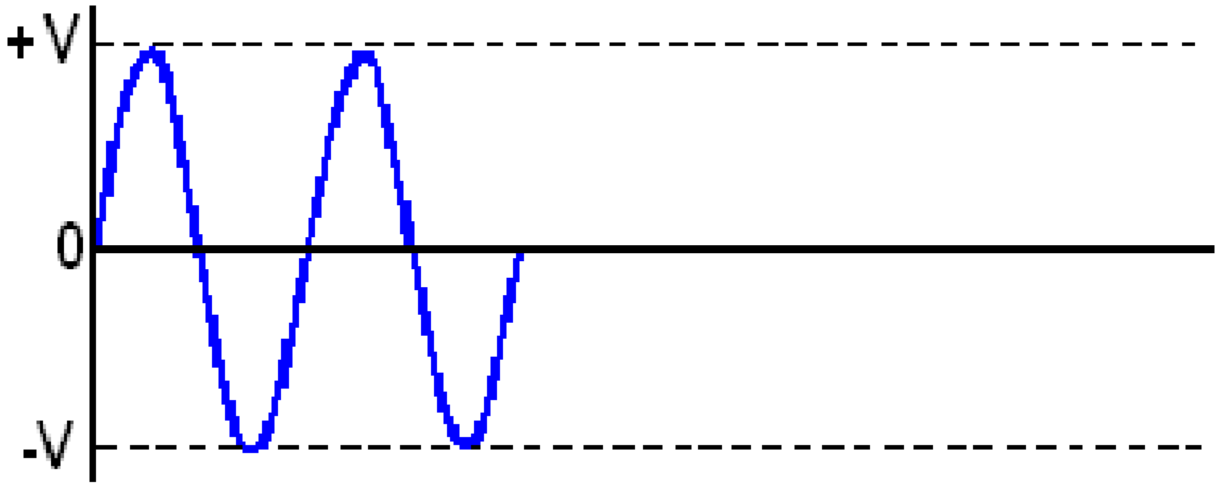


Figure I.14 Long Interruption[27]

Voltage spike

Any voltage applied to equipment whose peak value is outside the limitsof a template defined by a standard or specification is an overvoltage.

- Causes: break in neutral, operation of equipment and capacitors, lightning.
- Consequences: locking of variable speed drives, nuisance trips,destruction of equipment, fires, operating losses. [8]

[8] *Cahier Technique n° 53. Nicolas Gheorghe. janvier 2008*

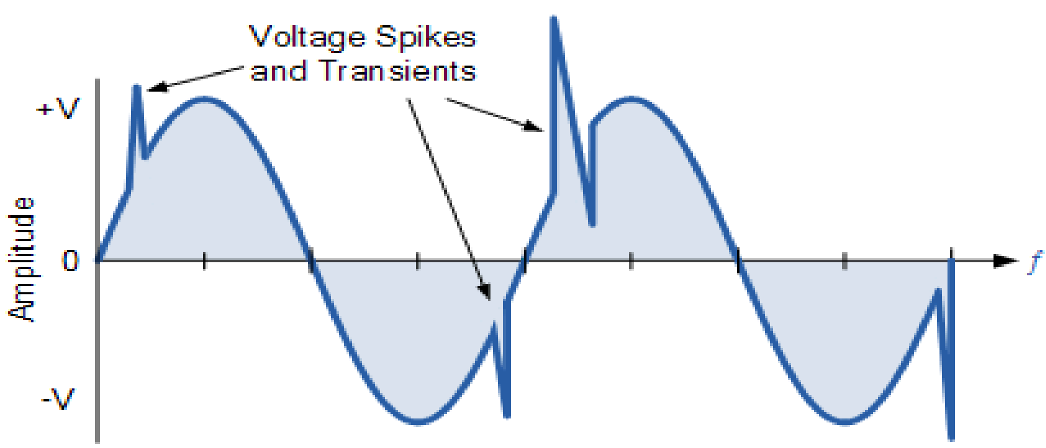


Figure I.15 Voltage Spike[28]

Voltage swell

Description: Momentary increase of the voltage, at the power frequency, outside the normal tolerances, withduration of more than one cycle and typically less than a few seconds.

- **Causes:** Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainlyduring off-peak hours).
- **Consequences**: Data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if thevoltage values are too high.

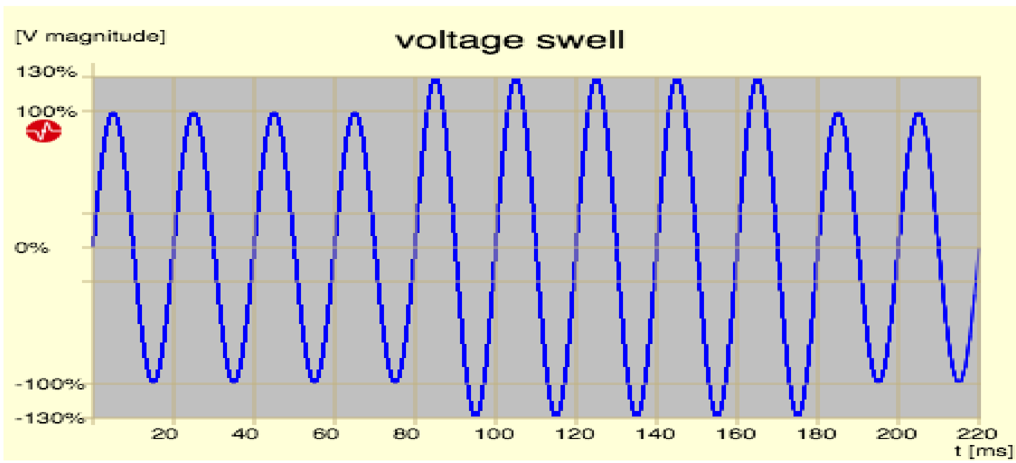


Figure I.16 voltage swell[29]

Harmonic distortion [24], [25]

Description: Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to thesum of different sine-waves with different magnitude and phase, having frequencies that are multiples ofpower-system frequency.

- **Causes:** Classic sources: electric machines working above the knee of the magnetization curve (magneticsaturation), arc furnaces, welding machines, rectifiers, and DC brush motors. Modern sources: all non-linearloads, such as power electronics equipment including ASDs, switched mode power supplies, data processingequipment, high efficiency lighting.
- **Consequences:** Increased probability in occurrence of resonance, neutral overload in 3-phase systems,overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interferencewith

communication systems, errors in measures when using average reading meters, nuisance tripping ofthermal protections.

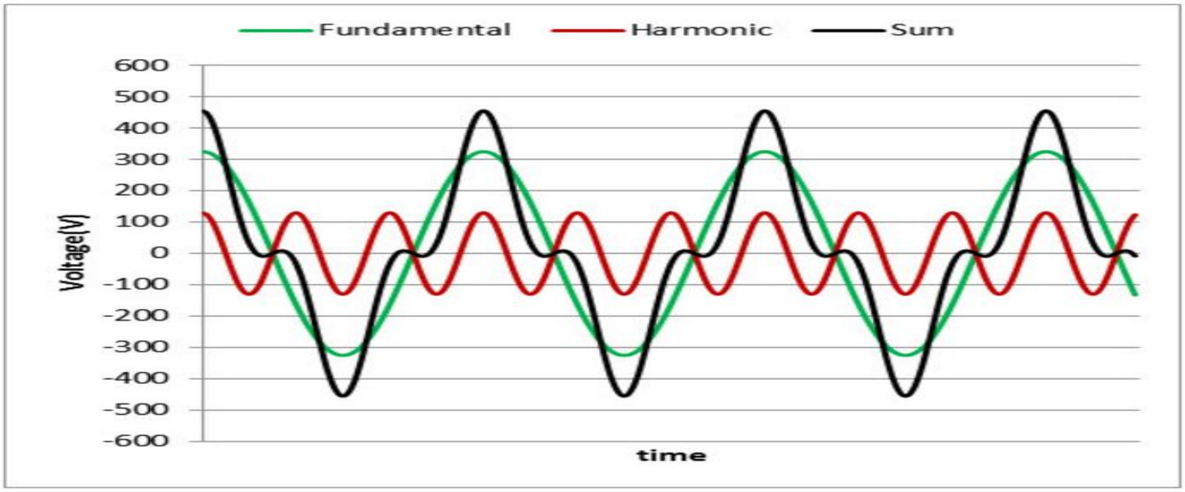


Figure I.17 Harmonic distortion [30]

Noise

Superimposing of high frequency signals on the waveform of the power-system frequency.

Causes:

Electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion,and radiation due to welding machines, arc furnaces, and electronic equipment.

Improper grounding may alsobe a cause.

Consequences: Disturbances on sensitive electronic equipment, usually not destructive, may cause data loss and data processing errors.

Voltage unbalance

Description: A voltage variation in a three-phase system in which the three voltage magnitudes or the phaseangledifferences between them are not equal.

Causes: Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phaseloads by the three phases of the system (this may be also due to a fault).

Consequences: Unbalanced systems imply the existence of a negative sequence that is harmful to all threephaseloads. The most affected loads are three-phase induction machines. [24], [25]

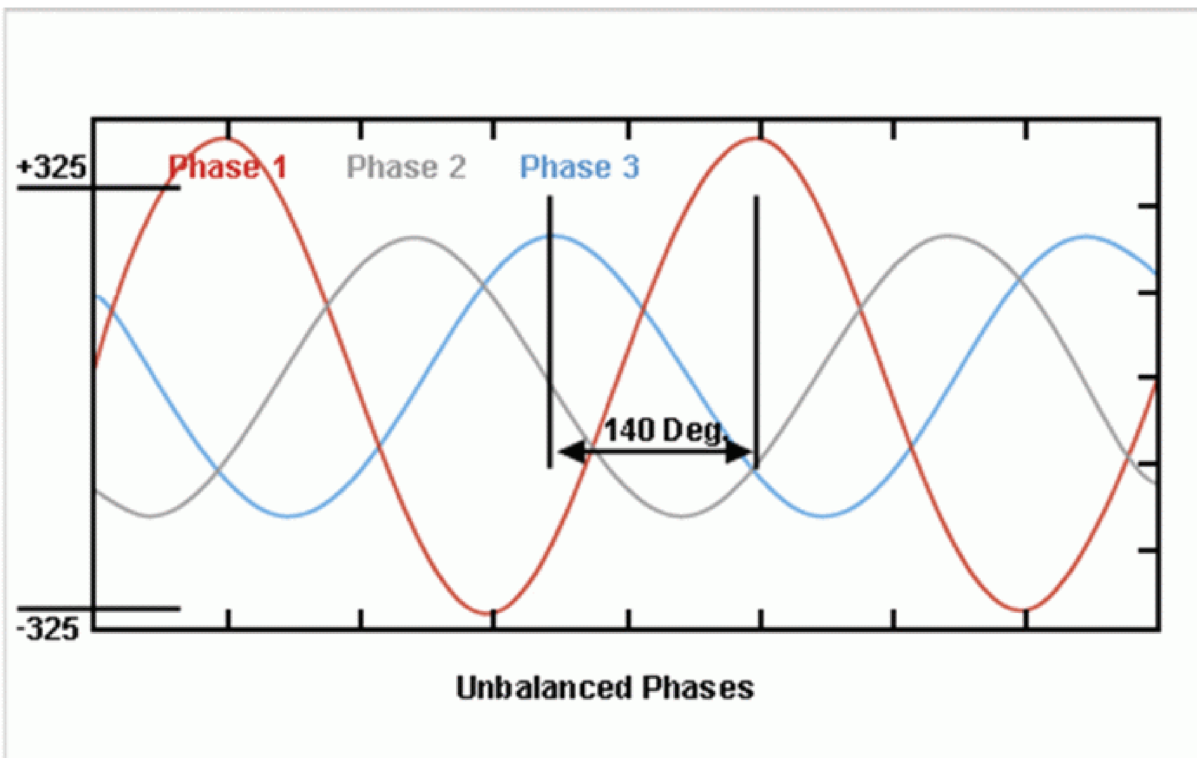


Figure I.18 unbalanced phases [31]

IEEE STANDARDS [32]

Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems This Standard contains the limit of Current harmonics and the Voltage harmonics for PCC (point of common coupling), Total Harmonic Distortion Limits are tabulated in this standard.

	Bus voltage at point of common coupling	Individual voltage distortion (%)	Total harmonic distortion (THD %)
	<69kV	3	5
	69<161	1.5	2.5
	161 above	1	1.5

Table : Harmonic voltage distortion limits

Isc/I1	<11th	11≤ h< 17	17≤ h< 23	23≤ h< 35	35 ≤h	TDD
<20	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100<1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20

Table Table -2: Harmonic current distortion limits

1100-1992 – IEEE

This standard is for giving power and doing grounding sensitive electronic devices or the equipment it also has recommended design and installation and also it contain maintenance of electronic equipment. In detail process for ground is given in this standard.

142-2007 - IEEE

This standard is for giving power and doing grounding for the industrial equipment’s which has very large rating it also contain some problems related to industrial equipment related to grounding and its solution it’s also contain problem related to neutral connection its problems and its solutions its advantages and disadvantages of grounded and ungrounded conditions. How to connect equipment frames to the ground problem related to bounding is also discussed in this standard.

141-1993 –IEEE

This standard is for installation of industrial equipment and distribution of industrial plants. Some of the major consideration related to installation and distribution for the industrial plant is given in this standard. This standard is one of the parts of color book. Proper guidance for the installation and distribution of industrial plant.It also consist of safety of industrial equipment's and the workers who is working in the industry

241-1990 - IEEE

This standard is for designing and installation of electrical power system in commercial buildings this book is one of the par of color book it covers the sources, load characteristics wiring system, necessary protection, electrical spacing, coordination of relays etc. It only contains reference but it is very helpful for commercial building. We must follow this stand for commercial buildings.

C57.110-1986 - IEEE

Recommended Practice for Establishing Transformer Capability When Supplying Non-Sinusoidal Load Currents. The purpose of the Standard is to establish uniform methods for determining the capability of transformers to supply non-sinusoidal load currents, without loss of normal life expectancy. Two methods are described. The first is intended for use by those with access to detailed information on loss density distribution within the transformer windings. The second is less accurate and is intended for use by those with access to transformer certified test report data only. It is anticipated that the first method will be used primarily by transformer design engineers, while the second will be employed primarily by users. This recommended practice will be applicable for evaluating the feasibility of applying non-sinusoidal load currents to existing transformers and for specifying new transformers to supply non-sinusoidal loads. **[32]**

1.3 THE INFLUENCE OF DIFFERENT TYPES OF DG SOURCES ON THE GRID POWER QUALITY

The incorporation of distributed generation (DG) into distribution systems can offer several advantages. However, besides providing many benefits, DGs may introduce several interfacing issues. Hence, impacts of DGs on existing distribution system must be evaluated thoroughly in order to ensure reliability of the system. Among all the issues, protection issues are considered a major concern as it directly relates to safety and reliability of the system.

In the following section most common issues related to integration of distributed generation to distribution system protection are discussed along with possible mitigation methods.

A. False Tripping of Feeders

Interconnection of DGs to a distribution feeder may result in false tripping of a healthy feeder. When a fault occurs in an adjacent feeder, DG installed in healthy feeder may also contribute to the fault current. If the DG contribution to the fault exceeds the pick-up level of over current protective devices connected to healthy feeder, then protective devices may trip causing healthy feeder out of service before actual fault is cleared in faulted feeder.

B. Nuisance Tripping of DG

Nuisance tripping is termed as disconnection of DG or any of the utility breakers for faults beyond its protective zones.

Nuisance tripping may happen due to power surges in the DG facility or due to fault outside DG facility [70], [71]. Power

Surges in a distribution network occur due to loss of large load such as motors in the presence of a DG. Loss of large load may lead to export of excessive power to the grid causing relay to trip. Similarly fault outside the protective zone may cause nuisance tripping of production units. This can lead to a sudden loss of generation from DGs.

C. Unintentional Islanding

The occurrences of unintentional islanding in a distribution network in the presence of DGs are due to tripping of utility breakers or de-energization of utility feeder for maintenance purpose. Due to the tripping of feeder breaker some portions of power system are disconnected from the grid and are fed by DG. This Islanded operations of DGs are avoided as it may lead to unacceptable limits of operating voltage and frequency, other power quality parameters, may complicate both automatic reclosing and manual switching operations and cause safety hazards to the working personnel.

D. Neutral Shifting

Neutral shifting occurs when distribution system becomes ungrounded after the isolation of the feeder breaker due to a single-line to ground fault. This is primarily due to the interconnection transformer. If the transformer used to interface DG with the utility has a delta or ungrounded Wye connection on the utility side, then this neutral shifting can cause overvoltage on the other un-faulted phases. This overvoltage on the other healthy phases could be 1.73p.u. This is a serious consequence which can damage customer equipments and may cause some safety hazards. Hence, to protect the customers normally surge arresters are placed in selected location [72].

E. Increase in Short Circuit Levels

Impacts of different types of DGs to the short circuit level of a distribution network depend on size and location of DGs. Typically short circuit contribution from an Inverter based DGs are compared to other DG types. As consequences of increased fault current, it may cause Fuse-Fuse, Fuse-Recloser, and Relay-Relay coordination failure which can lead to malfunction of protection operation [73]. Fault contribution from DGs also depends on the transformer connection between DG and Utility. If DG transformer is Wye grounded on utility side it can contribute to the zero sequence current for any fault on the utility side. So any fault on the utility side or on the DG side must be correctly identified by the corresponding protective devices and coordination must be taken to ensure proper operation of protective devices.

F. Blinding of Protection

Blinding of protection refers to desensitization of feeder relay in a faulted condition due to interconnection of DG to a distribution feeder. When a fault occurs in a feeder with DG connected to it, there would be a contribution of fault current from DG as well as grid. Fault contribution depends on network configuration, grid impedances, size and location of the DG. Interconnection of DGs close to the primary substation may result in decrease of fault current contribution from grid and may increase in total fault current. Due to reduction in fault current; it may happen that fault current seen by the relay never reaches pick-up current. So, the protection system based on over current relay principles may not operate because of reduced grid contribution until the DG unit trips. Thus DG with a relevant contribution to fault current can affect the sensitivity of protection system which can lead to serious consequences on power system. To mitigate this type of operational conflicts with addition of DGs, relay settings of the feeder relay need to be reduced upon addition of the DGs to the same feeder.

G. Resonance

DGs are connected to the network after extensive study of network resonance by system operators. So during normal operations, resonance may not occur in the system. However due to unwanted islanding or intentional islanding, resonance may occur in a distribution network in presence of DG due to interaction between system impedances and DG terminal capacitor and any capacitor present in the network. This may cause overvoltage in the system causing damage to network and customer equipments. Two types of resonance can occur in distribution network in presence of DG which is described as follows.

I) Linear Resonance

During intentional islanding conditions, interaction between generator reactance with system impedance can cause resonance with the existing compensating capacitors. Similarly, during asymmetrical fault condition, the total reactance changes as the sequence reactances becomes connected in different order (e.g, series and/or parallel combination). This may cause resonance with existing compensation capacitor of the system and is taken care of by changing the system reactances with switching capacitors or DGs.

II) Ferro-resonance

Ferro-resonance occurs due to interaction of system capacitance and variable inductance offered by transformer due to core saturation in ungrounded system. This core saturation occurs mainly due to DC offset caused by switching, energization of equipments in presence of DG etc.. Ferro-resonance causes overvoltage in the system which can damage protective system like instrument transformers, surge arresters as well as DG transformers. Hence, the common practice to mitigate this issue to damp out the overvoltage as fast as possible from instrumentation transformer which operates relay to isolate the DG from the system. Normally, to damp out this kind of high level overvoltage a damping resistor is used at the secondary of instrumentation transformer with an auxiliary winding in open delta configuration [74].

H. Automatic Reclosing

Interconnection of DG may affect the operation of auto reclosing devices during the fault. When a DG unit continues to operate during the open interval of the re-closer, fault arc may not be extinguished. This might lead a temporary fault to become permanent. Another potential problem could be connecting two asynchronously operating power systems. This can be happened when re-closer connects an islanded part which is operating at a different frequency due to active power imbalance to another network operating at power frequency.

Hence, in order to make a safe operation of power system, DG unit must be disconnected before re-closer.

I. Fuse Saving Operation

Fuse Saving schemes normally employed in urban/rural areas to make longevity of fuse lifespan. Normally, fuse operation is coordinated with feeder breaker or re-closer so that during the fault feeder breakers or re-closers are operated quickly than the fuses. This is accomplished by setting breaker or re-closer curves well below the fuse curves for first 2 to 3 cycles for faster operations followed by 2 to 3 times delayed operations. The faster operation is designed so that fuse would not melt for a temporary fault and temporary fault would be cleared without blowing the fuse. As DG contributes fault current, hence fuse saving operation might not be possible

1.4 QUALITY OF POWER SUPPLY AS A UNIVERSAL ASSESMENT MECHANISM IN GRIDS WITH DG SOURCES

BASIC DEFINITIONS OF QUALITY OF POWER SUPPLY

The following terms and definitions apply for the purposes of the **EN 50160 standards:**

Definitions concerning the normal (regular) state of the network operation

Network operator: the party responsible for operating, maintaining and, if necessary, developing the supply network in a given area in order to ensure that the network is able to meet reasonable long-term demands for electricity supply.

Network user: a party being supplied by or supplying to an electricity supply network.

Nominal voltage UN: the voltage by which a supply network is designated and to which certain operating characteristics are referred.

Supply terminal: a point in a public supply network at which electrical energy is exchanged between contractual partners. The terminal is designed for this task and its location is fixed in the contract. The point may differ from, for example, the electricity metering point or the point of common coupling.

Point of common coupling (PCC): the point on a public power supply network at which other loads are, or could be, connected. It is the point in the public network that is electrically the nearest to the connected load.

Supply voltage: the RMS value of the voltage at a given time at the supply terminal, measured over a given time interval.

Declared supply voltage Uc: the supply voltage agreed by the network operator and the network user. Generally the declared supply voltage Uc is the same as nominal voltage Un but it may also be different and defined by an agreement between network operator and the network user.

Reference voltage (for interruptions, voltage dips and voltage swells evaluation): is a value specified as the basis on which residual voltage, thresholds and other values are expressed in per unit or percentage terms. For the purpose of this standard, the reference voltage is the nominal or declared voltage of the supply system.

Frequency of the supply voltage: the repetition rate of the fundamental wave of the supply voltage measured over a given time interval.

Nominal frequency: the nominal value of the frequency of the supply voltage.

Levels of voltage have been divided as follows:

High voltage: a voltage whose nominal RMS value is 36 kV<Un<150 kV.

Medium voltage: a voltage whose nominal RMS value is 1 kV<Un≤36 kV.

Low voltage: a voltage whose nominal RMS value is Un≤ 1 kV.

In some countries, the boundary between MV and HV may be different as a result of pre-existing network structures.

Normal operating condition: an operating condition for an electricity network in which load and generation demands are met, system switching operations are made and faults are cleared by an automatic protection system, in the absence of exceptional circumstances,

A. Temporary supply arrangements

B. Non-compliance of a network user’s installation or equipment with relevant standards or with the technical requirements for connection

C. Exceptional situations, such as:

1. Exceptional weather conditions and other natural disasters

2. Third party interference

3. Acts by public authorities

4. Industrial actions (subject to legal requirements)

5. Force majeure

6. Power shortages resulting from external events [69]

Electric energy is supplied in the form of a voltage constituting a system three-phase sinusoidal with the following characteristic parameters:

- The frequency.
- The amplitude of the three tensions.
- The waveform.
- The imbalance.[34]

The quality of electrical energy

Criteria and definition

The electricity quality criteria are directly derived from the observation of electromagnetic disturbances in electrical networks. We talk about Compatibility Electromagnetic in order to characterize the aptitude of an apparatus, a device, to operate normally in an electromagnetic environment without producing itself disturbances harmful to other equipment or devices. The Electromagnetic Compatibility classifies these disturbances according to two groups:

- Low frequencies (<9 kHz).
- High frequencies (> 9 kHz).

Generally speaking, electrical engineering disturbances belong to the bass frequency. There are many observed phenomena: voltage dips and cuts, overvoltages, voltage fluctuations (flicker), frequency variations, imbalances in the three-phase system, harmonics and interharmonics

Energy quality assessment

The quality of electrical energy is of interest to both the supplier and the consumer.

The electric power supplier with the obligation of transmission and distribution, which it manages, certain quality parameters. The value of the frequency with the limits of variations admitted under different operating regimes and the continuity of the feeding of consumers with electrical energy.

The energy consumer, in turn, is interested in having adequate quality energy but, at the same time, it is involved in maintaining quality by type of receiver used and by the judicious exploitation of these. The main influences negative produced by consumer receptors relate to production of current and voltage harmonics, as well as operation in non-regulated symmetrical, unbalanced. The quality of the electrical energy at the terminals of the receivers is assessed mainly, in accordance with the standards for admissible deviations in value real parameters of nominal values.[35]

If we produce electricity, it’s not for the only pleasure of consuming it, but for uses it allows, such as lighting, strength drive, heating domestic hot water, operation of electronic devices.

The first expectation in terms of quality power supply, so it's the ability to fully render these services, in complete safety, when we need it. From a technical point of view, there are three dimensions of the power supply quality and how to measure these different aspects:

Continuity of electrical supply:

Which describes in frequency or duration the unavailability of the power supply, these are the famous "Interruptions" of current.

The technical standard thus distinguishes the long outage of more than 3 minutes; the short interruptions are between one second and three minutes, and the very brief cut below the second.

How to measure

It’s followed from the recording of incidents, their duration and resumption of service, to determine the number of users affected and the duration of the interruption involved. Traditionally tracked indicators are the number or frequency of brief outages and long periods perceived by customers and the duration of cumulative long outage. They can be followed

1)On average, especially to understand the evolution in trend of continuity of supply.

2) In acceptable thresholds, for targeted monitoring of the quality of difficult areas or on the contrary of users with high requirements of quality. These indicators are very sensitive to weather hazards (thunderstorms, gales, lightning, snow and frost ...). That is why they are often the subject of analyzes allowing distinguish the exceptional part from the part current.

Voltage quality,

Which deals with variations slow voltage in or out of ranges tolerated by standards to prevent devices that use electricity don't malfunction. It also deals with the measurement of transient variations of voltage (also called “voltage dip”), which may affect the proper functioning of certain sensitive devices, especially electronic.

The waveform

Finally, deals with "distortions «of the voltage wave. These disturbances (harmonics, flicker, over-voltages ...), can interfere with the proper functioning of certain electronic appliances. The admissible or desirable values are framed by standards, requirements regulatory or regulatory incentives, or finally by contracts between the manager of network and the user (the client directly) or their agent (the supplier).[36]

How to measure power quality supply

If we are ever called out to troubleshoot something on the electrical system, one of the first things considered is the supply voltage. We want to ensure we have a good electrical supply. Here are a few things we can quickly measure to get an impression on the quality of supply:

- Measure the supply voltage, current and frequency - you want to make sure all these are within expected limits. If any of the readings are more than 10% out of range, this indicates a problem.
- Check for phase unbalance - for three phase loads (i.e. motors), the system should be balanced; voltage unbalance of greater than 2% or current unbalance of greater than 6% would potentially indicate a problem. You can expect some unbalance for single phase loads the phase, however if this is excessive it may still indicate problems.
- Check for transients - these are more difficult to measure and will need some sort of recording instrument. Look for transients 50 V and more above nominal. You should measure for the duration in line with the observed symptoms.
- Check for voltage dip - look for dips 50 V and more below nominal. Again measure for the duration in line with the observed symptoms.
- Check the harmonics on the system - total harmonic distortion (THD) of greater than 6% could indicate problems.
- Check the power factor - this should be in line with expectations.

The above should provide a fair indication that everything is ok with the supply. If the supply looks good, we can then start investigating potential problems with the equipment itself.[37]

Technical control of quality

Network design, development, its maintenance, operation and renewal are the management levers of the quality of service of the distribution network.

It is by playing on these different factors that the network manager optimizes the service provided and its cost, in compliance of course with its obligations regulatory and contractual.

For the quality of voltage, the main levers are structural (dimensioning and means of network setting, increasingly “smart”).

Preserving the quality of the wave implies network users directly because disturbances are often exogenous to the network operation. Compliance with standards disruption and immunity to equipment connected is the main lever.

Beyond that, network users contribute also to quality management for themselves, through the desensitization of their uses. Indeed, for particularly uses sensitive and whose proper functioning is critical for the user, local protection against disruptions and ensuring continuity often a response economical to a targeted need for high quality that it would be more expensive to satisfy over the network. [36]

SUMMARY CHAP 1

Renewable energies represent a very important development in the field of electric power production. This type of energy manifests itself as a potential solution to reducing pollution. Among the production systems of this own energy wind turbines, hydroelectric power stations, photovoltaic systems.

The reliable power grid underpins our economy and quality of life, the operators have had a little set of tools at their disposal to balance power supply, demand and maintain proper frequency and voltage in the least times. Today, the evolution of the facility systems has provided new indices for maintaining reliability. As more variable generation is made, it are often wont to maintain reliability in ways almost like the generation it's replacing, and new, With this new toolbox (indices) and continued careful planning, coordination, and investment, reliability can remain a trademark characteristic of our evolving power grid.

In this chapter we tried to make a general view about the worldwide renewable energy systems , then the in the previous sections we listed the most common issues related to integration of distributed generation to distribution system protection are discussed along with possible mitigation methods.

This paper gives a review as well by analyzing about power quality problems, issues, related IEEE standards. A power quality audit can help determine the causes of your problems and provide a well-designed plan to correct them. The power quality audit checks the facility's wiring and grounding to ensure that it is adequate for your applications and up to code. The auditor normally will check the quality of the ac voltage itself, and consider the impact of the utility's power system. Many businesses and organizations rely on computer systems and other electrical equipment to carry out the mission critical functions, but they aren't safeguarding against the dangers of an unreliable power supply. It is time utilities as well as businesses engage in more proactive approach to power quality treats by engaging in power quality analysis.

CHAPTER 2. POWER SUPPLY QUALITY ASSESMENT METHODS

Making an attempt to define: what is power quality in electrical networks, by which factors is it determined, and on the basis of which premises should it be assessed, it is necessary to clarify the actual meaning of the term power quality. This term is often used as synonymous with supply reliability [38,39] to indicate the existence of an adequate and secure power supply. Another, broader definition [39,40] has described service quality covering the three aspects of: reliability of supply, quality of power offered and provision of information. Taking into consideration the content of numerous contributions to the topic in recent years, the term power quality is generally used to express the quality of the voltage [39, 41, 42]. There is increasing acceptability of the latter interpretation with the expansion of power electronic control in the transmission and utilization of electrical energy. At the same time many efforts in this area have been concerned with harmonics [42,43]. When harmonics distortion was an increasing quality problem, a wider power quality concept was needed which would include non-periodical and transient deviations from the ideal waveforms. Such deviations are used to assess Electromagnetic Compatibility (EMC), i.e. a subject concerned with the satisfactory operation of components and systems without interfering with or being interfered by other systems components [39, 42]. Finally, taking into consideration the electrical power system,

The power quality is usually defined by the following voltage or current parameters [39, 41, 42, 44, 45]:

- waveforms,
- frequency,
- magnitude,
- Symmetry in three-phase systems whose limits are appropriately standardized.

POWER QUALITY STANDARDS

As the power system is the conducting vehicle for possible interference between consumers, an important aspect of power system quality is the system ability to transmit and deliver electrical energy to the consumers within the limits specified by the EMC standards [39]. The two most widely referenced standards and guidelines are the IEC EMC series, including among others [46,47,48,49,50] and the IEEE 1159 [51].

The IEC series is published in separate parts covering the following elements [39,42]:

- General (IEC 61000-1-x): the overview of the series of standards and definitions,
- Environment (IEC 61000-2-x): a description of the characteristics of the environment and the compatibility levels for various disturbances.
- Limits (IEC 61000-3-x): a definition of emitted interference limits for voltage fluctuations, harmonics and flicker,
- Testing and Measurements Techniques (IEC 61000-4- x): a description of testing methods for emitted interference and interference immunity,
- Installation and Mitigation Guidelines (IEC 61000-5- x): a description of remedial measures,
- Generic Standards (IEC 61000-6-x): the interference immunity requirements and emitted interference limits

The IEEE 1159 standard contains several additional terms related to the IEC terminology. The IEEE categorization of electromagnetic phenomena used for the power quality community is defined and explained in this standard [51].

ELECTRICAL POWER QUALITY PHENOMENA AND INDICES

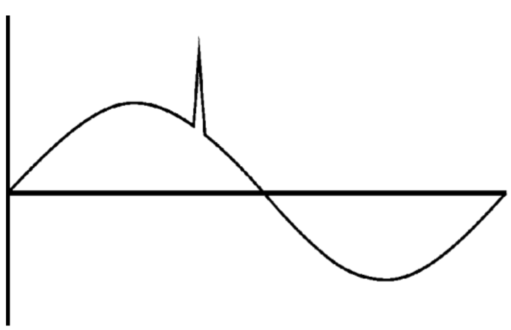
The electromagnetic phenomena dealing with electrical power quality in engineering systems should be analyzed in steady as well as non-steady states. The former has an effect mainly on the economic efficiency of the electrical power systems exploitation and due to its nature does not require fast measurements. The latter has a paramount importance for safety of the analyzed systems exploitation in the meaning of jeopardizing of human life or/and environment (dire economic effects are present as well).

Analyzing the power quality problem in the light of accepted standards it is necessary to concentrate among others, on the commonly accepted indices for the characterization of the disturbances. Commonly used indices may be discussed in relation to disturbances, waveform distortions, voltage unbalance and voltage fluctuation and flicker. However, electromagnetic phenomena should cover steady-states as well as non- steady-states of respective power systems [39,41,52].

Disturbances

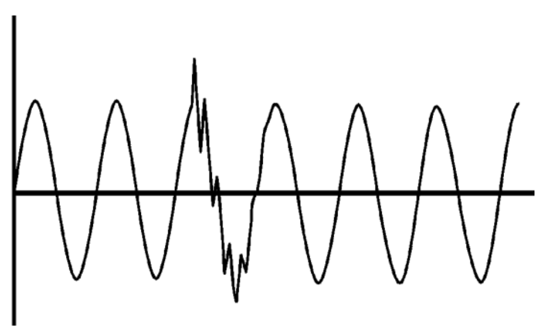
Disturbance has been understood as a temporary deviation from the steady-state waveform, being in fact a short-term phenomenon. This concept is often used to refer to a non- repetitive change in the amplitude of the system voltage at the fundamental frequency for a short period of time [39].This deviation can be a high-frequency phenomenon (impulsive, oscillatory and periodic transients) or a low- frequency phenomenon (voltage dips, interruptions and swells). Examples of voltage disturbances are illustrated in Fig.1 [39].

a)



Impulsive

b)



Oscilatory

b)

c)

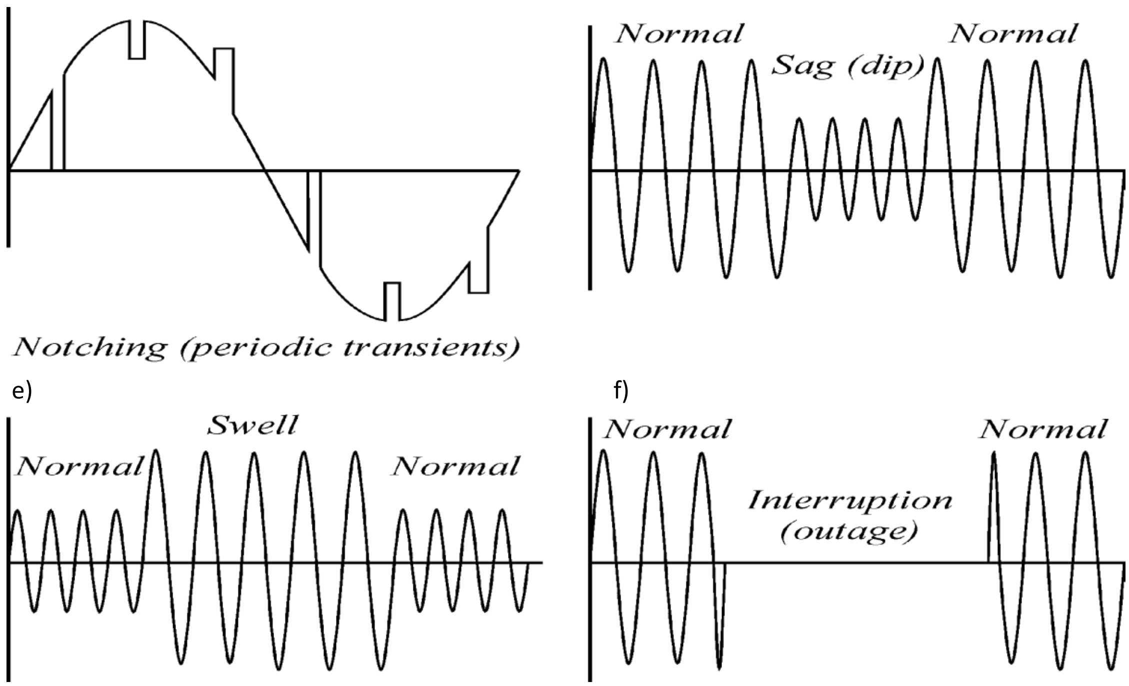


Figure II.1 Voltage disturbances: a), b), c) high-frequency, d), e) and f) low-frequency

The main attributes for characterizing these kinds of disturbances are the change in the amplitude and duration of the occurrence. In some regulations [39,42,45] permissible voltage deviations are defined dependently on a voltage level as voltage range for a time period: steady state, less than 1min, less than 10s and impulse voltage respectively. In practice, recorded parameters dependently on the needs can be averaged by the day, week or month

Waveform Distortion

This area covers harmonics, interharmonics, harmonics phase-angle, harmonic symmetrical components and notching.

The most frequently used harmonic and interharmonic indices are [39,41,42,43,44]:

- Harmonic Distortion (HD)
- Total Harmonic Distortion (THD)
- Total Interharmonic Distortion (TIHD)

– Total Demand Distortion (TDD) and Distortion Band Factor (DBF)

The THD, HD and TIHD indices are defined as the rms of the harmonics or interharmonics respectively expressed as a percentage of the fundamental or the original distorted signal [39,42,53]. The TDD is similar to the THD concept except that the distortion is expressed as a percentage of some rated or maximum load current magnitude, rather than as a percentage of the fundamental current. Using the THD or HD indices, the lack of information about the value of respective harmonics may be observed. It is very important if detection of higher order harmonic is considered. The problem may be eliminated by estimation of waveform distortion caused by the frequency component of a respective frequency band. It can be done by estimation of waveform distortion as distortion band factors DBF [44]:

$$DBF_{f_1-f_2} = \frac{U_{rms(f_1-f_2)}}{U_{rms}}$$

Where Urms(f1-f2) – rms value of voltage components of (f1-f2) frequency band.

Only if respective DBF factor has relatively great value, the measurement of harmonics content of the band is needed.

Voltage Unbalance

Unbalance describes a situation, in which either the voltages of a three-phase voltage source are not identical in magnitude, or the phase differences between them are not 120 electrical degrees, or both [39,42]. The degree of unbalance is usually defined by the proportion of negative and zero sequence components.

$$C_{vu} = \frac{\Delta u}{U_a}$$

Where C_{vu} the voltage unbalance coefficient

According the IEC settlements (IEC Report 892/1987) if the voltage unbalance exceeds 5%, the work of the electrical motor should be analyzed with regard to negative - sequence voltage. At smaller voltage unbalance load limitation to a degree dependent on this unbalance is recommended.

Voltage fluctuations and flicker

Voltage fluctuations are described as the cyclical variations of the voltage envelope or a series of random voltage changes, the magnitude of which does not exceed the range of permissible operational voltage changes mentioned in IEC 38 (i.e. up to ±10%) [39].

Fluctuations in the system voltage (concerning its rms value) can cause perceptible, low frequency light flicker depending on the magnitude and frequency of the variations [39,42].

A common method of analyzing the severity of a flicker disturbance is to measure the fluctuation of light luminosity of an incandescent lamp. [48,50]. This assessment of flicker can be broadly divided into two parts: measurement of instantaneous flicker sensation as perceived by human eyes, and statistical evaluation of this severity level. Two severity indices short-term flicker severity (Pst) and long term flicker severity (Plt) have been proposed for flicker evaluation [39,49,50].

2.1 POWER QUALITY ASSESMENT METHODS

METHODS AND TOOLS

A) The proper analysis of electrical energy quality requires measurement of quite a deal of different parameters. Usually the measurements for electrical power quality assessment are carried out with the use of digital signal processing algorithms. But it is worth underlining that the harmonic and transient analysis (waveform analysis) requires indeed much more computational power than determining the remaining power quality indices. Traditionally, the Fourier Transform has almost exclusively been used in power engineering for higher frequency components extraction. Nevertheless, in recent literature with reference to the potential power systems applications, three principal alternative have been discussed [44, 52,54,55,56]. These are the Walsh, Hartley and Wavelet Transform. Especially the latter one is worth recommending. The Wavelet Transform (WT) provides a fast and effective way of analyzing non-stationary voltage and current waveforms. So, it could be stated that this tool becomes paramount for transients detection and analysis. Similarly to the Fourier case, the WT decomposes a signal into its frequency components, but unlike the Fourier transform, the Wavelet can tailor the frequency resolution [39]. The WT has a digitally implementable version, the Discrete Wavelet Transform. In this kind of transformation, the scale and translation variables are discredited [39].

B) Compliance with the standardized level of power quality and optimum power distribution is ensured by general and local power systems. The reliability of the operation of such system depends on the reliability of each element, the consistency of their parameters and the structural relationships between them.

Since the DG sources have unstable potential, there is a need to ensure the conditions for reliable parallel operation of different DG sources within the LPS [57, 58, 60], as well as reliable parallel operation of the centralized Ems from the LPS, maintaining a balance between the consumed and generated electric power in the LPS, reliable and uninterrupted transmission of electricity in LPS to consumers fed by DG sources.

Reliability is one of the key concepts in power supply theory [59, 60]. The reliability of the energy system is a feature of the continuous supply of electricity to consumers to meet their needs. The concept of reliability includes such features as failure-free operation, durability and maintainability. But this terminology has not become common place; it has not embraced or streamlined many terms for reliability. Thus, the sources use the concepts of structural, mode (functional) and balance reliability. This division is made conditional, first, to simplify the task of assessing the reliability of complex electricity networks, and secondly, on the basis of quantitative assessments of the components that can be outlined with measures to improve the level of reliability.

Changes in electricity networks related to the introduction of market relations and distributed generation require an update of the terminology on the basis of which the decomposition of the task of reliability assessment can be performed. Because assessing the reliability of even distribution grids in today's environment is quite a challenge.

In market conditions, the consumer is crucial in assessing reliability. At the same time, the reliability of the energy object itself, which is estimated by the cost indicators (the cost of providing it, the cost of repairing the damaged equipment, etc.) becomes as if it was the internal business of the supplier of products and services.

Thus, depending on the system of assumptions and constraints, as well as on then mathematical apparatus used, the task of calculating reliability can be conditionally divided into three groups, which characterize the reliability of the EES: structural (schematic), mode (functional) and balance reliability (see Fig.).

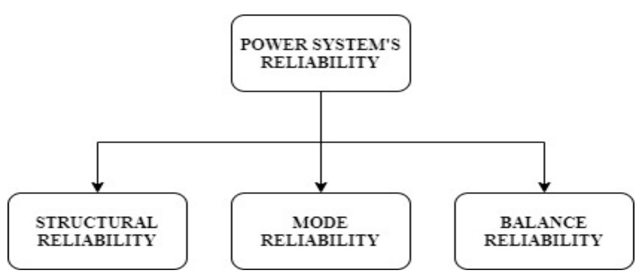


Figure II.2 *Classification of reliability of power systems by type of calculation models*

Structural reliability means the reliability of an object when the design model is determined by the circuit of electrical connections; mode reliability means the reliability of an object when the design model takes into account the modes of loading (functioning) of the elements of the object (mode reliability can be static when it comes to steady or long post-crash modes, and dynamic when it comes to transient modes) ; balance reliability means the reliability of an object when the design model is determined by the balance of production and consumption of products without taking into account restrictions on its transmission [61].

According to the definitions of modes and balance reliability, the influence of distributed generation and renewable energy sources in particular can be stated. As state-stimulated RES development is gaining momentum, we are talking about distributed generation at tens and hundreds of mega watts, which is significant both at the level of specific elements of power systems (mode of operation and load) and at the level of balancing between generated and consumed capacity.

2.2 RELIABILITY ASSESMENT METHODS

In general way, power system reliability addresses the issues of service interruption and power supply loss. In several cases, it is defined as an objective to attempt in terms of indices directly related to the customer. Typical reliability index values for US utilities are SAIFI, SAIDI, and CAIDI. Over time, they become standard values for evaluating the reliability of electrical systems and used in several publications. In the beginning, the methods used were classical to evaluate reliability indices of distribution systems such as failure frequency, mean failure times, mean time between failure and energy not supplied. These indices help decision makers to define technical and management measures to perform systems. After that was introduced the notion of loss of load probability (LOLP), which has a lot of applications in load modeling and electrical parameters dimensioning. It is significant for any power enterprise to analyze customer satisfaction.

A variety of indices have been developed to measure reliability and its cost in power systems area such as loss of load probability (LOLP), loss of load expectation (LOLE), expected frequency of load curtailment (EFLC), expected duration of load curtailment (EDLC), expected duration of a curtailment (EDC), and expected energy not supplied (EENS) [62]

Reliability indices for distribution power system

The most common indices are SAIFI, SAIDI, CAIDI, and ASAI. SAIFI and SAIDI are system-oriented measures of frequency and duration of interruptions. CAIDI and ASAI are customer-oriented measures of outage duration (per outage) and fraction of demand satisfied. CAIDI and CAIFI are also important measures of outage duration and interruption frequency experienced by customers.

- -System average interruption duration index (SAIDI)

The most often used performance measurement for a sustained interruption is the system average interruption duration index (SAIDI). This index measures the total duration of an interruption for the average customer during a given time period. SAIDI is normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or for any other time period. (Brown 2002).

- -Customer average interruption duration index (CAIDI)

Once an outage occurs the average time to restore service is found from the customer average interruption duration index (CAIDI). CAIDI is calculated similar to SAIDI except that the denominator is the number of customers interrupted versus the total number of utility customers. (Brown 2002).

- -System average interruption frequency index (SAIFI)

The system average interruption frequency index (SAIFI) is the average number of times that a system customer experiences an outage during the year (or time period

under study). The SAIFI is found by dividing the total number of customers interrupted by the total number of customers served.
SAIFI which is a dimensionless number. (Brown 2002).

- -Customer average interruption frequency index (CAIFI)

Similar to SAIFI is CAIFI, which is the customer average interruption frequency index. The CAIFI measures the average number of interruptions per customer interrupted per year. It is simply the number of interruptions that occurred divided by the number of customers affected by the interruptions. The CAIFI (Brown 2002).

- -Average service availability index (ASAI)

The average service availability index (ASAI) is the ratio of the total number of customer hours that service was available during a given time period to the total customer hours demanded. This is sometimes called the service reliability index. The ASAI is usually calculated on either a monthly basis (730 h) or a yearly basis (8,760 h), but can be calculated for any time period. (Brown 2002). [63]

According to the Law of Ukraine "On Electricity" No.575/97-BP, electricity suppliers are obliged to ensure reliable supply of high quality electricity to consumers in the most economical way. In accordance with Resolution No.232 of the National Electricity Regulatory Commission of Ukraine dated February 17, 2011 On approval of the report #17-NERC (quarterly) "Report on Electricity Supply" and No.18-NERC (quarterly) "Report on Performance of Commercial Quality of Service "and their instructions filling, reliability of electricity supply to consumers in Ukraine reliability indicators are defined as follows (Table2) :

The indicators described above were taken from IEEE1366-Guide for Electric Power Distribution Reliability Indices. This standard concerns operational reliability and conditionally separates performance across distribution networks (see Table3).

Table-Performance indicators according to IEEE1366

No	Reliabilityindex	No	Reliabilityindex
1	SAIFI	2	ASIFI
	SAIDI		
	CAIDI		ASIDI
	CTAIDI	3	MAIFI
	CAIFI		MAIFIe
	ASAI		CEMSMIn
	CEMIn		
	CELID		

When choosing the indicators that characterize the balance sheet reliability of electrical distribution systems with RES, the simple and obvious recommendations should be taken into account. Their number should be minimal and at the same time sufficient to make decisions to ensure the required level of balance sheet reliability. Complex PSDs should be avoided; they must have a simple physical content and allow the ability to evaluate values by different methods.

Reliability index	Definition	Reliability index	Definition
SAIFI	System Average Interruption Frequency Index	ASIFI	Average System Interruption Frequency Index
SAIDI	System Average Interruption		

	Duration Index		
CAIDI	Customer Average Interruption Duration Index	ASIDI	Average System Interruption Duration Index
CTAIDI	Customer Total Average Interruption Duration Index	MAIFI	Momentary Average Interruption Frequency Index
CAIFI	Customer Average Interruption Frequency Index	MAIFIe	Momentary Average Interruption Event Frequency Index
ASAI	Average Service Availability Index	CEMSMIn	Customers Experiencing Multiple Sustained Interruption and Momentary Interruption Events
CEMIn	Customers Experiencing Multiple Interruptions		
CELID	Customers Experiencing Long Interruption Durations		

Table3-Performance indicators according to IEEE1366

The selected RES distribution grids with RES must be sensitive to disturbances that lead to a decrease or increase of system reliability (changes in the mode of generation of renewable energy sources).

Theaboveindicatorscanbeusedonlyindeterminingtheperformanceandbalancereliab ilityofthesystem,whichareusuallyusedinparallelworkwiththenetwork,sotheLPSmust usethemodereliabilityindicatorsnamely(formulas1-4)[64]:

Loss of load expectation (LOLE) index:

$$LOLE = \sum_{i=1}^{n} P_i(C_i - L_i) \quad (1)$$

EIR and LOEE indexes:

$$EIR = 1 - LOEE \quad (2)$$

$$LOEE = \sum_{k=1}^{n} \frac{E_k \cdot P_k}{E} \quad (3)$$

Equivalent factor of the equipment readiness:

$$EFOR = \frac{equipment\ failure\ probability}{ammount\ of\ equipment} \quad (4)$$

Modes reliability of EPS depends on weather conditions, composition of network and generating equipment, volumes of reserve of active and reactive power, current mode of functioning of the system (values of node voltages, load of network equipment, etc.).

A prerequisite for reliable operation of the EES is the admissibility of the modes, I e its stay in the area, which is determined by the permissible limits for current, voltage, static stability, etc. In this case, the condition of reliability criterionn–0 is said. The test of this condition is to control the actual values of the power flows, voltage and other mode parameters and compare them with the set limit values.

So far, there are no indicators of modes reliability that would be widely used. This is especially true of modes reliability indicators that reflect the probabilistic nature of power systems.

Since the features of RES work in the ni criterion are problematic, mainly because of the probabilistic nature of the latter, it is necessary to choose indicators by which the impact of distributed generation on mode reliability can be evaluation

2.3 RELIABILITY ASSESMENT IN ALGERIA

Reliability analysis of transmission lines protection systems of the SONELGAZ power system

Electricity transmission lines occupy an important place in electrical networks by their functions and by their weight. Their role is to send electricity from the production plants to the distribution networks. Indeed, the development of Algerian network leads to increased powers of short circuits on high voltage power lines. The secure operation of these lines requires systems high level of protection. The use of suitable protective devices, operating in such a way accurate and reliable with a decisive effect on safety operating networks and electrical installations.

We will proceed in the following to the analysis of operation of line protection systems high voltage electrical transmission network electricity from Algeria.

II. ANALYSIS OF SOME LINKED HIGH VOLTAGE INCIDENTS

According to the statistics given by the structures

GRTE (SONELGAZ) techniques, several incidents have been recorded following the failure of the protection of high voltage power lines in Algeria.

In 2011 an important incident badly eliminated by protection systems has been registered at 60/30 kV station REGHAIA. The incident, which was triggered following the triggering of the 60 kV line ALGER EST-REGHAIA at the ALGER EST substation for maximum emergency protection current. This trigger is caused by the rupture of the conductor of phase 0 at the level of pylon N ° 19, the broken conductor touching the ground on the REGHAIA side like the shows the following diagram:

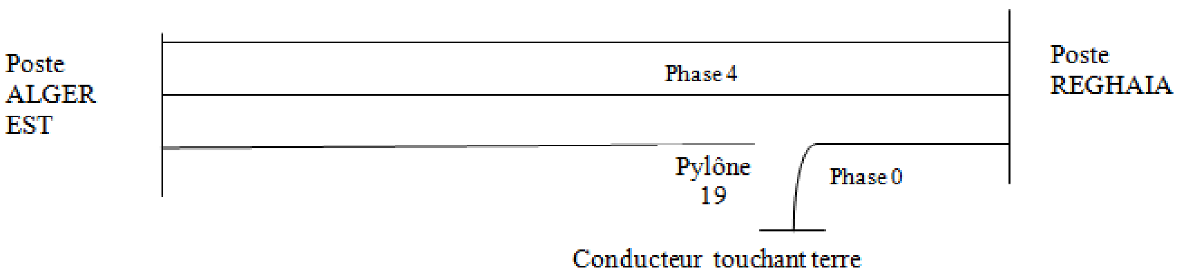


Figure II.3. Diagram illustrating the line with the phase 0 conductor cut

After the positive dismissal of the operator, the post of REGHAIA is then supplied by the station ALGIERS IS in biphasic 4 - 8. Refeeding of the two 60/30 kV transformers on the 60 kV side by two phases only resulted in the circulation of fault currents on phases 0.4 and 8 of the two 60/30 kV transformers of the REGHAIA post as follows:

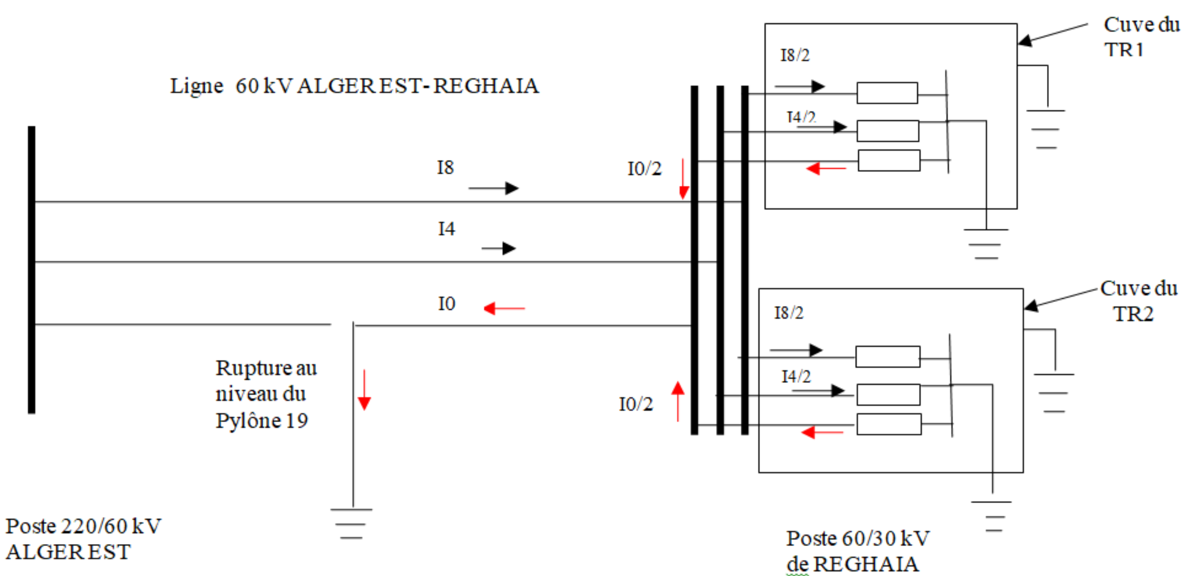


Figure II.4 Circulation of fault current during phase 0 shutdown

Indeed, this zero sequence current crosses the primary windings of the two transformers but do not can be evacuated by the neutral 60 kV because in secondary transformers there is no possibility for the current zero sequence to circulate through the neutral 30 kV (feeders 30 kV open).

This fault current caused overheating important transformers and which caused (Figure 3):

- Expansion of tanks

-Destruction of tank joints and fusion of some bolts. This resulted in the oil ejecting.

-Smoke emission due to the calcined paint of tanks in particular on TR2.

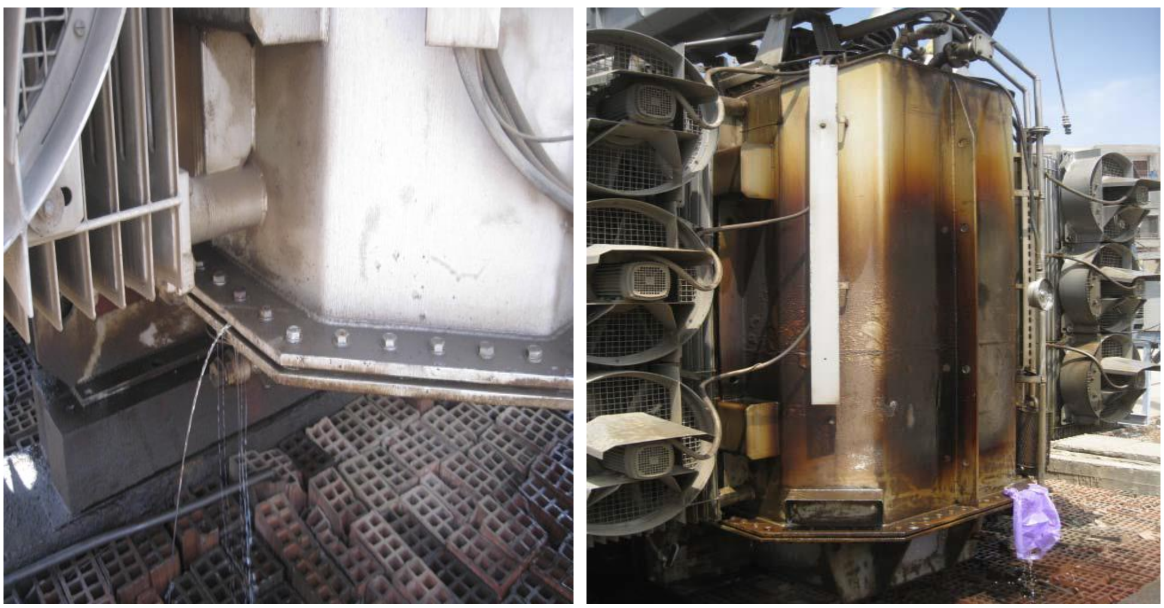


Figure II.5. Damage to power transformers at REGHAIA substation

Given the location of the single-phase 0-earth fault on the 60 kV line at the height of pylon N ° 19:

- The distance protection at the ALGER EST substation could not perceive it (out of starting range).

- Over current protection of the 60 kV flow at ALGIERS EST did not trigger after the refueling of the REGHAIA post because the 720 a threshold is not achieved.

- Additional PSW residual power protection does not react given the distance from the fault (appearance of low zero sequence voltage at the substation ALGIERS EAST).

- Max I current protections on the 60 kV side on transformers did not trip because the current threshold is not reached.

The incidents cited above were consequence of significant material damage which had a negative impact on the quality of service and the image of SONELGAZ. The analyzes carried out by the departments

SONELGAZ techniques have shown that failures of protection systems are the main cause of these incidents. Protection systems therefore have a strong impact on the operating safety of power lines, because they must eliminate a defect as soon as possible to protect people and property against its consequences (accident damage to property). To best guarantee safety power lines, reliability and availability of protection systems must be mastered. In what follows we proceed to the relay operation analysis which represent the main protection of high voltage lines.

PRESENTATION OF LINES PROTECTION SYSTEMS

HIGH VOLTAGE ELECTRICS

Protective equipment has the main mission detection of network faults by monitoring various parameters (current, voltage ...) and the issue of the order opening the circuit breaker in the event of an abnormal situation. A protection system can be defined as a more or less complex set of devices whose role is the immediate shutdown of an organ or element network when it becomes the seat of a fault electric [67]. A protection system consists of:

- Detection and decision-making bodies (measuring or measuring chain, comparator and decision)

-Intervention organ

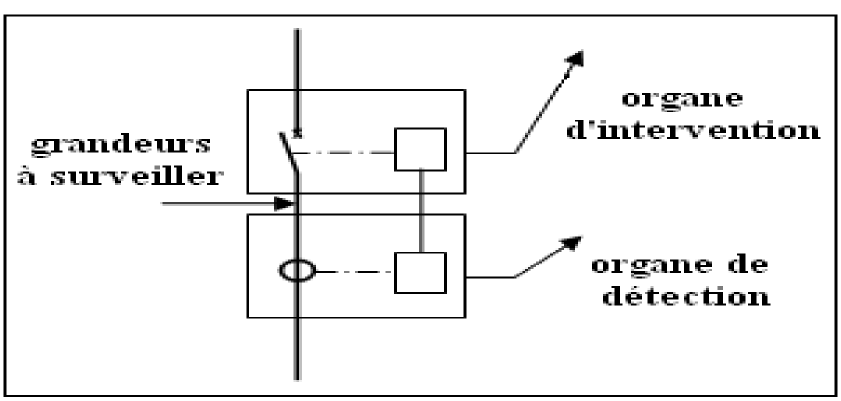


Figure II.6. Principle of operation of a protection

A. Principle of adjustment of line protections high voltage electric

In electric power transmission networks, power lines are protected by the devices of following protections: distance protection, protection additional and emergency protection [68]

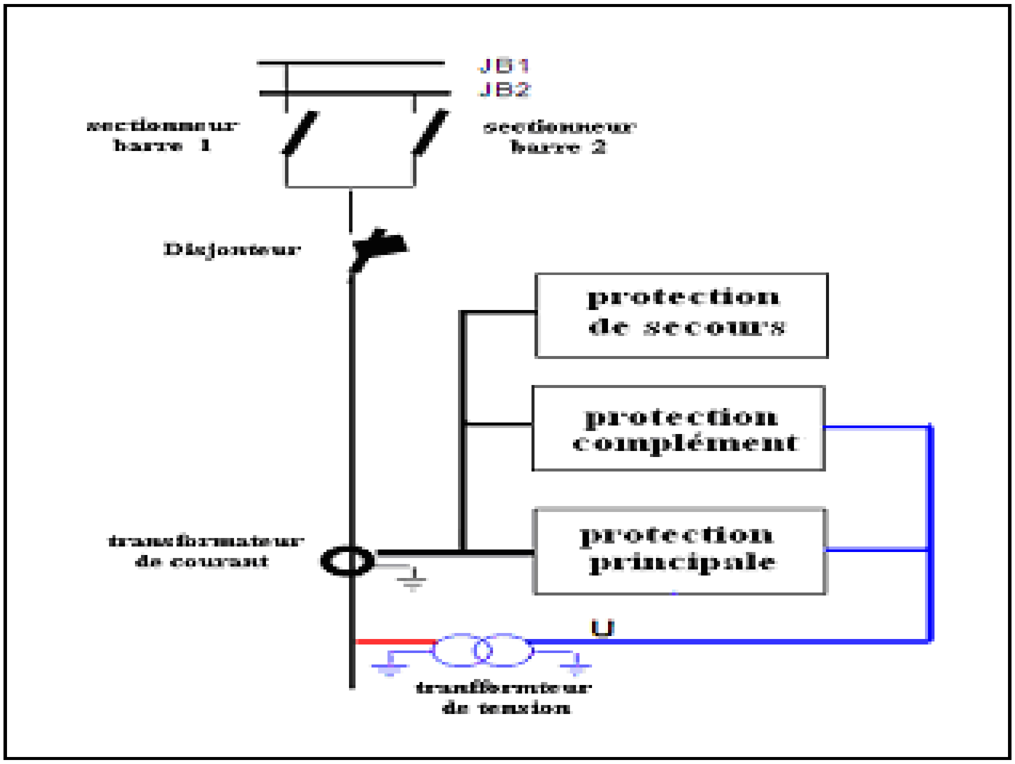


Figure II.7. Protection of a high voltage power line

-Main distance protection

This protection exploits the principle of significant reduction impedance of an element when it is short-circuited. The principle is to measure the impedance of a line to the location of the fault. Indeed, the impedance of a line is directly proportional to its length. In the absence of a fault it is the service impedance Z (identical for the three balanced diet phases) which is considered. In the event of a fault, the impedance measurement of fault depends on the magnitude of the fault current detected by the equipment, as well as the voltage at the relay point.

This allows the distance protection equipment to trigger selectively based on location of the fault on the line.

To prevent the protection from reacting to a fault located on a section outside of its surveillance, we adapt a time-distance characteristic. Generally we divide the power line in three measurement zones:

-The first area X1 covers 80% of the line.

-The second zone X2 covers 120% of the line.

-The third zone X3 covers 140% of the line.

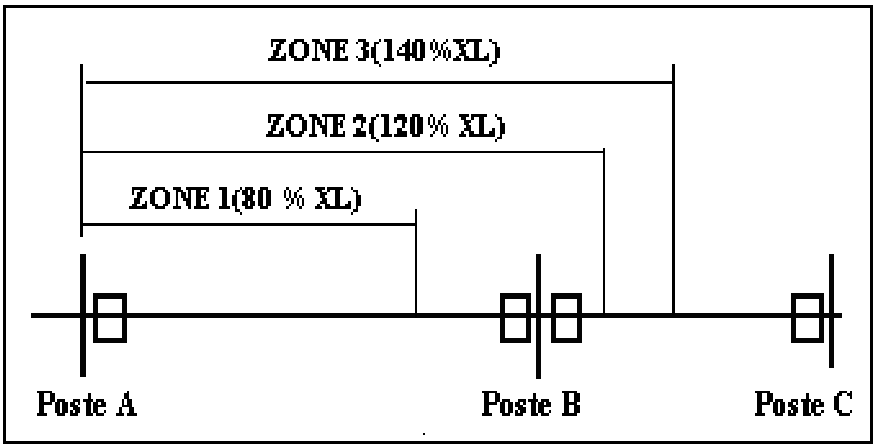


Figure II.8 Adjustment of measurement areas

-Additional protection:

This directional earth protection is intended for play the role of protection complementary to protection main for resistant faults to which protection main distance remains unresponsive.

But it should not interfere with the normal functioning of distance protection. Its operation is delayed not only by its inverse time characteristic but again by a delayed power up of the element directional.

- Over current backup protection:

Its role is to provide first aid to main protections and additional protections against short circuits of any kind but also of trigger inadmissible overloads on the line.
The protection action time is chosen account given protection timings at least current from the lines and surrounding transformer for ensure good operating selectivity.

SUMMARY CHAP 2

In this chapter we are trying to define: what's power quality in electrical networks, by which factors is it determined, and on the idea of which premises should it’s assessed, it's necessary to clarify the particular meaning of the term to point the existence of an adequate and secure power supply. Another, broader definition has described service quality covering the three aspects of: reliability of supply, quality of power offered and provision of data.

And in the part about Algeria we have shown that the achievement of a system satisfying an objective of safety requires identifying and taking into account the causes possible faults. The results of the analysis go up therefore that the current HV line protection system of

SONELGAZ is unable to detect all types of disturbance that can affect high power lines voltage. The current configuration of protection system

HV lines must be reviewed and updated taking into account consideration the different techniques exist currently in the protection of electrical networks

Chapter 3

Modeling and simulation of a photovoltaic system connected to the electricity grid

III.1. Introduction

Mathematical modeling and numerical simulation of energy systems are essential tools and means for the exploitation and for the explanation of the hidden physical phenomena generated during the operation of these systems.

The first goal of this chapter is the mathematical presentation of the most important stages installed in a PV system connected to the electrical network to the suitable for a well defined use.

The second goal is to put in digital simulation of our system and to analyze the behavior of the PV system in any point.

III.2. Electric grid

The electrical system is structured in several levels, ensuring specific specific Functions, and characterized by voltages adapted to these functions. It is divided into three main subdivisions, namely the transmission, distribution and distribution network. A notion of border can be defined between the voltage levels of the electrical network, these borders being defined by the source stations and the transformers (see figure III.1).

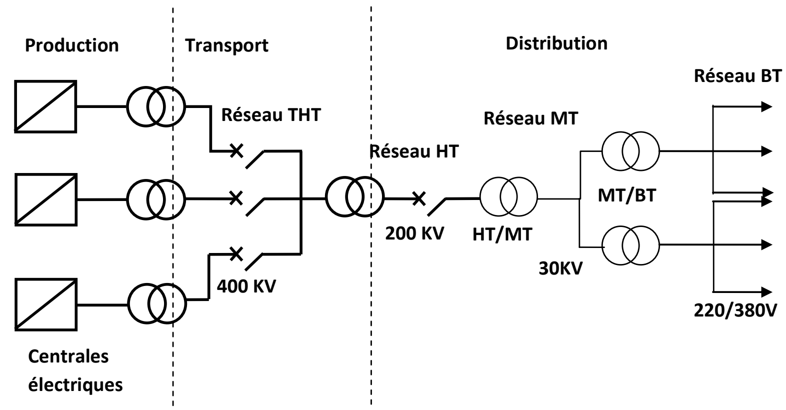


Figure III.1: *General diagram of an electrical network*

- Very high voltage transmission networks (THT.400 kV). It is at this level of tension that the interconnections between regions are ensured at the national level and the exchanges (import / export) of electrical energy at the international level. High-voltage distribution networks (HT, from 60 kV to 220 kV) ensure, on a regional scale, ensuring the transport of electricity to consumption areas and to a few large industrial customers directly connected to it.
- Distribution networks are the supply networks for all customers. There are two sub-levels: medium voltage networks (MV, from 5.5 kV to 30 kV) and low voltage networks (LV, from 110 V to 220 V). Medium-voltage distribution networks transport energy to low-voltage networks. Low-voltage networks are intended to supply customers with low energy demand.

III.2.1. Problem of connection of photovoltaic systems to the network

The problems concerning the interconnection of the photovoltaic system to the grid are:

- The removal of the photovoltaic system if the network has a fault.
- Lightning protection.
- The quality of power supplied to the network.
- The effects of multiple systems on part of the network, in particular unbalanced single-phase.
- Reliable dosing of power flows.

- Technical and financial risks.

III.2.2. Electrical network disturbances

The electrical energy is supplied in the form of voltage constituting a three-phase sinusoidal system whose characteristic parameters are as follows:

- The frequency
- The amplitude of the three tensions
- The waveform which must be the closest point of a sinusoid
- The symmetry of the three-phase system (equality of the modules of the three voltages, their phase shift and the sequence of the phases).

Contractual relationships can be established between energy supplier and end user, but also between producer and transporter or between transporter and distributor within the framework of a market. A contractual application requires that the terms be defined jointly and accepted by the different parties. In order to describe certain disturbances and to give the level of conformity of the energy supplied. Electrical disturbances affecting one of the four parameters mentioned above can be manifested by: a dip or a voltage cut, a fluctuation in voltage, an imbalance in the three-phase voltage system, a fluctuation in frequency, the presence of harmonics and / or inter-harmonics.

III.2.3. LV network modeling

III.2.3.1 Mathematical model

The three-phase network three sinusoidal magnitudes of the same frequency, phase-shifted by $2\pi / 3$, and having the same effective value, form a balanced three-phase system.

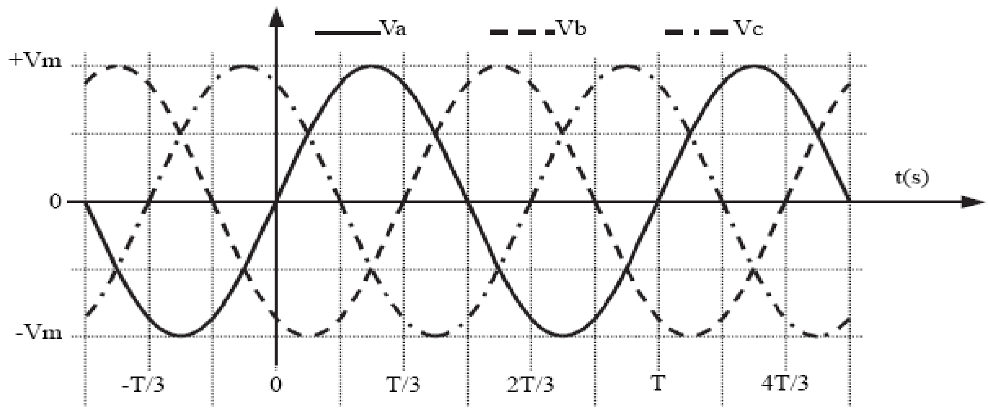


Figure III.2: *Balanced three-phase voltage system*

The electrical distribution network is based on a three-phase voltage system. We can generally consider that (V_a, V_b, V_c). Is a direct balanced three-phase voltage system.

$$\begin{cases} V_a = V_m \sin(\omega t) \\ V_b = V_m \sin\left(\omega t - \frac{2\pi}{3}\right) \\ V_c = V_m \sin\left(\omega t - \frac{4\pi}{3}\right) \end{cases} \tag{III-1}$$

$$\begin{cases} U_{ab} = V_a - V_b \\ U_{bc} = V_b - V_c \\ U_{ca} = V_c - V_a \end{cases} \tag{III-2}$$

$$\begin{cases} V_m = \sqrt{2} V_{eff} \\ U_m = \sqrt{3} V_m \\ U_{eff} = \sqrt{3} V_{eff} \end{cases} \tag{III-3}$$

III.2.3.2. Network simulation scheme

We will use a LV network (220 V / 380 V) with a frequency of 50 Hz connected to a current smoothing filter such as: The ratio. $\frac{X}{R} = 7$

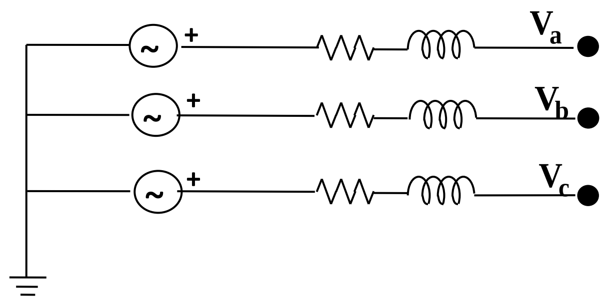


***Figure III.3**: Network simulation scheme*

III.3. Continuous adaptation stage "Chopper"

The step-up chopper converter places the operating point of the photovoltaic generator at the maximum MPP point, so it will increase the input voltage to the desired value, which will charge the capacitor (C).

We use the algorithm which is presented in the previous chapter (III.4), to calculate the coordinates of the maximum points VPPM and IPPM according to the given illumination which is equal to 1000 W / m², for an input voltage at inverter equal to 500V, which corresponds to the duty cycle value equal to 0.45

Such as: $C_1 = 100\,\mu F$, $L_1 = 5000\,\mu H$, $R_1 = 0.005\,\Omega$, $C2 = 12000\,\mu F$,

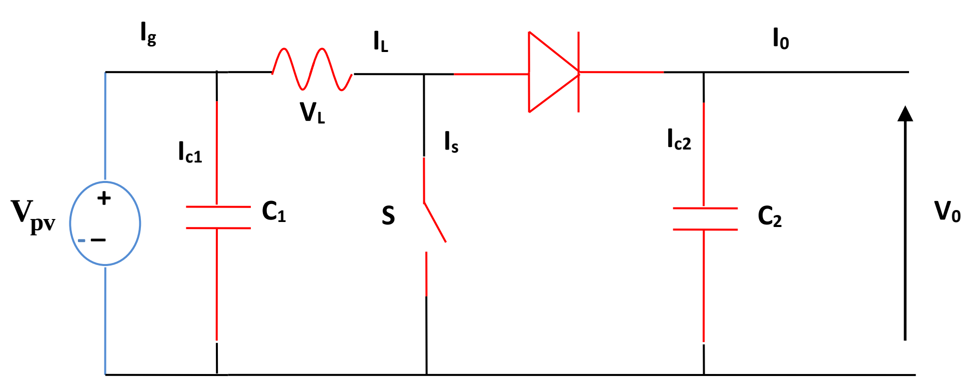


***Figure III.4:** Diagram of the continuous adaptation stage*

III.3.1 Types of DC / DC Converters (Choppers)

In this part, we deal with unidirectional current and voltage converters. This implies that the energy fluency can be done, within the converter, only in one direction. It also comes down to considering:

- non-reversible voltage sources, unidirectional in current.
- non-reversible current sources, unidirectional in voltage.

This leads to the study of the simplest DC-DC converters that can be. In this context, there are three families of static converters (or choppers).

- lifting chopper (or boost),
- step-down chopper,
- buck-boost chopper.

III.3.2. Equivalent mathematical model

The application of Kirchhoff's laws on the two equivalent circuits of the two operating phases gives:

For the first period αT_s:

$$I_{c1} = C_1 \frac{dV_g}{dt} = I_g - I_L \qquad \text{(III-4)}$$

$$I_{c2} = C_2 \frac{dV_o}{dt} = -I_o \qquad \text{(III-5)}$$

$$V_L = L \frac{dI_L}{dt} = V_g - R_L I_L \qquad \text{(III-6)}$$

For the second period (1-α) T_s

$$I_{c1} = C_1 \frac{dV_g}{dt} = I_g - I_L \qquad \text{(III-7)}$$

$$I_{c2} = C_2 \frac{dV_o}{dt} = I_L - I_o \qquad \text{(III-8)}$$

$$V_L = L\frac{dI_L}{dt} = V_g - V_o - R_L I_L \quad \text{(III-9)}$$

III.3.3. Approximate model of the lifting chopper

The basic systems of equations (III. (4, 5, 6)) and (III. (7, 8, 9)) Represent the functioning of the Boost converter for a period αT_s and $(1-\alpha)T_s$ respectively.

The converter oscillating between these two states with a high frequency, we must find an approximate dynamic representation valid for the two time intervals. For this we consider that the variation of dynamic variables C_1, V_L is linear, in other words we can make an exponential approach by a segment

($e^{\varepsilon} \approx 1+\varepsilon$ if ε<<1) and thus the derivative of these quantities will be constant.

This approach allows us to decompose the expression of the average value of the derivative of the dynamic variable x over the two time periods. αT_s and $(1-\alpha)T_s$:

$$\langle\frac{dx}{dt}\rangle T_s = \frac{dx}{dt_{(\alpha T_s)}}\alpha T_s + \frac{dx}{dt_{((1-\alpha)T_s)}}(1-\alpha)T_s \quad \text{(III-10)}$$

Where $\langle\frac{dx}{dt}\rangle$ is the average value of the derivative of x over a period Ts. This relationship is valid if valid if:

$\frac{dx}{dt_{(\alpha T_s)}}$ And $\frac{dx}{dt_{((1-\alpha)T_s)}}$ are constant over the periods αT_s and $(1-\alpha)T_s$ respectively in other words this approximation is valid if the periods αT_s and $(1-\alpha)T_s$ are very weak compared to the time constant of the circuit

$C_1 R_g, C_2 Z, L/R_L$ [65].

In this case the exponential form of the current which crosses the inductor and the tension across the terminals of the capacity is of linear form as the figure shows (III-5).

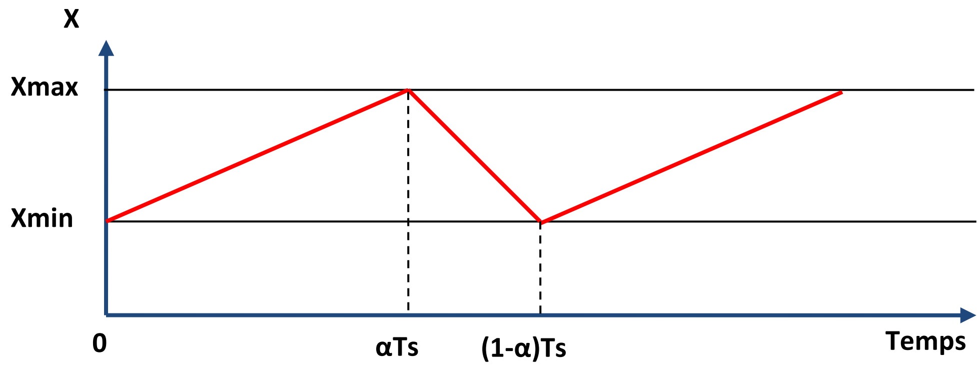


Figure III.5: *Look of dynamic variables I_L*

By applying the relation (III-10) on the systems of equations (III. (4, 5, 6)) And (III. (7, 8, 9)) We obtain the equations which govern the system over a whole period:

$$I_{c1} = C_1 \frac{dV_g}{dt} \alpha T_s = \left(I_g - I_L\right)\alpha T_s + (1-\alpha)T_s \left(I_g - I_L\right) \qquad \text{(III-11)}$$

$$I_{c2} = C_2 \frac{dV_o}{dt} \alpha T_s = -\alpha T_s I_o + (1-\alpha)T_s \left(I_g - I_o\right) \qquad \text{(III-12)}$$

$$V_L = L \frac{dI_L}{dt} \alpha T_s = \left(V_g - R_L I_L\right)\alpha T_s + (1-\alpha)T_s \left(V_g - V_o - R_L I_L\right) \qquad \text{(III-13)}$$

By arranging the terms of the previous equations, (so that we can interconnect the Boost with the other simulation blocks), we obtain the dynamic modeling of the Boost converter

$$I_L = I_g - C_1 \frac{dV_g}{dt} \qquad \text{(III-14)}$$

$$I_o = (1-\alpha) I_L - C_2 \frac{dV_o}{dt} \tag{III-15}$$

$$V_g = (1-\alpha) V_o + L \frac{dI_L}{dt} + R_L I_L \tag{III-16}$$

III.3.4. Ripples of currents and voltages

For the dimensioning of the various components of the circuit in order to reduce the undulations of the currents and the voltages without making an oversizing which would increase the weight and the price of the circuits, a calculation of these components according to the desired undulations is necessary. This remark is very important for the dimensioning of the inductance L in order to respect the current admissible by the MOSFET transistor S, where in the practical case the ripples of the current I_L are more important compared to the other undulations.

By applying the relation $V_L = L \frac{dI}{dt}$ and by the approximation of the exponential segments by lines, the slope of the current I_L during the first period of operation is given by:

$$\frac{dI_L}{dt} = \frac{V_L}{L} \approx \frac{V_g - R_L I_L}{L} \tag{III-17}$$

From relation (III.14), the peak-to-peak value of the current I_L is:

$$I_{L_{cc}} = 2\Delta I_L \approx \frac{V_g - R_L I_L}{L} \alpha T_s \tag{III18}$$

The value of the inductance L to choose for certain ripple ΔI_L is:

$$L \approx \frac{V_g - V_o - R_L I_L}{2\Delta I_L} \alpha T_s \tag{III-19}$$

For capacity calculation C_1 and C_2 we have

$$\frac{dV_g}{dt} = \frac{I_{C_1}}{C_1} = \frac{I_g - I_L}{C_1} \quad \text{(III-20)}$$

$$\frac{dV_o}{dt} = \frac{I_{C_2}}{C_2} = \frac{-I_o}{C_2} \quad \text{(III-21)}$$

The values of the peak-to-peak ripples of the input and output voltages are:

$$V_{c1_{cc}} = 2\Delta V_{c1} = \frac{I_g - I_L}{C_1}\alpha T_s \quad \text{(III-22)}$$

$$V_{c2_{cc}} = 2\Delta V_{c2} = \frac{-I_o}{C_2}\alpha T_s \quad \text{(III-23)}$$

Capacity values C_1 and C_2 are respectively given by :

$$C_1 = \frac{I_g - I_L}{2\Delta V_{C_1}}\alpha T_s \quad \text{(III24)}$$

$$C_2 = \frac{-I_o}{2\Delta V_{C_2}}\alpha T_s \quad \text{(III-25)}$$

III.3.5. Study in continuous regime

The continuous regime is obtained by eliminating the derivatives of the dynamic variables and by replacing these signals by their average values the system of equations (III. (14, 15, 16)) Gives:

$$I_L = I_g \quad \text{(III-26)}$$

$$I_o = (1-\alpha) I_L \quad \text{(III-27)}$$

$$V_g = (1-\alpha) V_o \quad \text{(III-28)}$$

As shown in figure (III-10), when the switch of the transistor (S) is in position (on), the current of the chopper inductance increases linearly and at this instant the diode (D) is blocked (off) and when (S) turns to position (off), the energy stored by the inductor is dissipated in the circuit (RC) although the diode (D) is on. The voltage and load current characteristics of the Boost converter in the case of continuous conduction are described by the figure (III.6), as follows:

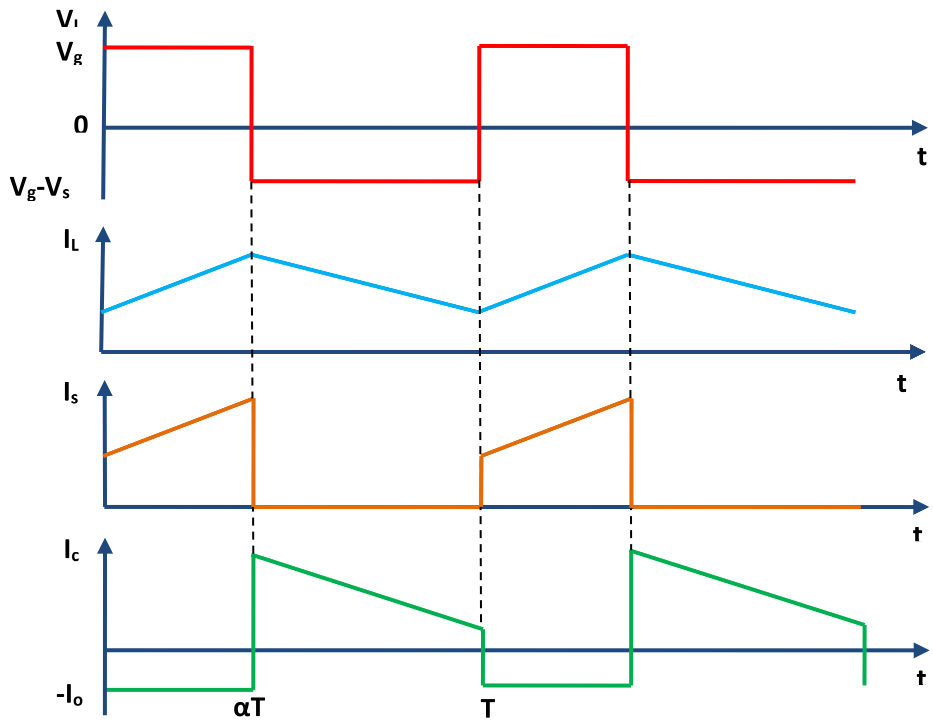


Figure III.6: *Voltage and current characteristics of the booster chopper*

III.4. Etage d'adaptation Alternatif « Convertisseurs Continus-Alternatifs »

The "Continuous-Alternative" converters are distinguished mainly by the nature of the continuous stage and by the number of phases of the alternative source. If the DC stage is seen as a source of current, the associated DC-AC converters are current inverters. If the DC stage is seen as a source of voltage, the associated DC to AC converters are voltage inverters. Most often, two or three phases are used. These DC-to-AC converters are direct converters, they are composed only of semiconductor switches, and the nature of the DC source imposes the nature of the

AC source: The current switches are connected to an AC voltage source (Figure III.7): The voltage inverters are connected to an alternating current source (Figure III.8).

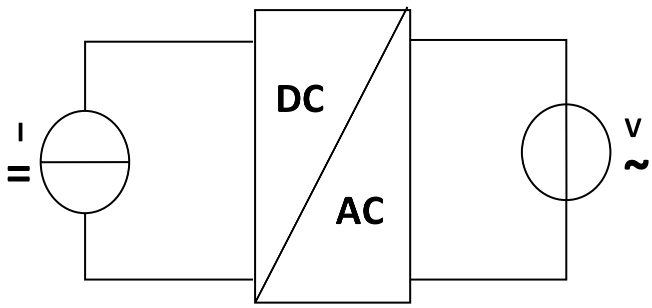


Figure III.7 : Current inverter

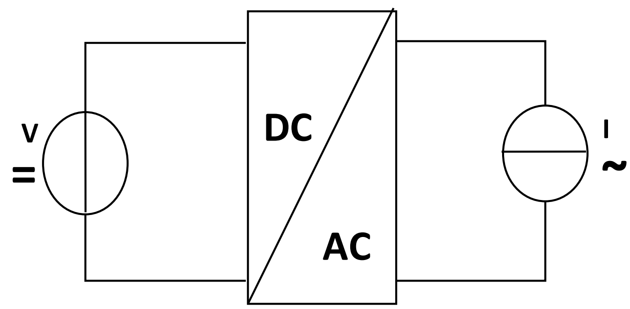


Figure III.8 : Voltage inverter

III.4.1. Onduleur de tension

Figure III.9 shows a three-phase inverter with voltage structure. It consists of three arms with reversible current switches, controlled on closing and opening, made from a transistor (GTO or IGBT) and an antiparallel diode. The energy storage on the continuous side is done via a capacitor Cdc of voltage Udc, or two capacitors with a midpoint (Cdc1, Cdc2), [66]. The output filter is a passive filter usually of the first order (Lr, Rr) used to connect the voltage inverter to the grid.

The mode, where the semiconductors of the same arm are both closed, only exists during the switching operations. In order to avoid a short circuit due to the switch blocking delay, a waiting time, also called dead time, must be inserted between the switch blocking command and the control command on the same arm. Priming the other. With the assumption of instantaneous switching, this operating mode will not be taken into account and therefore, there is no risk of short-circuiting the capacitor.

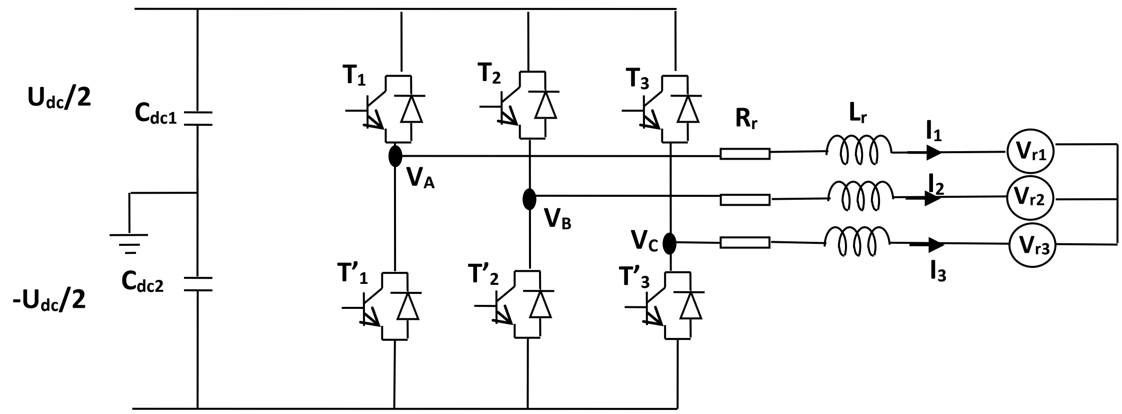


Figure III.9: *Three-phase voltage inverter*

III.4.2. Control strategies

The structure of the inverter control system can be separated into two subsystems with different dynamics: one called fast which is linked to currents, and another called slow which is associated with direct voltage. Therefore, a synthesis of two regulators for the internal loop of currents, and for the external loop of direct voltage can be done. On the other hand, it is well known that the performance of the current loop plays an essential role in the overall performance of the system; this is why a command with a fast response and good behavior in steady state is necessary. For the adjustment of the DC voltage, the use of conventional controls, in particular of the integral proportional type, seems to be sufficient to obtain acceptable performance. This work is devoted to the study of different control laws for the internal loop of currents].

III.4.3. Inverter control

The objective of the command is to generate the opening and closing orders of the switches so that the voltage created by the inverter is closest to the reference voltage. Two control methods can be used:

- Control by hysteresis,
- Control by PWM (Pulse Width Modulation).

III.4.4. Hysteresis control

The principle of current control by hysteresis consists in maintaining each of the currents generated in a band enveloping the reference currents.

Each violation of this band gives a switching order.

In practice, this is the technique shown in Figure III.10 that we use. The difference between the reference current and the measured current is applied to the input of a hysteresis comparator, the output of which directly provides the control order of the switches of the corresponding arm of the inverter

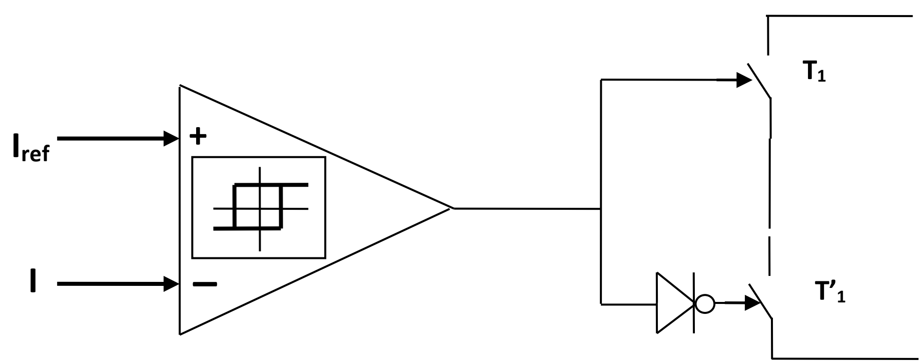


Figure III.10: *Current control by hysteresis*

The simplicity of implementing this strategy is its advantage, while the variable switching frequency can be its disadvantage. This can be remedied by another version of hysteresis control with a fixed switching frequency.

The only regulation parameter in this command is the width of the hysteresis band which determines the error on the currents and the switching frequency although the latter remains unknown. The principle of the switch control is shown in the Figure III.1

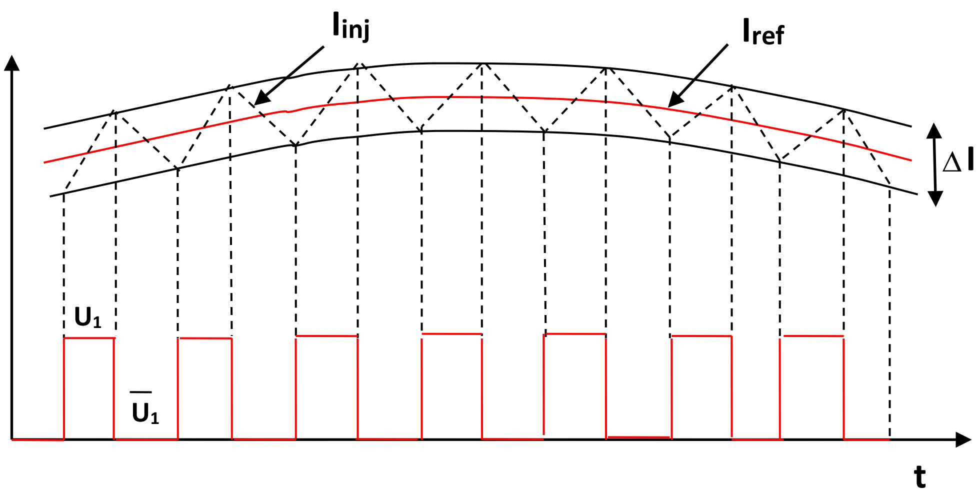


Figure III.11: *Switch control by hysteresis*

III.4.5. Control by PWM

The PWM-based method first implements a regulator which, from the difference between the current and its reference, determines the reference voltage of the inverter (modulator). The latter is then compared with a saw tooth signal at high frequency (carrier).

The comparator output provides the switch control order. The block diagram of this method is given in Figure III.12:

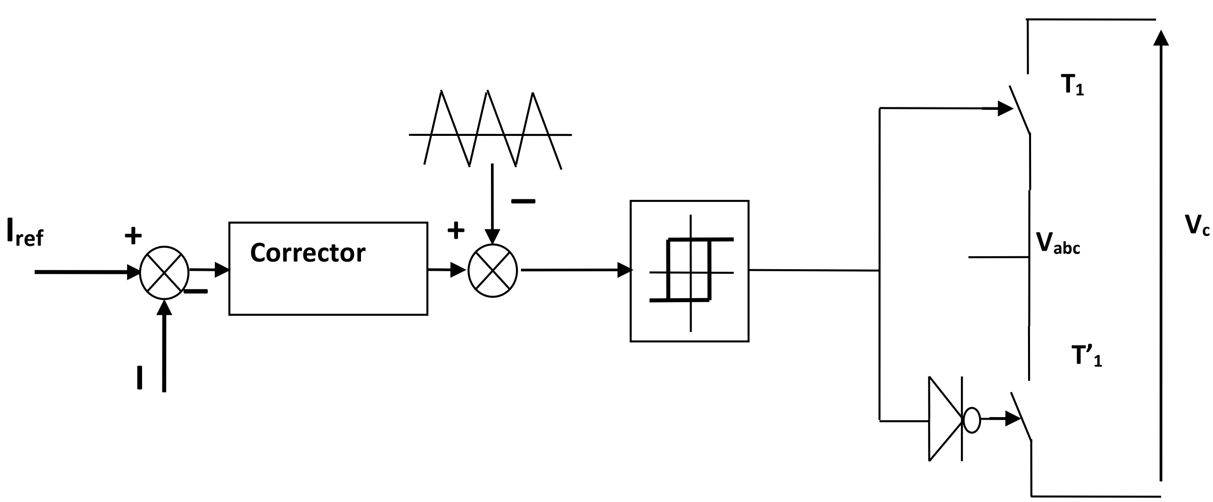


Figure III.12: *Current control by PWM*

The block diagram of the command is given in Figure III.13 below:

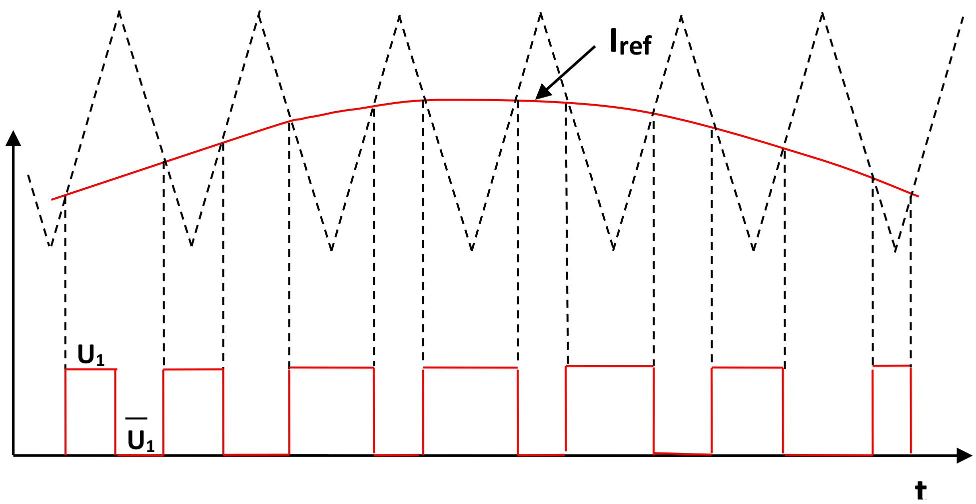


Figure III.13 : *Commande des interrupteurs par PWM*

Other PWM techniques also exist in the literature, such as regular sampling PWM, where two methods can be distinguished:

- The PWM with symmetrical regular sampling where the reference is sampled at each period of the carrier,
- PWM with asymmetric regular sampling where the reference is sampled at the carrier half-period.
- The development of a regulator must take into account the following criteria:
- the bandwidth of the regulator must be wide enough so as not to introduce a significant delay,
- The operation of the regulation must not be disturbed by the harmonics due to the switching of the inverter. These harmonics must be attenuated at the output of the regulator.

III.5. Filter

The L filter eliminates the switching harmonics almost perfectly and its behavior is almost ideal, when working at no load (zero output current) with signals of frequencies close to the fundamental frequency. To be able to connect the voltage inverter in parallel with the grid and make its behavior similar to a current source, it is necessary to use a connection filter of the inductive nature (L or LCL). The function of this filter allows on the one hand converting the compensator into a current dipole from the point of view of the network, and on the other hand to reduce the dynamics of the current so as to make it easier to control. The type filter (L) makes it possible to reduce the harmonics around the switching frequency. To obtain this, the value of this inductance must be relatively high.

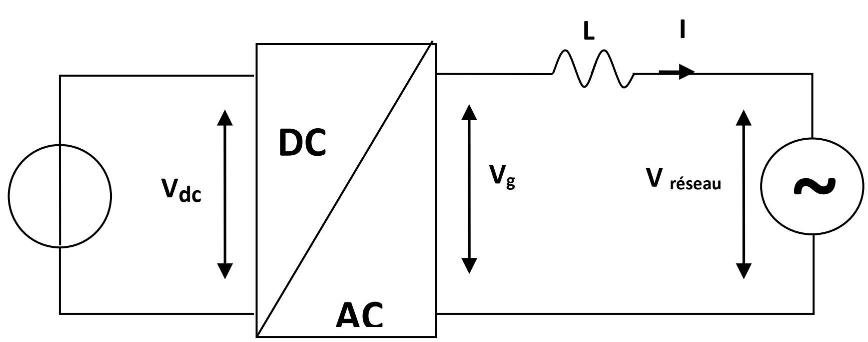


Figure III.14: *Voltage inverter with L filter.*

Such as: R_L = 0.0022 Ω et L=0.0025 H.

III.6. Simulation Results

The results obtained by simulation on MATLAB / SIMULINK software, all the blocks of MATLAB / SIMULINK have been configured (parameterized) and are represented by the graphs in the following section.

Load: We have chosen a balanced load (RL) on the alternative side (AC).

Such as: R= 20 Ω and L= 0.02 H.

The electric grid: We represent the electrical distribution network of amplitude *V* network =220 V, frequency f=*50 Hz and* the rapport $\frac{X}{R} = 7$.

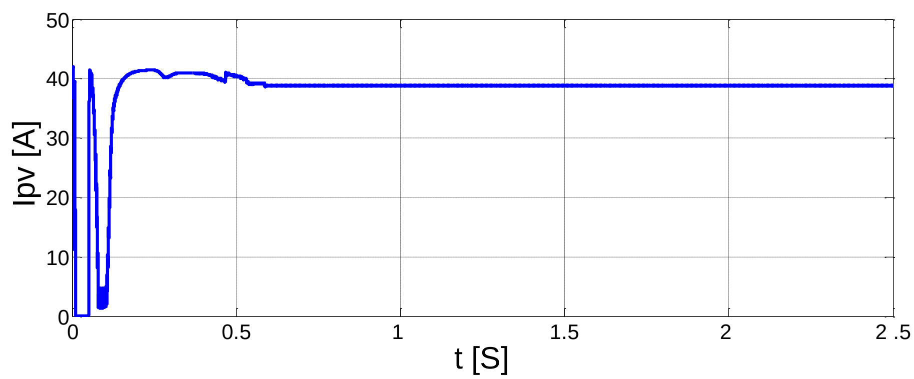


Figure III.15: *Current supplied by PV generator*

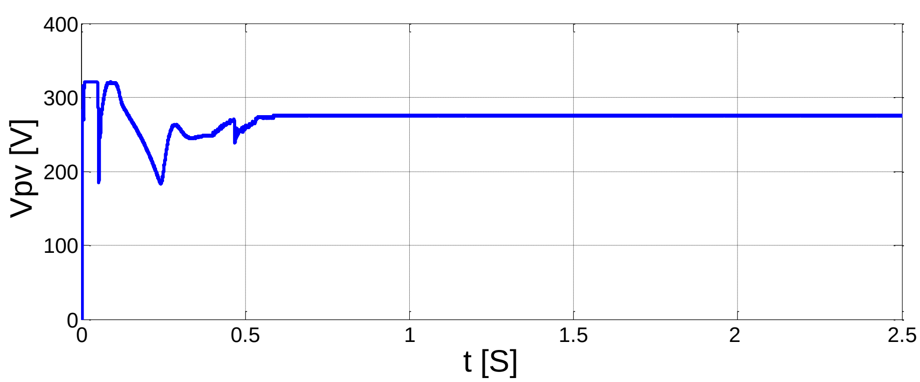


Figure III.16: *Voltage at the output of the PV generator*

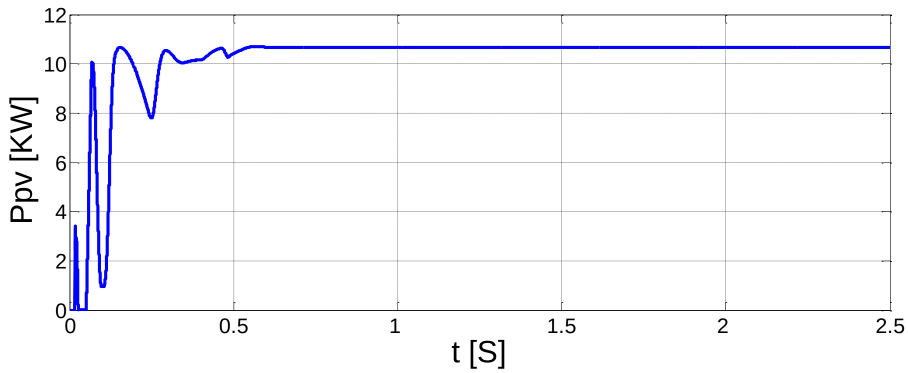


Figure III.17: *Power output by PV generator*

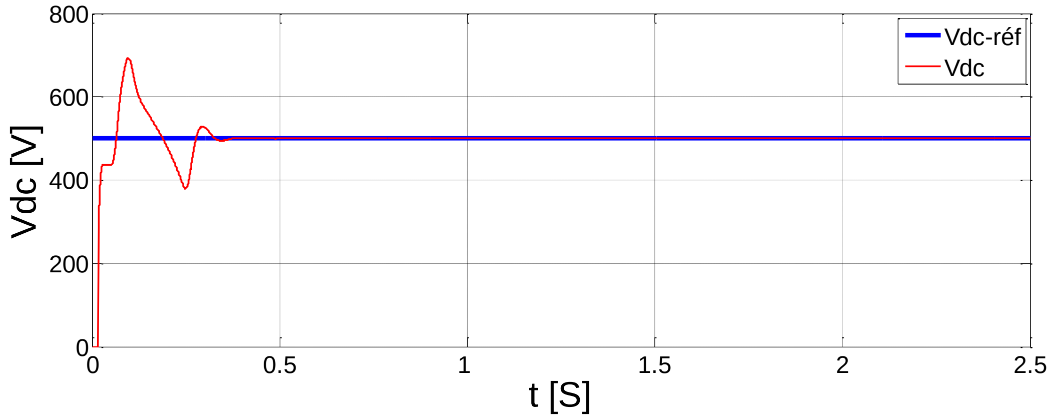


Figure III.18 : *Inverter input terminal voltage*

We notice that the PV generator current in figure III.15 takes a jump so that it stabilizes after a time of 0.5s at the desired value (39.06 A), so the GPV voltage in figure III.16 also takes a jump so that it stabilizes at the desired value (273.5V). In figure III.17, we notice that the power of the PV generator is equal to the nominal power 10.68 kW. This maximum power is provided by the MPPT control. We also note in Figures III.18 and III.19 that the chopper functions in booster mode because the input voltage of the inverter is higher than that of PV. With a duty cycle α = 0 .45 which corresponds to the value

Vdc = Vdc-ref = 500V.

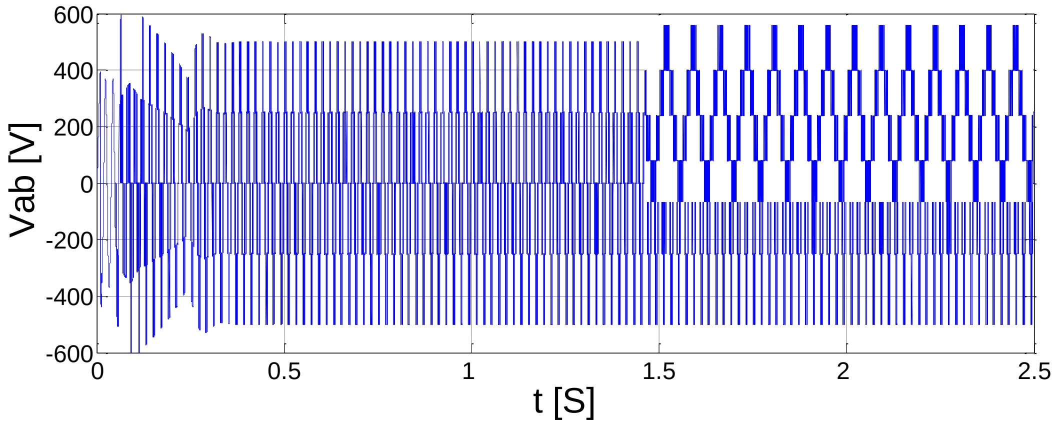


Figure III.19: *Compound voltage at the inverter output terminals*

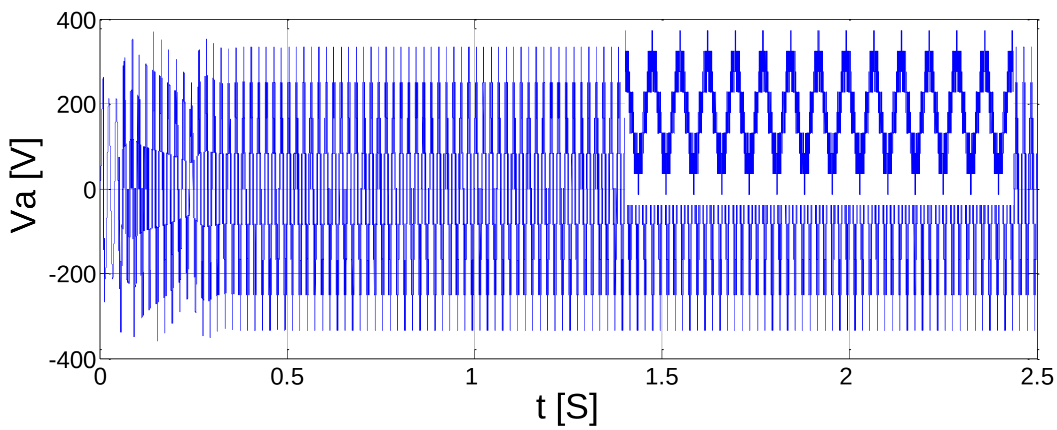


Figure III.20: *Single voltage at the inverter output terminals*

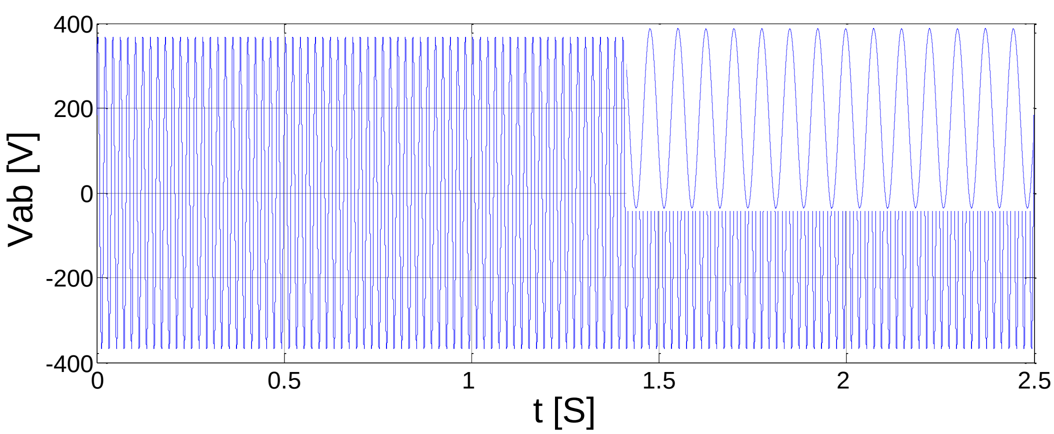


Figure III.21: *Compound filtered voltage*

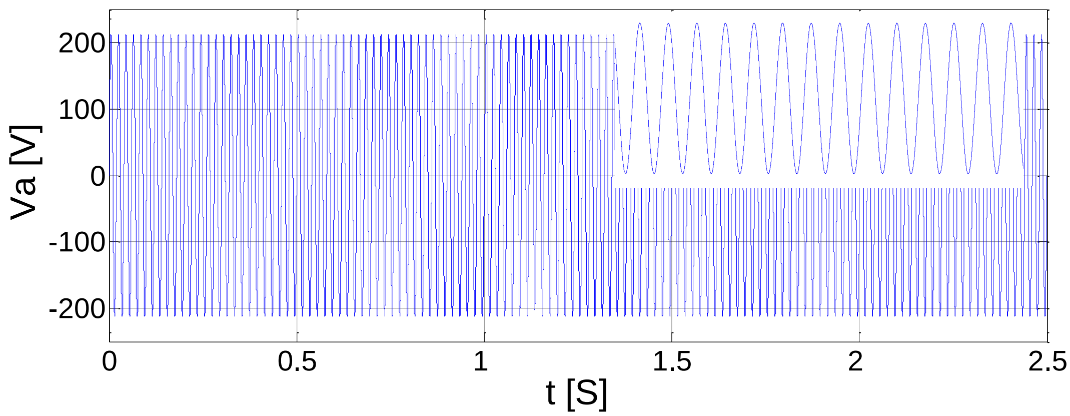


Figure III.22: *Simple filtered voltage*

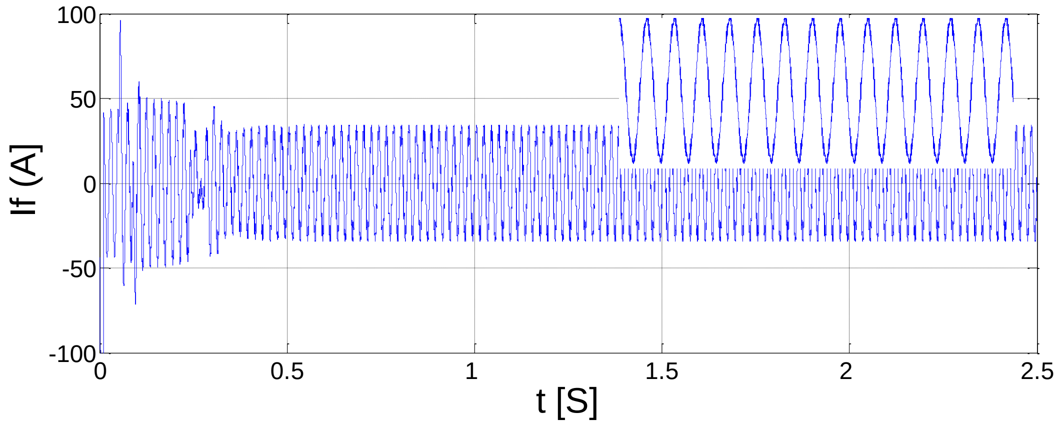


Figure III.23: *Filtered alternating current (after inverter)*

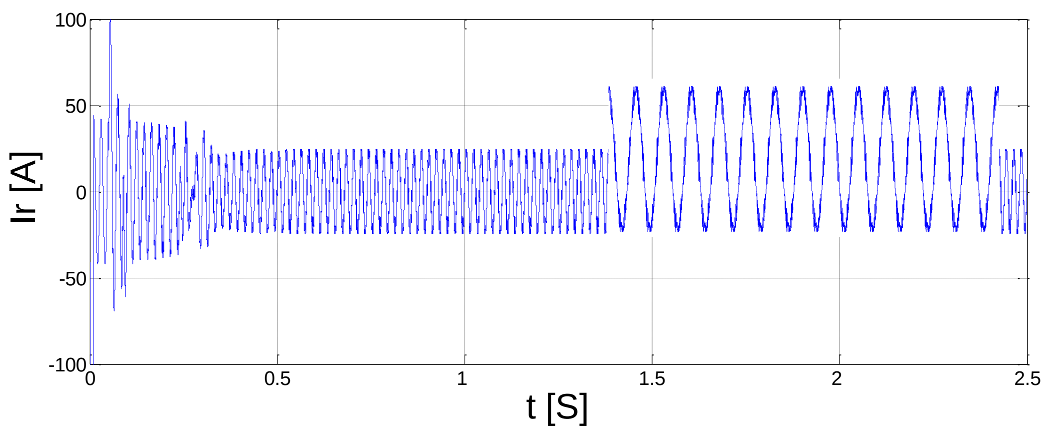


Figure III.24: *Current injected into the low voltage network*

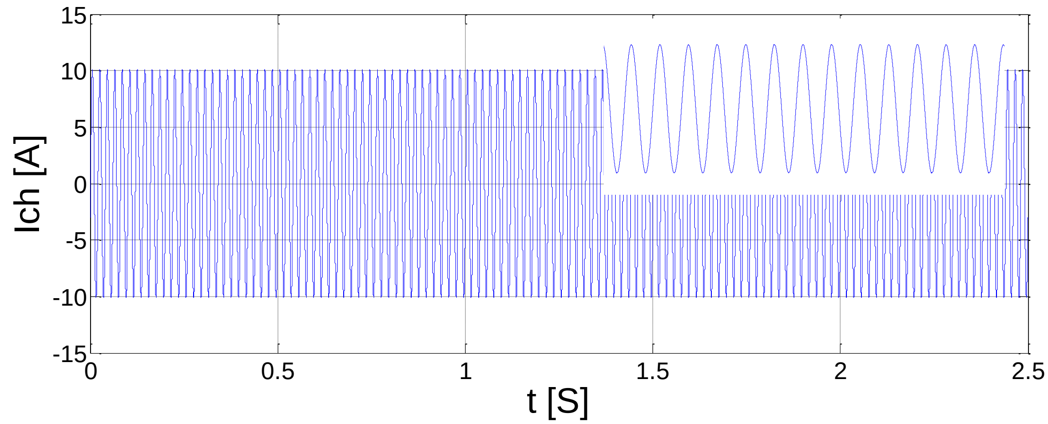


Figure III.25: *Current consumed by the load (inductive)*

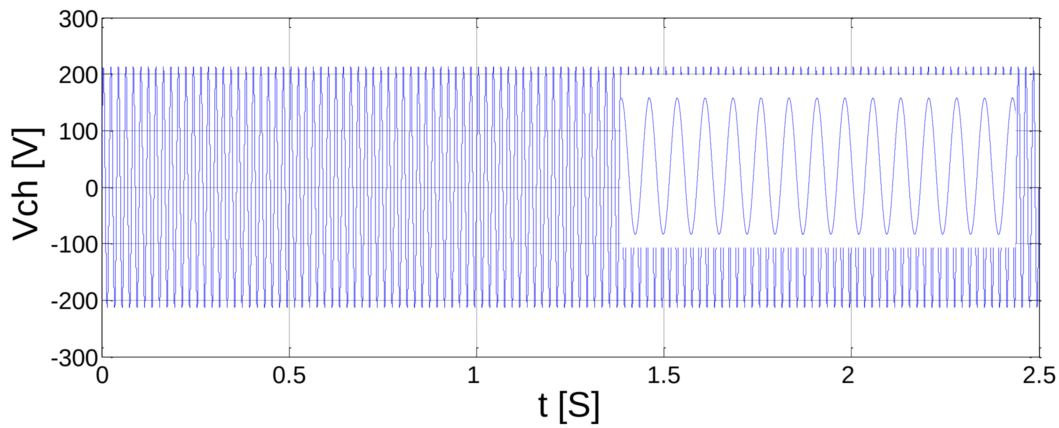


Figure III.26 : *Load terminal voltage*

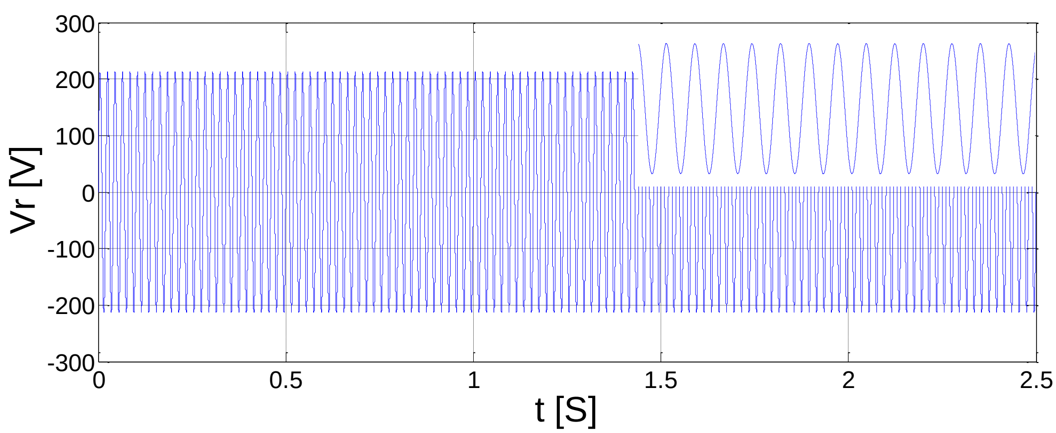


Figure III.27: *Line side voltage*

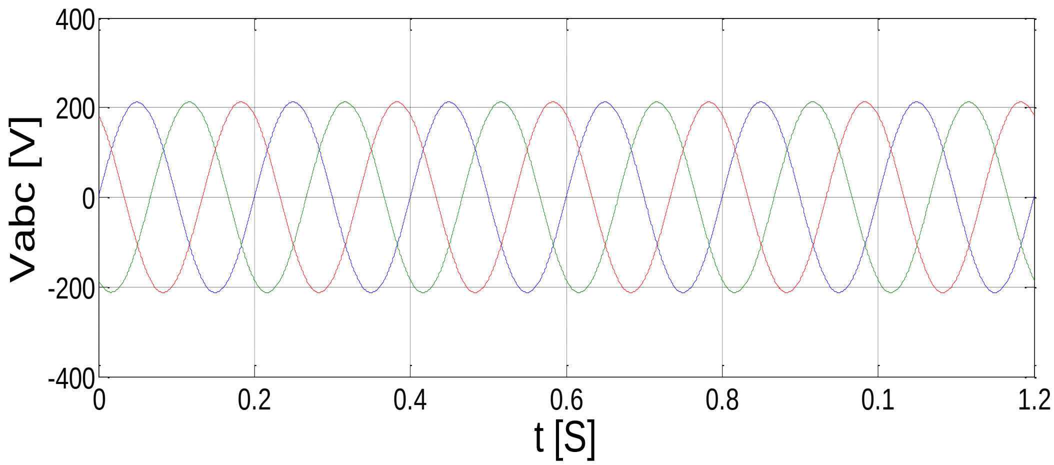


Figure III.28 : *Simple filtered voltages*

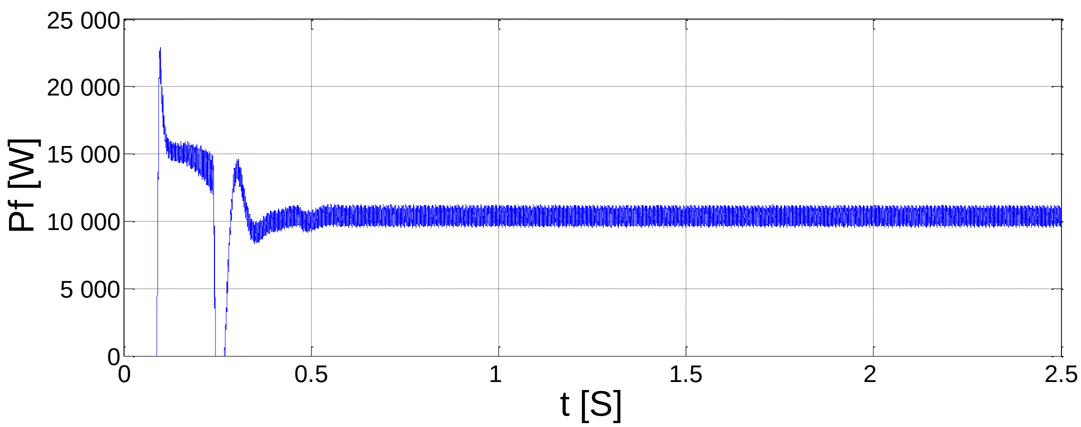


Figure III.29: *Active power supplied by PV generator (filtered)*

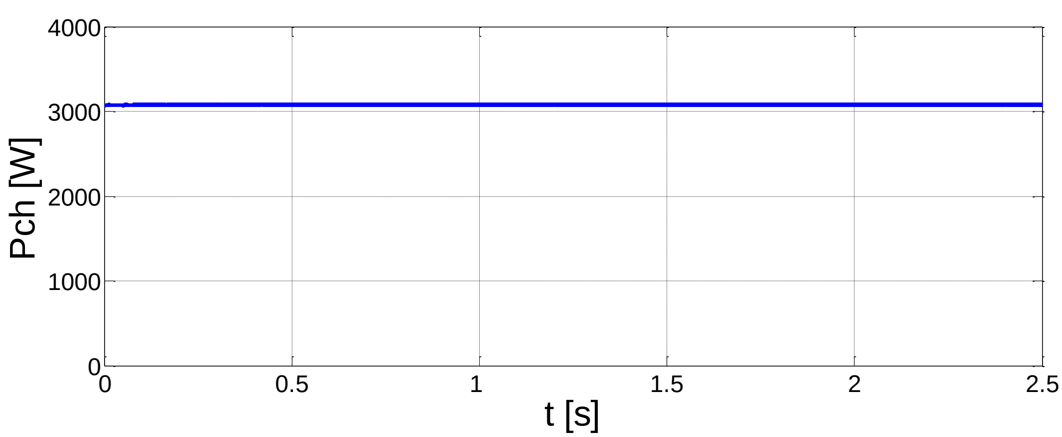


Figure III.30: *Active power consumed by the load (inductive)*

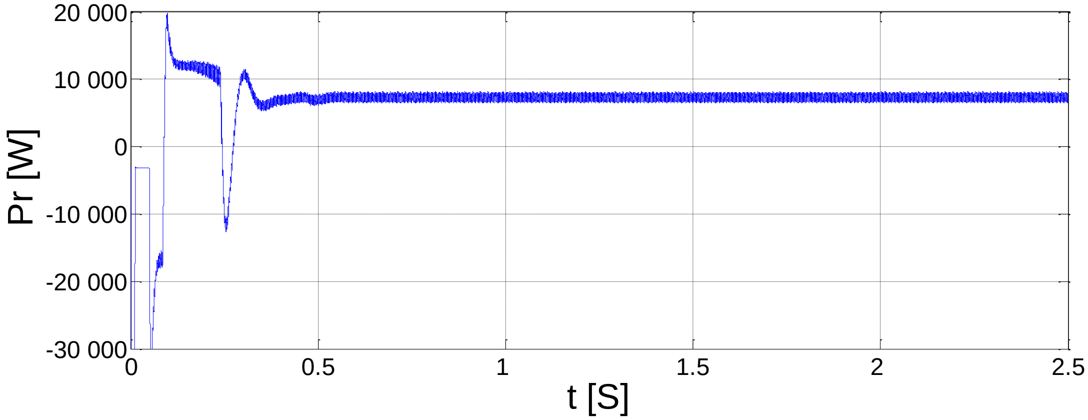


Figure III.31: *Active power injected into the LV network*

From the figures (III.18 and III.19), we note the maximum value of the compound voltage is equal to that of the DC voltage of the input as well as the shape of the simple voltage and the compound voltage is cut out. .

We also noticed in the figures (III.19 to III.22) the compound voltage, the simple voltage and the filter output current has a sinusoidal form of frequency 50 Hz with the maximum values respectively (380 V, 220 V, 33.8 AT).

The simple network voltage and the load are presented on figures (III.26 to III.28) at a sinusoidal form of frequency 50 Hz with the same maximum value According to the figure (IV -27) we show that our signal and sinusoidal and its frequency is 50 Hz, amplitude of 220 V and a phase shift between the three signals of 2π / 3.

According to the figures (III.29 to III.30) the network power is lower compared to the power of PV generator because the latter supplies a load.

The following table summarizes the maximum values of the simulation results

PV System		Grid	
$V_{pv} = 275.28V$		V_{simple}= 220V	$V_{composeé}$= 380V
I_{pv}= 38.80 A		$I_{réseau}$= 23.5A	
P_{pv}= 10.68 KW		$P_{injécté\text{-}réseau}$= 7 .5 KW	
V_{dc}= 500 V			
$V_{f\text{-}simple}$=220V	$V_{f\text{-}composée}$= 380V		
I_f = 34 A			
P_f = 10.55 KW			
I_{ch}= 10.13 A			
$V_{ch\text{-}simple}$= 220V	$V_{ch\text{-}composée}$= 380V		
P_{ch}= 3.08 KW			

Tableau III.1: *Power budget for PV system and LV network*

III.7. Maximum power tracking test

In order to test the pursuit of the maximum power ensured by the MPPT when the climatic conditions change, we have chosen a sun set point in parabolic form which varies from 500 W / m2 to 800 W / m2 for a period of 1.8 s, then it remains constant for the rest of the simulation time. The choice of the parabolic form and not a rung is closer to the reality of the phenomenon. In practice, the variations in sunshine are rather gradual and not in the form of steps. The results of simulation of the photovoltaic system with MPPT, while using as sunshine instruction that reported in Figure III.3

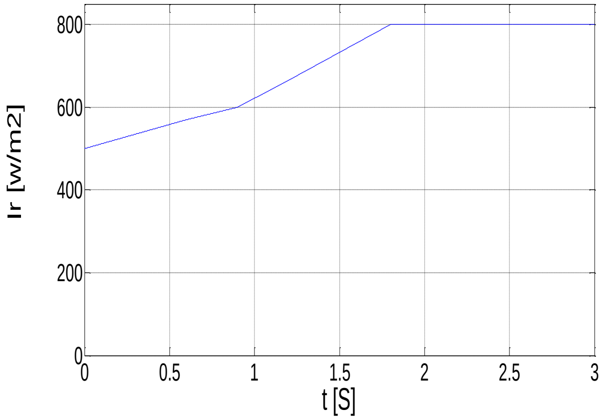


Figure III.32: irradiation variation

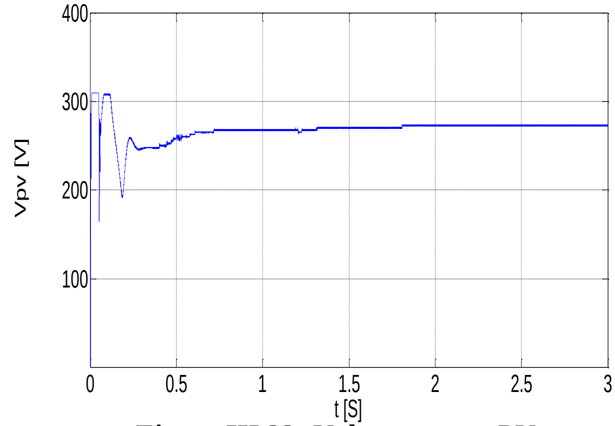


Figure III.33: Voltage across PV generator

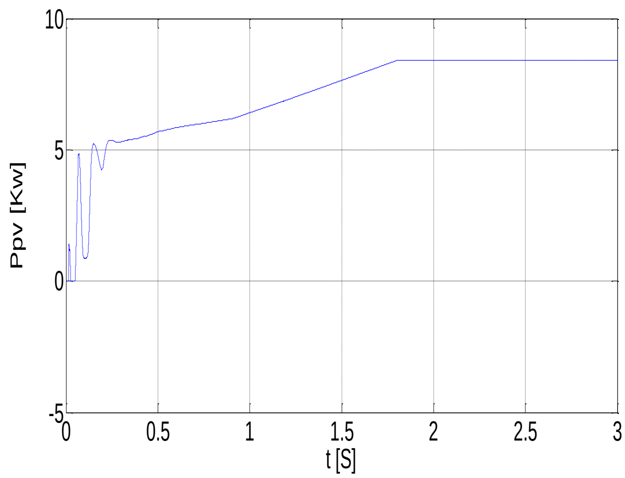


Figure III.34: Power supplied by the PV generator

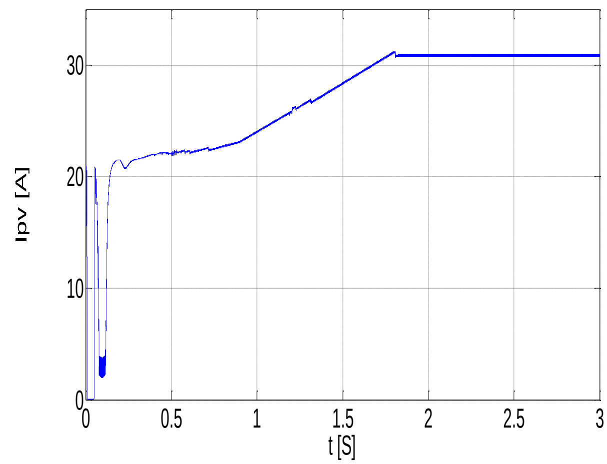


Figure III.35: Current supplied by the PV generator

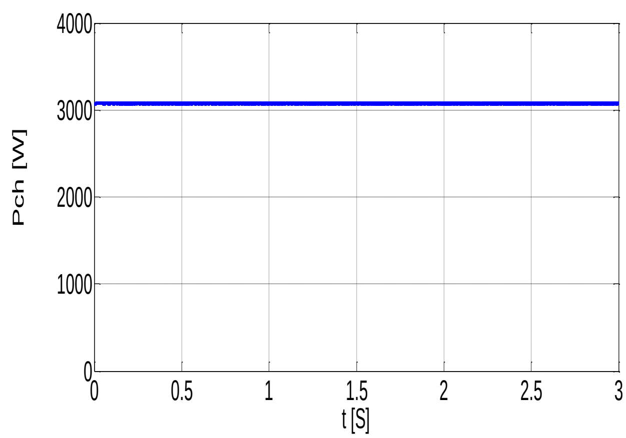


***Figure III.36**: Power consumed by the load*

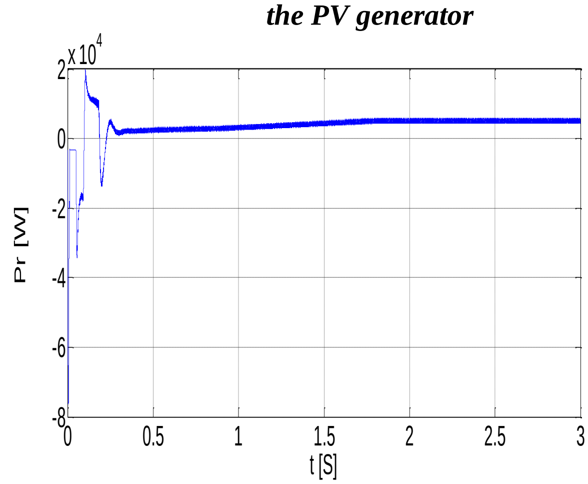


***Figure III.37**: Power injected into the network*

Notes :

Note from Figure III.33 that the voltage across the PV generator during operation with MPPT is stable.

From Figure III.34 we notice that the current takes the same form of irradiation because the current is proportional to the change in irradiation.

In figure III.35 the power varied with the same form of the current (Ppv = Vpv * Ipv) and the same form of the variation of irradiation as a function of time.

From Figures III.36 and III.37 we note that the power consumed by the load and that injected into the network remains almost stable.

3.2 RELIABILITY ASEESMENT IN THE GRIDS WITH DG SOURCES

Reliability vs. quality

• Reliability incorporates the passage of time

• Quality is a static descriptor of an item

Reliability functions

Assumptions

• The binary model applies to components and systems

• The *n* components must be *no repairable*

• The components are independent

Definition 2.9 The random variable denoting the state of component *i*, *Xi*, is

Xi =

0 *if component i has failed*

1 if component i is functioning

For *i* = 1, 2. . . *n*.

Random component states

• These *n* values can be written as a random system state vector **X**

• $p_i = P[X_i = 1]$ is the *reliability* of the *ith* component, $i = 1, 2, \ldots, n$

• Reliability vector $\mathbf{p} = (p_1, p_2, \ldots, p_n)$

• must specify the time to which the reliability applies (e.g., 5000-hour reliability is 0.83)

• The *system reliability*, *r*, is defined by $r(\mathbf{p}) = P[\phi(\mathbf{X}) = 1]$

• $r(p)$ used when all component reliabilities are equal

Technique 1: Definition of $r(\mathbf{p})$

Example 2.12 *Series* system of *n* independent components

$r(\mathbf{p}) = P[\phi(\mathbf{X}) = 1] = P[\prod_{i=1}^{n} X_i = 1] = \prod_{i=1}^{n} P[X_i = 1] = \prod_{i=1}^{n} p_i$

"Weakest link" for series systems

• System reliability less than smallest component reliability

• Improvement of weakest component most effective

Special case: identical components $r(p) = p^n$

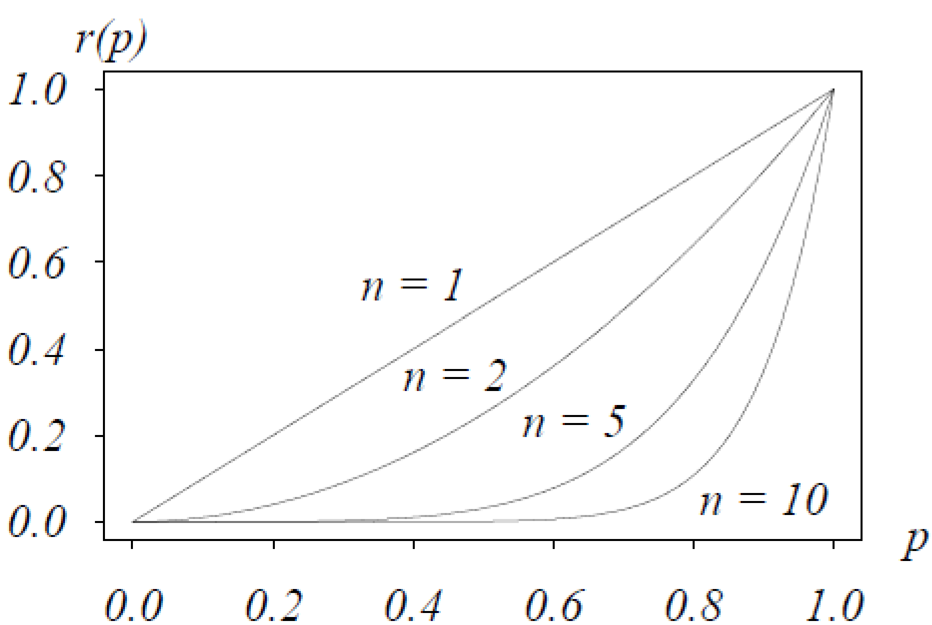


Figure III.12 Reliability of *n*-component series systems.

Technique 2: Expected value of f (X) P[f (X) = 1] = E[f (X)]

Since f (X) is a Bernoulli random variable. Example parallel system of n independent components.

r(p) = E[f (X)] = E[1 – n i = 1 P (1 - Xi)] = 1 –n i = 1 P E[1 - Xi] = 1 – n i = 1 P (1 - pi)

Special case: identical components

r(p) = 1 - (1 - p)n

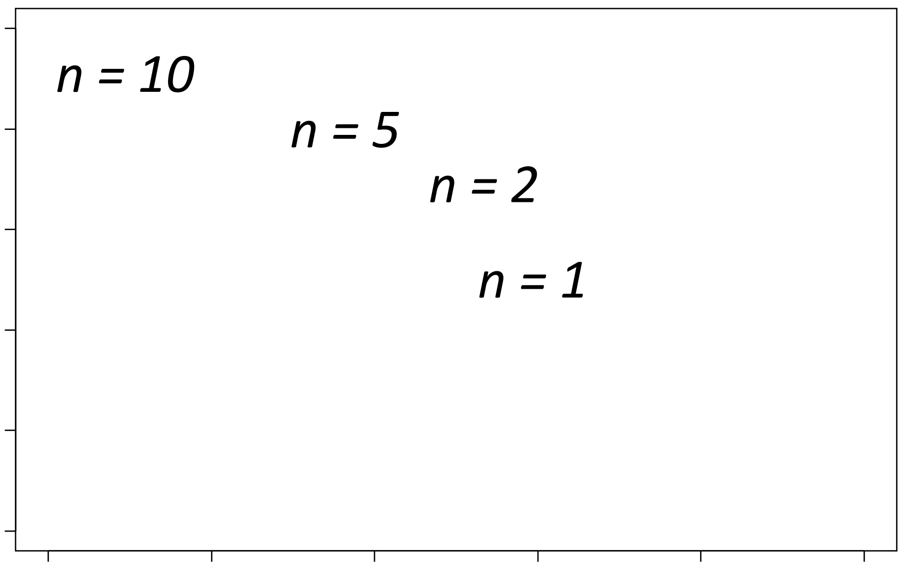


Figure 2.13 Reliability of *n*-component parallel systems.

"Law of diminishing returns" for parallel systems

- marginal gain in reliability decreases dramatically as more components are added
- improvement of the strongest component is the most effective

Notes on parallel systems

- standby system
- shared-parallel system

1. Lifetime Distributions

Motivation

Up to this point, reliability has only been considered at one particular instance of time.

Outline

- lifetime distribution representations
- discrete distributions
- moments and fractiles
- system lifetime distributions
- distribution classes

Distribution representations

Five functions that define the distribution of *T*

- survivor function
- probability density function

- cumulative hazard function mean residual lifetime function

Survivor function (reliability function)

$S(t) = P[T \geq t] \qquad t \geq 0$

All survivor functions satisfy three conditions

$S(0) = 1$

$\lim S(t) = 0$

$S(t)$ *is nonincreasing*

Interpretations

- $S(t)$ is the probability that an individual item is functioning at time t
- $S(t)$ is the expected fraction of items surviving to time t

Conditional survivor functions

$$S_{T \mid T \geq a}(t) = \frac{P[T \geq t \text{ and } T \geq a]}{P[T \geq a]} = \frac{P[T \geq t]}{P[T \geq a]} = \frac{S(t)}{S(a)}$$

i

Hazard function (failure rate, force of mortality)

$$h(t) = f(t) / S(t) \qquad\qquad t \geq 0$$

$$h(t)\Delta t = P[t \leq T \leq t + \Delta t \mid T \geq t]$$

for small Δt values. Units: failures per unit time.

Interpretations

- $h(t)$ is the amount of *risk* an item is under at t
- $h(t)$ is a special case of the intensity function for a nonhomogeneous Poisson process

All hazard functions must satisfy

$$\int_0^\infty h(t)\, dt = \infty \qquad\qquad h(t) \geq 0 \text{ for all } t \geq 0$$

Cumulative hazard function (integrated hazard function and the renewal function)

$$H(t) = \int_0^t h(\tau)\, d\tau \qquad\qquad t \geq 0$$

All cumulative hazard functions satisfy

$H(0) = 0$ $\qquad \lim_{t \to \infty} H(t) = \infty$ $\qquad H(t)$ *is nondecreasing*

Applications

- variate generation in Monte Carlo simulation
- implementing certain procedures in statistical inference
- defining certain distribution classes

3.3 POWER SUPPLY QUALITY INDICATORS FOR GRIDS WITH DG SOURCES

Three types of parameters:

- location
- scale
- shape

Location (or shift) parameters

Shift a distribution along the time axis. If c_1 and c_2 are two values of a location parameter for a lifetime distribution with survivor function $S(t;\ c)$, then there exists a constant α such that $S(t;\ c_1) = S(\alpha + t; c_2)$.

Scale parameters

Used to expand or contract the time axis by a factor of α . If λ_1 and λ_2 are two values for a scale parameter for a lifetime distribution with survivor function $S(t;\ \lambda)$, then there exists a constant α such that $S(\alpha\ t;\ \lambda_1) = S(t;\ \lambda_2)$.

Example Exponential scale parameter λ.

Shape parameters

Affect the shape of the probability density function.

The exponential distribution

Motivation :

The exponential distribution plays a central role in reliability modeling since it is the only continuous distribution with a constant hazard function.

$$S(t) = e^{-\lambda t} \qquad f(t) = \lambda e^{-\lambda t} \qquad h(t) = \lambda$$

$$H(t) = \lambda t \qquad L(t) = \frac{1}{\lambda}$$

Property 4.1 (Memoryless property) If $T \sim$ exponential (λ) then

$$P[T \geq t] = P[T \geq t + s \mid T \geq s] \qquad t \geq 0;\ s \geq 0.$$

The weibull distribution

Motivation

The exponential distribution's constant failure rate is often too restrictive or inappropriate.

$$S(t) = e^{-(\lambda t)^{\kappa}} \qquad f(t) = \kappa \lambda^{\kappa} t^{\kappa - 1} e^{-(\lambda t)^{\kappa}}$$

$$h(t) = \kappa \lambda^{\kappa} t^{\kappa - 1} \qquad H(t) = (\lambda t)^{\kappa} \text{ for all } t \geq 0.$$

Notes

- λ is a positive scale parameter
- κ is a positive shape parameter
- exponential distribution is a special case ($\kappa = 1$)
- hazard function increases from 0 when $\kappa > 1$ (IFR)
- hazard function decreases from ∞ to 0 when $\kappa < 1$ (DFR)
- $\kappa = 2$ known as the Rayleigh distribution
- when $3 < \kappa < 4$ the probability density function resembles that of a normal random variable
- The mode and median of the distribution are equal when $\kappa \approx 3.26$
- the *characteristic life* is a special fractile

- since $H(t) = -\log S(t)$, all Weibull cumulative hazard functions pass throu $(\frac{}{\lambda}, 1)$

- if T has the Weibull distribution, then $Y = \log T$ has the *extreme value* distribution

- self-reproducing property: if $T_i \sim \text{Weibull}(\lambda_i, \kappa)$ for $i = 1, 2, \ldots, n$, then

$$\min\{T_1, T_2, \ldots, T_n\} \sim \text{Weibull}\left(\sum_{i=1}^{n} \lambda_i, \kappa\right)$$

Other lifetime distributions

Table 4.4 Distribution classes.

Distribution	IFR	DFR	BT	UBT
Exponential	**YES**	**YES**	**NO**	**NO**
Muth	**YES**	**NO**	**NO**	**NO**
Weibull	**YES**	**YES**	**NO**	**NO**
Gamma	**YES**	**YES**	**NO**	**NO**
Uniform	**YES**	**NO**	**NO**	**NO**
Log normal	**NO**	**NO**	**NO**	**YES**
Log logistic	**NO**	**YES**	**NO**	**YES**
Inv. Gaussian	**NO**	**NO**	**NO**	**YES**
Expon. power	**YES**	**NO**	**YES**	**NO**

Pareto	**NO**	**YES**	**NO**	**NO**
Gompertz	**YES**	**NO**	**NO**	**NO**
Makeham	**YES**	**NO**	**NO**	**NO**
IDB	**YES**	**YES**	**YES**	**NO**
Gen. Pareto	**YES**	**YES**	**NO**	**NO**

SUMMARY CHAP 3

The objective of this chapter is that the mathematical presentation of the foremost important stages installed during a PV system connected to the electrical network to the acceptable for a well defined use. The second goal is to place in digital simulation of our system and to research the behavior of the PV system in any point.
Using Matlab/Simulink for the digital simulation.
In this chapter we have modeled and simulated all the equipment representing the photovoltaic system connected to the low voltage electrical network, such as the photovoltaic generator, the booster chopper, the inverter and the load. Also the configuration and structure of a PV system connected to the low voltage network are presented.
Subsequently, we carried out a robustness test "continuation to the variation of sunshine" where we found that whatever the situation, the MPPT will be able to operate the solar generator at its maximum power.

CHAPTER 4

4 STARTUP PROJECT DEVELOPMENT

4.1 Purpose and objectives of the section

Evaluation of power supply quality in systems with sources of distributed generation

Objective: to improve the quality of power supply of local systems with sources of distributed generation through the introduction of an improved system for evaluating the structure and processes in these systems

After analyzing the results of this dissertation on assessing the quality of power supply in systems with sources of distributed generation by analyzing the quality and reliability of the local type system and its operation using various methods, including linear programming. From this we can conclude that having a large volume of consumers in the middle of such a network (tens, hundreds, maybe thousands), a matrix of numbers is formed, which directly depends on the number of consumers. Since the design of the proposed system involves operations with a large array of data, which according to the traditional method of calculation takes a significant amount of resources to reduce the lead time, it was decided to create a way out of this problem. Automation of the calculation process, on the example of software (SOFTWARE) using the method of "ant algorithm" significantly increases the speed of the task.

The idea of forming increased efficiency of solar modules was also formed by introducing some technical changes in the structure of the equipment. This means combining the generation of electricity and heat in one. After analyzing the operation of photovoltaic modules (FEM), it was found that when the sun's rays hit the surface of the crystal, this energy is distributed in the following ratio:

- 15-19% for electricity generation (depending on the efficiency of FEM);
- 18-30% of reflection (depends on the coating and surface color);
- 55-63% of dissipated thermal energy.

The latter indicator of the distribution of energy from the sun became the founder of the formation of this idea of combining the generation of electricity and heat. This section of the master's dissertation considers the implementation of a startup project in the following areas:

- market demand for this product, and its future prospects;
- stages of development;
- creation of a prototype of equipment;
- ways of introduction to the market;
- determination of the main advantages and competitiveness of the product;
- formation of economic strategy of project promotion on the market;
- attracting investment funds to support and improve the project;
- entering the market with a ready-made product promotion strategy and an established economic plan for the future.

- 2.1 Description of the project idea
- The content of the project idea is to automatically plan the best functioning of systems with distributed generation sources with high reliability and quality of power supply, as well as technical intervention in the structure of the solar panel to improve it and additional heat generation.
- Areas of application:
- 1. Engineering field of activity (power supply, energy audit, design, etc.);
- 2. Manufacturers and suppliers of various fields of activity;
- 3. The end consumer
- Advantages of the proposed ideas:
- 1. Software:
- a) reduction of project development time;
- b) cost minimization;
- c) reducing the impact of the "human factor";

- d) integration of software into certain design systems;
- 2. Advanced solar panel:
- a) reducing the value of the crystal temperature (reducing the level of change in efficiency);
- b) increase of the “COP” coefficient;
- c) more efficient use of space.
- Given the trend of the market for energy efficient equipment not only in Ukraine but also around the world in general, the demand for energy efficient equipment, Smart-Grid systems will grow. This direction of development will require the availability of highly qualified specialists in the labor market and the appropriate software tool. The offered product on automation of design processes, will allow to carry out qualitatively cumbersome work in a fast pace and the convenient form that will allow to analyze certain factors of the set task for its optimum decision. From a technical point of view, the introduction of the proposed solar panels will abandon the heat pump, as this alternative will be more efficient and will not take up additional space.
- The main task of developing a startup project is:
- - automation of design and analysis of the functioning of energy supply systems;
- - speed and efficiency of calculation;
- - efficient use of usable space;
- - increasing the efficiency of the system as a whole.

2.1 Development of market strategy

To confidently enter the market with the proposed products requires a strategy that includes:

1. Attention of potential buyers (marketing).

2. Competitiveness (efficiency, price, speed, etc.).

3. A number of advantages that characterize the product at a level higher than the products of competitors.

4. Formed a certain economic plan (from and to a certain period).

5. Certain conditions for cooperation with future intermediaries have been developed.

Technological aspects of software for automated planning of optimal system operation will be presented in several implementations:

1. Gadgets under control:

a) iOS;

b) Android;

c) Windows.

2. Computers running:

a) Mac;

b) Windows;

c) Linux.

The ability of software to operate on popular systems of modern OEMs makes it versatile in use, which does not set a specific framework for the user. The lack of restrictions on the use of the operating system expands the range of potential users of the program, which will lead to increased demand, and consequently increase the investment budget to support, improve and develop software.

Regarding the technological aspects of the photovoltaic panel with the ability to generate heat simultaneously with the generation of electricity, this proposal is new to the market, given that we do not reduce the characteristics of the solar panel itself (on the contrary, reduce the temperature in summer and thus reduce efficiency from the temperature) and use the same area. Interest in this product should be very high because:

1. The amount of electricity generation increases (due to lower crystal temperature in summer).

2. Additionally, we obtain heat generation from the same area.

3. Heat generation can occur even at night (up to 20% of the daytime norm).

4. The “COP” value is higher than the heat pump (5.2 vs. 4.6).

5. The total cost of such a panel will be approximately 25-40% higher than the usual model.

2.2 Analysis of market opportunities

The analysis of market opportunities and threats that will be used in the implementation of the project on the market, allows you to plan the development of the project taking into account the state of the market environment, the needs of potential customers and competitiveness. For the implementation of the proposed projects it is necessary to anticipate possible threats when entering the market, to form a development and strategy for competitiveness with other products.

Preliminary characteristics of the startup project market are given in Tables 4.1 and 4.2 for software and advanced solar panel, respectively.

A comparison of the average rate of return in the industry with the discount rate of the National Bank of Ukraine (interest on investment), which is 18% in the national currency, shows that the project is financially attractive for investment.

4.1 Development of a marketing program

To create a marketing program, you need to determine the key features of the proposed product, and possibly create new benefits that will be introduced into products in the future for the customer to understand what to expect in the near future when buying a product.

Table 4.1. Preliminary description of the potential startup project market

Market indicators (name) Characteristics	Characteristics
Number of main players, units	3
Total sales, UAH / unit	6351,2
Market dynamics (qualitative assessment)	Growth
The average rate of return in the industry,%	42%

Table 4.2. Preliminary description of the potential startup project market

Market indicators (name)	Characteristics
Number of main players, units	2
Total sales, UAH / unit	189 431,8
Market dynamics (qualitative assessment)	Growth
The average rate of return in the industry,%	73%

Table 4.3.Determination of key benefits of software

Need	The benefits offered by the	Key competitive advantages (existing or emerging)

	product	
Optimal functioning of the system, the choice of the best solution to the problem.	Automation of choosing the optimal solution to the problem	Solving the problem in a short period of time, the ability to process any data set, analysis of the obtained values.

Table 4.4. Identification of key benefits of improving the structure of FEM

Need	The benefits offered by the product	Key competitive advantages (existing or emerging)
Generation of electricity, heat, earnings on the "green tariff"	Generation of electric and thermal energy from the same area, increased efficiency of FEM in summer, higher "COP".	Using the same area to generate two types of energy, reduced increase in crystal temperature (increased efficiency), higher level of "COP", heat generation at an ambient temperature not lower (minus 35 ° C)

4.1 Product operation

Based on the fact that for the improved structure of the FEM an important factor is the coefficient of reflection of sunlight, the best solution for improvement will be modules that have the darkest surface area that has contact with sunlight. An approximate view of the panel for improvement is shown in Fig. 4.1. Another type of panel can be selected for improvement, but the efficiency of the obtained result may be lower. Because the FEMs have standardized dimensions, the additional heat-generating panel will also be a certain size to be able to connect to other types of FEMs. The view of the panel that will generate heat is shown in Fig. 4.2. The way in which the refrigerant will move (in our case - freon R410A) is highlighted in gray. The two connections at the top of the panel allow you to connect them together. After improvement (connection of panels) the general look of the solar panel will hardly change fig. 4.3, only conclusions under refrigerant are visible.

The expected change in the weight of the panel is- + 4 kg per 1 m2.

The operation of such a panel in the general system does not differ from the usual. The electrical part is unchanged - the panels are interconnected and connected to the MPRT of the inverter tracker. Panels that generate heat energy are, in a way, a remote circuit of the heat pump where freon circulates. To such panels the main pipe from which branch on each row of panels can be executed (no more than 6 pieces in one branch) then all heated freon arrives to the compressor where it passes additional compression for receiving higher temperatures is brought. After the compressor, the freon passes to the heat exchanger, where it gives its potential energy to another source (water - in the case of hot water, another coolant - in the case of heating), with a lower temperature. 4.4. (yellow line - freon, red - hot heating coolant, orange - cooled coolant).

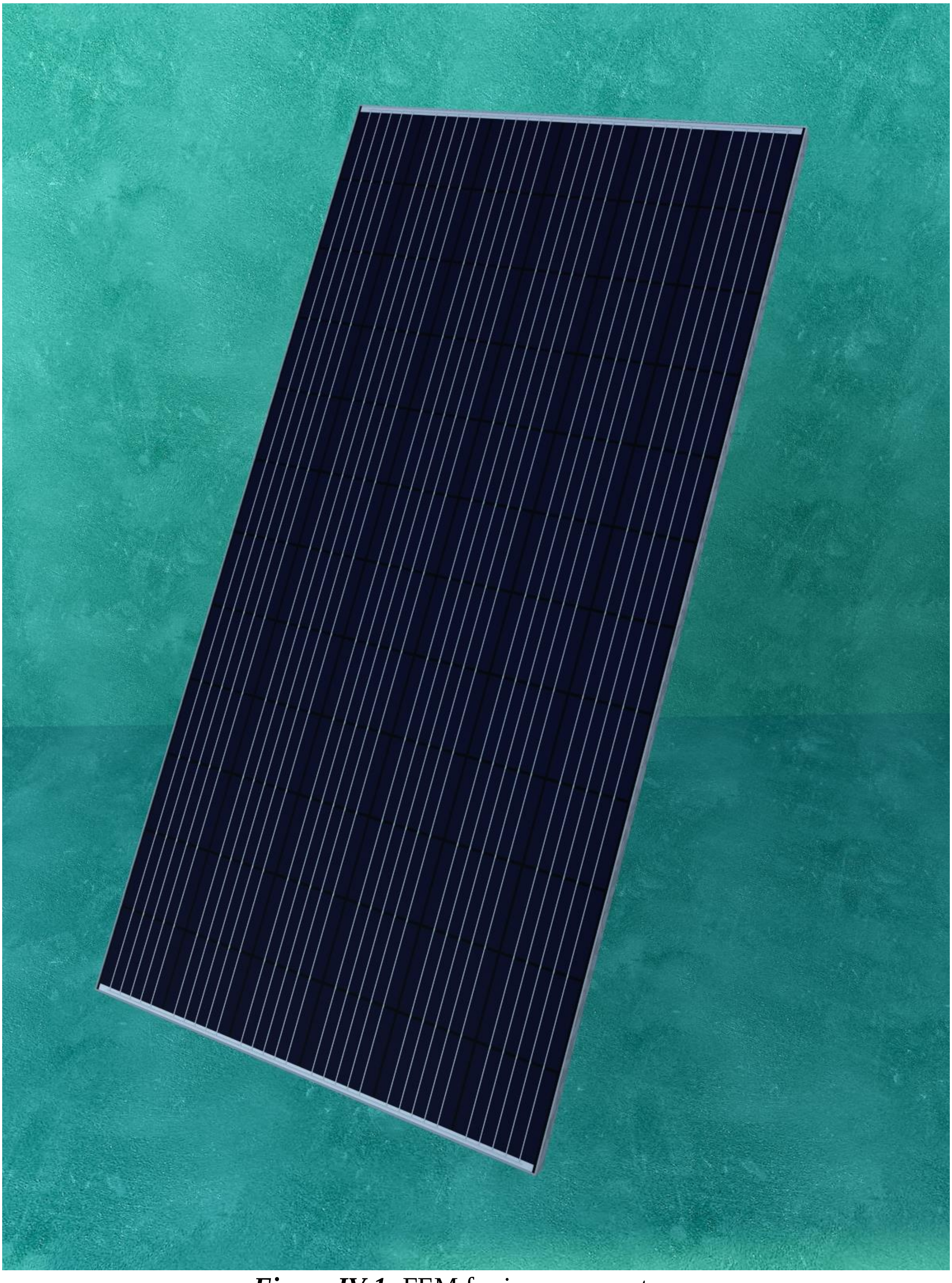


Figure IV.1- FEM for improvement

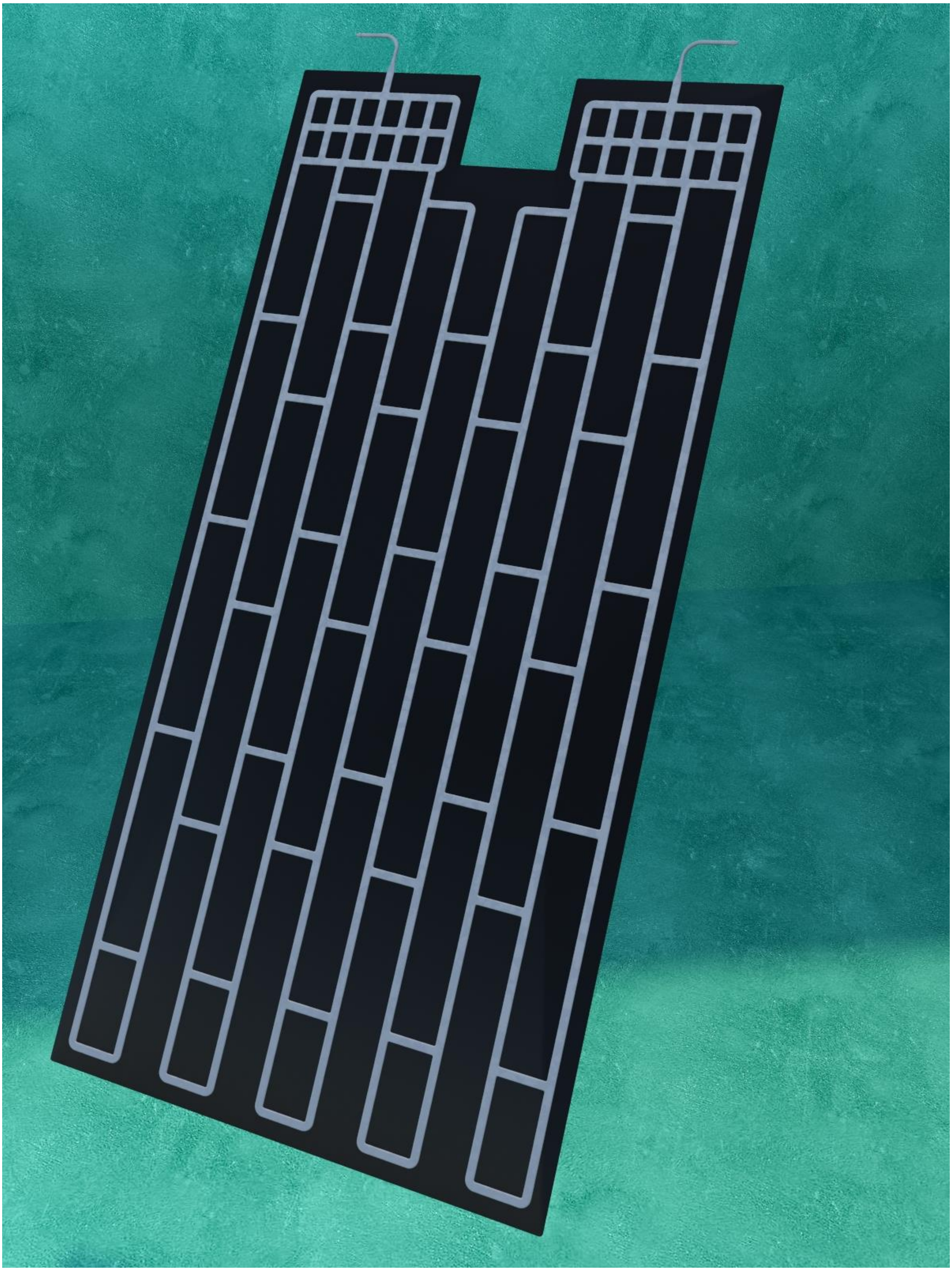


Figure IV.2 **-** Panel of thermal energy generation

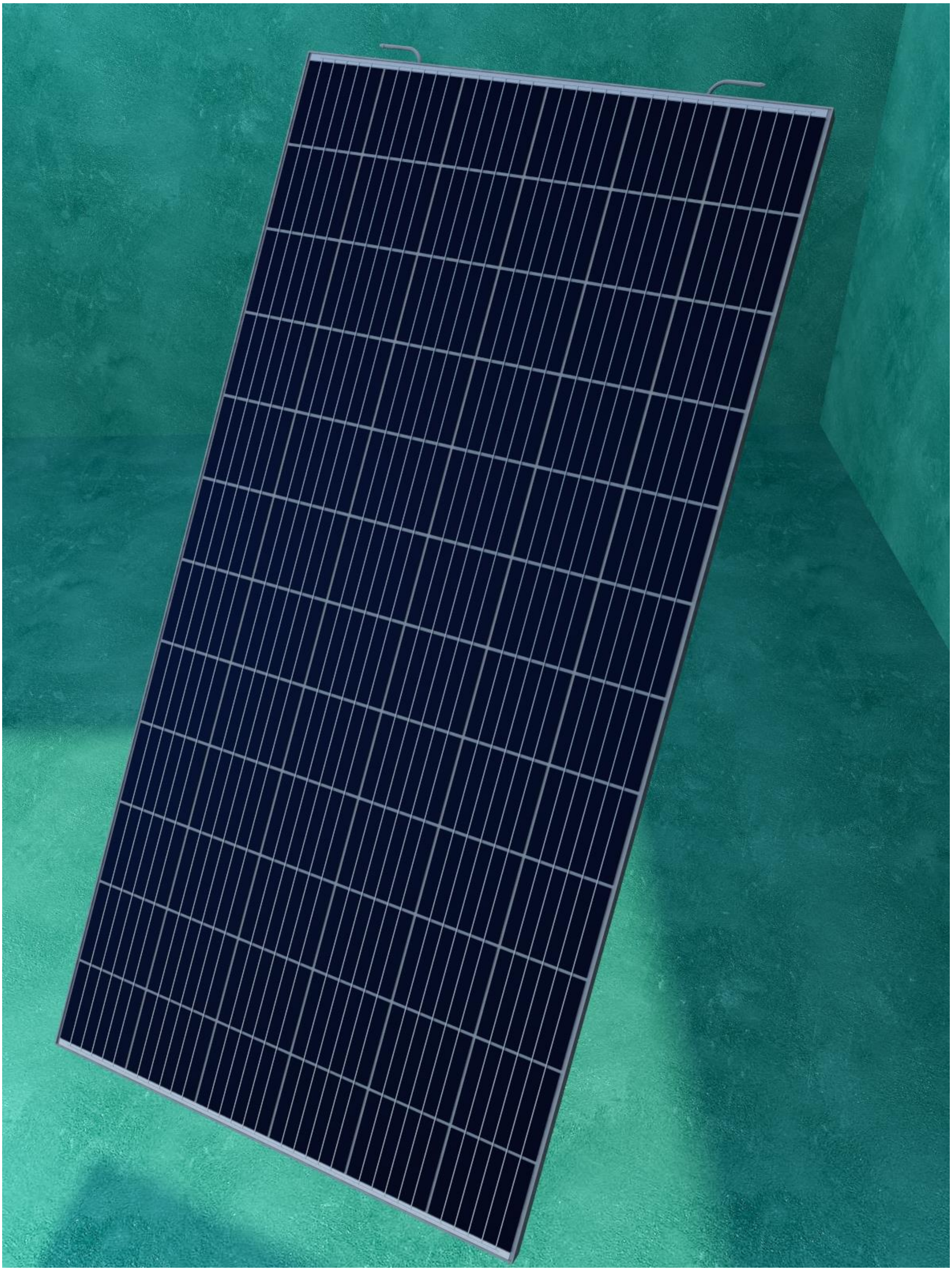


Figure IV.3- Panel after improvement

Figure IV.4 - Scheme of operation of the heat generating panel

This heating and hot water system allows heating water / coolant up to 60 ° C. The service life of such panels corresponds to the service life of solar - 25 years, which is a complementary factor.

The following is the software code of the ant algorithm proposed to automate the search for optimal solutions to the problem.

```
% ant algorithm (on the example of the salesman problem)


% ------------------------------------------------ ------------------------
tic


% clearvars -except cities
clearvars


% ----------------------------- ITERATIONS ----------------- -----------------
```

```
% number of iterations (generations)
age = 50;

% number of ants in the generation
countage = 30;

% number of seats
n = 30;
% ------------------------------PARAMETERS-----------------------------------

% alpha - odor ratio, at 0 we will focus only on
% shortest path
a = 1;

% beta - distance coefficient, at 0 we will
% focus only on the remaining odor
b = 2.5;

% evaporation rate (generation memory)
e = 0.5;

% number of pheromones produced
Q = 1;

% number of elite ants (increase the best distance in elite times)
elite = 1;

% initial pheromone
ph = 0.01;
```

```
% ------------------------------ MEMORY ----------------------------------
% distance matrix
dist = zeros (n, n);

% matrix of inverse distances
returndist = zeros (n, n);

% matrix of the route of ants in one generation
ROUTEant = zeros (countage, n);

% vector of ant distances in one generation
DISTant = zeros (countage, 1);

% vector of the best distances on each iteration
bestDistVec = zeros (age, 1);

% best starting route
bestDIST = inf;

% optimal routes
ROUTE = zeros (1, n + 1);

% permutation of places without repetitions (for ants)
RANDperm = randperm (n);

% probability matrix
P = zeros (1, n);
% ------------------------------------------------------------------------
```

```
% generation of seats (x, y)
cities = rand (n, 2) * 100;

% matrix of initial pheromones
tao = ph * (ones (n, n));

% create a matrix of distances and a matrix of inverse distances
for i = 1: n

    for j = 1: n

        % dist
        dist (i, j) = sqrt (cities (i, 1) - cities (j, 1)) ^ 2 + ...
          (cities (i, 2) - cities (j, 2)) ^ 2);

          % nn (reverse distances)
          if i ~ = j
          returndist (i, j) = 1 / sqrt (cities (i, 1) - cities (j, 1)) ^ 2 + ...
             (cities (i, 2) - cities (j, 2)) ^ 2);
          end

    end

end

% iteration
for iterration = 1: age
% ants (one generation)
```

```
            for k = 1: countage

   % *********** INITIAL LOCATION OF ANTS *************
            % select the desired

            % each ant is located randomly
          % ROUTEant (k, 1) = randi ([1 n]);

            % from each place leaves one ant (without coincidences), number
            % of places and number of ants in the generation should be equal
             ROUTEant (k, 1) = RANDperm (k);

            % from a specific place all ants in this case from the 1st
          % ROUTEant (k, 1) = 1;

          % here we set the route to the first generation either arbitrarily, or from
each
          % of places are different, or from one place all, and the next generation
comes out
          % at the end of the first

          % if iterration == 1
          % ROUTEant (k, 1) = randi ([1 n]);
          %% ROUTEant (k, 1) = RANDperm (k);
          %% ROUTEant (k, 1) = 1;
          % else
          % ROUTEant (k, 1) = lastROUTEant (k);
          %     end
   % ***********************************************************
```

% the path of each ant, starting with the 2nd, since the first is already selected

for s = 2: n

% we get the index of the selected place

ir = ROUTEant (k, s-1);

% probability of visiting places (numerator), in the numerator we have

% the following: tao ^ a * (1 / S) ^ b

% 1 / S is a returndist.

% because this value will be repeated (number of ants * on

% colony * number of places) times, it is not profitable to write another cycle

% speed of work at such explanations falls. Therefore, at this point

% described vector.

% for c = 1: n

% P (1, c) = tao (ir, c). ^ A * returndist (ir, c). ^ B;

% end

P = tao (ir,:). ^ A. * Returndist (ir,:). ^ B;

% received a numerator (in the formula for the probability of transition to the k-th place)

% for n places, however in some ants already were, it is necessary to exclude them

```
            % put zeros in the numerator where there were already ants to
            % the probability of transition was 0, the probability of transition
was 0, hence the sum of the denominator
            % of the formula this place will not be taken into account
            P (ROUTEant (k, 1: s-1)) = 0;

            % we get the probability of transition (sum of rows should be = 1)
            P = P ./ sum (P);

            % look at where the transition is made
            RANDONE = rand;
            getcity = find (cumsum (P)> = RANDONE, 1, 'first');

            % if there is a probability that something is wrong, issue an error
            if isempty (getcity) == 1
               disp 'Probability error!'
            end

            % is assigned to the s-th place in the path of the k-th mursi
            ROUTEant (k, s) = getcity;

         end

         % we get the route of the k-th ant



      ROUTE = [ROUTEant (k, 1: end), ROUTEant (k, 1)];
```

```
            % reset length
            S = 0;

            % calculate the route of the k-th ant
            for i = 1: n
                S = S + dist (ROUTE (i), ROUTE (i + 1));
            end

            % path of the k-th ants, array of distances of the k-th ants
            DISTant (k) = S;

            % assign the best route and S
            if DISTant (k) <bestDIST
                bestDIST = DISTant (k);
                bestROUTE = ROUTEant (k, 1: end);
            end

            % vector of "last" cities of k-th ants (selected for start
            % of ants of the new generation from those cities where they finished
the way
            % previous generation)

        % lastROUTEant = ROUTEant (1: end, end);
         End



% ----------------------ЗМІНЮЄМО КІЛЬКІСТЬ ФЕРОМОНІВ------------------
        % Evaporate pheromones of the "old" way e - evaporation rate
```

```
tao = (1-e) * tao;

for u = 1: countage

    % we get the route of the u-th ant
    ROUTE = [ROUTEant (u, 1: end), ROUTEant (u, 1)];

    % for each city
    for t = 1: n

        x = ROUTE (t);
        y = ROUTE (t + 1);

        % count the new pheromone
        if DISTant (u) ~ = max (DISTant)
            % here by the formula of the pheromone additive depending on
            % of distance
            tao (x, y) = tao (x, y) + Q / DISTant (u);
        else
            % strengthen the edges of the better path
            tao (x, y) = tao (x, y) + (elite * Q) / DISTant (u);
        end

    end



 end
```

```
end

% build a schedule
citiesOP (:, [1,2]) = cities (bestROUTE (:), [1,2]);
plot ([citiesOP (:, 1); citiesOP (1,1)], [citiesOP (:, 2); citiesOP (1,2)], '. r-')

clearvars -except cities ROUTE bestDIST bestROUTE ROUTEant

toc
```

Summary Chapter 4

The idea of automation designing of systems and their functioning on the optimum decision of a problem is offered. This software reduces the resources required when calculating large data sets to a minimum by transferring all the calculation to automated mode. Such implementation allows to reduce the influence of the "human factor" on the obtained calculation result. It is also proposed to improve the structure of photovoltaic modules with an additional panel that generates thermal energy. The advantages and areas of application of the proposed ideas are given. A market strategy aimed at potential buyers has been developed, as well as attracting investors to further promote the project. An analysis of market opportunities is conducted, where the obtained value of market profitability makes both ideas attractive for investment. There is a description of the operation of the proposed products, a visual view of the improved FEM, and the full program code with comments.

GENERAL CONCLUSION

Renewable energies represent a really important development within the field of electrical power production. This sort of energy manifests itself as a possible solution to reducing pollution. Among the assembly systems of this own energy wind turbines, hydroelectric power stations, photovoltaic systems.

The reliable power system underpins our economy and quality of life, the operators have had a touch set of tools at their disposal to balance power supply, demand and maintain proper frequency and voltage within the least times. Today, the evolution of the power systems has provided new indices for maintaining reliability. As more variable generation is formed , it are often used to maintain reliability in ways almost just like the generation it's replacing, and new, With this new toolbox (indices) and continued careful planning, coordination, and investment, reliability can remain a trademark characteristic of our evolving power system .

In this chapter we tried to form a general view about the worldwide renewable energy systems, then the within the previous sections we listed the foremost common issues associated with integration of distributed generation to distribution system protection are discussed along side possible mitigation methods.

This paper gives a review also by analyzing about power quality problems, issues, related IEEE standards. an influence quality audit can help determine the causes of your problems and supply a well-designed decide to correct them. the facility quality audit checks the facility's wiring and grounding to make sure that it's adequate for your applications and up to code. The auditor normally will check the standard of the ac voltage itself, and consider the impact of the utility's power grid. Many businesses and organizations believe computer systems and other electrical equipment to hold out the mission critical functions, but they aren't safeguarding against the risks of an unreliable power supply. It's time utilities also as businesses engage in additional proactive approach to power quality treats by engaging in power quality analysis.

In this thesis we try to define: what's power quality in electrical networks, by which factors is it determined, and on the thought of which premises should it's assessed, it is necessary to clarify the actual meaning of the term to point the existence of an adequate and secure power supply. Another, broader definition has described service quality covering the three aspects of: reliability of supply, quality of power offered and provision of knowledge .
And within the part about Algeria we've shown that the achievement of a system satisfying an objective of safety requires identifying and taking under consideration the causes possible faults. The results of the analysis go up therefore that the present HV line protection system of
SONELGAZ is unable to detect all kinds of disturbance which will affect high power lines voltage. the present configuration of protection system
HV lines must be reviewed and updated taking under
consideration consideration the various techniques exist currently within
the protection of electrical networks

The objective of this chapter is that the mathematical presentation of the foremost important stages installed during a PV system connected to the electrical network to the suitable for a well defined use.
The second goal is to put in digital simulation of our system and to research the behavior of the PV system in any point.
Using Matlab/Simulink for the digital simulation.
In this chapter we've modeled and simulated all the equipment representing the photovoltaic system connected to the low voltage electrical
network, like the photovoltaic generator, the booster chopper, the inverter and

therefore the load. Also the configuration and structure of a PV system connected to the low voltage network are presented.
Subsequently, we administered a robustness test "continuation to the variation of sunshine" where we found that regardless of the situation, the MPPT are going to be ready to operate the solar generator at its maximum power.

The idea of automation designing of systems and their working on the optimum decision of a drag is obtainable. This software reduces the resources required when calculating large data sets to a minimum by transferring all the calculation to automated mode. Such implementation allows scaling back the influence of the "human factor" on the obtained calculation result. it's also proposed to enhance the structure of photovoltaic modules with a further panel that generates thermal energy. the benefits and areas of application of the proposed ideas are given. A market strategy aimed toward potential buyers has been developed, also as attracting investors to further promote the project. An analysis of market opportunities is conducted, where the obtained value of market profitability makes both ideas attractive for investment. there's an outline of the operation of the proposed products, a visible view of the improved FEM, and therefore the full program code with comments.

REFERENCES

[1] Marcacci, Silvio, and Silvio Marcacci. "IEA: Renewables Will Exceed Natural Gas And Nuclear By 2016". *Cleantechnica*, 2020, https://cleantechnica.com/2013/06/26/iea-renewables-will-exceed-natura l-gas-and-nuclear-by-2016/.

[2] «Centrales Solaires Au Sol - IEL". *IEL*, 2020, https://www.iel-energie.com/solutions-techniques/centrales-solaires-au-sol/.

[3] A. Chouder and S. Silvestre, "Automatic supervision and fault detection of PV systems based on power losses analysis," Energy Conversion and Management, vol.51, pp. 1929-1937, 2010.

[4] «2.Composition Du Rayonnement Solaire - Le Rayonnement Solaire". *Sites.Google.Com*, 2020, https://sites.google.com/site/tpesoleil2012/fayolle/composition-des-rayons.

[5] "Photovoltaic Cell - Energy Education". *Energyeducation.Ca*, 2020, https://energyeducation.ca/encyclopedia/Photovoltaic_cell.

[6] "Memoire Online - Réalisation D'un Régulateur Solaire À Base De Microcontrôleur Pour Le Contrôle De L'état De Charge Et La Protection Des Accumulateurs - Souade Zaamta". *Memoire Online*, 2020, https://www.memoireonline.com/08/09/2558/m_Realisation-dun-regulateur-solaire--base-de-microcontrleur-pour-le-contrle-de-letat-de-ch2.html.

[7] "Wind Energy And Solar | Installed GW Capacity - Worldwide And By Country". *Fi-Powerweb.Com*, 2020, http://www.fi-powerweb.com/Renewable-Energy.html.

[8] "Horizontal-Axis Wind Turbine (HAWT) Working Principle | Single Blade, Two Blade, Three-Blade Wind Turbine")

[9] ("Electrical Academia | Learn Electrical Technology Online For Free")

[10] ("ScienceDirect.Com | Science, Health and Medical Journals, Full Text Articles and Books.")

[11] (www.explorateurs-energie.com/index.php/les-energies/hydraulique)

[12] ("Renewable Energy: The Clean Facts")

[13] L'énergie Géothermique." *Www.Explorateurs-Energie.Com*,

www.explorateursenergie.com/index.php/enseignants/les-energies/geothermique.

[14] "Geothermal Explained - U.S. Energy Information Administration (EIA)." *Eia.Gov*, 2016,

www.eia.gov/energyexplained/geothermal/

[15] *National Energy Education Development Project graphic*

[16] "Introduction to Microgrids - What Is a Microgrid | ABB." *Abb.Com*, 10 Sept. 2019,

new.abb.com/distributed-energy-microgrids/introduction-to-microgrids.

[17] Wikipedia Contributors. "Microgrid." *Wikipedia*, Wikimedia Foundation, 16 June 2019, en.wikipedia.org/wiki/Microgrid. Accessed 22 June 2019.

[18] *Microgrid Projects*, 13 Jan. 2017, microgridprojects.com/types-of-microgrids/. Liu, Joel. *Microgrids Microgrids -Future of the Power Syste*

[19] Himri Y, Boudghene Stambouli B, Draoui B. Prospect of wind farm development in Algeria. Desalination. 2009; 239:130-138

[20] Mounir K, Kamel B, Ilyes K. Modeling and real time simulation of wind power systems using Rt Lab platform. In: Opal-Rt Conference, Paris. 2017

[21] “Réseau Intelligent (Smart Grid).” *Connaissance Des Énergies*, 2010, www.connaissancedesenergies.org/fiche-pedagogique/reseau-intelligent-smart-grid.

[22] REFERENCE "Voltage Fluctuation - An Overview | Sciencedirect Topics". *Sciencedirect.Com*, 2020, https://www.sciencedirect.com/topics/engineering/voltage-fluctuation.

[23] J. Delgado, “Gestão da Qualidade Total Aplicada ao Sector do Fornecimento da Energia Eléctrica”, Thesis submitted to fulfilment of the requirements for the degree of PhD. In Electrotechnical Engineering, Coimbra, September 2002.

[24] M. Bollen, “Understanding Power Quality Problems– Voltage Sags and Interruptions”, IEEE Press Series on Power Engineering – John Wiley and Sons, Piscataway, USA (2000).

[25] REFERENCE "What Is A Voltage Dip Event? | CLOU GLOBAL". *CLOU GLOBAL*, 2020, https://clouglobal.com/what-is-a-voltage-dip-event/.

[26] Pérez, Nicolás, and Manuel Donsión. "Technical Methods For The Prevention And Correction Of Voltage Sags And Short Interruptions Inside The Industrial Plants And In The Distribution Networks". *Semanticscholar.Org*, 2020, https://www.semanticscholar.org/paper/Technical-Methods-for-the-Prevention-and-Correction-P%C3%A9rez-Donsi%C3%B3n/3d72b523040356142c8f3c1fc035f29ff57fb528/figure/1.

[27] Singh, Bindeshwar et al. "Electrical Power Quality Problem : A Key Issues , Challenges & Opportunities". *Semanticscholar.Org*, 2020, https://www.semanticscholar.org/paper/Electrical-Power-Quality-Problem-%3A-A-key-Issues-%2C-%26-Singh-Gupta/89de7fd085a6edbe0e887fc42dd7f60fd81b5551.

[28] 2020,https://www.quora.com/What-is-voltage-spike.

[29] "What Is A Voltage Swell Event? | CLOU GLOBAL". *CLOU GLOBAL*, 2020, https://clouglobal.com/what-is-a-voltage-swell-event/.

[30] Team, Seenco. "Total Harmonic Distortion – What Happened To My Perfect Wave?". *Seenco Group*, 2020, https://www.seencogroup.com/en/total-harmonic-distortion-what-happened-to-my-perfect-wave/

[31] "Power Quality Issues – Part 4 – Voltage Imbalance". *EM Magazine*, 2020, https://www.energymanagermagazine.co.uk/power-quality-issues-part-4-voltage-imbalance/

[32] P. M. Balasubramaniam, S. U. Prabha” POWER QUALITY ISSUES, SOLUTIONS AND STANDARDS: A TECHNOLOGY REVIEW”, Journal of Applied Science and Engineering, Vol. 18, No. 4, pp. 371_380 (2015) DOI: 10.6180/jase.2015.18.4.08

[33] Abc

[34] Djaffar OULD ABDESLAM«Techniques neuromimétiques pour la commande dans les systèmes électriques : application au filtrage actif parallèle dans les réseaux électriques basse tension», mémoire de doctorat, Université de Haute- Alsace U.F.R. des Sciences et Techniques, décembre 2005

[35] Éditeur : Académie de Poitiers. http://www.edcasources.education.fr/detail.asp?ID=79631

[36] “La Qualité d’alimentation Électrique.” *Observatoire de l’Industrie Electrique (OIE)*, observatoire-electricite.fr/fiches-pedagogiques/La-qualite-d-alimentation. Accessed 14 May 2020.

[37] "How To Measure Power Supply Quality". *Myelectrical.Com*, 2020, 1-38 https://myelectrical.com/notes/entryid/105/how-to-measure-power-supply-quality.

[38] Billington R., Allan RN, Reliability Assessment of Large Electric Power Systems, Kluwer Academic Publishers, 1988

[39] Arrillaga J., Watson N.R., Chen S., "Power system quality assessment", *John Wiley & Sons Ltd*, 2000

[40] Meeuwsen J., Kling W, The influence of different network structures on power supply reliability, Quality of Power Supply, ETG Conference, November 1997

[41] Dugan R., McGranaghan M., Beaty H. "Electrical power systems quality", *McGraw-Hill Companies*, 1996.

[42] Schlabbach J., Blume D. and Stephanblome T., Voltage Quality in electrical power systems, The Institution of Electrical Engineers, Power and Energy Series 36, London, 2001

[43] Arrillaga J., Smith BC, Watson NR, Wood AR, Power System Harmonic Analysis, John Wiley and Sons, London 1997

[44] Mindykowski J., Tarasiuk T., "Measurement of supply voltage properties in ships' electrical power systems", *Metrology and Measurement Systems. Polish Scientific Publishers PWN*, vol. IX, No. 1/2002 Warsaw 2002, pp. 19-30.

[45] Mielczarski W., Michalik G., "Complex Approach to Power Quality in Open Electricity Markets, Electrical Power Quality and Utilisation, vol.V, N□2, September 1999, pp. 13-19

[46] IEC 61000-2-1, 1990 Electromagnetic Compatibility (EMC), Part 2: Environment, Section 1: Description of the Environment - Electromagnetic Environment for Low- Frequency Conducted Disturbances and Signalling in Public Power Supply Systems

[47] IEC 61000-3-3: 1994, Electromagnetic Compatibility (EMC), Part 3: Limits, Section 3: Limitation of Voltage Fluctuations and Flicker in Low-Voltage Supply System for Equipment with Rated Current □16 A

[48] IEC 61000-4-7, 1991 Electromagnetic Compatibility (EMC), Part 4: Limits, Section 7: General Guide on Harmonics and Inter-harmonics Measurements and Instrumentation, for Power Supply Systems and Equipment Connected Thereto.

[49] IEC 6100-4-15 Ed.1, 1997, Electromagnetic Compatibility (EMC), Part4: Limits, Section 15: Flickermeter-Functional and Design Specification

[50] IEC 868-0, 1991, Flickermeter-Evaluation of Flicker Severity

[51] IEEE 1159:1995 IEEE Recommended Practice on Monitoring Electric Power Quality

[52] Mindykowski J. Assessment of Electric Energy Quality in Ship Systems fitted with converter subsystems, shipbuilding and shipping, Gdańsk 2001 (in Polish)

[53] Bucci G., Landi C., "On-line digital measurement for the quality analysis of power system under non-sinusoidal conditions", *IEEE Instrumentation and Measurement Technology Conference*, Brussels, Belgium, June 1996, p. 934-938.

[54] Angrisani L., Daponte P., D'Apuzzo M., Testa A., "Ameasurement method based on the wavelet transform forpower quality analysis," Trans. Power Systems, Jan. 1988.
[55] Heydt GT, Electric Power Quality, Stars in a Circle Publications, West LaFayette (USA), 1991
[56] Weon-Ki Yoon, Devaney M.: Power Measurement Using the Wavelet Transform. IEEE conference, USA, May 1998, pp. 801-806
[57] A. Zharkin, V. Popov, V. Tkachenko The solution of the problem of optimal partitioning of overhead lines under conditions of normalization of reliability indicators, Technical electrodynamics. - 2013. - № 5. - P. 61-69.
[58] A.F. Zharkin, V.A. Popov, V.V. Tkachenko. Optimal sectioning of overhead distribution networks in the case of distributed generation applications, Technical electrodynamics № 2, 2017, pp. 61-69, ISSN: 1607-7970.
[59] Denysiuk S. A novel method of complex reliability assessment in Microgrids with Distributed Generation / Denysiuk S., Derevianko D. // Proceedings of the International Conference on Modern Electrical and Energy Systems, MEES 2017– p. 212-215.
[60] European standard EN 50160 Voltage characteristics of electricity supplied by public distribution systems, CENELEC TC 8X, 2006. NRS-048-2, Electricity Supply - Quality of Supply Part 2: Voltage characteristics, compatibility levels, limits and assessment methods.
[61] Kyrylenko OV, Technical Aspects of Implementation of Distribution Generation Sources in Electric Networks / Kyrylenko OV, Pavlov VV, Lukyanenko LM. // Technical electrodynamics. - 2011. - №1. - P.46-53.
[62] Medjoudj R, Aissani D, Haim KD. Power customer satisfaction and profitability analysis using multi-criteria decision making methods. International Journal of Electrical Power and Energy Systems (Elsevier). 2013;45(1):331-339. DOI: 10.1016/j.ijepes.2012.08.062
[63] Brown Richard E (2002) Electric power distribution reliability. ABB Inc., Raleigh
[64] European standard EN 50160 Voltage characteristics of electricity supplied by public distribution systems, CENELEC TC 8X, 2006. NRS-048-2, Electricity Supply - Quality of Supply Part 2: Voltage characteristics, compatibility levels, limits and assessment methods.
[65] R. Khezzar et al. « Comparaison entre les différents modèles électriques et détermination des paramètres de la caractéristique I-V d'un module photovoltaïque ». Revue des Energie Renouvelables Vol.13 N° 3, pp 379-388, 2010.
[66] Abbassen Lyes « Etude de la connexion au réseau électrique d'une centrale photovoltaïque». Thèse de magister .Université de Tizi Ouzou 2011
[67] C.Prèvè, "protection des réseaux électriques,", Edition HERMES, Paris, 1998.
[68] " Philosophie de réglage des protections électriques,", document technique, SONELGAZ ,2004.
[69] ENERGY, L. (2019, June 25). Voltage characteristics of grid electricity (EN 50160). Retrieved from https://www.slideshare.net/sustenergy/voltage-characteristics-of-grid-electricity-en 50160 Standard

[70] W. G. Hartmann,"How to Nuisance Trip Distributed Generation," in Proc. 2003 IEEE Rural Electric Power Conference, pp. C.5-1 –C.5-11.

[71] W. G. Hartmann,"How Not to Nuisance-Trip Distributed Generation," in Proc. 2005 IEEE Technical Conference on Industrial and Commercial Power System, pp. 52-61.

[72] G. Kaur and M. Vaziri Y., "Effect of Distributed Generation (DG) Interconnections on Protection of Distribution Feeders," in Proc. 2006 IEEE Power Engineering Society General Meeting, pp. 8.

[73] A. Girgis and S. Brahma, "Effect of Distributed Generation onProtective Device Coordination in Distribution System," in Proc. 2001IEEE Large Engineering Systems Conference on Power Engineering, pp. 115-119.

[74] Wojciech Piasecki, Marek Florkowski, Marek Fulczyk, Pentti Mahonen and Wieslaw Nowak,"Mitigating Ferroresonance in Voltage Transformers in Ungrounded MV Networks," IEEE Transactions on Power Delivery, vol. 22, no. 4, Oct' 2007.