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Title:

Enhancing Power System Continuity of Service in the West of Algiers: A Comprehensive Study Using ETAP

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Abstract

The electrical network of the west of Algiers experiences ongoing issues that lead to disruptions, blackouts, and reduced reliability. Factors such as inadequate infrastructure, aging equipment, and sudden incidents like short circuits contribute to the failure of lines, cables, and generators, affecting system stability and service continuity. This study analyzes the impact of line and generator failures on the power system and proposes effective solutions, including protection schemes and power reserve capacity enhancements, validated through simulations.

Acknowledgements

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Dedication

This work is dedicated to the memory of my father, who passed away on April 27, 2022. He was the best dad in the world, always working hard to provide for us without any complaints. His strength, dedication, and love continue to inspire me every day.

To my courageous mother, whose unwavering support and love have been my foundation. She has stood alone and fought tirelessly to take care of us, demonstrating incredible resilience and strength.

To my brother and two little sisters, who bring joy and inspiration into my life.

To a special person who has been a constant source of encouragement and support, helping me through the toughest times.

To the team at Dr Djawal, my colleagues and friends at the phone and repair store, for their invaluable assistance and camaraderie.

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Dedication

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To my loving mother, Your endless love, support, and encouragement have been the foundation of my success. Your sacrifices and unwavering belief in me have carried me through every challenge. This project is a reflection of your dedication and the values you have instilled in me. Thank you.

To my brother and my two sisters thank you for your support and I wish to see you graduating one day like your oldest brother and you will have all my support.

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Rafik

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Genenral Introduction

Over the past two decades, Algeria has made significant strides in developing its power system network to meet the growing energy demands of its population and support its economic growth.

During the 2000s Approximately 97% of domestic power plants in Algeria used natural gas to generate electricity , at that time exactly in February 2003 Algeria experienced a significant power system blackout that disrupted electricity supply across the country, collapse due to a combination of factors, including equipment failures, inadequate maintenance, and insufficient grid management.The total load of the system at the time was approximately 4797 MW.The blackout affected millions of people, disrupting daily life, businesses, and essential services.This blackout underscored the need for better grid management, maintenance, and investment in infrastructure.It prompted authorities to review and improve their emergency response procedures , the blackout was a wake-up call for algeria ,its started upgrading transmission and distribution infrastructure , Aging equipment was replaced, and new substations were built to improve grid stability, The Algerian government focused on modernizing grid control systems, including automation, monitoring, and communication.[1] Algeria shifted its focus towards diversifying its energy mix and integrating renewable energy sources into its power system. The government launched ambitious programs to develop solar and wind power, with the goal of increasing the share of renewable energy in the country's electricity generation. This led to the construction of several large-scale solar and wind power projects, which have helped to reduce Algeria's reliance on fossil fuels and lower its carbon emissions. This helped the country expanded its power generation capacity to meet growing demand , in addition Cross- border interconnections were strengthened to enhance regional grid stability.

Today, Algeria's power system network is a complex and interconnected system that includes a mix of thermal, hydroelectric, and renewable energy source. In 2021, solar energy constituted around 2% of Algeria's installed capacity, with 448 MW , The country's total installed capacity has grown significantly, reaching over 20 gigawatts (GW) in 2022. The power system is also increasingly integrated with neighboring countries, with several high-voltage transmission lines connecting Algeria to Tunisia, Morocco, and Libya. The length of Algeria's electricity transportation network increased by 240% between 2000 and 2019, reaching 100% coverage. This expansion has facilitated better electricity distribution across the country , Approximately 9 million customers are now connected to Algeria's electricity network, ensuring broader access to power.[2] Looking to the future, Algeria has ambitious plans to further expand and modernize its power system network. The government has set a target of increasing the share of renewable energy in the country's electricity generation to 27% by 2030, which will require significant investments in solar, wind, and other renewable energy technologies, the Solar 1,000 MW project is expected to produce its first power by the beginning of 2025. A 30 MW solar PV park in Beni Ounit (Bechar region) will contribute to this project, with power sold exclusively to state-owned distributor Sonelgaz for 25 years , Algeria also plans to auction 4 GW of solar capacity by 2024 and achieve 22 GW of renewable capacity by 2030, including 62% from solar PV and 23% from wind. Additionally, the country is exploring the potential of developing its vast solar energy resources to export electricity to Europe and other regions.[3][4]

Chapter 1

Presentation of the Algerian Electrical Network

1.1 Introduction

A system of foundations that ensures the flow of electrical energy from production locations to final consumers is called an electrical network. It consists of interconnected power lines operating at various voltages within electrical substations. Transformers are used in these stations to distribute power and convert it between different voltages. In order to maintain overall system stability, the electrical system must also provide dynamic administration of the entire power generation, transmission, and consumption process. [5] Electrical networks are used to link energy-producing resources, including thermal power plants and hydraulic power plants, to areas of use, like cities, towns, and industrial sites. In order to minimize losses resulting from the Joule effect, which is proportional to the square of the electric current's magnitude, electricity is transferred at high voltages. Subsequently, the voltage is progressively lowered to the point where the end users demand it. All the equipment required for producing, distributing, and transmitting power—from generating facilities to the most remote locations—makes up power systems.[5]

1.2 Description of the Algerian network

The Algerian electricity transmission network consists of five major regions: Algiers, Oran, Annaba, Setif, and Hassi Messaoud. It is an interconnected network in the northern part of the country, with international interconnections to Europe through Morocco (via the Oran region) and Tunisia (via the Annaba region). Additionally, there is an isolated network in the southern part of the country (Adrar). This network transports high-voltage electrical energy (at 220 kV and 400 kV) and is managed by the company GRTE (Gestionnaire du Réseau de Transport d'Électricité) and the system operator. Here are some key components of the Algerian power system:

- Transmission Lines: The network comprises a total of 25,147 kilometers of transmission lines, including 2,745 kilometers at 400 kV.
- Substations: There are 283 transformation substations, with 12 of them operating at 400 kV.
- Transformers: A total of 773 transformers are responsible for converting electrical power, with a combined capacity of 48,806 MVA. [6]

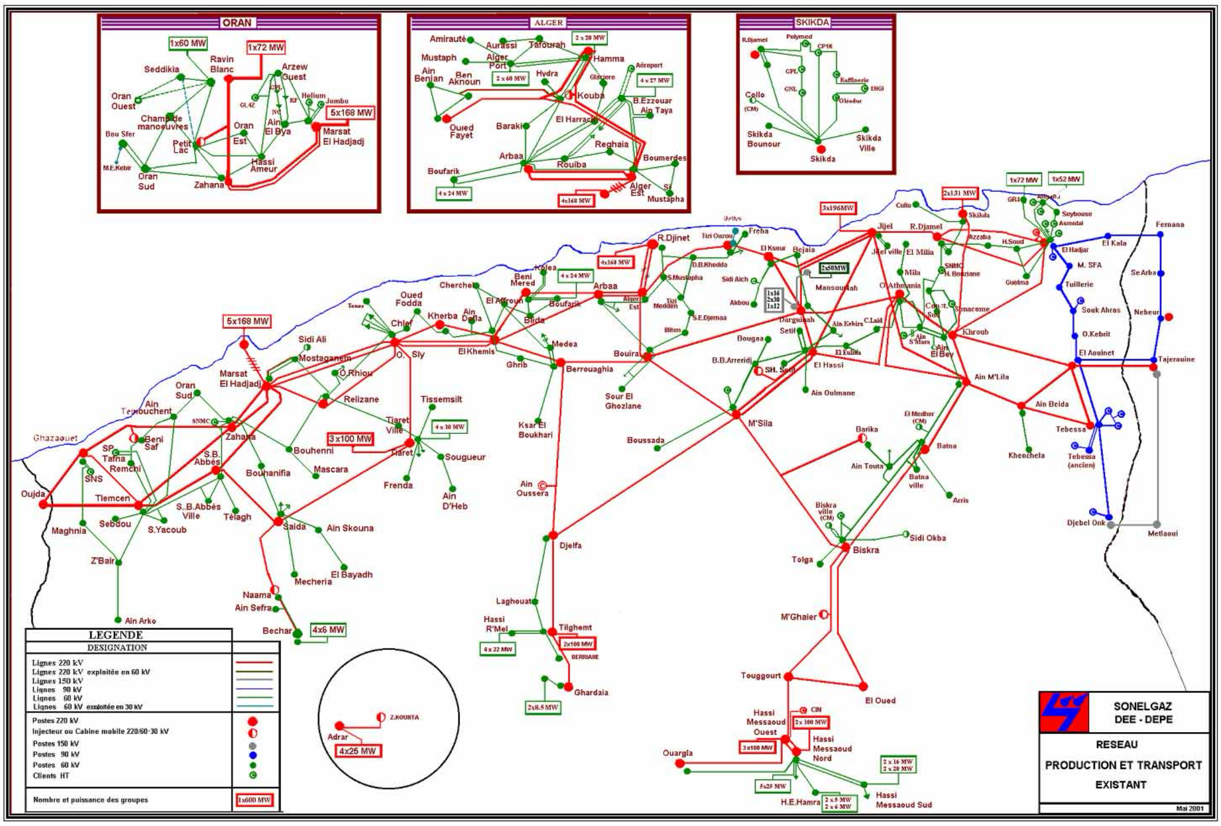


Figure 1.1: Algerian Network Map
[7]

The Algerian electrical transmission network is responsible for transporting electric energy to the four electricity and gas distribution companies (SDA, SDC, SDE, SDO). The backbone of this network is the 400 kV (highway) transmission line, which spans 1,758 kilometers from east to west. It comprises six transformation substations (400/220 kV). Additionally, there are plans to reinforce the network with another north-south backbone to ensure the country's power supply security and facilitate international exchanges.

- **Growth of Network**

  The consistency of the network in terms of line length and the number of substations is expected to double by the end of the period from 2010 to 2021. The development of the Algerian network allows it to cope with a strong growth in electricity demand and ensures the transmission of electrical energy under optimal service quality conditions. Peak electricity demands reach 14,300 MW, which the Algerian network is capable of producing and transmitting to neighboring countries (Tunisia and Morocco) during their peak hours. [6]

Table 1.1: Year vs Number of transformers stations, Network length and Power of transformers

Year	**2000**	**2010**	**2021**
Number of transformations stations	147	227	456
Network lenght	13722 km	21639 km	48286 km
Power of transformation	16842 MVA	35111 MVA	74851 MVA

1.2.1 Voltage levels

The choice of voltage level and frequency is based on technical-economic criteria and historical factors. Each country has its own voltage and frequency levels, depending on its particularities and its historical evolution. Range of voltages used by the SONELGAZ group in Algeria, defines the alternating voltage levels as follows :

- HTB refers to high voltage and very high voltage. 60 kV – 90 kV – 150 kV – 220kV – 400 kV
- HTA refers to medium voltage. 5.5 kV – 10 kV – 15 kV – 20 kV – 30 kV
- BTB and BTA refers to low voltage 400V

Table 1.2: Electric Voltage Levels [8]

	Voltage Level	**Voltage Range (U)**
HTB	High Voltage	$U > 50000$
HTA	Medium Voltage	$1000 < U \leq 50000$
BTB	Low Voltage	$500 < U \leq 1000$
TBT	Very Low Voltage	$U \leq 50$

1.2.2 Different topologies of electrical network structures

The distribution network can be classified beneath some categories. The most common way to classify a network is by its design. Sometimes it's also called "the method of connection". [9]

There are three main sorts of network designs that we can differentiate :

- Mesh structure :

  The connection of electrical substations to each other is guaranteed by a complex network of electrical lines, ensuring a reliable and secure power supply. commonly used for the transmission (High voltage)

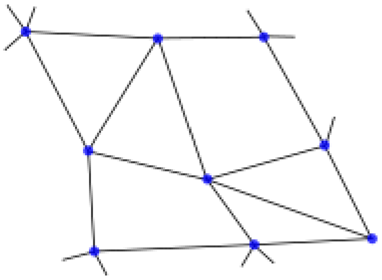


Figure 1.2: Mesh Structure.

- Radial or loop structure :

  Despite slightly lower power security than the mesh system, the structure remains highly reliable. The red posts symbolize energy supply points. commonly used for the distribution (Low voltage)

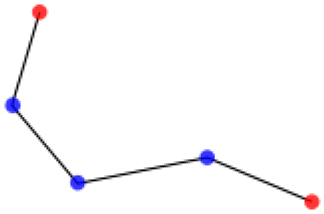


Figure 1.3: Radial Structure.

- Tree structure :

  Power reliability is compromised since any breakdown on the line or red station results in a total interruption of power to all downstream clients. (Red stations represent energy supply points. Used also for distribution (Very low voltage)

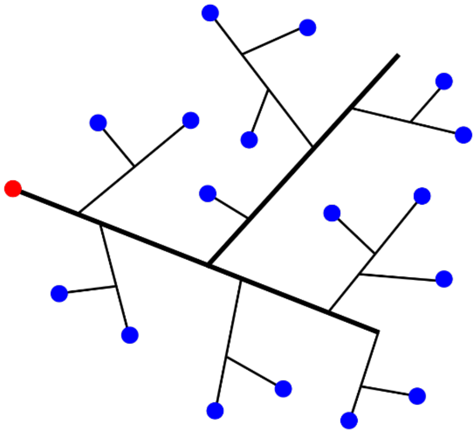


Figure 1.4: Tree structure.

1.3 Presentation of electrical networks

Power systems are divided into 3 different parts: generation, transmission and distribution. The figure represents the general architecture of an electric network.

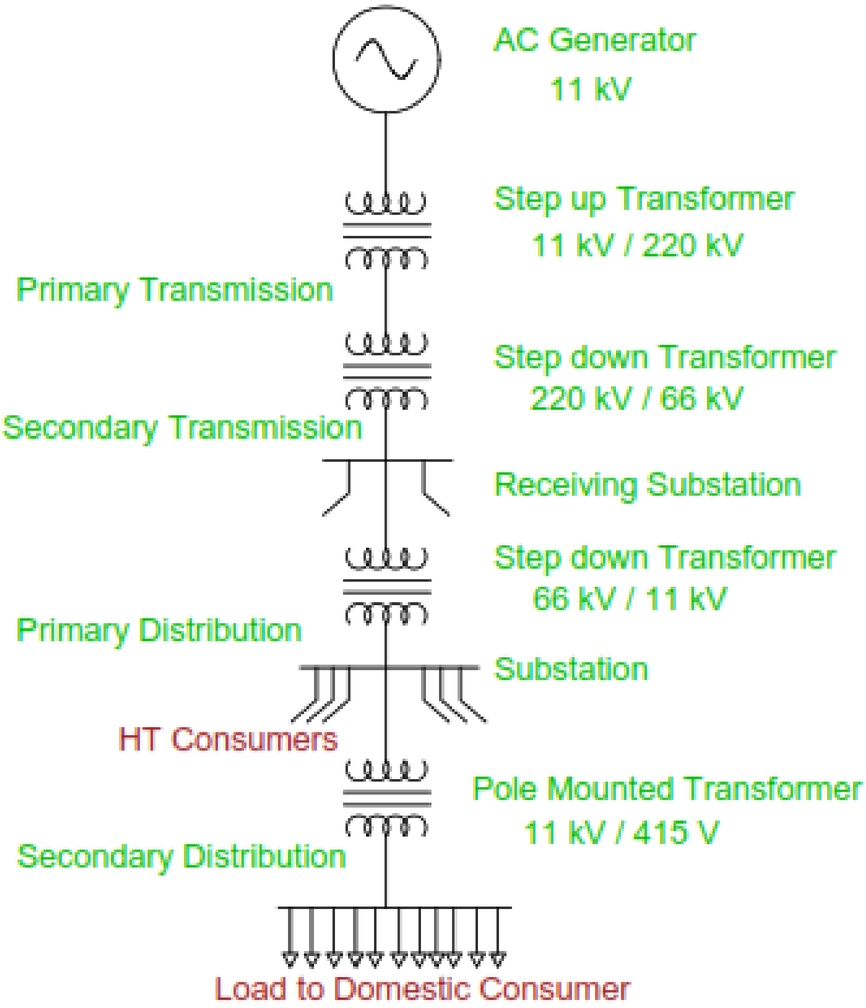


Figure 1.5: The different parts of an electrical power system.
[10]

1.3.1 Generation

Consists of using different energies in order to turn alternators which produce three-phase electrical voltages and currents. We hence distinguish between generation plants: thermal, nuclear, hydraulic, wind, photovoltaic, geothermal, etc.

The advantages and disadvantages of each type basically come from the ease of operation and the support of resources and their renewability and above all the efficiency of energy transformation. [11]

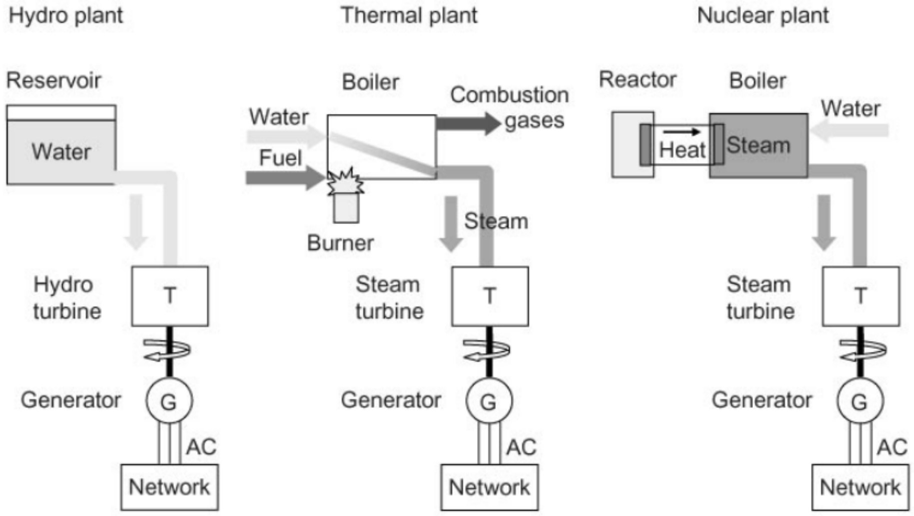


Figure 1.6: The different methods of generating electric power. [11]

1.3.2 Transmission System

Based on using lines or cables to carry the energy produced by power plants to consumers with the minimum possible losses. The main functions of the transmission and interconnection networks are:

- Collect power generated by huge capacity power plants and transport it until consumption regions (transmission function).

- Guarantee economical and secure operation of the means of generation by compensating various hazards (interconnection function).

These networks operate at voltages of 150 kV, 220 kV and more recently 400 kV. They are designed in a mesh network, with direct earthing of the neutral. [11]

- **Sub-Transmission System**

The sub-transmission system is the section of the transmission network that links the high voltage substations to the distribution substations (transmission at the regional level).

Their voltage varies depending on the region, but is above 63 kV.

These networks are mainly composed of overhead lines, capable of transporting more than 60 MVA over distances of a few tens of kilometers. They supply electricity to distribution networks via HV/MV transformer stations, as well as to industrial users whose demand (greater than 60 MVA) requires a connection at this voltage. [11]

- **A.Electrical substations**

Introduction

Ordinarily huge power-generating stations are built far away from load centres. There are a number of transformations and switching stations built between generating stations and the clients. These are generally known as substations. A typical substation may include the following equipments:

transformers, circuit breakers, disconnecting switches, station buses and insulators, reactors, capacitors, current and potential transformers, grounding system, lightning arrestors and spark gaps, wave traps, protective relays, station batteries, etc. [12]

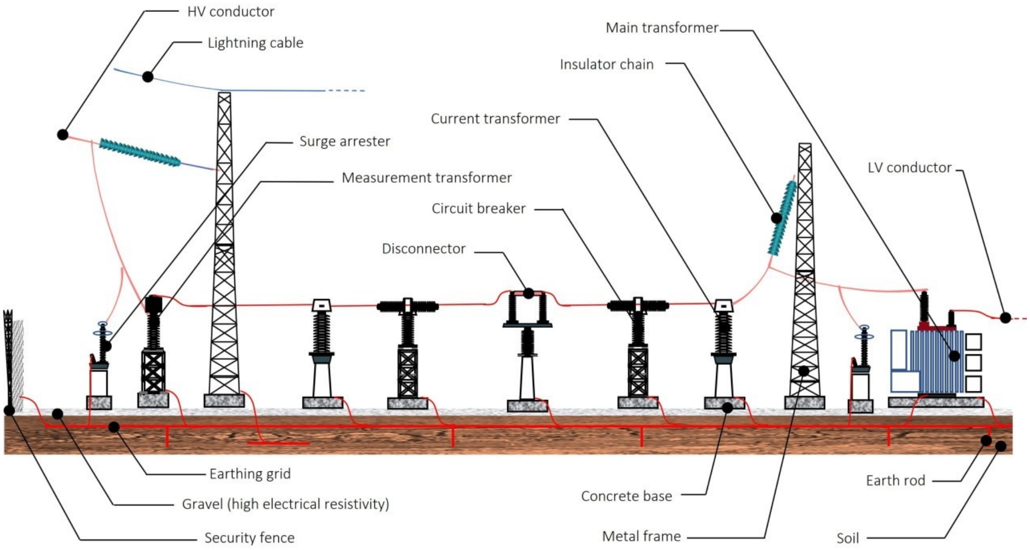


Figure 1.7: The representation of an electrical substation. [12]

Types of substations

A substation functions as a connection and switching points for transmission lines, subtransmission feeders, generating units, and transformers. Depending upon the purpose, the substations may be classified into five categories:

1. **Generating substations or step-up substations:**

   Ordinarily the generating voltages are limited and have to be be stepped up to the transmission voltage so that huge amount of power can be transmitted economically over long. Each generating unit is connected to generating transformers to increase the secondary voltage up to transmission voltage levels

2. **Grid substations:**

   These substations are located in the intermediate points between the generating stations and load centres. The purposes of these substations are to supply connections of low voltage lines, a few compensating devices, etc.

3. **Secondary substations**

   These substations are connected with the main grid substation with the assistance of secondary transmission lines. The voltage at these substations is stepped down to the sub-transmission voltage (primary distribution voltage). A few large power customers are connected to these substations also.

4. **Distribution substations**

   These are made where the sub-transmission voltage (primary distribution voltage) is to be stepped down to the supply voltage. These substations feed power to the clients through distributors and service lines

5. **Special purpose substations**

   A few special substation for bulk power and a few industrial loads are set up. Traction substations and mining substations are the examples of these. [12]

Equipment of an electrical substation

- **Power transformer :**

  A power transformer is an essential component of the high voltage electrical network. It converts effectively power from one voltage level to another (to higher voltage for long distance transmission and back down to low voltages suitable for client utilization)

  It is a static device that uses electromagnetic induction to convert one system of alternating voltage and current into another system of voltage and current usually of different values, but at the same frequency. Its main role is to minimize losses in electrical systems. [13]

Figure 1.8: Power Transformer 220kV/60kV.

- **Circuit breaker**

  Circuit breakers are used to perform routine operations essential for the proper functioning of the energy transmission network, such as switching off lines or transformers, opening or closing interconnection loops, etc. They also play a critical role in rapidly eliminating faults to protect the system.

  It is a mechanical switch that interrupts fault currents. When circuit-breaker contacts isolated while carrying current, an arc is created. It is designed to extinguish the arc by elongating and cooling it. The fact that ac arc current actually passes through zero twice during its cycle helps the arc extinction process. Circuit breakers are classified as power circuit breakers when they are intended for service in ac circuits above 1500 V and as low voltage circuit breakers in ac circuits up to 1500 V. The main types of circuit breakers depending on the medium (air, oil, SF6 gas, or vacuum) in which the arc is elongated. [14]

Figure 1.9: Sulfur Hexafluoride (SF6) Circuit Breakers.

- **Current transformer**

Current transformers (CTs) are used to transform high currents into safer and low currents, thereby enabling the CT secondary output to be utilised for the protection and control of the power systems and for revenue metering. Current transformers are also called ”step-down transformers”. [15]

Figure 1.10: Current transformer.

- **Isolating switch :**

  A switching device which can be opened or closed only under no current conditions. It provides isolation of a circuit for the purpose of maintenance. It has two states : open and closed

  - It is capable of carrying currents under normal circuit conditions and currents under irregular conditions such as those of short-circuit.

  - It guarantees isolation between the two parts of the network to which it is connected when the switch is at open state [16]

Figure 1.11: High voltage isolating switch.

- **Voltage transformer :**

  The voltage transformer plays a crucial role in the accurate transmission of primary voltage to monitoring, control, protection and measurement systems. It is essential to monitor the transformation ratio, polarity and measure its charge to ensure reliable and accurate transmission.

  The high voltage line is connected to the primary side of the transformer to power measuring devices such as voltmeters and wattmeters connected to the secondary side of this transformer. This provides a reduced representation of the HV line voltages, making precise measurement easier. In addition, the voltage transformer isolates the measuring devices from high voltage, thus ensuring their safety. [13]

Figure 1.12: Voltage transformer.

- **Surge arrester:**

  It is a device that protects other electrical equipment by arresting or discharging surge currents brought about by external forces like lightning or internal forces like switching events. [17]

  They are generally connected in parallel with the equipment to be protected to deflect the surge current.

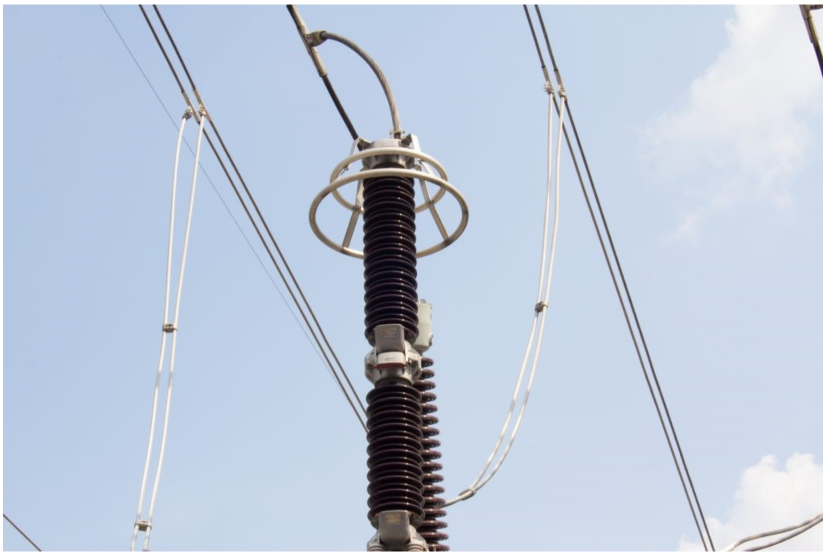


Figure 1.13: High voltage surge arrester.

- **Insulator :**

The operating performance of a substation depends upon insulators. All the current carrying parts in a substation are supported on insulators. The insulators provide mechanical support to the conductors and are subjected to normal operating voltage and transient over voltages. The insulators should not fail due to mechanical load or over voltages. The materials used in the fabricating of insulators are porcelain, glass and Epoxy type. [18]

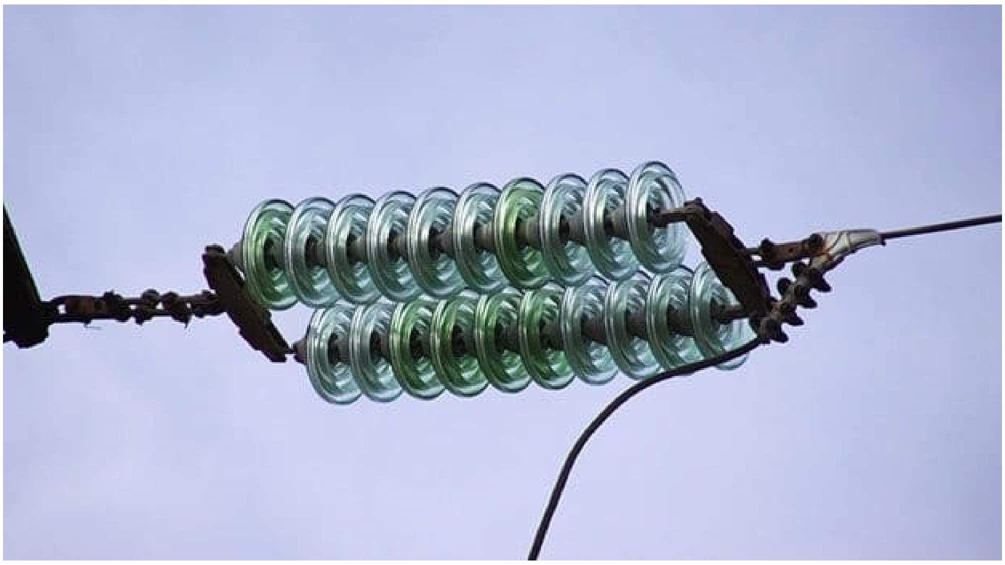


Figure 1.14: Insulator.

- **Bus-bars:**

A bus-bar is a thick strips of copper or aluminum that conduct electricity within the substation. The size of the bus-bar is critical in determining the greatest amount of current that can be safely carried. The bus-bar should be able to carry the maximum load current and short-circuit current without exceeding the temperature limit.

Different types of bus-bars, namely, single bus-bar, single bus-bar with bus sectionalizer, main and transfer bus, double bus-bar, double bus-bar with double breaker scheme and mesh scheme are used in a substation in accordance with the safety and reliability considerations. [13]

Figure 1.15: Bus-bars.

- **Line trap**

This equipment is installed in the substation to catch the high frequency communication signals sent on the line from remote substation and redirecting them to the telecom panel in the substation control room. [19]

Figure 1.16: Line trap.

- **B.Transmission lines**

There are two types of power lines

- **Underground cables :**

  Underground networks are generally used in urban areas, in order to avoid the congestion and dangers presented by overhead lines. [13]

Figure 1.17: Underground cables

- **Overhead lines :**

Figure 1.18: Overhead transmission lines.
[13]

- Line specification :

Table 1.2: Line Specifications

Type of Conductor	**Line Specification (kV)**	**Cross Section (mm^2)**	**Steel Layer Strands**
Aluminum Steel	60	288	6
Aluminum Steel	220	2×288 (or) 411	9+
Aluminum Alloy	400	2×411 (or) 570	9+
Aluminum Alloy	> 400	570+	9+

- Line types :

1. **LV distribution lines**

   These are lines installed inside buildings, factories and homes to power motors. These lines are usually cables or bars operating at voltages below 400V.

2. **MV distribution lines**

   These are lines that connect customers to the electricity company's main transformer stations. Their voltage is between (5.5kV – 30kV).

3. **HV transmission lines**

   These are lines connecting main transformation stations to generation plants. The lines generally operate at voltages below 230kV.

4. **EHV transmission lines**

   These are lines that connect remote power plants to consumption or use centers. These lines can reach lengths of up to 1000Km and operate at voltages of up to 750kV. [13]

Properties of transmission lines :

The fundamental role of a line is to transport active power. If it must also carry reactive power it has be low compared to the active power.

In addition to these requirements, a transmission line must have the following basic characteristics:

- The voltage must remain constant over the entire length of the line and for all loads between zero and the nominal load.

- Losses must be low so that the line has good efficiency.

- Joule losses must not cause the conductors to overheat. [13]

1.3.3 Distribution system

The distribution systems are set up from voltages lower than 63 KV, from HTB/HTA transformer stations. They are supported by medium voltage lines or cables which carry power to the HTA/HTA distribution station. The HTA/BTA transformer station represents the final link in the distribution chain and is responsible for the power supply for all sorts of uses. [8]

Chapter 2

Algerian Power System Operator Mission and Constraints

2.1 Introduction

Created in January 2006, the power system operator subsidiary of the SONELGAZ group belongs to the energetic industries cluster. The operator is the manager of the generation-transmission system of electrical energy.

2.2 Definition of the power system operator

The main mission of the system operator is to maintain the balance of the Algerian electricity network by satisfying the equation: Generation = Consumption, thus keeping the network frequency stable (50 Hz). [20]

2.2.1 The mission of the power system operator

The system operator manages the transmission of electricity, so it is responsible for:

- Real-time management of the power generation-transmission system.
- Ensuring the generation-consumption balance, safety, reliability and efficiency of the power supply

- Implementing means of production and transmission in the best economic and safe conditions for continuity of service.
- Management of critical situations in the electric network.
- Participation in international work linked to the development of interconnections. [8]

2.2.2 The organization of the system operator

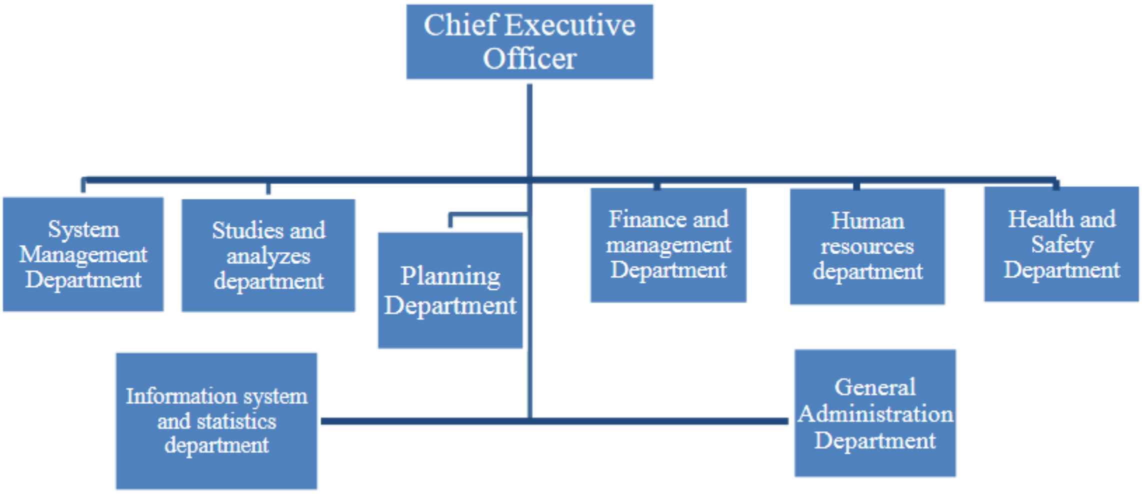


Figure 2.1: The organization of the system operator.

- The system operator is administered by a board of directors in addition to a member representing the Ministry of Energy and Mines.
- The management of the company is ensured by a CEO. [20]

2.3 Presentation of the Algerian Control Centers of dispatching

To be able to properly manage the control of the Algerian electric network, it was divided into five regions interconnected between each other and managed by regional control centers (RCC of Algiers, RCC of Setif, RCC of Annaba, RCC of Oran and the RCC of Hessi Massoud) and a national control center (NCC) which coordinates between them and controls generation through direct contact with generation centers and also manages interconnections between neighboring regions and countries.

Our practical internship was carried out in the RCC of Algiers, which has direct contact with 60KV 220KV and 400KV substations and lines. This region includes the following wilayas: Algiers, Tizi-Ouzou, Tipaza, Bouira, Djelfa, Média, Ain Defla, Blida and Boumerdes. [6]

2.3.1 The Control Center

The dispatching center represents the brain of the electrical transmission network and monitors all its infrastructure. It coordinates and regulates the flow of power in an electrical power system so as to meet the highest demand at any time within the limits supported by the network transmission lines. [6]

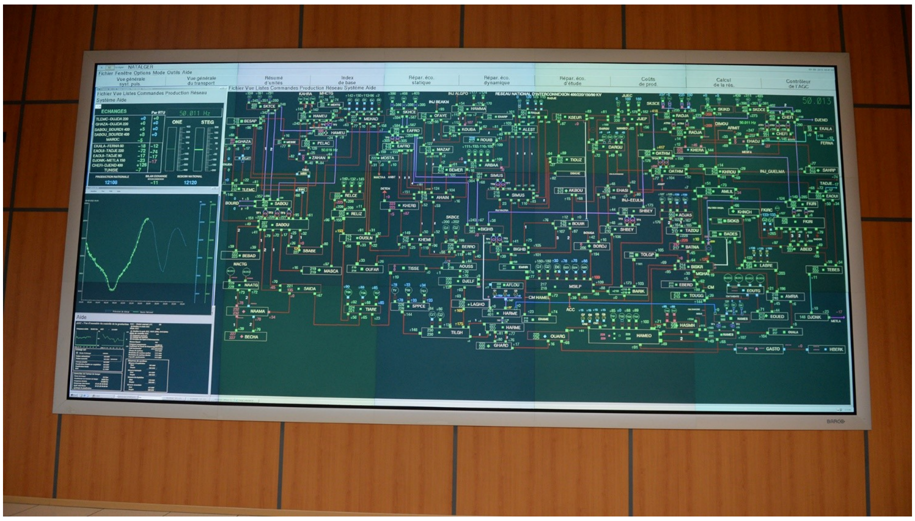


Figure 2.2: Control center of dispatching.

2.3.2 The duties of a Regional Control Center

- Manage the flow of power on the system including regional distribution networks.
- Monitor changes in demand and make the necessary adjustments.
- Ensure the plan of resuming power supply to operating clients after an incident and minimize the duration of the service interruption.

- Analyze and establish incident reports and participate in the analysis of major incidents on the network.
- Establish specific operating plans.
- Establish operating reports and daily analysis of control. [6]

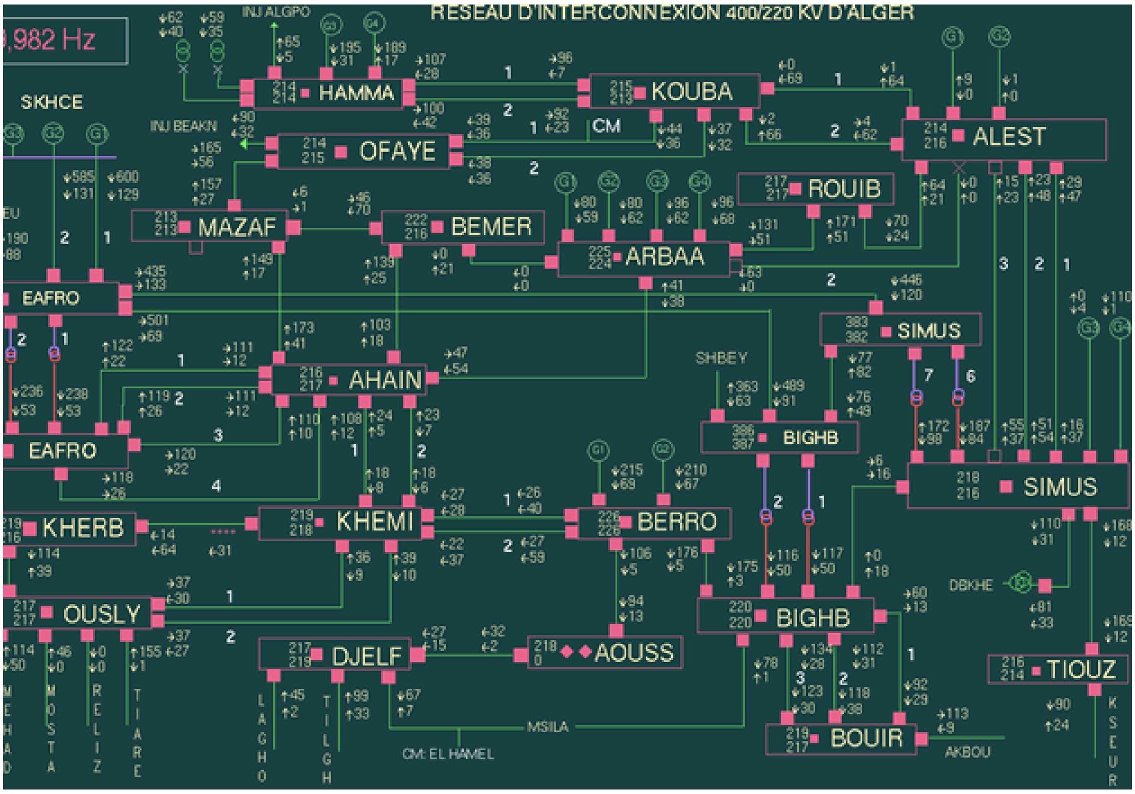


Figure 2.3: The 400/220 kV interconnection network of Algiers.

2.3.3 Voltage Ranges

The OS continuously ensures that the electricity transmission network operates within the following voltage ranges:

- Voltage between 372 – 428 kV for the 400 kV network.
- Voltage between 205 – 235 kV for the 220 kV network.
- Voltage between 141 – 159 kV for the 150 kV network.
- Voltage between 84 - 95 kV for the 90 kV network.
- Voltage between 56 - 64 kV for the 60 kV network. [8]

2.3.4 Frequency Range

The frequency regulating band operating within the following range :

- 50.2 – 49.8 (Hz) [8]

2.3.5 The communication system

Sonelgaz made a private telecommunications network which is based on digital transmission systems primarily using fiber optic cables deployed on power transmission lines [[8]

The communication front end is a split piece of equipment, based on an industrial PC, intended to ensure the exchange of information between all types of controlled stations (RTU's) and the control centers. [18]

- **Span unit:** grouping of span information (remote control, simple remote signaling, telemetry, etc.)
- **RTU (Remote Terminal Unit):** it is used to collect information from field instrumentation and transmit it to the MTU through the communication system.
- **MUX:** multiplexed the data and sent it in a fiber optic communication channel through the Back Bone networks.
- **Bône back network:** fiber optic networks.
- **DMUX:** data demultiplexing.
- **PCU (Process Communication Unit):** the communication unit plays the role of a processor protocol converter, it communicates the data collected from the station with the application server of the SCADA system to restore the display of the single-line diagram of the stations on optical signs.
- **Application server:** it is a machine which forms the interface between the IT and telecommunications part

This communications system is used for:

- Ensure the presence of priority communication links for the operation and safety of the electrical system
- Satisfy the communication needs of the Sonelgaz Group subsidiaries

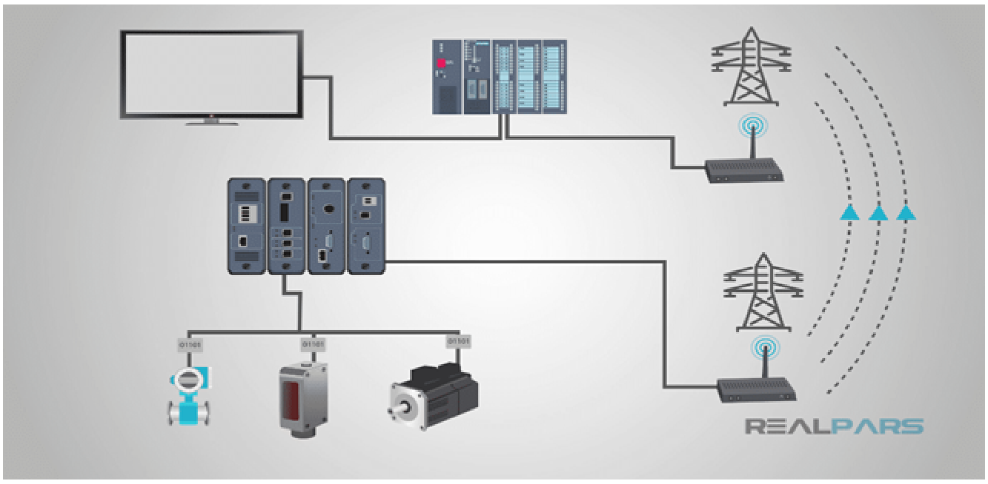


Figure 2.4: Typical diagram of an RTU.

- Real-time remote control of the electrical network and the means of generation of power which allows the operator to manage the electrical network from dispatching (opening, closing, adjusting, etc.)

2.4 The protection of the transmission and generation electrical system

The regional electricity network, like all electrical networks, includes a protection system designed to safeguard equipment (such as power transformers) and ensure stable power supply to specific areas. Let's delve into the details:

1. General protection plan for Generation-Transmission System:

- The protection plan for the generation-transmission system is meticulously designed to incorporate all necessary equipment. Its purpose is to ensure safe and selective protection for transmission lines, transformers, and busbars.

- The General Transmission and Electricity Distribution Company (GRTE) has developed a philosophy that outlines the adjustment parameters and functions necessary to prioritize actions for continuity and service quality. [6]

2. Adjustment parameters for protection

The protection system settings consider several key factors:

• Network Type: Depending on whether it's a high-voltage or extra-high-voltage network, specific protection measures are applied.

• Network Topology: The network's physical layout and configuration impact protection strategies.

• Type of Protection: Different types of protection (such as overcurrent, differential, or distance protection) are tailored to specific needs. [6]

3. Dynamic evolution of protection

• The protection plan is not static, it continually evolves due to technological advancements.

• Ongoing research and development contribute to enhancing the effectiveness and reliability of the protection system. [6]

4. Technological criteria :

- **Selectivity:** Protection systems must act specifically on the fault zone. They should isolate the faulty section while minimizing the impact on the rest of the network.
- **Speed:** Rapid response is crucial to prevent further damage during faults. Protection devices should detect and react promptly.
- **Reliability:** Protection mechanisms must be dependable and consistent. They should operate correctly under various conditions.
- **Autonomy:** Protection systems should function independently, even if other parts of the network fail.
- **Precision:** Stability and selectivity are essential. Protection devices should accurately identify faults and avoid unnecessary tripping.
- **Sensitivity:** Protection should react to faults within the specified adjustment limits. It should not miss genuine faults or trip unnecessarily.
- **Low Power Consumption:** Efficient protection systems minimize energy usage to maintain overall network efficiency [6]

5. Types of protection :

- **Distance Protection:** This type of protection is used to detect faults in the power system by measuring the impedance between the protection location and the fault point. It helps prevent damage to equipment and ensures reliable operation of the network.

- **Differential Protection:** Differential protection compares currents entering and leaving a protected zone. If there's a significant difference, it indicates a fault and triggers protective actions.

- **Overcurrent Protection:** Overcurrent protection safeguards against excessive current flow in the system. It prevents equipment damage and ensures stability.

- **Thermal Overload Protection:** This protection monitors the temperature of equipment (such as transformers, motors, and cables) and prevents them from overheating. It helps maintain system reliability.

- **Unbalance Protection:** Unbalance protection detects voltage or current imbalances caused by faults or unbalanced loads. It ensures proper system operation and prevents damage.

- **Maximum Voltage Protection:** This protection prevents excessive voltage levels that could harm equipment. It's crucial for maintaining system integrity.

- **Loss of Synchronism Protection:** Loss of synchronism can lead to instability or damage. This protection detects deviations in synchronous operation and takes corrective actions.

- **Wattmetric Protection:** Wattmetric protection monitors real power (watts) and ensures that it remains within safe limits. It contributes to system stability and reliability.[6]

Line Protection

1. **Main Protection 1:**

   This is a longitudinal differential protection that integrates the following functions:

   - Maximum current (max I)
   - Maximum voltage (max U)

- Thermal overload protection
- Fault locator
- Synchronization control
- Parallel re-closer
- Directional residual power
- Disturbance recorder (perturbograph)
- Remote-action

These protections operate based on measurements of current (I), voltage (U), real power (P), reactive power (Q), and frequency (f). [6]

2. **Main Protection 2:**

It is a distance protection that includes the same functions as Main Protection 1 (PP1). [6]

3. **Supplementary protection**

Line protection requires settings characterized by time/distance:

- First stage: 80% of the line length – T1 = 0 s
- Second stage: 120% of the line length – T2 = 0.3 s
- Third stage: 140% of the line length – T3 = 1.5 s
- Fourth stage: -40% of the line length – T4 = 3 s.

Transformer Protection

Transformers have two types of protection: internal protection and external protection. [6]

- **Internal Protection:**
  - Buchholz Relay: Monitors oil-filled transformers for gas accumulation due to internal faults.

  - Temperature Relay: Protects against excessive temperature rise.
  - Pressure Relief Valve: Ensures safe pressure levels within the transformer.
  - Additionally, each winding incorporates the following protections:
    1. Thermal Overload Protection
    2. Maximum Current I_{max} Protection
    3. Perturbograph Protection

- **External Protection:** Protects against faults external to the transformer:
  1. Maximum Current I_{max} Protection
  2. Overload Protection
  3. Lightning Protection
  4. Tank Grounding Protection
  5. Medium Voltage Neutral Protection

- Transformers are equipped with on-load tap changers to compensate for voltage drops. These tap changers are typically manually operated for high-voltage transformers.

- One common issue with transformers is parallel operation. It depends on several criteria, including:

- Matching Output Voltage
- Matching Hourly Index of Transformers
- Matching Short-Circuit Voltage (Ucc %)

Protection of Power Plants

Electric power plants are equipped with protection systems that come into play during faults in the electrical network. The effectiveness of this protection depends on the settings that match the network characteristics. [6]

- Minimum Impedance Relay:

o Installed on the high-voltage side (THT) of transformers and at the machine's output.

o Threshold setting:

$$ZR=ZT+ZG$$

- Minimum Voltage Relay:

o Installed with a setting of:

$$UR=0.7Un$$

(where Un represents the rated voltage).

- Current Unbalance Relay:

o Setting: Ides=0.05In (where In is the rated current).

- Neutral Relay for Transformers:

o Depends on the homopolar current.

o Setting: Ih=0.2In

2.4.1 Defense strategy

- Electric Power System Stability:

Electric energy cannot be stored in large quantities, which is why the energy produced must be consumed simultaneously. Maintaining a balance between production and consumption is crucial for the stability of the electrical grid. Ensuring this balance is a top priority.

- The Role of a Defense strategy:

To protect the national electrical grid, the Algerian National Electricity and Gas Company (CNC) relies on a defense plan. This plan operates based on frequency thresholds beyond the normal 50 Hz ±1% range. At each frequency stage, the CNC implements defensive measures, including load shedding and islanding, to prevent a blackout that could worsen the system's situation. [6]

Table 2.1: Frequency Stages

Number of stages	**Frequency (Hz)**	**Charge Performed**	**Temporisation (s)**
1st stage	49.3	10%	0.2
2nd stage	49	10%	0.2
2nd stage (temporarily)	49	10%	0.2
3rd stage	48.5	10%	0.2
4th stage	48	10%	0.2

Load Shedding

- Load shedding involves intentionally disconnecting one or more consumers from the power supply to quickly restore the balance between production and consumption in the network.
- It serves as a safeguard measure to prevent the risk of voltage or frequency collapse, which could lead to a complete blackout across the entire network.
- There are two types of load shedding:

o Manual Load Shedding: Controlled by operators based on system conditions.

o Automatic Load Shedding: Triggered automatically by protective relays during abnormal events. [6]

Islanding

- Islanding is a preventive measure taken by the CNC (Algerian National Electricity and Gas Company).
- It involves dividing the electricity transmission network into sub-networks (islands) where auxiliary loads can continue to be supplied.
- This ensures that each island remains operational and can be reconnected to the main grid when conditions stabilize. [6]

Blackout

- A “blackout” refers to a widespread interruption of electricity supply across all or part of a territory.
- Blackouts can last for several hours and have serious economic and energy-related consequences.

2.4.2 The Critical Challenges Faced By The Control and Monitoring Center (CRC)

The Control and Monitoring Center (CRC) it frequently encounters critical situations such as short circuits and various faults and incidents that require the activation of protective systems (circuit breakers). Another issue arises from load peaks often experienced in the regional network of Algiers due to the high density of consumers. Throughout the year, there are two types of load peak

- winter peaks and summer peak:

The summer peak is particularly dangerous because it represents the maximum consumption during the year, and it increases by 5% annually due to the growth of domestic consumers (resulting from the construction of new cities). Within a single day of the year, two consumption peaks occur

- the morning peak and the evening peak:

The morning peak is characterized by industrial consumption, while the evening peak is dominated by domestic consumption. The latter is more significant because Algeria's industrial sector is weaker compared to developed countries (such as France).

Consumption peaks generally depend on temperature, with the theoretical load curve influenced by the season, temperature, and historical consumption patterns. The maximum consumption peak in the Algiers regional network occurs during summer evenings (in July), reaching 4200 MW, which corresponds to 45% of the national consumption peak (14000 MW).

The System Operator (CRC of Algiers) monitors consumption peaks and ensures normal operation. In case of overload, defined as 90% of the transmission limit, the CRC instructs distribution centers (SDA and SDC) to implement preventive load shedding. This measure prevents widespread power outages in heavily loaded areas and ensures the continued operation of transformer substations within their limits, the protection of electrical transformers is paramount to maintaining their functionality.[6]

Chapter 3

Faults and Failures in Power System

3.1 Introduction

An electrical power system is a dynamical system linked to many random parameters, because of that, the system is not fully fault-proof. A fault can occur at any point of the grid and at any time whether due to natural causes, operational errors, cyber-attacks or physical attacks. [21] Faults in power systems might result in problems like network device damages, service interruption or instability of the network, Faults can also produce excessive currents that pose safety threats to personnel and property, and even cause major disasters, like widespread fires. This chapter will discuss the different types of faults that might occur by classifying them according to their causes and their characteristics. [23]

3.2 Definition of an electrical fault

A fault is any disturbance which causes a modification of the current or the voltage compared to a nominal values within their maximal tolerances. Involuntary contact between two conductors, for example, causes an increase in electrical current and can endanger the entire electrical circuit and cause fires or accidents. In some cases, a fault can lead to the electrical collapse of the network and endangering its environment. [22] [23]

[24]

3.3 Classification of the origins of faults

Faults in a power network can have different causes: [25] [26] [27]

3.3.1 External source

• **Atmospheric:** Overhead lines are subject to external disturbances such as lightning, storms, frost. Earthquake, Flood, Snowfall forms ice over the power lines, Fire. Such weather conditions can damage the generation, transmission, and appliances connected to a power system.

• **Mechanical:** The fall of a body on a conductor or the mechanical degradation of conductors.

• **Human:** There are certain safety rules and regulations that must be followed when installing any power system. However human error can still cause faults due to : Installing devices and components of improper ratings, Improper maintenance, Switching circuit during its maintenance

3.3.2 Internal source

These are the faults which arise in the networks without any external cause, for example the case of over-voltages due to resonance phenomena, over-currents which can be produced by an over-load current, a short circuit or insulation fault and the opening of electrical circuits under load.

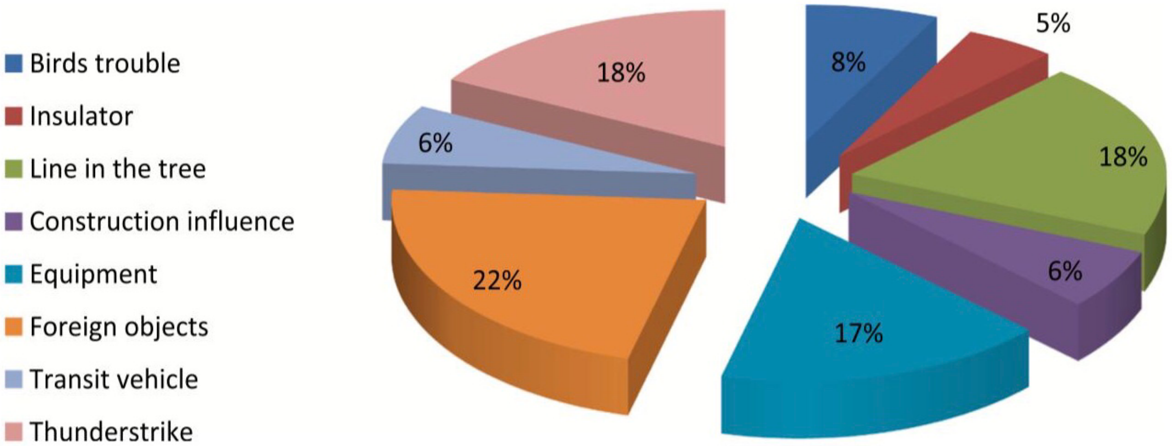


Figure 3.1: Origins of faults.
[28]

3.4 Transient and permanent faults

- **Transient fault**

Transient faults are faults, which do not damage the insulation permanently and allow the circuit to be safely re-energized after a short period. A typical example would be an insulator flashover following a lightning strike, which would be successfully cleared on opening of the circuit breaker, which could then be automatically closed. Transient faults occur mainly on outdoor equipment where air is the main insulating medium.

- **Permanent fault**

Permanent faults are the result of permanent damage to the insulation. In this case, the intervention of operating personnel is required and the equipment has to be repaired and recharging must not be entertained before restoration. [29]

3.5 Types of faults

The different types of faults encountered are overcurrents, overvoltages, oscillations and unbalances. [30]

3.5.1 Over-currents

Over-currents can occur because of over-loads and short circuits.

- **Overload:** The overload can be due to the increase in the number of loads fed simultaneously or to the increase in the power absorbed by one or more loads. It results in an over-current which causes a rise in temperature prejudicial to the characteristics of insulators and the longevity of the transformer. [[23]

- **Short circuits:** They are due to accidental contact between phases or between a phase and earth, either to an insulation fault or an external cause. The increase in current magnitude can be very high, resulting a risk of an accident. It can be classified to :

- One Phase-to-ground (L-G Fault) : Unpredictable or incidental contacts between the single conductor to the ground 80

- Phase-to-phase (L-L Fault) : Interconnection between two conductors with unequal potential differences. 15

- Two phases-to-ground (L-L-G Fault) : Interconnection between two conductors to ground with unequal potential differences. 10

- Three phases (L-L-L Fault) : Interconnection between three conductors with unequal potential differences. 5

- Three phases-to-ground fault (L-L-L-G Fault) : Interconnection between three current carrying conductors and ground with different potential variations. 3

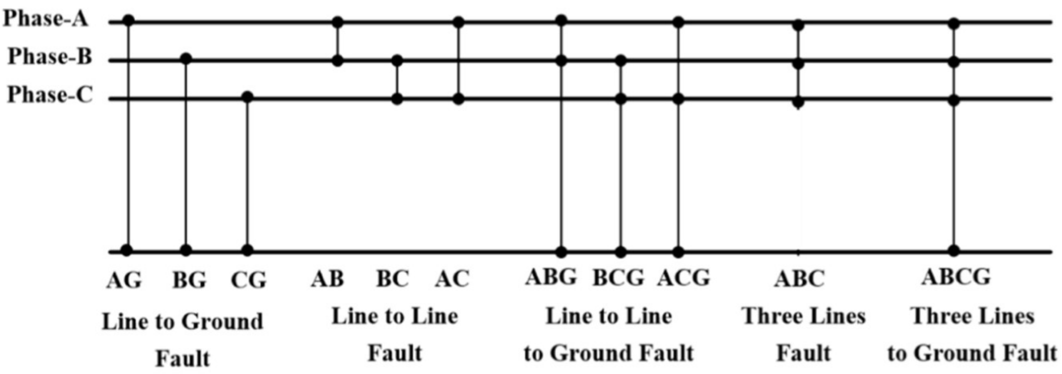


Figure 3.2: Different types of short circuits.
[31]

3.5.2 Over-voltages

Over-voltages are any voltage between the phase conductor and earth or between two phase conductors, that its peak value exceeds the maximum voltage value for the equipment, greater than 110 percent or 0.11pu for a duration longer than 1 min. Over-voltages are of external or internal origin. They result because either the system is too weak for the desired voltage regulation or voltage controls are inadequate. Incorrect tap settings on transformers can also result in system over-voltages. [32]

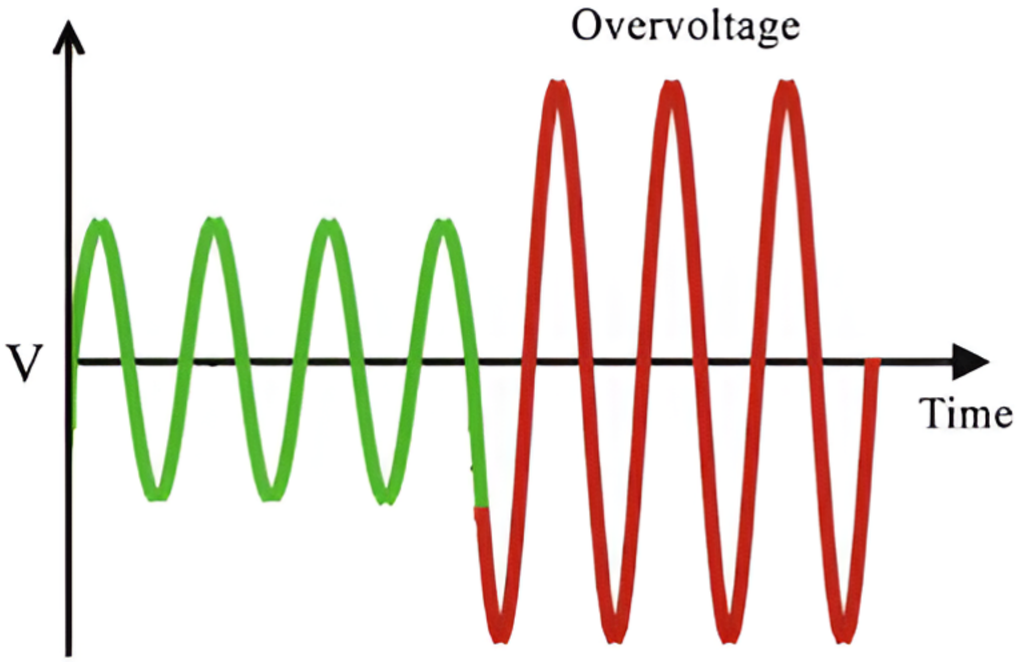


Figure 3.3: Waveform for overvoltage.

3.5.3 Under-voltages

An undervoltage is a decrease in the rms ac voltage to less than 90 percent at the power frequency for a duration longer than 1 min. Undervoltages are the result of switching events that are the opposite of the events that cause overvoltages. A load switching on or a capacitor bank switching off can cause an undervoltage until voltage regulation equipment on the system can bring the voltage back to within tolerances. [32]

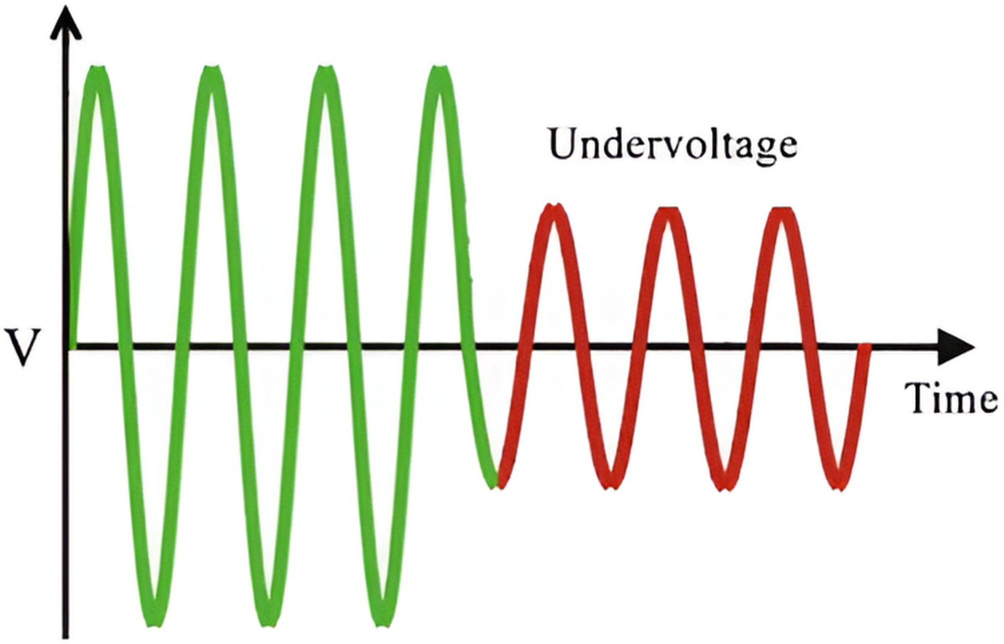


Figure 3.4: Waveform for under-voltage.

3.5.4 Unbalances

Unbalance on a three-phase installation is when there is a difference between the three phase currents in amplitude or when they are displaced from their normal 120 degree phase relationship. Frequently expressed as the ratio of the negative sequence or zero-sequence voltage to the positive-sequence voltage, in percent [[**?**] Unbalances are generally due to poor load distribution across the three phases or can also be the result of blown fuses in one phase of a three-phase capacitor bank. Severe voltage unbalance (greater than 5 percent) can result from single-phasing conditions.

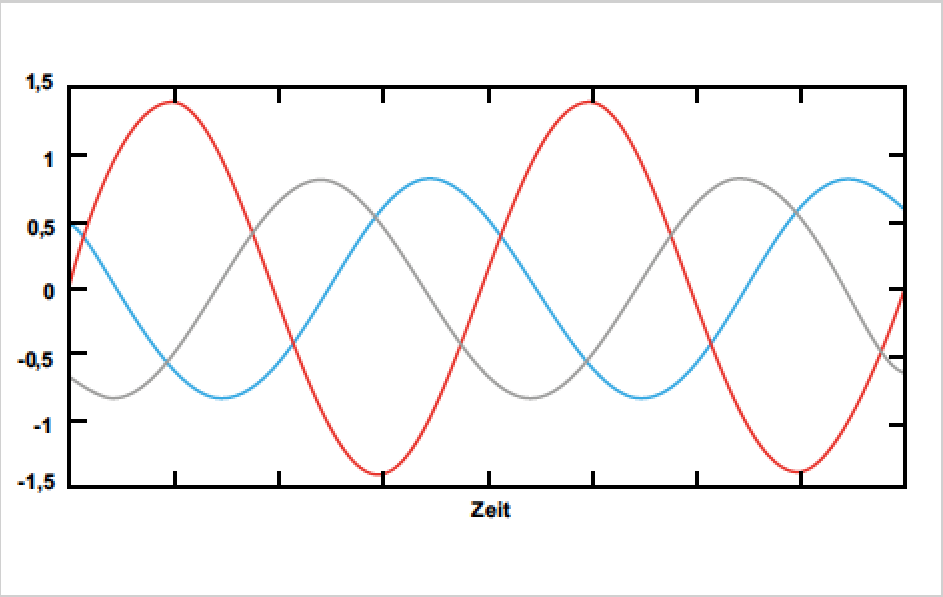


Figure 3.5: Unbalanced three phase system.

3.5.5 Harmonics

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the supply frequency (fundamental frequency 50 Hz) Harmonics are due to the variations in the load which affects directly the speed of rotation of the alternators. [?]

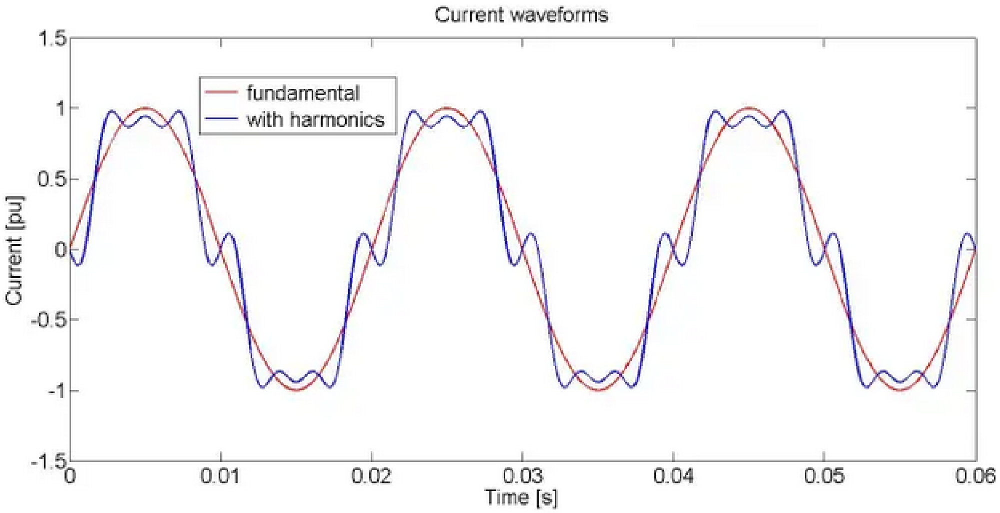


Figure 3.6: current wave form.

3.6 Effects of Electrical faults

- **Open Circuit fault:** The open circuit faults are less severe and it causes in reduction of load at the alternator. In turn, it results in the acceleration of the alternator causing over frequency. It also causes an imbalance in the load. The intact phases take the load current of the broken phases. This affects the life span of the connected load. [30]

- **Over-current fault:** it creates very low impedance causing a huge fault current that can damage the insulation and equipment connected to the circuit. [30]

- **Over-voltage fault:** Tends to stress the insulation of the electrical equipment's and likely to cause damage to them when it frequently occurs. Over voltage caused by surges can result in spark over and flash over between phase and ground at the weakest point in the network, breakdown of gaseous/solid/ liquid insulation, failure of transformers and rotating machines. [32]

- **Under-voltage fault:** It can expose electrical devices to problems such as overheating, malfunction, premature failure and shut down, especially for motors. Operating in under-voltage conditions for long periods of time can drastically reduce the life of the equipment and eventually lead to premature failure.[32]

- **Unbalances:** Voltage unbalance at the motor terminals causes high current unbalance, which can be 6 to 10 times as large as the voltage unbalance which leads to torque pulsation, increased vibration and mechanical stress, increased losses, and motor overheating. Voltage and current unbalances could also indicate maintenance issues such as loose connections and worn contacts. [[33]

- **Harmonics:** Harmonics create inefficiencies in equipment operations due to the increased need for power consumption. The increase of overall current required creates higher installation and utility costs, overheating and decreased profitability. [34]

3.7 Failures in electrical power system

3.7.1 Definition of a failure

The failure is the termination of the ability of an item or an equipment used to generate, transmit, distribute, or control electrical power to perform a required function. This can include generators, transformers, circuit breakers, switches, relays, and other infrastructure components. [[35]

3.7.2 Types of failures in electrical power system

Failures in power systems can be categorized into several types:

Equipment failures:

- **Generator failure:**

This can happen because of:

- Severe phase voltage imbalance
- Severe line current imbalance
- Under or over voltage
- Under or over frequency
- Excessive active or reactive power
- Insufficient active or reactive power
- Earth fault
- Loss of synchronisation
- Severe harmonic distortion
- Unstable active or reactive power

When a generator fails in the power system, it can lead to a reduction in available power supply in the affected area. This can potentially cause voltage and frequency fluctuations. [36]

- **Transformer failure :**

This can happen because of:

- Open or short circuit
- Earth fault primary or secondary
- Primary to secondary fault
- Over or under voltage
- Excessive power consumption from auxiliaries

The failure of a transformer may lead to a loss of power supply, voltage fluctuations in the affected area, overloading of other transformers and other safety hazards depending on the nature of the failure. [40]

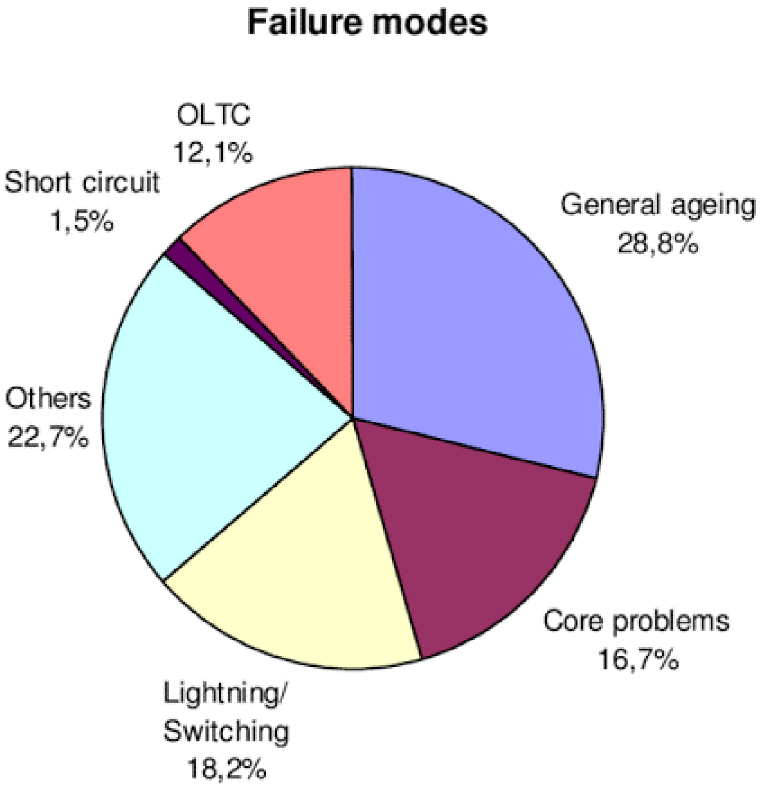


Figure 3.7: Failure modes.

- **Transmission line failure :**

This can happen because of:

- Open or short circuit
- Earth fault
- Over or under voltage
- Over or under frequency
- Severe power system transient associated with crash synchronisation of generator or power system
- Excessive export or import of power
- Severe harmonic distortion
- Circuit breaker fails to open
- Unbalanced current
- Severe voltage dip

The failure of a transmission line may disrupt the balance of voltage and frequency in the power system. Voltage might drop in areas affected by the outage due to reduced power supply, while in other areas, it could rise due to rerouted power. Frequency might also fluctuate, as the system tries to rebalance itself. [37]

Protection system failures :

Malfunctions or misoperations in relays, protective devices, or control systems designed to detect and respond to faults and abnormal conditions in the power system. This affect the system by increasing the risk of equipment damage, delay or prevent the isolation of faults, allowing faults to propagate and cascade through the system, pose safety hazards to personnel, longer restoration times and increased costs. [38]

Communication failures:

Improper communication and mismatching of parameters between the dispatching centers and generating units, adjustable loads and over the entire network and lead to losing the control of the power flow and affects the efficiency and quality of power service. This can happen because of hardware failures, human error and old equipment. [[39] [40]

Chapter 4

Solutions of Failures Using ETAP

4.1 Introduction

In this research a study has been done in The regional electricity transmission network of west Algiers, situated in the central-northern part of the country, is bounded by the following regions:

- North: Wilaya of Algiers
- South: Wilaya of Médéa
- East: Wilaya of Tizi-Ouzou
- West: Wilaya of Chlef

The regional network west Algiers has a total production capacity of 800 MW, and a total load consumption 618 MVA.

Additionally, there are several transformers, substations for electricity transmission, each operating at different voltage .

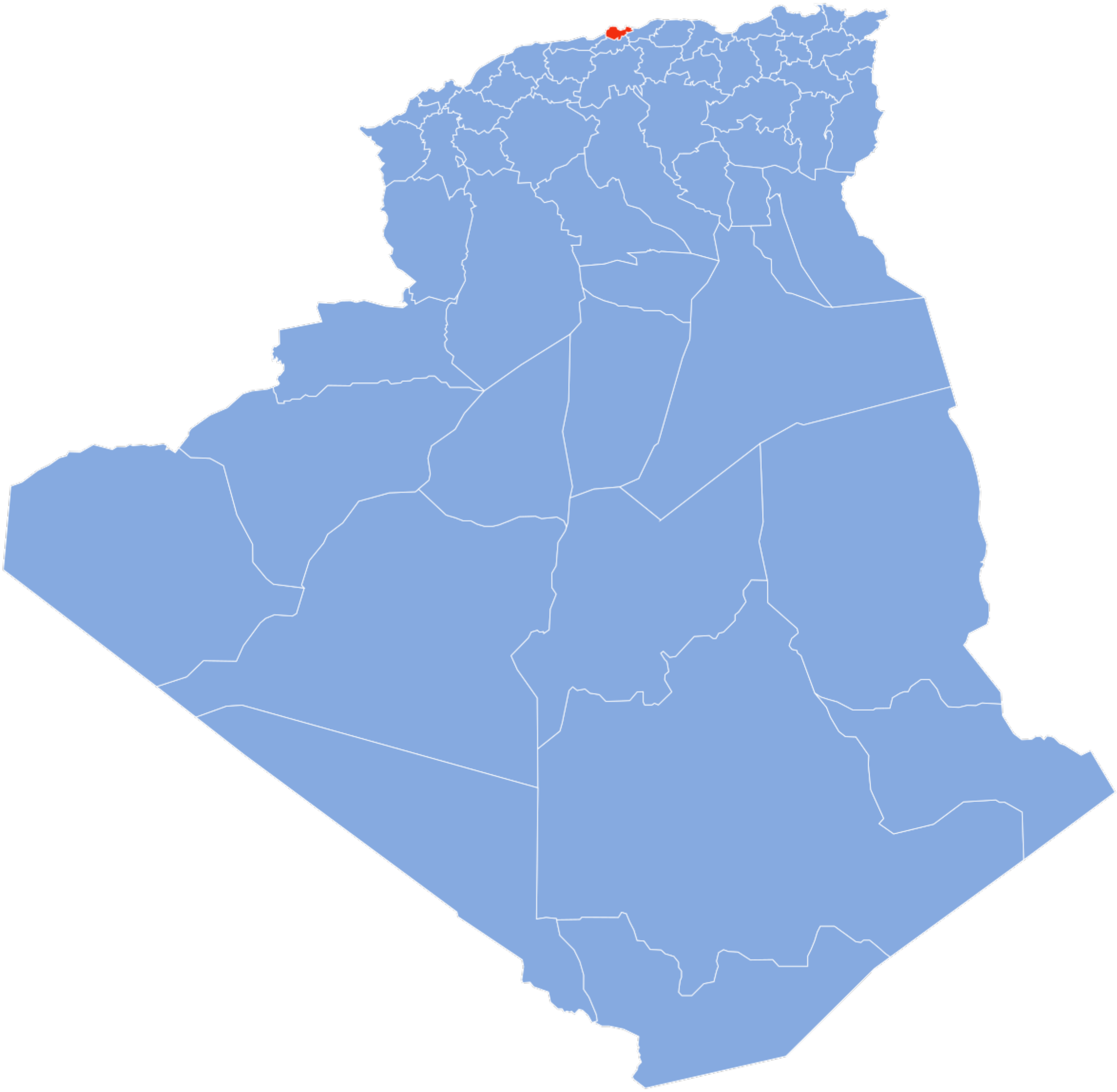


Figure 4.1: The location of Algiers in the map.

4.2 Electrical Network of West Algiers

This network countains four power production plants and is interconnected with other regional networks in Algiers (specifically east of Algiers).

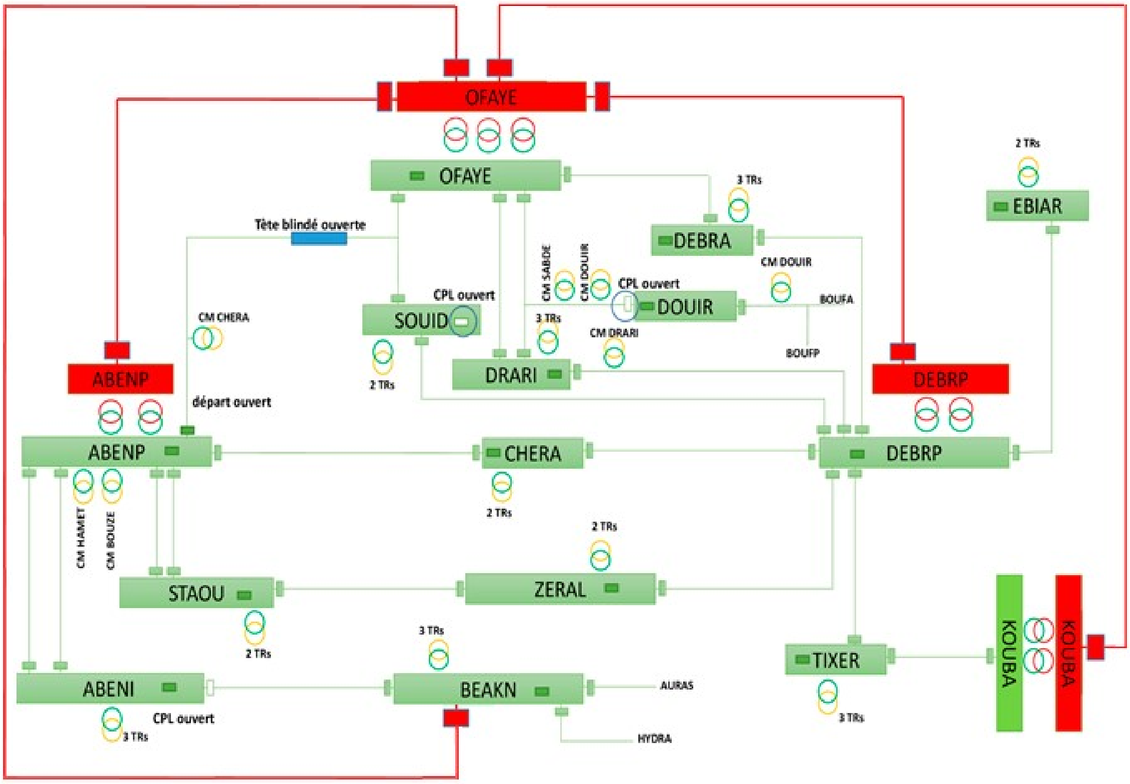


Figure 4.2: One line diagram of the network of the west of Algiers.

Table 4.1: Power generation plant and capacity

Power Generation Plant	**Capacity (MW)**
Boufarik	250
Hamma 1	200
Hamma 2	200
Larbaa	150

Substations Red These substations operate at higher voltage levels, playing a crucial role in the transmission network:

Table 4.2: Substations and locations with voltage level

Substation	**Location**	**Voltage Level (kV)**
OFAYE	Ouled Fayet	220/60
ABENP	Ain Benian	220/60
DEBRP	Dely Ibrahim	220/60
KOUBA	kOUBA	220/60

Substations Green operate at lower voltage levels, facilitating the distribution of power to local areas:

Table 4.3: Substations and locations with voltage

Substation	**Location**	**Voltage Level (kV)**
DEBRA	Dely Ibrahim	60/10
DOUIR	Douira	60/30
STAOU	Staouali	60/30
ABENI	Ain Benian	60/10
CHERA	Cheraga	60/10
ZERAL	Zeralda	60/30
BEAKN	Ben Aknoun	220/60/10
TIXER	Tixeraine	60/10
SOUID	Souidania	60/30

Transmission Lines These lines connect the substations and power plants, forming the backbone of the power distribution network:

Table 4.4: Transmission Line Lengths

Transmission Line	**Length (m)**
ABENI-ABENPI	1000
ABENI-ABENP2	1000
ABENP-CHERA	6000
ABENP-STAOU	6000
ABENP-STAOU2	6000
BEAKN-OFAYE	4000

Continued on next page

Table 4.4 – continued from previous page

Transmission Line	**Length (m)**
CHERA-DEBRP	3000
DEBRA-DEBRP5	1000
DRARI-DEBRP	6000
EBIAR-DEBRP2	5000
KOUBA-ARBA	12490
KOUBA-HAMMA1	3000
KOUBA-HAMMA2	3000
KOUBA-OFAYE	14200
KOUBA-OFAYE2	14200
KOUBA-TIXER	6000
OFAYE-ABENP	12000
OFAYE-Boufarik	12000
OFAYE-DEBRP	6000
OFAYE-DRARI	7000
OFAYE-SOUID	6000
SOUID-DEBRP	14000
STAOU-ZERAL	8000
TIXER-DEBRP	8000
ZERAL-DEBRP	18000

The current capacity for transmission lines (TL) differs depending on the voltage. For a 60kV transmission line, the maximum current it can carry is 850 amperes (A), whereas for a 220kV transmission line, the current capacity increases to 950 A. This discrepancy in current capacity is due to the varying electrical characteristics and insulation requirements associated with different voltage levels in transmission systems.

Loads:

SUBSTATION	LOAD (MVA)
DEBRA	60
ABENI	81
TIXER	35
ZERAL	31
OFAYE	104
KOUBA	115
DRARI	83
EBIAR	53
STAOU	37
SOUID	25
CHERA	47
BEAKN	61
DOUIR	28

Table 4.5: Total load connected to each substation

4.3 Study of failures in the network

- At steady state the power flow of the system is shown in the figure below :

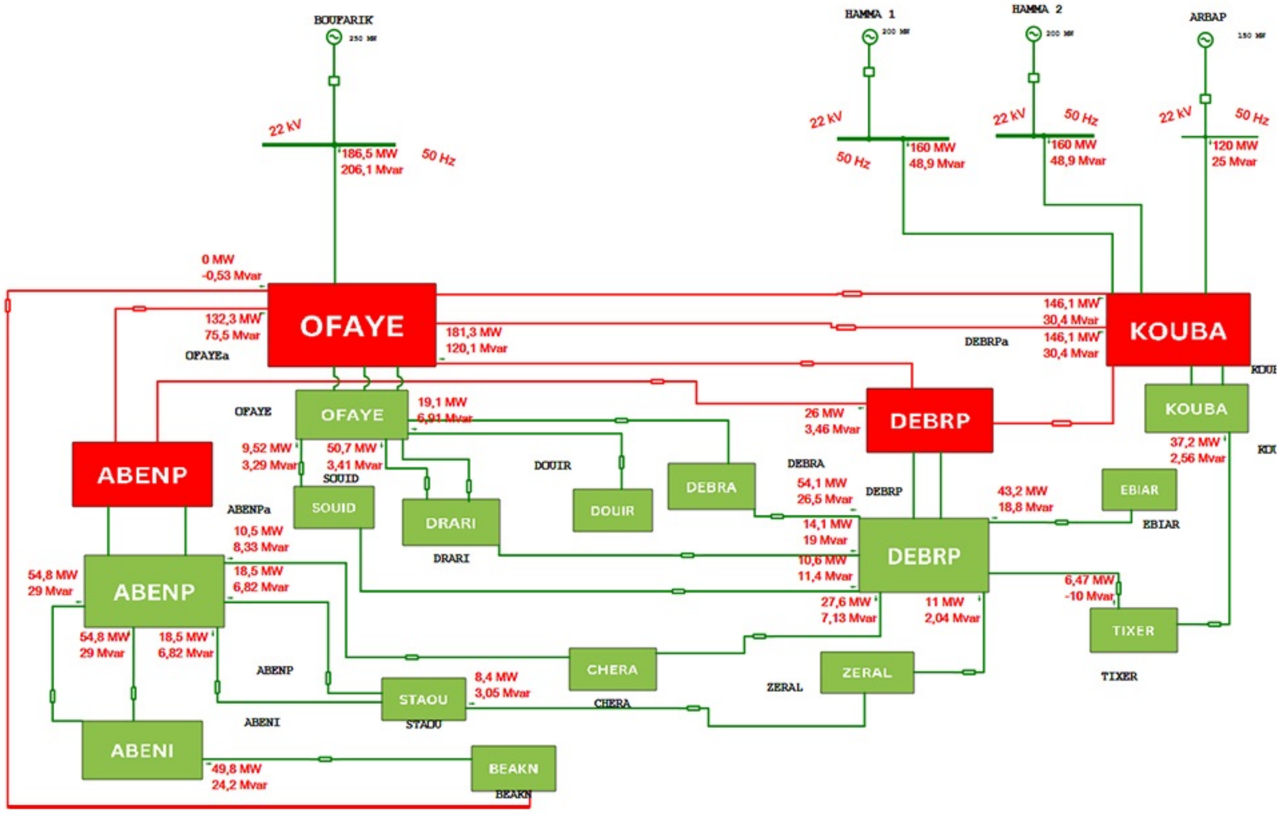


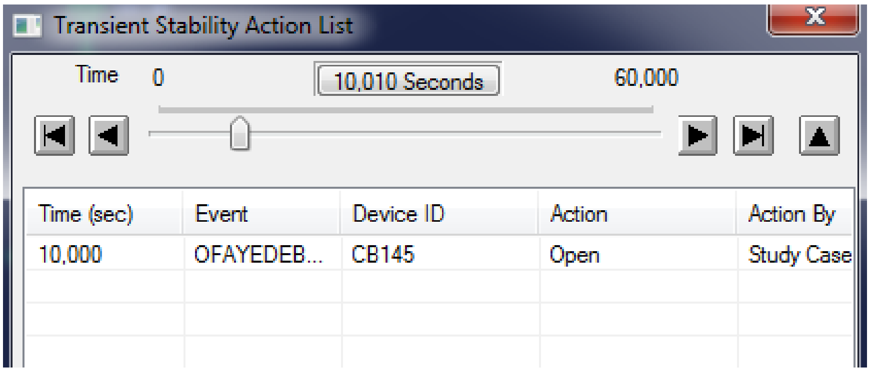
Figure 4.3: The power flow between substations before any failure .

Table 4.6: Power Flow between substations before any failure.

LINES	**MW**	**MVAR**
ABENI-ABENP	54.8	29
ABENI-ABENP2	54.8	29
ABENP-CHERA	10.5	8.33
ABENP-STAOU	18.5	6.82
ABENP-STAOU2	18.5	6.82
BEAKN-OFAYE	0	0
CHERA-DEBRP	27.6	7.13
DEBRA-DEBRP	64.1	26.5
DRARI-DEBRP	10.6	11.4
EBIAR-DEBRP	43.2	18.8
KOUBA-ARBA	120	26
KOUBA-HAMMA1	160	48.9
KOUBA-HAMMA2	160	48.9
KOUBA-OFAYE	146.1	30.4
KOUBA-OFAYE2	146.1	30.4
KOUBA-TIXER	37.2	2.56
OFAYE-ABENP	132.3	75.5
OFAYE-BOUFARIK	186.5	206.1
OFAYE-DEBRP	181.3	120.1
OFAYE-DRARI	50.7	3.41
OFAYE-SOUID	9.52	3.29
SOUID-DEBRP	10.6	11.4
STAOU-ZERAL	8.4	3.05
TIXER-DEBRP	5.91	9.76
ZERAL-DEBRP	6.47	-10

4.3.1 Line failure

- At t= 10s, a failure of the line (OFAYE - DEBRP) occurs :



Time (sec)	Event	Device ID	Action	Action By
10,000	OFAYEDEB...	CB145	Open	Study Case

Figure 4.4: time and events in the system .

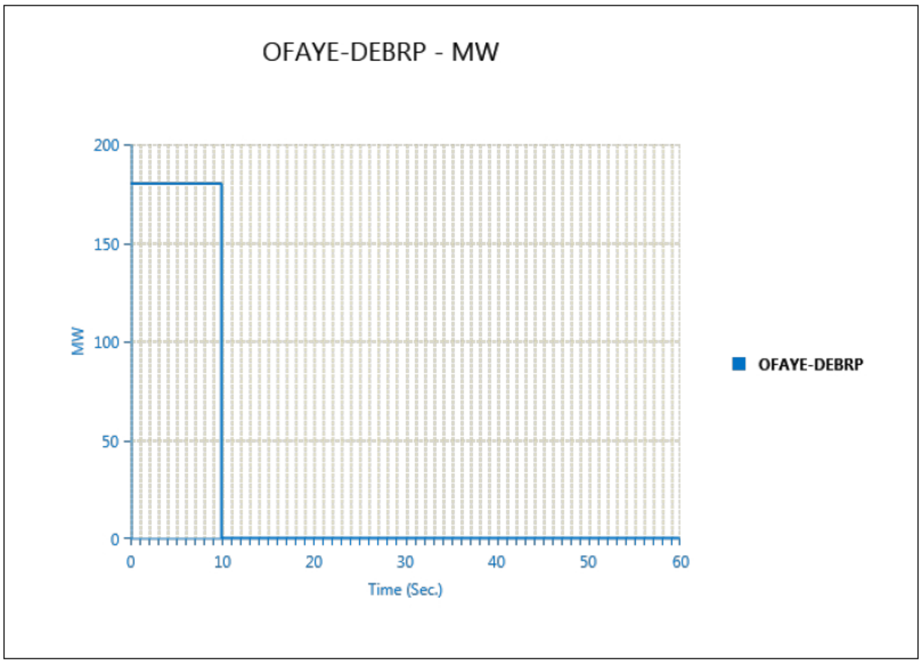
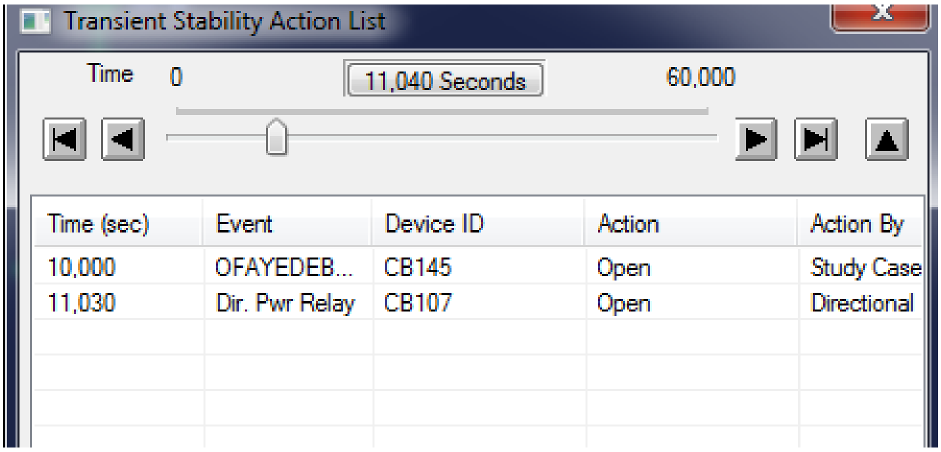


Figure 4.5: Real Power of the line (OFAYE-DEBRP) after Failure.

- Because of the previous failure, the line (OFAYE-ABENP) exceeds the limits of transmitted power (overload) : P $= 298MW > 270MW$

- The directional power relay trips the circuit breaker to open the line after 1s (setting time)



Time (sec)	Event	Device ID	Action	Action By
10,000	OFAYEDEB...	CB145	Open	Study Case
11,030	Dir. Pwr Relay	CB107	Open	Directional

Figure 4.6: time and events in the system

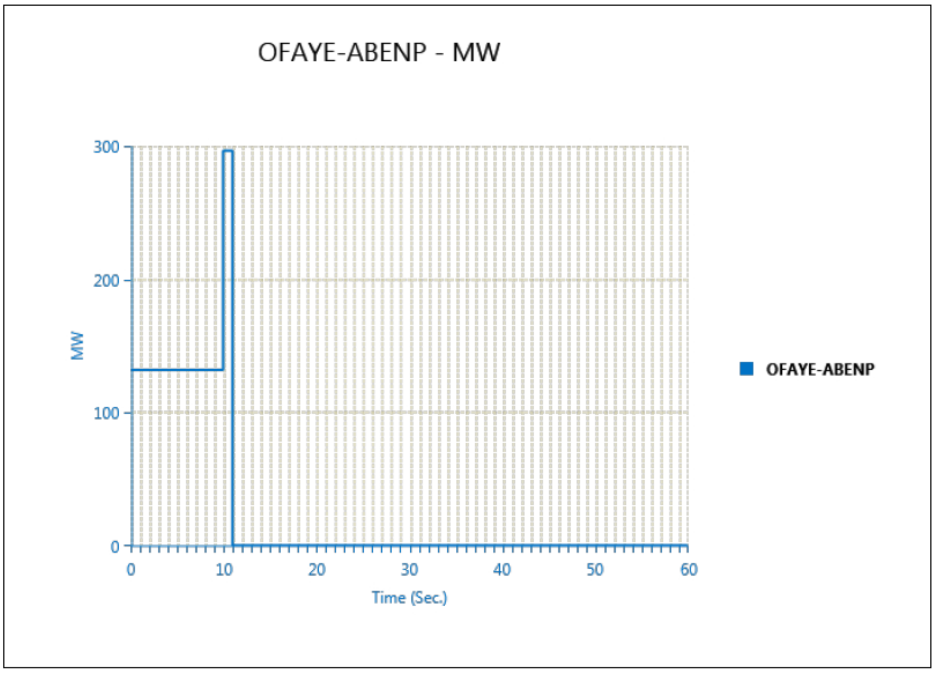


Figure 4.7: Real Power of the line (OFAYE-ABENP) after Failure

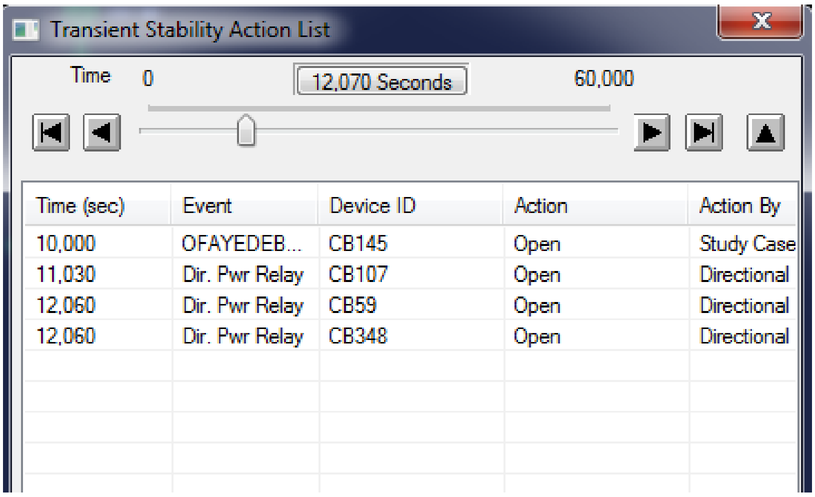
- The failure of the second line leads to :

1. Overload at the line (DRARI-DEBRP) : P= $90MW > 70MW$

- The directional power relay trips the circuit breaker to open the line after 1s

2. Overload at the line between (TIXER-DEBRP) : P= $90MW > 70MW$

- The directional power relay trips the circuit breaker to open the line after 1s



Time (sec)	Event	Device ID	Action	Action By
10,000	OFAYEDEB...	CB145	Open	Study Case
11,030	Dir. Pwr Relay	CB107	Open	Directional
12,060	Dir. Pwr Relay	CB59	Open	Directional
12,060	Dir. Pwr Relay	CB348	Open	Directional

Figure 4.8: time and events in the system.

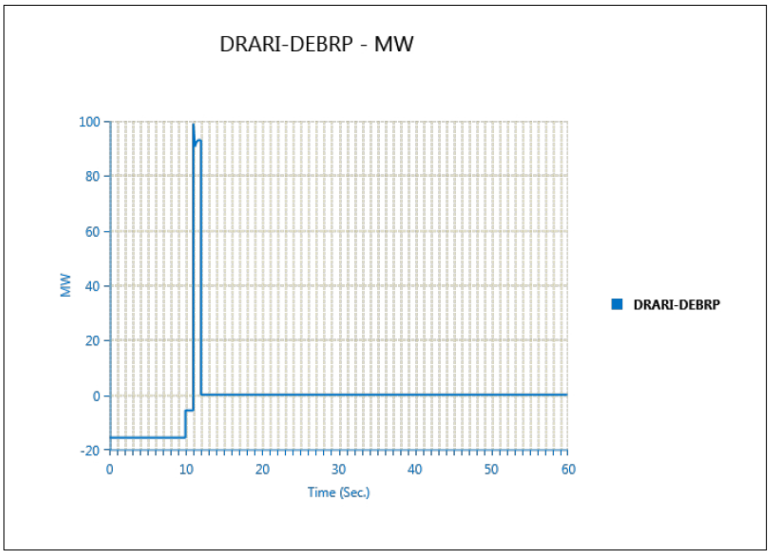


Figure 4.9: Real Power of the line (DRARI-DEBRP).

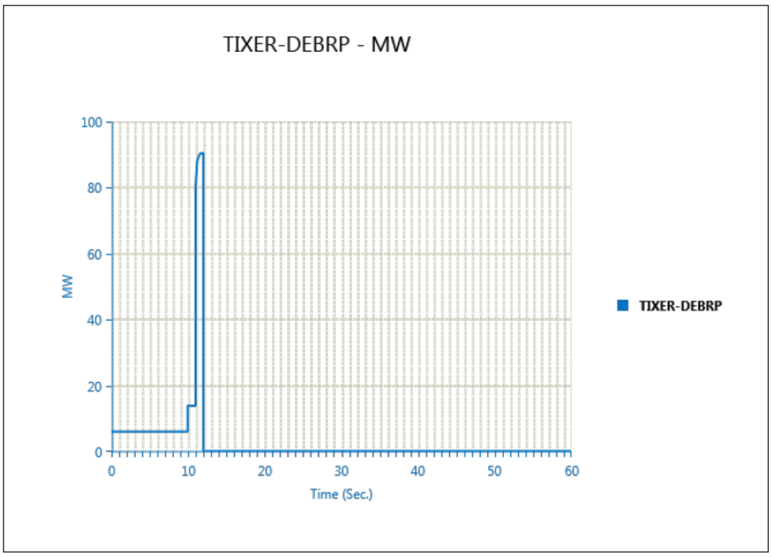


Figure 4.10: Real Power of the line (TIXER-DEBRP).

-At (t=12.6s) a blackout happens and no power is transmitted to all the above substations : ABENP, DEBRP, DEBRA, STAOU, ABENI, CHERA, ZERAL, EBIAR, BEAKN :

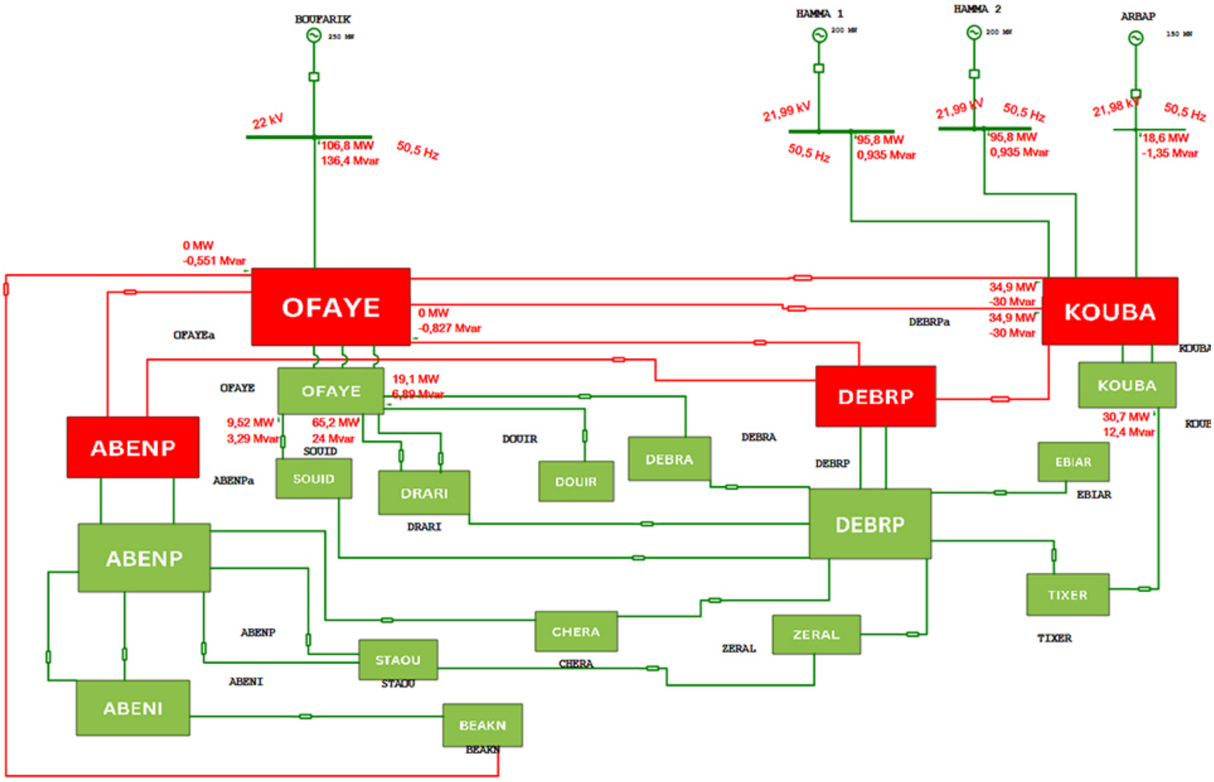


Figure 4.11: The power flow between substations after the failure of the line.

Table 4.7: Power Flow between substations after the failure of the line.

LINES	**MW**	**MVAR**
ABENI-ABENP	0	0
ABENI-ABENP2	0	0
ABENP-CHERA	0	0
ABENP-STAOU	0	0
ABENP-STAOU2	0	0
BEAKN-OFAYE	0	0
CHERA-DEBRP	0	0
DEBRA-DEBRP	0	0
DRARI-DEBRP	0	0
EBIAR-DEBRP	0	0
KOUBA-ARBA	18.6	1.35
KOUBA-HAMMA1	95.8	0.94
KOUBA-HAMMA2	95.8	0.94
KOUBA-OFAYE	34.9	-30
KOUBA-OFAYE2	34.9	-30
KOUBA-TIXER	30.7	12.4
OFAYE-ABENP	0	0
OFAYE-BOUFARIK	106.8	136.4
OFAYE-DEBRP	0	0
OFAYE-DRARI	62.5	24
OFAYE-SOUID	9.52	3.29
SOUID-DEBRP	0	0
STAOU-ZERAL	0	0
TIXER-DEBRP	0	0
ZERAL-DEBRP	0	0

- The power generated by generators is distributed to loads connected to substations : OFAYE, SOUID, DRARI, DOUIR, KOUBA, TIXER.

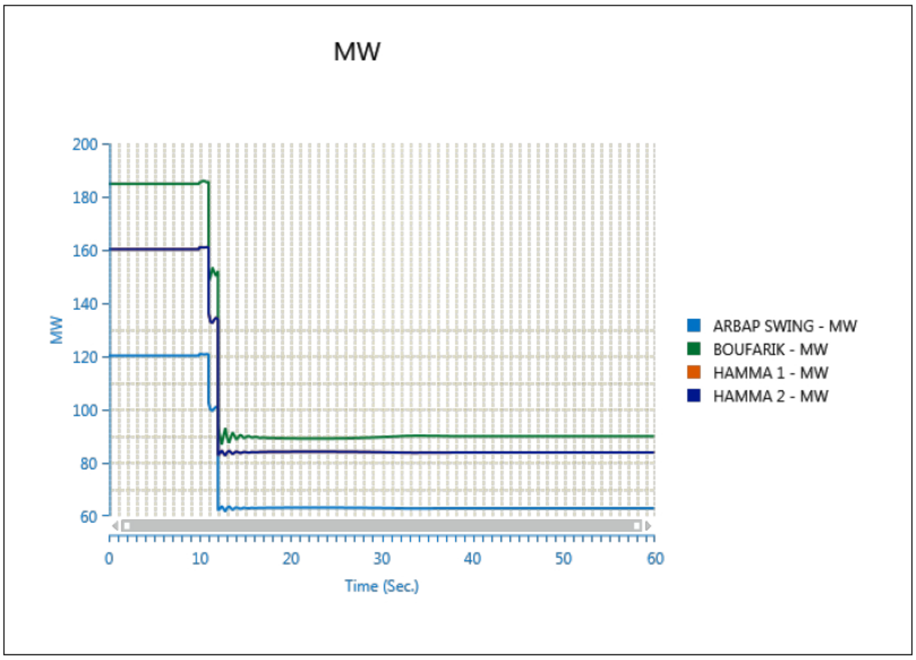


Figure 4.12: Real power of the generators.

Line failure cost

The cost of the non distributed energy to loads can be calculated using the following formula:

Cost = Non distributed energy x time x 0.6 DA

Cost = 295 MVA x PF x 0.6 DA x time

Cost = 295 MVA x 0.8 x 0.6 DA x time

Cost = 236 MW x 0.6 DA x time

Cost = 141600000 DA/h

Solution to avoid the blackout and minimize the cost

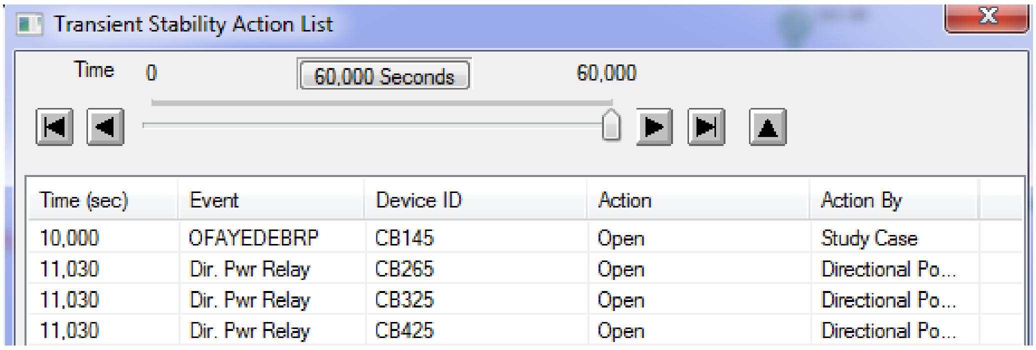
To solve the problem of overload at the line (OFAYE-ABENP), and prevent the cascading failures of the lines (DRARI-DEBRP) and (TIXER-DEBRP), and to prevent the blackout at substation: ABENP, DEBRP, DEBRA, STAOU, ABENI, CHERA, ZERAL, EBIAR, BEAKN. - The power transmitted by the 220kV line (OFAYE-ABENP) must be redirected to loads following other paths.

- The proposed solution after the failure of any line in the network is to connect a relay to that line, this relay must be configured to react instantaneously when the line fails, and execute multiple tasks by sending signals to different circuit breakers in order to transfer the power that was supposed to be transmitted by that line to other lines in the network, the tasks executed by the relay are selected after doing a series of simulations.

- In the case of the failure of the line (OFAYE-DEBRP) the relay will execute the following tasks :

1. Isolate the two bus-bars in each of the following substation: STAOU, BEAKN, CHERA. This is done by opening the circuit breaker that connects the two bus-bars.

- The signals are sent from the directional power relay that measures power at line (OFAYE-DEBRP), and the signals are sent after the failure of the line :



Time (sec)	Event	Device ID	Action	Action By
10,000	OFAYEDEBRP	CB145	Open	Study Case
11,030	Dir. Pwr Relay	CB265	Open	Directional Po...
11,030	Dir. Pwr Relay	CB325	Open	Directional Po...
11,030	Dir. Pwr Relay	CB425	Open	Directional Po...

Figure 4.13: time and events in the system.

a. This action is applied in STAOU substation so the loads in this substation are fed by the line (STAOU-ZERAL) which leads to reduce the power transmitted by the line (OFAYE-ABENP).

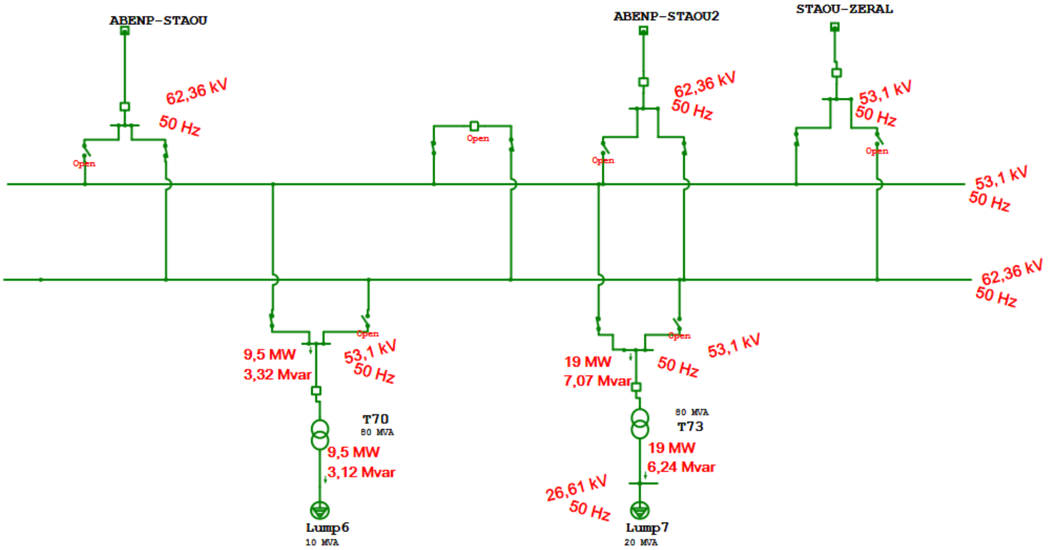


Figure 4.14: The power flow in STAOU substation.

b. At CHERA substation the action is applied to divide the loads connected to the two bus-bars in the substation, so they can receive power separately. From the two lines (ABENP-CHERA) and (DEBRP-CHERA).

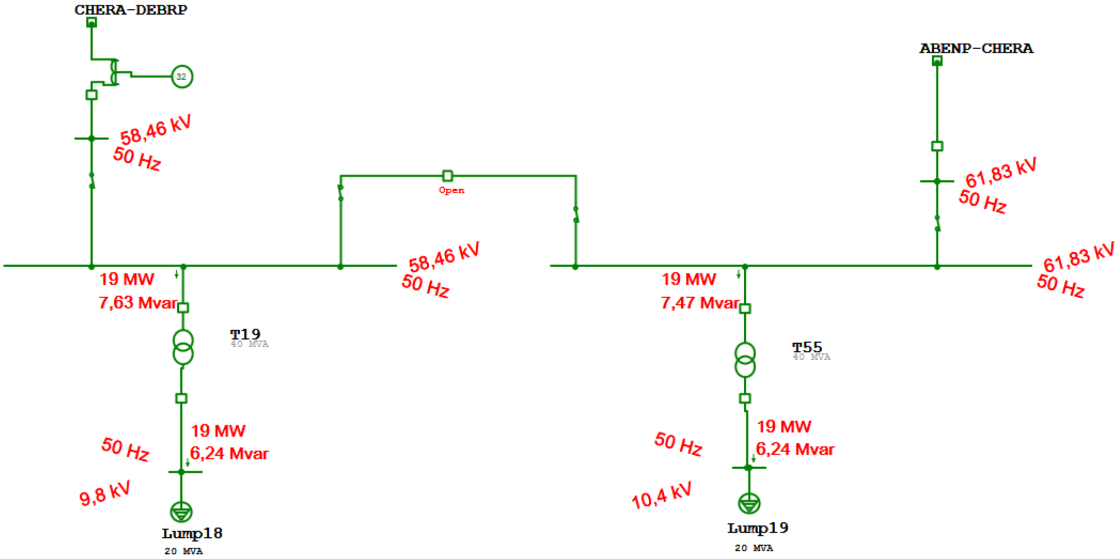


Figure 4.15: The power flow in CHERA substation.

c. At ABENI substation the action is applied to divide the loads connected to the two bus-bars in the substation, so they can receive power separately. From the two lines (ABENI-BEAKN) and (ABENP-ABENI).

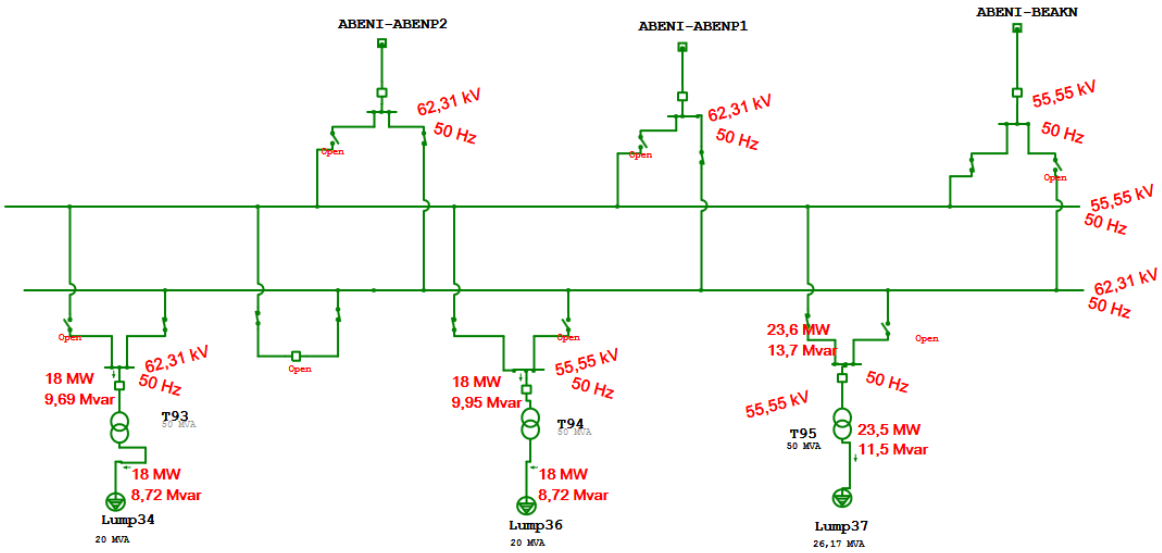
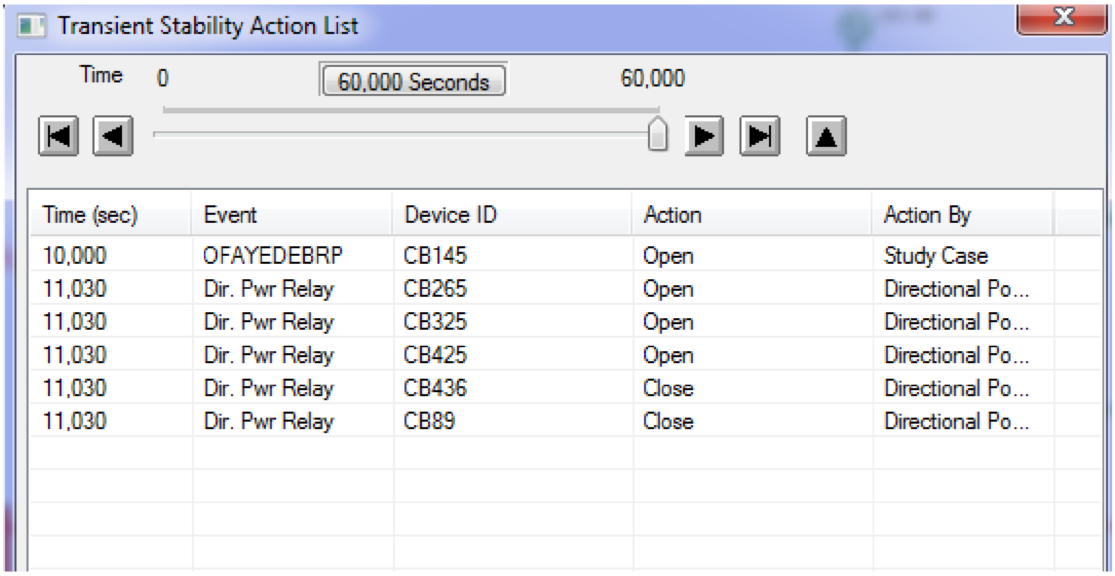


Figure 4.16: The power flow in ABENI substation.

- The objective of all this is to reduce the power transmitted from ABENP substation to other substations which leads to reduce the power transmitted by the line (OFAYE-ABENP).

2. Set the 220kV line (BEAKN-OFAYE) and the 60kV line (DEBRA-OFAYE) in service by closing the circuit breakers of the two lines.

- The CB closing signal is sent from the directional power relay that measures power at line (OFAYE-DEBRP), and the signal is sen after the failure of the line :



Time (sec)	Event	Device ID	Action	Action By
10,000	OFAYEDEBRP	CB145	Open	Study Case
11,030	Dir. Pwr Relay	CB265	Open	Directional Po...
11,030	Dir. Pwr Relay	CB325	Open	Directional Po...
11,030	Dir. Pwr Relay	CB425	Open	Directional Po...
11,030	Dir. Pwr Relay	CB436	Close	Directional Po...
11,030	Dir. Pwr Relay	CB89	Close	Directional Po...

Figure 4.17: time and events in the system.

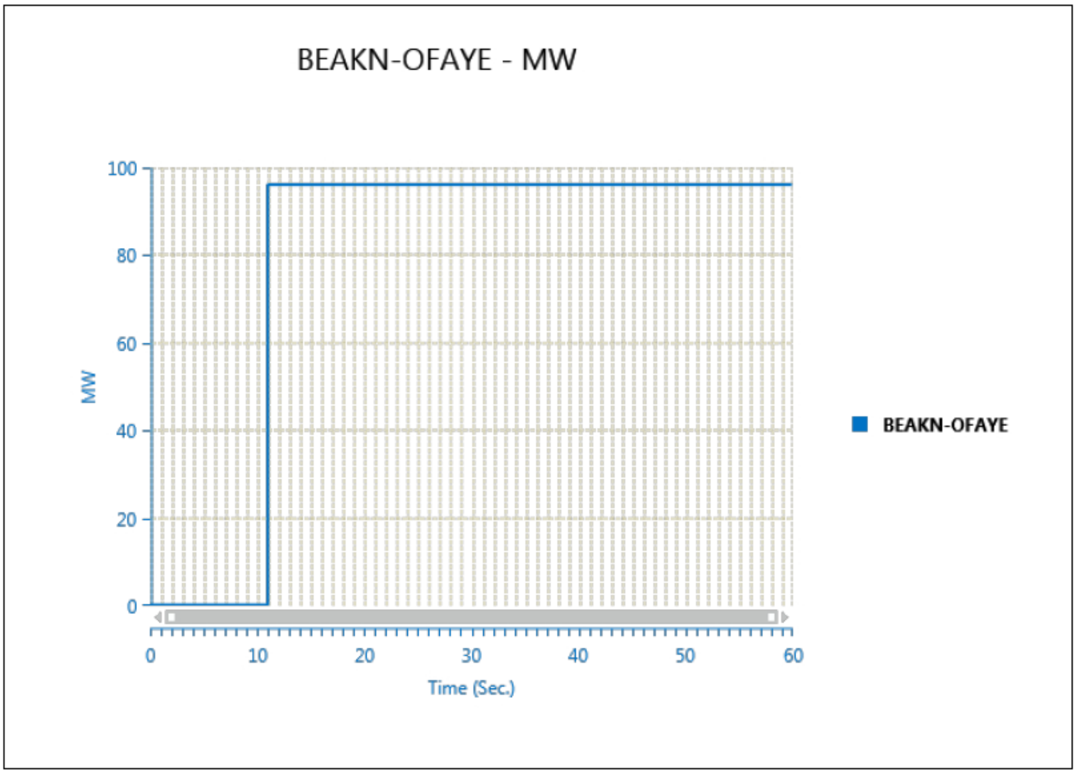


Figure 4.18: Real Power of the line (BEAKN-OFAYE).

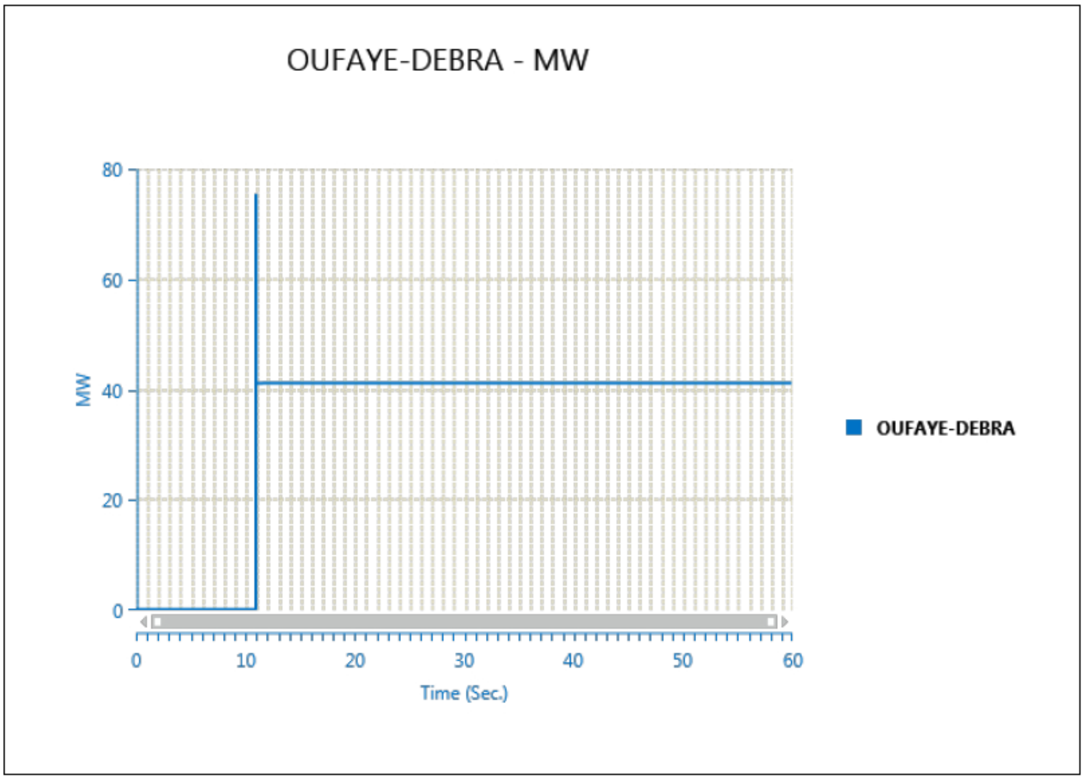


Figure 4.19: Real Power of the line (OFAYE-DEBRA)..

- By applying this solution the power transmitted by the line (OFAYE-ABENP) is reduced from 290 MW to 175.6 MW, and the line is not overloaded anymore to trip and fail causing other lines to fail also (cascade).

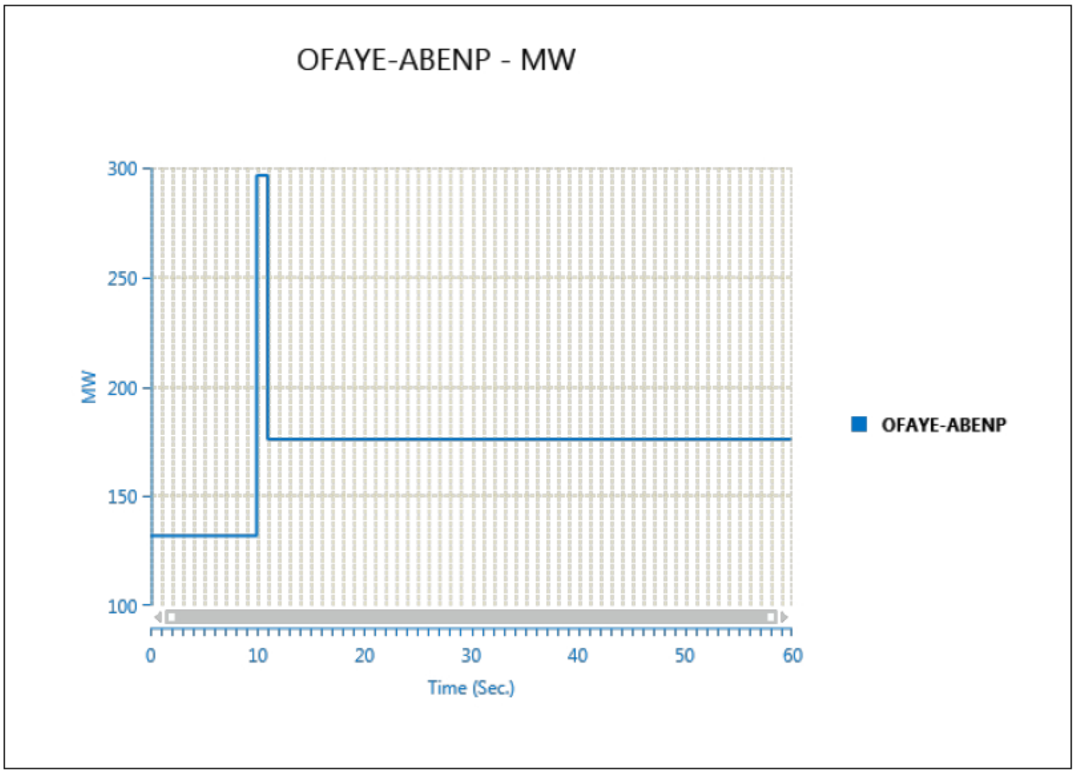


Figure 4.20: Real Power of the line (OFAYE-ABENP) after solution.

- The two lines TIXER-DEBRP and DRARI-DEBRP will not overload and will not trip :

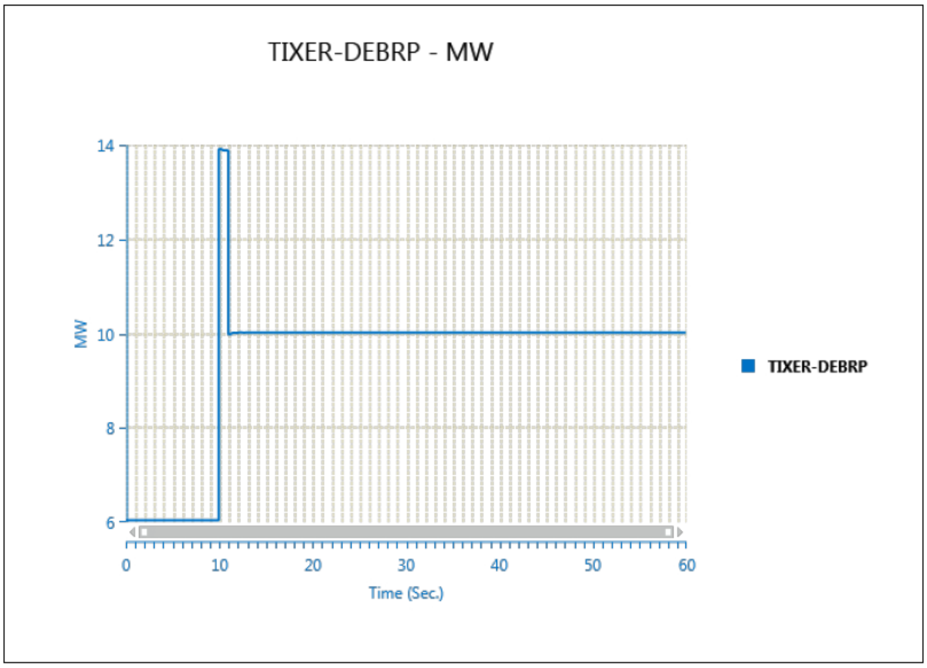


Figure 4.21: Real Power of the line (TIXER-DEBRP) after solution.

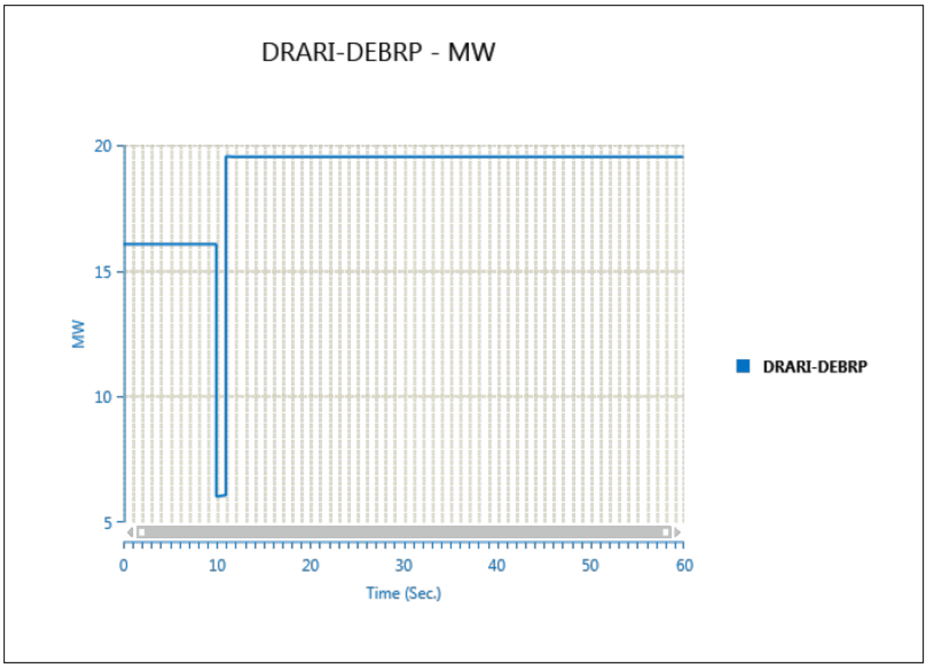


Figure 4.22: Real Power of the line (DRARI-DEBRP) after solution.

- The generators will not be affected by the failure :

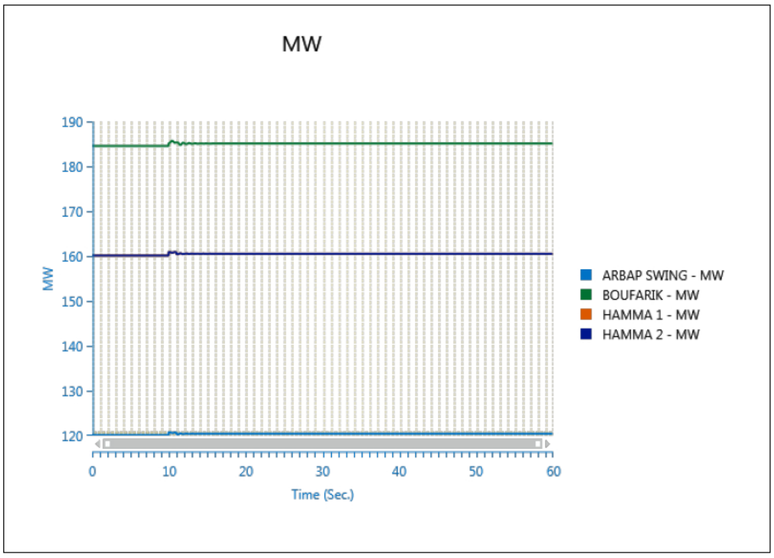


Figure 4.23: Real Power of the Generators after solution.

- The voltage and frequency at the terminal bus of the line OFAYE-DEBRP are regulated rapidly by the solution :

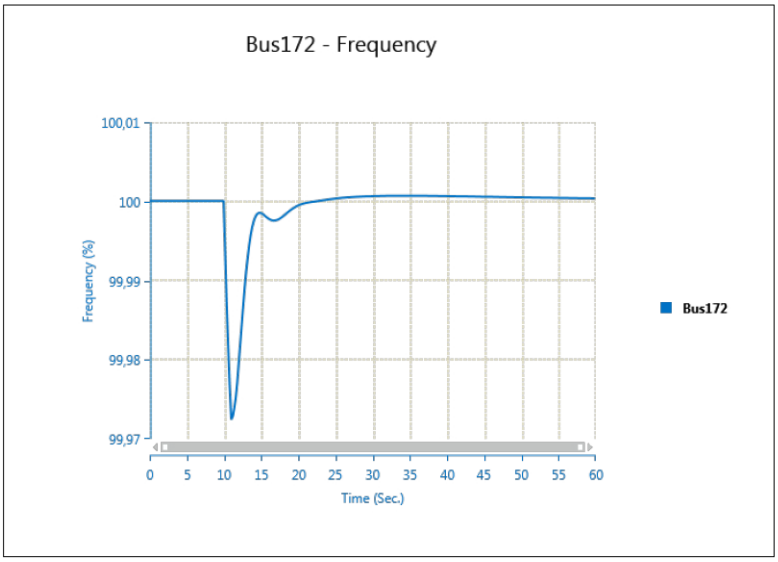


Figure 4.24: The frequeny at the terminal bus of the line (OFAYE-DEBRP).

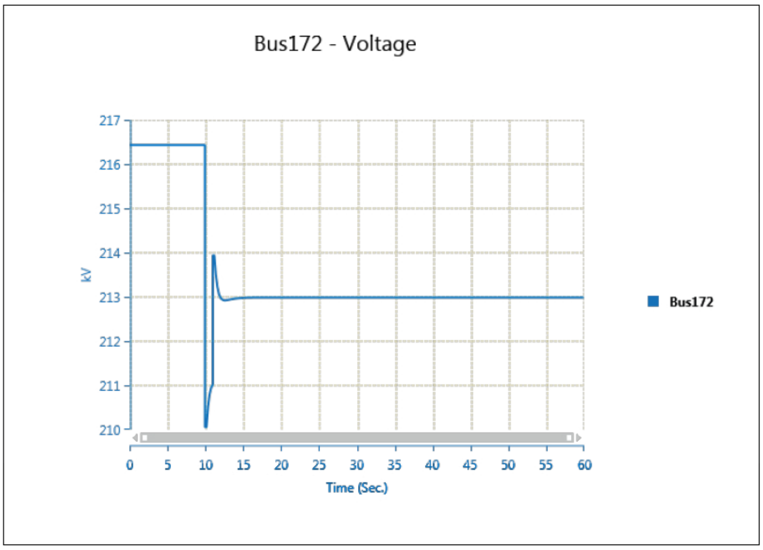


Figure 4.25: the voltage at the terminal bus of the line (OFAYE-DEBRP).

- After applying the solution:

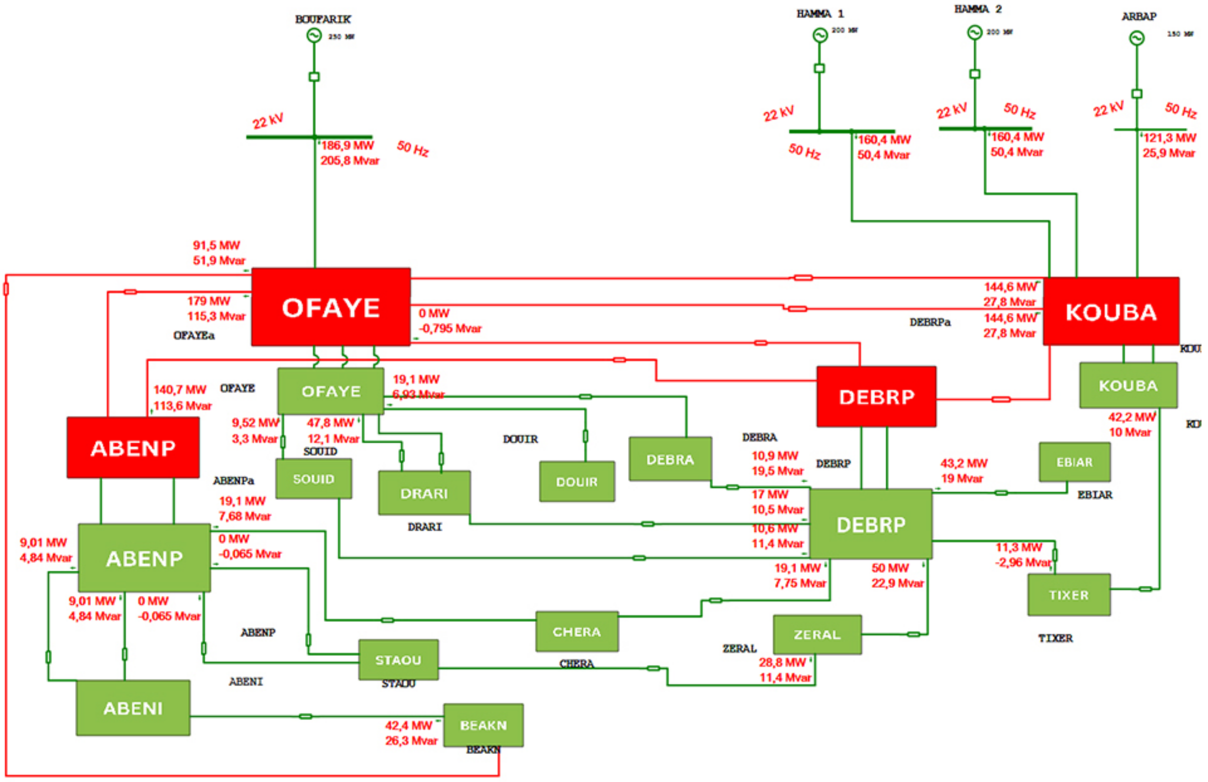


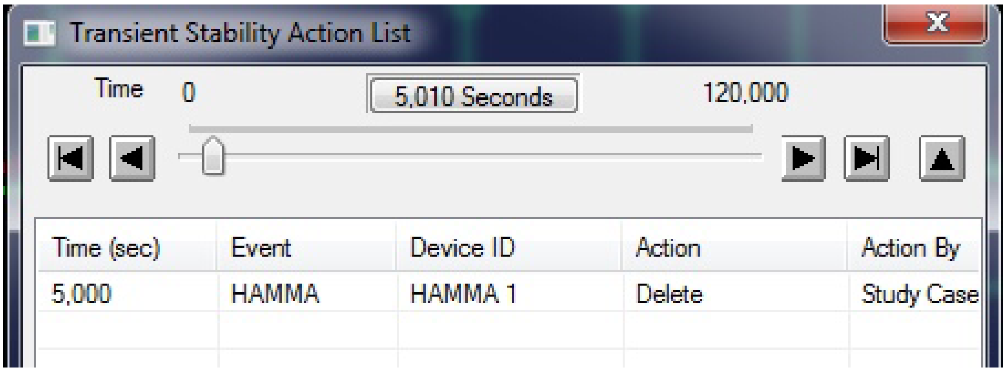
Figure 4.26: The power flow between substations after applying the solution.

Table 4.8: Power Flow between substations after the failure of the line and applying the solution.

LINES	**MW**	**MVAR**
ABENI-ABENP	9.02	4.84
ABENI-ABENP2	9.02	4.84
ABENP-CHERA	19.1	7.68
ABENP-STAOU	0	0.065
ABENP-STAOU2	0	0.065
BEAKN-OFAYE	42.4	26.1
CHERA-DEBRP	19.1	7.72
DEBRA-DEBRP	10.4	14.8
DRARI-DEBRP	10.6	11.4
EBIAR-DEBRP	43.2	18.9
KOUBA-ARBA	120.2	22.2
KOUBA-HAMMAI	160.3	45
KOUBA-HAMMA2	160.3	45
KOUBA-OFAYE	144.7	21.7
KOUBA-OFAYE2	144.7	21.7
KOUBA-TIXER	40.8	8.58
OFAYE-ABENP	175.7	104
OFAYE-BOUFARIK	185.2	200.6
OFAYE-DEBRP	41	6.44
OFAYE-DRARI	47.7	9.31
OFAYE-SOUID	9.53	3.29
SOUID-DEBRP	10.6	11.4
STAOU-ZERAL	28.8	11.3
TIXER-DEBRP	9.96	4.26
ZERAL-DEBRP	28.8	11.3

4.3.2 Generator failure

The failure of the generator (Hamma 1) is set at t=5s :



Transient Stability Action List

Time 0 5,010 Seconds 120,000

Time (sec)	Event	Device ID	Action	Action By
5,000	HAMMA	HAMMA 1	Delete	Study Case

Figure 4.27: time and events in the system.

- The output power of the generators is shown in the figures below:

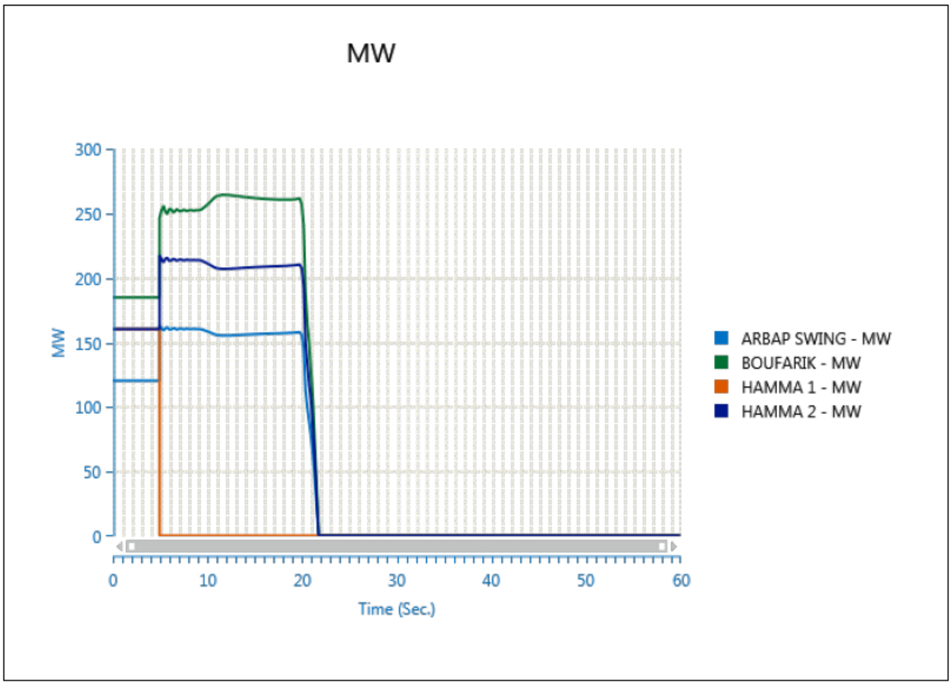


Figure 4.28: Real Power of Generators after (HAMMA1) Failure.

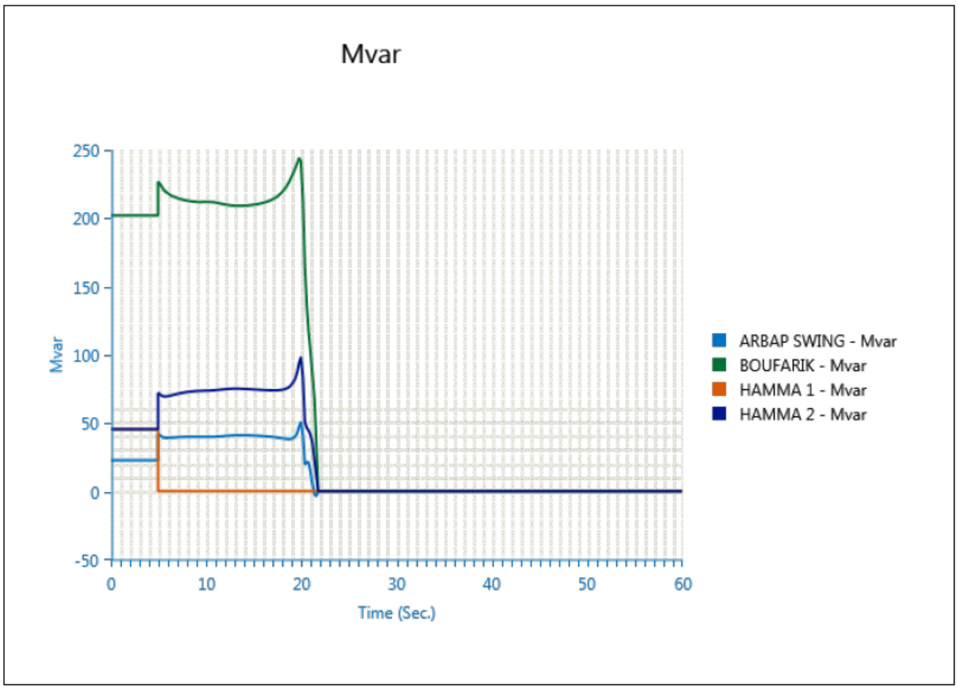


Figure 4.29: Reactive Power Generators after (HAMMA1) Failure.

- After the generator HAMMA 1 fails, the system will lose its stability because of unbalance $Generation < Demand$, and the remaining generators can not feed 612.9 MW of load.

- The frequency of the system after the incident is shown in the figure below :

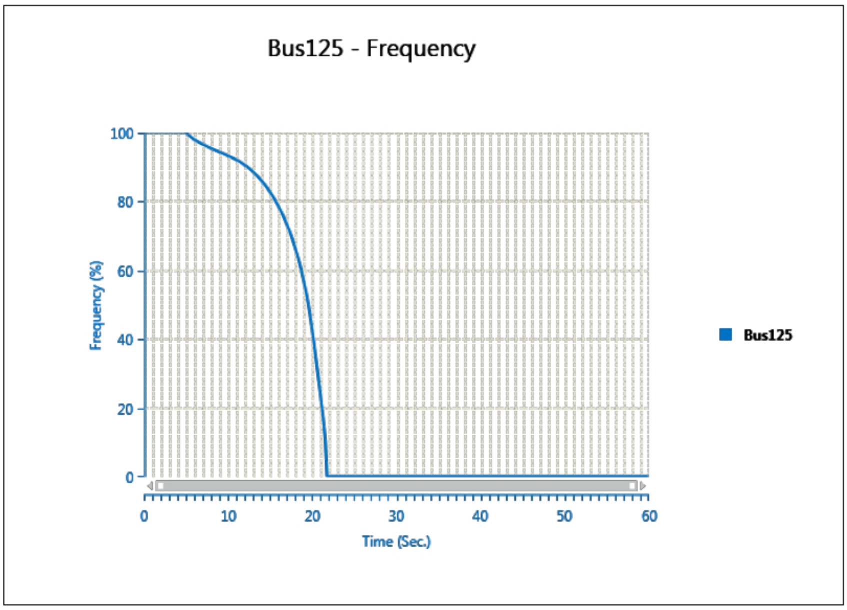


Figure 4.30: The Frequency of the System after Failure.

Preventive solution to maintain stability in case of failure of a generator.

The solution provided to prevent the system from losing stability that leads to a total blackout in the system is by making a preventative solution to the failure of any of the generator. The system has 4 generators working with 80% of their capacities (20% of power reserve) as Sonelgaz

Table 4.9: Generators rating, operating and reserve power.

Generator	**Rating (MW)**	**Operating power (MW)**	**Reserve power (MW)**
BOUFARIK	250	186.5	63.5
HAMMA 1	200	160	40
HAMMA 2	200	160	40
ARBA	150	120	30

- Total operating power = 626.5 MW
- Total reserve power = 173.5 MW
- Total load = 612.9 MW

- The failure of any of the generators will lead to :

Table 4.10: Power shedded from the system and the remaining reserve after the failure of each generator.

Failure	**Generated power shedded from the system (MW)**	**Remaining reserve power in the system (MW)**
HAMMA 1	160	133.5
HAMMA 2	160	133.5
ARBA	120	143.5
BOUFARIK	186.5	110

- A failure of any generator with operating power less than the remaining reserve power in the system after its failure will lead to an unbalance *Generation* $<$ *Demand* and this will lead to a total blackout.

- The solution of this problem is done by :

1- Dividing the capacity of each generator to multiple generators

Table 4.11: Generators rating, operating and reserve power after applying the solution.

Generator	**Rating (MW)**	**Operating power (MW)**	**Reserve power (MW)**
BOUFARIK 1	50	40	10
BOUFARIK 2	50	40	10
BOUFARIK 3	50	40	10
BOUFARIK 4	50	40	10
BOUFARIK 5	50	25.1	24.9
HAMMA 1	50	40	10
HAMMA 2	50	40	10
HAMMA 3	50	40	10
HAMMA 4	50	30.9	19.1
HAMMA 5	50	40	10
HAMMA 6	50	40	10
HAMMA 7	50	40	10
HAMMA 8	50	30.9	19.1
ARBA 1	50	40	10

ARBA 2	50	40	10
ARBA 3	50	25.8	24.2

2. Use renewable energy sources to feed multiple substations according to their location :

- For substations in cities higher than 600 ft (BEAKN, DEBRA, DRARI) we use wind turbines with total capacity of 5 MW in each substation.

- For other substations (ABENI, ZERAL, STAOU) we use solar energy PV sells with total capacity of 5 MW in each substation.

- After applying the solution :

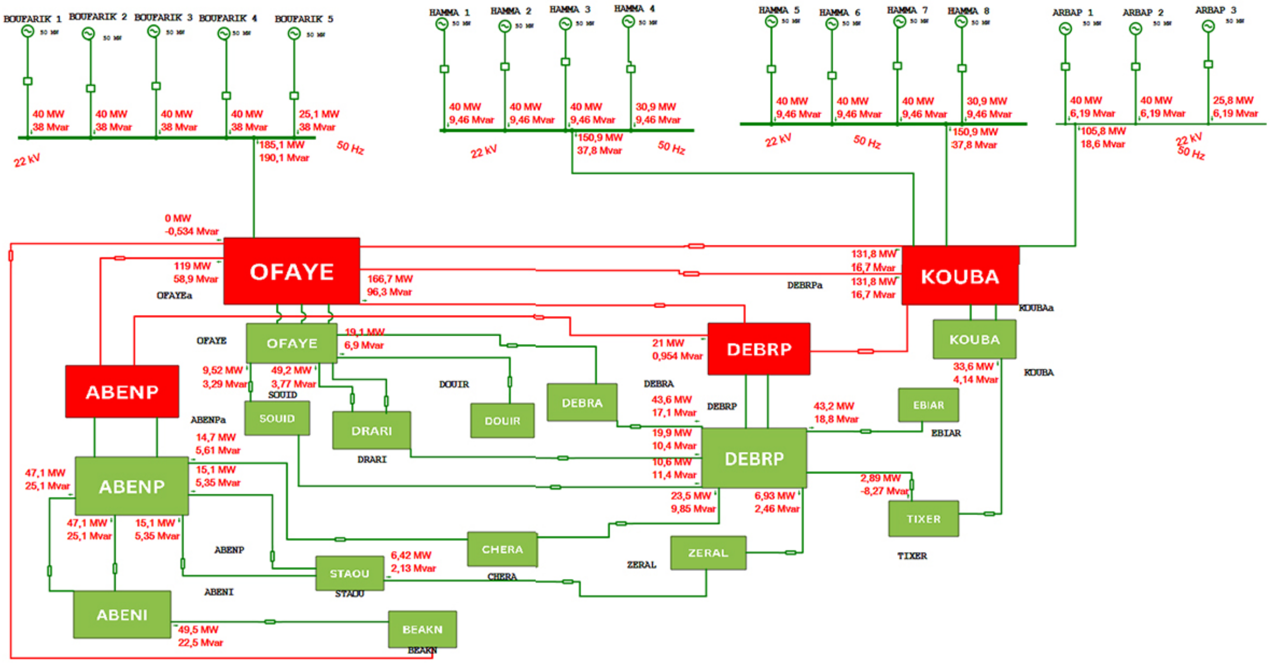


Figure 4.31: The power flow between substations after applying the solution.

- Total generated power by generators = 592.7 MW
- Total generated power by wind turbines and PV sells = 30 MW
- Total reserve power = 207.3 MW

- Losses = 9.8 MW
- Total load = 612.9 MW

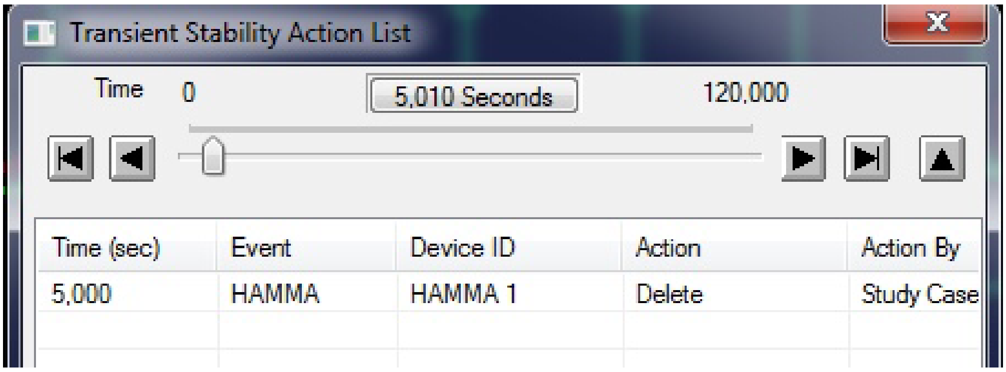
- A failure of any of the generators will result in:

Table 4.12: Failure Generated power shedded from the system and the remaining reserve power in the system (MW)

Failure	**Generated power shedded from the system (MW)**	**Remaining reserve power in the system (MW)**
BOUFARIK 1	40	197.3
BOUFARIK 2	40	197.3
BOUFARIK 3	40	197.3
BOUFARIK 4	40	197.3
BOUFARIK 5	25.1	182.4
HAMMA 1	40	197.3
HAMMA 2	40	197.3
HAMMA 3	40	197.3
HAMMA 4	30.9	188.2
HAMMA 5	40	197.3
HAMMA 6	40	197.3
HAMMA 7	40	197.3
HAMMA 8	30.9	188.2
ARBA 1	40	197.3

ARBA 2	40	197.3
ARBA 3	25.8	183.1

- The system can resist for the failure of any generator :



Time 0 5,010 Seconds 120,000

Time (sec)	Event	Device ID	Action	Action By
5,000	HAMMA	HAMMA 1	Delete	Study Case

Figure 4.32: time and events in the system.

- Power shedded from system = 40 MW
- Remaining reserve power in the system = 207.3 – 10 = 197.3 MW

- Power shedded from system (MW) <Remaining reserve power in the system (MW)

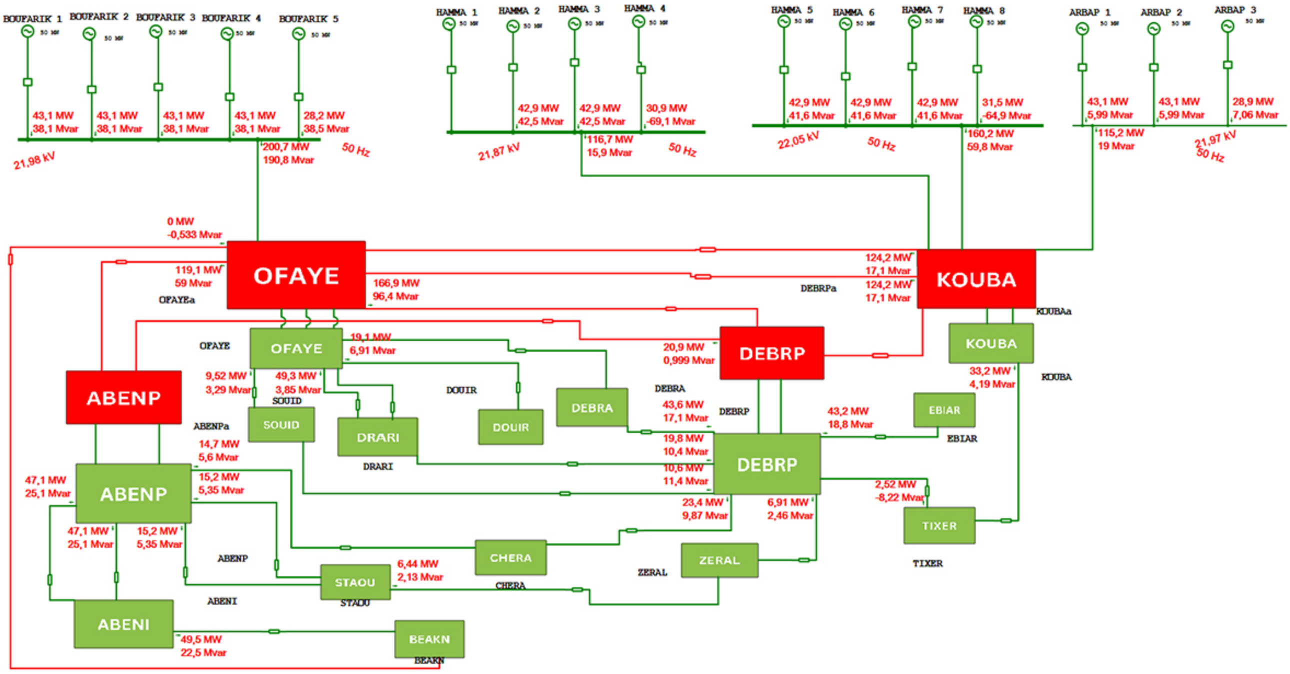


Figure 4.33: The power flow between substations after applying the solution.

- The power generated by generators after the failure :

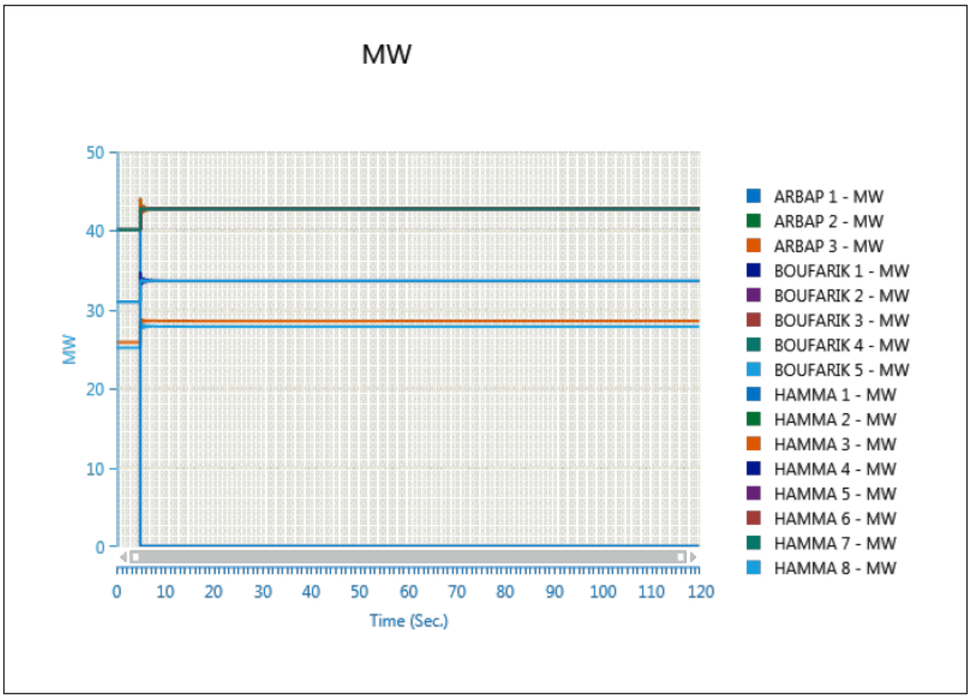


Figure 4.34: Real Power of Generators after (HAMMA1) Failure with solution

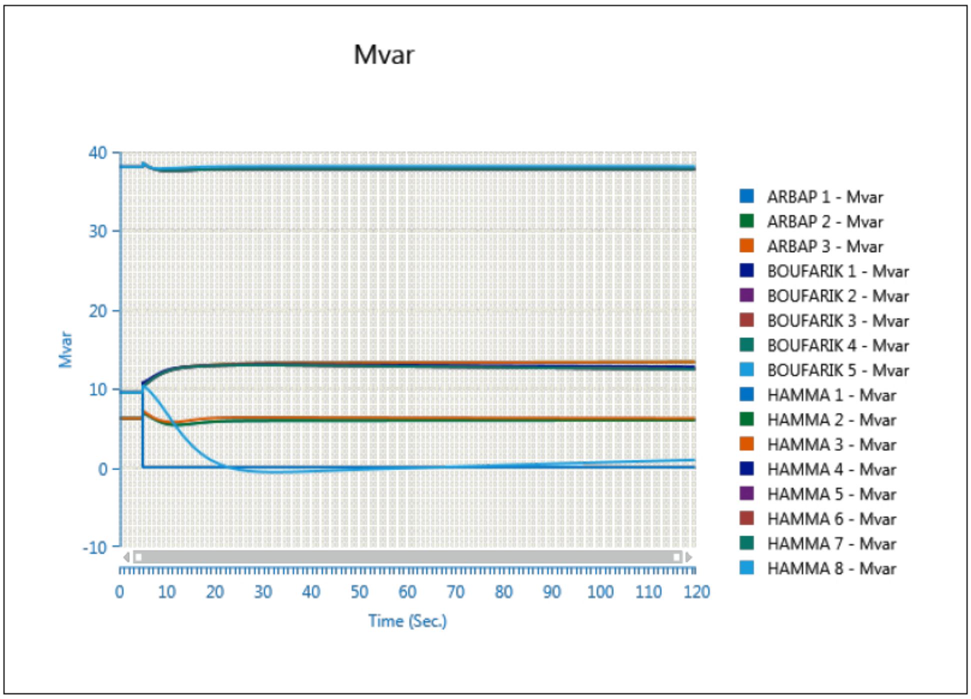


Figure 4.35: Reactive Power of Generators after (HAMMA1) Failure with solution.

- The frequency decreases by 0.55% or 0.275 Hz for 40 MW of generated power shedded from the system.

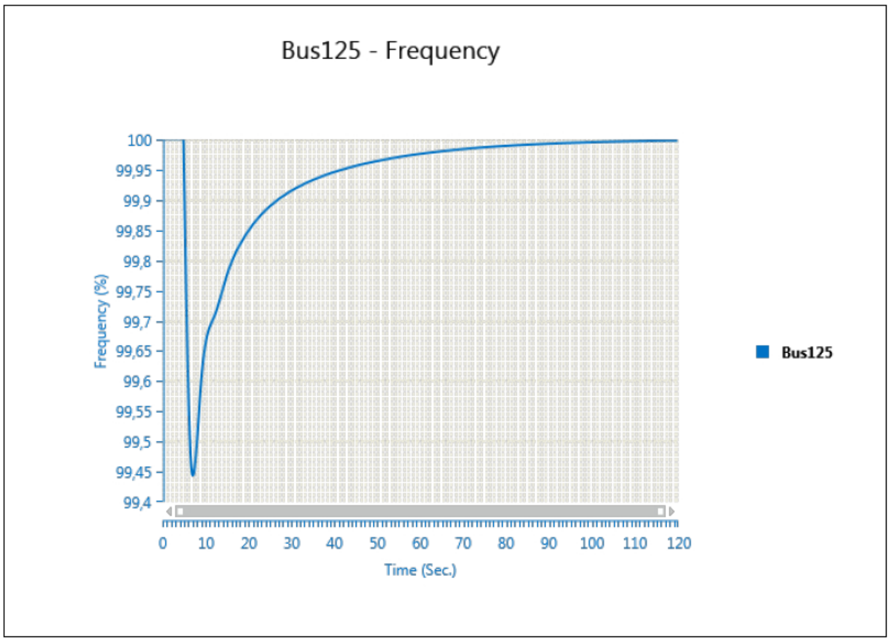


Figure 4.36: The Frequency of the System after Solution.

- The voltage at the terminal bus of the generator decreases to 218.1kV and regulated rapidely :

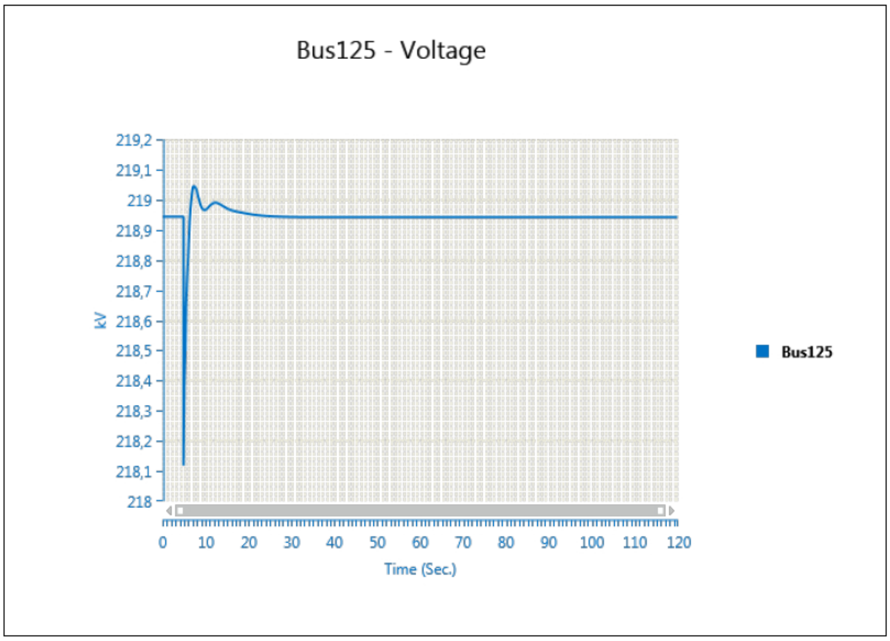


Figure 4.37: The Voltage at the terminal bus of the generator after the failure.

Chapter 5

General Conclusion

The project aimed at enhancing the electrical network in West Algiers, carried out with OS Sonelgaz Dispatching, represents a significant advancement in ensuring a stable and resilient power supply. The network, designed to operate as an islanded system, incorporates several strategic schematic solutions to maintain uninterrupted power and avoid blackouts. The key enhancements implemented include:

Directional Flow Change with Relay Activation: The ability to change the direction of electricity flow is crucial for maintaining network stability. Relays that detect faults instantaneously trigger the connecting of alternate lines and substation couplings. This immediate response ensures that the system adapts dynamically, maintaining continuous power supply without any loss.

Substation Coupling Management: By opening couplings in multiple substations upon fault detection, the loads of each substation are separated so generators can share the total load effectively. This segmentation allows the network to continue operating normally, enhancing overall system stability.

Instantaneous Fault Detection and Response: The integration of advanced relays ensures rapid fault detection and response. These relays open alternate pathways and couplings instantly upon detecting a fault, minimizing downtime and maintaining the integrity of the power supply.

Strategic Division of Generators: Dividing four primary generators (Hamma 1, Hamma 2, Arbaa, and Boufarik) into 16 smaller units has provided greater flexibility and resilience. This modular configuration allows for efficient load management and redundancy, ensuring that power supply is maintained even if several generators experience issues.

Incorporation of Renewable Energy: The addition of renewable energy sources such as wind and solar cells has significantly enhanced the system. These renewable sources contribute to the overall power supply, reduce dependency on traditional generators, promote a more sustainable energy mix and reduce the power losses in transmission lines.

Continuity of Service in Substations: As a result, the continuity of service in substations is achieved without any disruptions in case of failures. This ensures reliable power delivery even when individual components face issues.

Avoidance of Summer Overloads: The summer disruptions caused by overloads are avoided. By enhancing the network's capacity and flexibility, the system can handle peak loads more effectively, preventing outages during high-demand periods.

Under-Frequency Management: In case of generator failure, the under-frequency duration is about 5 seconds, but its value remains within the allowed limit and is regulated quickly and successfully. This ensures that frequency deviations are minimized and corrected promptly, maintaining system stability.

Economic Benefits: By avoiding blackouts and ensuring continuous power supply, the project has resulted in significant cost savings. The prevention of power outages reduces economic losses for businesses and improves overall efficiency, thus saving a considerable amount of money.

In conclusion, the enhancement of the electrical network in the West of Algiers marks a substantial improvement in ensuring reliable and resilient power supply. Through the strategic use of relays for fault detection and response, directional flow changes, substation coupling management, the division of generators, and the incorporation of renewable energy sources, the network is well-equipped to handle faults efficiently and effectively. These schematic solutions collectively ensure a stable and reliable power supply for residents and businesses in the West of Algiers, avoiding blackouts, preventing summer overloads, and resulting in significant economic benefits.

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