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Filière : **Electrotechnique**

Spécialité : **Traction électrique**

## Thème :

# Study and Sizing of the Algiers Metro's Third Rail Power Supply

Présenté par :

TOUMINE Ahlem

Encadré (e) par : Dr. BENACHOUR Ali

Co-encadré(e) par : Ing.MEHAL Sofiane

Soutenu publiquement, le :30/06/2022, Devant le Jury composé de :

| | | |
|---|---|---|
| Dr. Lazhar ROUBACHE : | ESSA-Alger | Président |
| Dr. AISSIOU Mohamed : | ESSA-Alger | Examinateur |
| Dr. Ali BENACHOUR : | ESSA-Alger | Encadreur |
| Ing. Sofiane MEHAL : | COLAS RAIL | Co-Encadreur |

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# Dedication

“

*I dedicate my dissertation work to my family and Me.djeroud . A special feeling of gratitude to my loving father and mother, whose words of encouragement and push for tenacity ring in my ears. My sisters Besma , imen,and my niece Loulou,to my two little brothers youcef and younes. I also dedicate this dissertation to my brothers Hamza and Ahmed who have supported me throughout the process. I will always appreciate all they have done.*

”

**- *Ahlem***

# Acknowledgement


“

*In the name of Allah, the Most Gracious and the Most Merciful Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this project.*

*I would like to express my deepest and sincere gratitude to my project Supervisor **Dr. BENACHOUR Ali** . It was great a privilege and honor working studying under your supervision. And many thanks to all personals in **Colas rail Algeria** consultant office especially my co-supervisor **Mr MEHAL Sofiane** whom I can't thank enough, without you this work wouldn't have come to light. Thanks ever so much!! Last but not least, I am infinitely grateful to my family members, particularly my parents for their patience, unwavering support, continuous encouragement, and belief in me throughout my whole life. I would have never made it this far without them beside me every step of the way. Finally, a special thanks go to all **ESSA-Alger** Community. **Algiers Higher School of Applied Sciences***

”

**abstract**

The objective of this thesis is to study the system of the Algiers metro extension C's third rail power supply between HAI EL BADER and AIN NAADJA, high voltage and traction cables using **NF13-200** , **NF15-105** and **NF13-205** and other standards also the mitigation of the stray current induced corrosion.

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**Keywords : cable sizing, third rail, Traction, standards**

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**ملخص**

الهدف من هذه الاطروحة هو دراسة نظام السكة الحديدية الثالثة لمترو الجزائر للامتداد C من حي البدر الى عين النعجة و كذا امداد كابلات الجهد العالي و معايير اخرى. أيضا دراسة التخفيف من التآكل NF15-105/NF13-205/NF13-200 و الجر باستخدام المعايير الناجم عن ظاهرة التيارات الضالة.

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**الكلمات المفتاحية: تحجيم الكابلات ، السكة الثالثة ، الجر ، المعايير**

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**Résumé**

L'objectif de cette thèse est d'étudier le système d'alimentation électrique du troisième rail du métro d'Alger de l'extension C entre HAI EL BADER et AIN NAADJA, le dimensionnement des câbles haute tension et de traction en utilisant les normes **NF13-200**, **NF15-105** et **NF13-205** et d'autres normes aussi. ainsi que l'atténuation de la corrosion induite par les courants vagabonds.

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**Mots clés : dimensionnement des câbles, Le troisième rail, Traction, Normes**

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# Liste des sigles et acronymes

| | |
|---|---|
| **PHT** | *Post Haute Tension* |
| **PR** | *Post de redressement* |
| **PEF** | *Post d'Eclairage Force* |
| **HV** | *High Voltage* |
| **SF6** | *Sulfur Hexafluoride* |
| **PCE** | *Poste de Commande Energie* |
| **HMI** | *Human Machine Interface* |
| **PMA** | *Poste Manoeuvre Atelier* |
| **AIN** | *Station Ain Naadja* |
| **GDC** | *Gué de Constantine* |
| **RMS** | *Reseau Multi Service* |
| **PLC** | *Programmable Automation controllers* |
| **CT** | *Cellule de Terre* |
| **CCP** | *Cellule Coupon de Protection* |
| **AHT** | *Autorisatiob Haute Tension* |
| **RU** | *Rupteur d'Urgence* |
| **SIA** | *Sectionneur d'Isolement Automatique* |
| **DUR** | *Disjoncteur Ultra-Rapide* |
| **DUR C** | *Disjoncteur Ultra-Rapide de Couplage* |

| | |
|---|---|
| **CSPN** | *Cellule Surveillance Potentiel Négatif* |
| **PT3** | *Cellule départ Transformateur Traction* |
| **PT4** | *Cellule départ Transformateur Auxiliaire* |
| **CRN** | *Cellule de Retour Négative* |
| **DDT** | *Détecteur De Tension* |
| **TRT** | *Transformateur de Traction* |
| **TRSA** | *Transformateur des services auxiliaire* |
| **CMP** | *Coffret de Mise en Parallèle* |
| **DC** | *Direct current* |
| **TSA** | *Tableau service auxiliaire* |
| **TGBT** | *Tableau Général Basse Tension* |
| **GIS** | *Gas insulated switchgear* |
| **SCCS** | *Stray Current Collection System* |
| **TSS** | *Traction Supply System* |

# General Introduction

Electric traction has become increasingly important for the collective transport of people and goods, and has undisputed advantages in areas where levels of performance , economy of service must be guaranteed ,such as the rapid transit of urban and sub urban populations. One of the major advantages of electric traction is pollution free atmosphere to the surrounding environment. The electric traction is proven to be less pollutant than the existing diesel mode.[1]

A railway electrification system supplies electrical energy to railway locomotives and multiple units in order to operate without having an on-board prime mover. There are several providers of traction power in electrified rail systems throughout the world such as cateneries,third rail and fourth rail.

About half of the worldwide railway systems uses DC traction substations which causes the circulation of high currents. Therefore in a normal DC traction system there are always a significant percentage of stray currents which flow through the earth out of the rails, because the isolation level of the railway running rails is quite high, but not infinite ,Stray currents leak into the earth until they finally emerge at the negative return of the substation. The main effect of the leakage currents in DC systems is the degradation of metallic infrastructures.

From 31/01/2022 to 31/05/2022, I accomplished an internship at COLAS RAIL Algeria company. the objective is to study and sizing the power supply of the third rail that feeds the Algiers metro also to develop solutions used to reduce and collect the stray current at the extension C between HAI EL BADER and AIN NAAJA.

This work is divided in 4 main chapters as follow

- The first chapter is an introduction to the electrical traction with some historical study. It contains also a presentation of colas rail company in the traction sector.
- The second chapter describes the power supply of the third rail and the traction line.
- The third chapter describes and performs cable sizing from the high voltage substation to the rectifier unit (using the **NF13-200** standard ), traction cables (using the **NF15-105** , **NF13-200** standards )And the low voltage cables using Caneco bt that is conformed with the **NF15-100** standard .
- The fourth chapter introduce the problem of stray current definition , consequences , solution and measuring and all these sections are based on **EN 50122-2**, **EN 50122-1** and **EN 50162** standards.

# Chapter 1

# Introduction to Electrical Traction Systems

## 1.1 Introduction

Despite the competition of airplanes, buses, trucks and cars, trains still play a major transportation role in society, filling specific markets such as traction and non-traction trains. There are a lot of companies in competition in this domain especially in traction feeding system such as colas rail. This chapter is an introduction to electrical traction systems and it is as follows :

- The second Section presents a historical development of electrical railwaying and the railway electrification systems.
- The third section introduces the third rail electrification systems,description , history and a comparison with the other systems.
- The fourth section is about the DC traction system.
- The fifth section describes colas rail company and its projects in Algeria and finally a conclusion.

## 1.2 Historical development of electrical railwaying

begin with the wooden tracks in the shape of mining railways: wooden lorries, operating on wide wooden rails and guided by a track nail between the two rails. By the middle of the $18^{th}$ century, coal-mining companies in England replaced the wooden tracks with iron ones, guidance was achieved by angle irons affixed to the outside of the track.[2]

In 1804, F. Trevithick used Watt's high-pressure steam engine on a rail-bound vehicle for the first time: the steam locomotive was born(**figure1.1**). From 1810 on wards, such locomotives were in widespread service in coal mines. In 1825, the very first public transport railway was established between Stockton and Darlington in North-East England.[2]

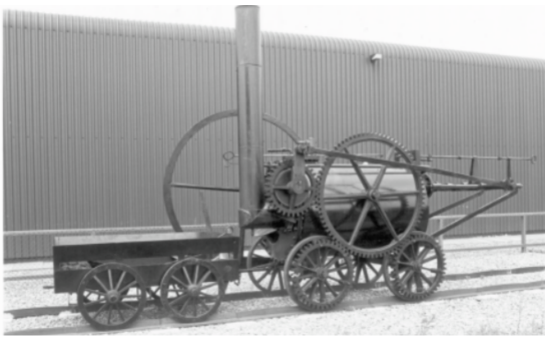


Figure 1.1: The first steam locomotive.


Figure 1.2: First electric locomotive by W. v Siemens, Berlin.

In 1879, Siemens displayed the first electrically powered locomotive (**figure1.2**) at the Berlin Commerce Fair. It was used for transporting visitors on the Fairgrounds and operated on a direct current (DC) motor of 2.2 kilowatts continuous output, which was fed from a current-carrying rail placed between the two main rails, which in turn re-routed the current from the engine to the generator. From 1882 onwards, this direct-current propulsion system was applied to tramways and mining railways, with power being usually supplied through an overhead contact line The first fully electrified railway was opened in 1895 by the Baltimore and Ohio RR in the United States of America: a five-kilometer city tunnel was electrified using a 675 Volt overhead system. The commutator bar voltage, however, limited maximum working voltage to about 750 Volt by the turn of the century.[2]

1908 saw the advent of the diesel locomotive(**figure1.3**), designed by R. Diesel and the Sulzer company of Switzerland. It yielded 1500 hp using a direct drive without gearing or clutch. Due to difficulties of starting up a heavy train using compressed air carried on board, this new technology first proved unsuccessful. Only in the 1930s, the success of the Electro-Motive Division of General Motors in introducing diesel-electric drive technology in the U.S. and the introduction of the hydraulic flow converter in Germany allowed for economical use of the diesel motor in railway traction.[2]

Figure 1.3: Diesel locomotive.

Figure 1.4: First diesel-electric locomotive.

In 1971, the first successful diesel-electric locomotive(**figure1.4**) with three-phase drive technology, produced by BBC and Henschel took up operations. Frequency converters are now allowed (by variable frequency/variable amplitude feed) to employ the robust squirrel-cage induction motors in place of the cost- and maintenance-heavy commutator motors. In 1979, three-phase drive technology was applied to overhead-system locomotives in the shape of the first high-performance universal locomotive, the class 120 of the DB (Deutsche Bundesbahn).[2]

Ever since 1990, this technology is the general standard for high-speed trains and heavy and/or fast goods trains as well as most commuter service railways. maglev, also called magnetic levitation train or maglev train(**figure1.5**), a floating vehicle for land transportation that is supported by either electromagnetic attraction or repulsion. Maglevs were conceptualized during the early 1900s by American professor and inventor Robert Goddard and French-born American engineer Emile Bachelet and have been in commercial use since 1984, with several operating at present and extensive networks proposed for the future.[3]

Figure 1.5: Meglev.

Figure 1.6: Coradia ilint.

In 2016 in Berlin Alstom presented the Coradia iLint for the first time(**figure1.6**). The launch of the CO2-emission-free regional train that represents a true alternative to diesel power positioned us as the first railway manufacturers in the world to develop a passenger train based on hydrogen technology. And just two years later, at 2018, the iLin entered into commercial service in Germany.[4]

## 1.3 Advantages and disadvantages of traction systems

The following statements list some advantages and disadvantages of electric traction when compared to diesel traction.

### 1.3.1 Advantages

- Preservation of limited oil reserves.
- Usability of hydroelectric power and low-yield coal.
- Environment-friendly operation, lower noise.
- Possible overload of electrical machinery can be utilized.
- Lower maintenance cost.
- Higher number of operational hours due to easier maintenance and no need for preheating the engine.
- Possibility of energy recovery when braking, less wear of brake shoes (especially for three-phase drives)
- Higher partial efficiency (nominal efficiency off primary energy source is comparable).[2]

### 1.3.2 Disadvantages

- High initial cost for catenaries and power-supply network.
- Problem of supply failure.

- The electrically operated vehicles have to move on guided track only.
- it produces electromagnetic interference with the neighboring telecommunication lines.[5]

## 1.4 Railway electrification systems

A railway electrification system supplies electrical energy to railway locomotives and multiple units so that they can operate without having an onboard prime mover. There are several different electrification systems in use throughout the world and are classified by three main parameters:

### 1.4.1 Direct current(DC)

Early electric systems used low-voltage DC. Electric motors were fed directly from the traction supply and were controlled using a combination of resistors and relays that connected the motors in parallel or series. The most common DC voltages are 600 V and 750 V for trams and metro. During the mid-20th century, rotary converters or mercury arc rectifiers were used to convert utility (mains) AC power to the required DC voltage at feeder stations. Today, semiconductor rectifiers usually do this after stepping down the voltage from the utility supply. The DC system is quite simple but it requires thick cables and short distances between feeder stations because of the high currents required.[6]

### 1.4.2 Alternating current (AC)

Alternating current can be transformed to lower voltages inside the locomotive. This allows much higher voltages and therefore smaller currents along the line, which means smaller energy losses along long railways.[6]

### 1.4.3 standardized voltages

Six of the most commonly used voltages have been selected for European and international standardization**(Table1.1)**. These are independent of the contact system used, so that, for example, 750V DC may be used with either third rail or overhead lines.

There are many other voltage systems used for railway electrification systems around the world, and the list of current systems for electric rail traction covers both standard voltage and non-standard voltage systems.

The permissible range of voltages allowed for the standardized voltages is as stated in standards **EN 50163** and **IEC 60850**. These take into account the number of trains drawing current and their distance from the substation.[6]

Table 1.1: Standardized voltages.[6]

| Electrification system | Lowest non-permanent voltage | Lowest permanent voltage | Nominal voltage | Highest permanent voltage | Highest non-permanent voltage |
|---|---|---|---|---|---|
| 600 V DC | 400 V | 400 V | 600 V | 720 V | 800 V |
| 750 V DC | 500 V | 500 V | 750 V | 900 V | 1 KV |
| 1500 V DC | 1000 V | 1000 V | 1500 V | 1800 V | 1950 V |
| 3 KV DC | 2 KV | 2 KV | 3 KV | 3 KV | 3 KV |
| 15KV AC 16.7 Hz | 11 KV | 12 KV | 17.25 KV | 17.25 KV | 18 KV |
| 25 KV AC 50 Hz | 17.5 KV | 19 KV | 27.5 KV | 27.25 KV | 29 KV |

# 1.5 Contact system

## 1.5.1 Overhead lines

Overhead lines or overhead wires are used to transmit electrical energy to trams, trolley-buses, or trains at a distance from the energy supply point. Overhead line is designed on the principle of one or more overhead wires or rails situated over rail tracks, raised to a high electrical potential by connection to feeder stations at regular intervals. The feeder stations are usually fed from a high-voltage electrical grid. Electric trains that collect their current from an overhead line system use a device such as a pantograph(**figure1.7**), bow collector (**figure1.8**), or trolley pole(**figure1.9**). The device presses against the underside of the lowest wire of an overhead line system. The current collectors are electrically conductive and allow current to flow through to the train or tram and back to the feeder station through the steel wheels on one or both running rails.[7]

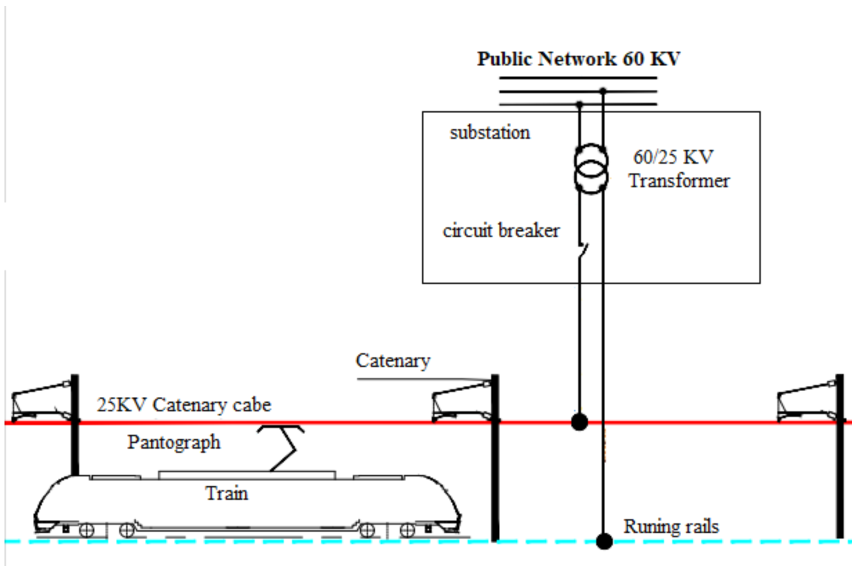



Figure 1.7: Catenary system.

Figure 1.8: Bow collector system.

Figure 1.9: Trolley pole system.

### 1.5.2 Third rail

Third tail is a method of providing electric power to a railway train, through a continuous rigid conductor placed alongside(**figure1.10**),or between the rails of a railway track. It is used typically in a mass transit or rapid transit system, which has alignments in its corridors, fully or almost fully segregated from the outside environment. In most cases, third rail systems supply direct current electricity.[7]

Figure 1.10: Algiers metro third rail.

### 1.5.3 Fourth rail

The fourth rail traction technology came to light as a post development of the third rail traction technology.
London Underground was the first to apply the fourth rail traction around 1903 to 1907 and it is still in use today. The prior additional rail in between the running rails (the fourth rail) now acts as a return path whereas the third rail is mounted outside of the running rails as it is shown in **figure 1.11** .

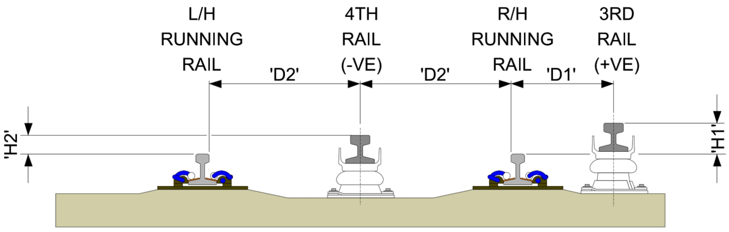



Figure 1.11: Fourth rail system.

# 1.6 The third rail

## 1.6.1 Description

Third rail systems are a means of providing electric traction power to railway trains, and they use an additional rail (called a conductor rail) for the purpose. On most systems, the conductor rail is placed on the sleeper ends outside the running rails, but in some cases, a central conductor rail is used. The conductor rail is supported on ceramic insulators or insulated brackets, typically at intervals of 10 feet (3 meters) or so. The trains have metal contact blocks called ”shoes” which make contact with the conductor rail. The traction current is returned to the generating station through the running rails. The conductor rail is usually made of high conductivity steel, and the running rails have to be electrically connected using wire bonds or other devices, to minimize resistance in the electric circuit. The conductor rails have to be interrupted at level crossings and crossovers, and ramps are provided at the ends of the sections to give a smooth transition to the train shoes. There is considerable diversity about the contact position(**figure1.12**) between the train and the rail. some of the earliest systems used top contact(less safe, as the live rail is exposed to people), but developments used side or bottom contact, which enabled the conductor rail to be covered, protecting track workers from accidental contact and protecting the conductor rail from snow and leaf fall.[7]

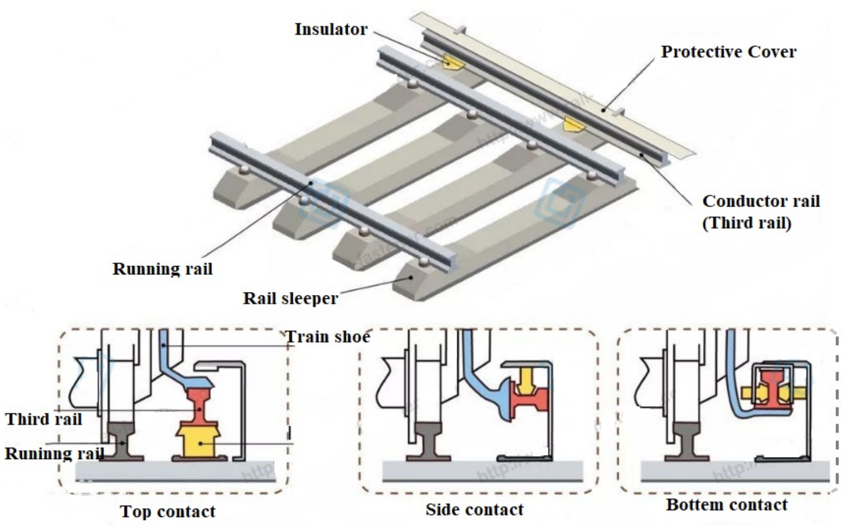



Figure 1.12: Third rail systems.

### 1.6.2 History

Third-rail electrification systems are, apart from on-board batteries, the oldest means of supplying electric power to trains on railways using their corridors, particularly in cities. An experimental electric train using this method of power supply was developed by the German firm of Siemens and Halske and shown at the Berlin Industrial Exposition of 1879, with its third rail between the running rails. Some early electric railways used the running rails as the current conductor, as with the 1883-opened Volk's Electric Railway in Brighton. The first railway to use the central third rail was the Bessbrook and Newry Tramway in Ireland, which opened in 1885 but now, like the Giant's Causeway line, closed. Also in the 1880s third-rail systems began to be used in public urban transport. Trams were first to benefit from it: they used conductors in conduit below the road surface, usually on selected parts of the networks. A third rail supplied power to the world's first electric underground railway, the City and South London Railway, which opened in 1890 . In 1893, the world's second third-rail-powered city railway opened in Britain, the Liverpool Overhead Railway . Main-line third rail electrification was later expanded to some suburban services.
Top contact third rail seems to be the oldest form of power collection. Railways pioneering in using other less hazardous types of the third rail were the New York Central Railroad on the approach to its NYC's Grand Central Terminal (1907 another case of third-rail mainline electrification), Philadelphia's Market Street Subway-Elevated 1907, and the Hochbahn in Hamburg 1912 all had bottom contact rail. However, the Manchester-Bury Line of the Lancashire and Yorkshire Railway tried side contact rail in 1917. The Hamburg SBahn has used a side contact third rail at 1200 V DC since 1939. In 1956 the world's first rubber-tyred railway line. This solution was modified on the 1971 Namboku Line of Sapporo Subway, where a centrally placed guiding/return rail was used plus one power rail placed laterally as on conventional railways.[7]

### 1.6.3 Comparison between the three traction providers

1. Overhead line

   - High catenary voltage implies lower currents ( means smaller conductor size) and smaller power losses,so fewer substations are required compared with lower voltage DC traction networks.
   - As the contact system is placed overhead, thus the voltage can be increased and the danger to personnel is greatly reduced .
   - It is not practical for tunnels.[8]

2. Third rail

   - The system similarly benefits from high reliability because it is fed on both sides by rectifiers from adjacent substations.
   - Third rail prefers DC as it can carry 41% more than an AC system operating same peak voltage and is more compact than overhead wire and be used in smaller diameter tunnels.

- Third rail systems are limited to relatively low voltage and allows only a limited amount of air conditioning on the train .

- Stray current are also possible , although improvements in technology are managing and controlling this factor. -rail systems are relatively cheap to install, compared to overhead wire

- Much less visual intrusion on the environment.

- Third rail systems using top contact are prone to accumulations of snow, and ice formed from refrozen snow, and this can interrupt operations.[8]

3. Fourth rail

- Fourth rail technology provided a solution to the stray current setback that third rail technology can not handle. The difference between fourth rail and third rail technology is that fourth rail refrains from using the running rails as its return circuit thus eluding the stray current issue. As those running rails are not insulated from the sleepers (the structures on which they are fixed to), that being so sets up a poor insulation from earth. This poor insulation permits a proportion of the traction return current to leak to earth hence the stray current.On the contrary, by making used of the fourth rail, its traction technology employs track insulated rail brackets or polymeric insulation the return current forces it to return through the appointed conductor.[8]

## 1.7 DC Traction system

In general all the traction systems power flow’s coming from the grid substation or the public network to the high voltage substation . A direct-current feeding system features a three-phase bridged silicon rectifier for conversion from alternating to direct current. Since the three-phase rectifier uses a 6-pulse system, it causes lower harmonics in the AC side and distortion in the voltage waveform, lowering the power quality. To reduce the harmonics, a more-modem rectifier design using a 12-pulse system featuring two sets of 6-pulse rectifying circuits, with AC input voltage phases 30° apart, connected in series or parallel, is used [9]. a contact system such as third rail or overhead line is used to provide energy to the traction motor after being converted to AC by an inverter inside the train. return back through the running rails .Figure 1.13 below presents the whole traction system.

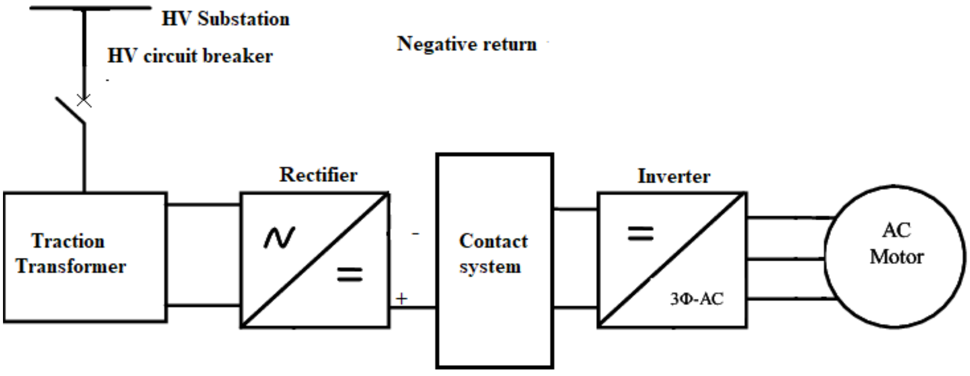



Figure 1.13: Traction system.

## 1.8 Colas rail company

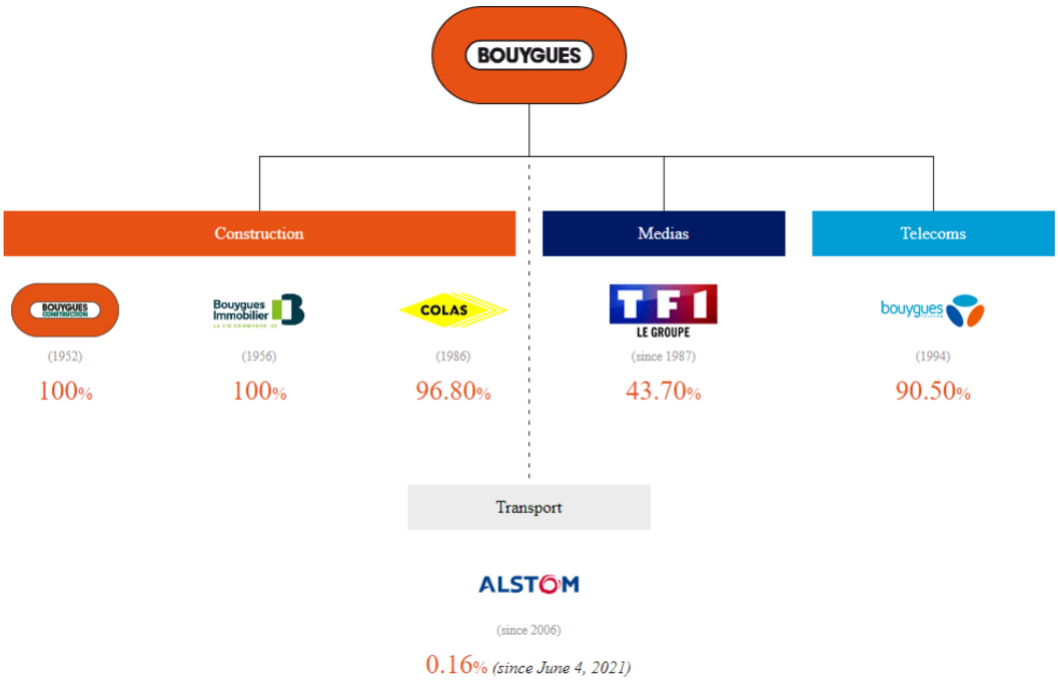



Figure 1.14: The filiales of Bouygues company.

Colas rail is a French public works company specializing in railway works, a wholly-owned subsidiary of the Colas Group (Bouygues Group)(**figure1.14**). It carries out projects in the fields of railways (tracks with and without ballast), electrification (sub-stations, catenaries), signaling, control, communications, electromechanical equipment, railway civil engineering, as well as rolling stock maintenance and infrastructure management activities. Its competencies cover all types of rail transport, from urban transport systems (metro, tram) to very high-speed lines.[10]

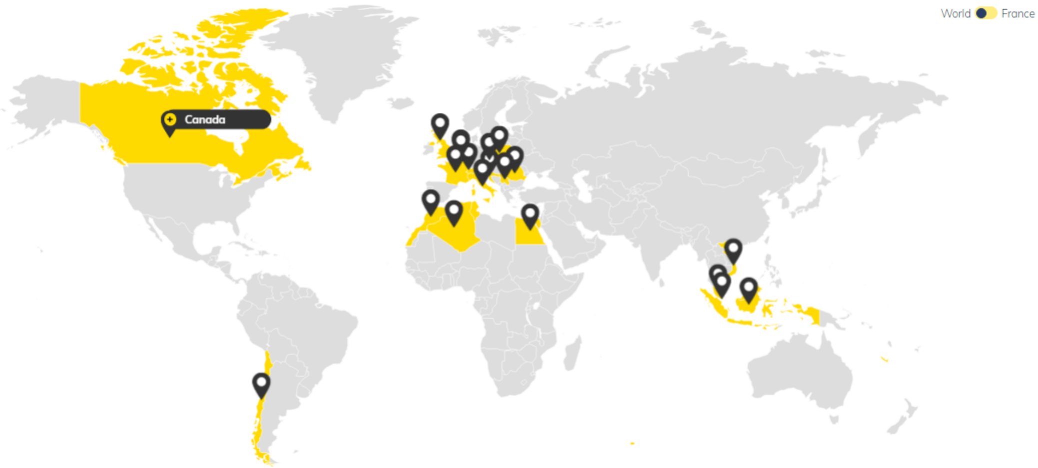



Figure 1.15: Colas rail in the world.

### 1.8.1 Colas Rail Algeria presentation

As part of the extension of the Algiers metro, Colas Rail, a subsidiary of the Colas Group (Bouygues) has won two contracts totaling 168 million euros (total share of Colas Rail: 86 million euros), in partnership with the Algerian public works company Kou.G.C. Colas Rail will carry out the works of railway, electrical supply, ventilation and smoke removal, low currents, and ticketing as well as the general coordination and system integration. The first contract of 117 million euros (Colas Rail share: 59 million euros), called "Extension C", consists in extending the existing metro line by 3.6 kilometers to the south and includes three new stations. The second contract, amounting to 51 million euros (Colas Rail share: 27 million euros), known as "Extension A", aims to extend the Algerian line by 1.7 kilometers to the north of the Algerian capital and includes two new stations in the heart of the old city, especially under the emblematic Place des martyrs. After the first Algerian contract was won in 2012 and successfully completed, these two contracts reinforce the local partnership with Kou.G.C. and place Colas Rail as the reference company and preferably the contracting authority EMA (Entreprise du Metro d'Alger) for full rail system projects.[10]

### 1.8.2 Major projects

1. Extension A of line 1 of Algiers metro:
   - Ali Boumendjel Station (SAB).
   - Place des Martyres Station (SPM) for a total of 107 Km.
2. Extension B of line 1 of Algiers metro:
   - Hai El Badr (HEB).
   - Bach Djerrah Tennis (BDT).
   - Bach Djerrah (BD).
   - Harrach Gare (HAR).

- Harrach Centre (HAC) for a total of 3.6 Km.

3. Extension C of line 1 of Algiers metro:

- les Ateliers Station (SAT)
- Gue de Constantine Station (GDC)
- Ain Naadja Station (AIN) ) for a total of 3.6 Km.[10]

## 1.9 Conclusion

This chapter introduce the electrical traction systems a presents the development of electric railwaying from the wooden track to the Meglev and hydrogen trains , different electrification systems in particularly the third rail its description , history and comparison with the other systems also the whole DC traction system was described. The main conclusions that can be drawn are the following:

AC traction system is preferred to be delivered via overhead wires as it has the capability of delivering a much higher voltage hence enabling it to operate long runs at a much higher speed or pulling heavier loads, on the flip side, DC traction system is preferred to be delivered through third rail as it has the advantage of carrying more power than an AC voltage operating at the same peak voltage. Third rail traction is a technology that resorts the issue of sleepers being an imperfect insulation when delivering the DC power through the running rails. Accordingly, stray current from a DC third rail is an inevitable consequence of using the running rails as the return path for the traction supply current.

Subsequently, a fourth rail traction technology came to light as a post development of the third rail traction technology, by providing another additional rail acting as the return path.

# Chapter 2

# Study of a 3rd Rail Power Supply

## 2.1 Introduction

Algiers metro is fed through a third rail contact system which is supplied by a rectifier unit that is fed from an HV substation, this system, is presented in the current chapter which is entitled ”Study of a third rail power supply” and includes two main sections.
The first section is about the high voltage substation,equipments and its Functioning in normal and degraded modes.
The second section presents the rectifier unit(PR) power supply,equipment and the traction network configuration. The system under study is the Algiers metro extension C (between Hai el Badr and Ain Naadja).
This extension extends over a length of approximately 3.6 km in double track. it includes two new rectifier units: PR 31 GUE DE CONSTANTINE(GDC)”T-shaped PR” and PR 32 AIN ANAADJA(AIN)”PR in double $\pi$”.

## 2.2 High voltage substation

Algiers Metro’s main source of energy is SONELGAZ’s network . The power delivery station is a PHT High Voltage Subtation. This energy required for the operation in each station, in the workshops , the traction line and distributed by an internal 30 kV HTA power network. This internal network is distributed as an antenna to the PR rectifier units and to the Workshops , and is distributed as a loop along the channels to supply the PEFs Force Lighting Stations (figure2.1)(appendixA.1).

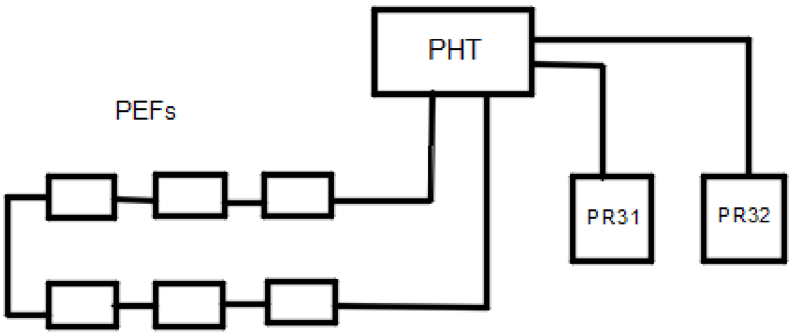



Figure 2.1: PRs and PEFs network distribution

### 2.2.1 The electrical installations in the high voltage substation

The main equipments of the PHT are :

- Gas Insulated Switchgear (GIS) type shielded equipment with SF6 .
- Two 60/30 kV power transformers of 31.5/45 MVA each one .
- 30 kV HV(heigh voltage) cell bridges.
- 30 kV cables.

### Gas insulated switchgear (GIS)

Gas insulated switchgear (GIS)(figure2.2) is a compact assembly of fully operational disconnectors, control and protection equipment, instrument transformers, earthing switches, interlocking and monitoring services in an earthed metal enclosure free from electric shock and external contaminations.
GIS technology is one of the major breakthroughs in the field of dielectrics for the modernization of the power sector due to its compactness and advanced features in addition to its high quality and reliability.
The introduction of SF6 in circuit breakers during the 1960s has shown excellent insulating features resulting in the construction of the first 550 kV GIS by the end of the 1980s . The demerits of air-insulated switchgear (AIS) such as inflated cost, large space occupancy, completely exposed to environment and climatic conditions, are removed with GIS making which the most suitable solution for the power sector.[11]


Figure 2.2: General view of the GIS

### GIS Components

it is composed of(appendixA.2) :

- 2×60KV arrivials (KOUBA and HAMMA).
- 2 Line and earthing electrical disconectors.
- 2×60 KV circuit breakers.
- Double busbar 60KV (annex shema pht et double jeux de bar).
- Busbar coupling circuit breaker.

- 2 circuit breakers Transformer protection.
- 2 Earthing disconnectoer.
- 2 Lightning disconectors.
- Current and voltage transformrs for protection and measuring .[12]

#### Key features and benefits of gas insulated switchgears

- High reliability and safety.
- Facilitates installation, maintenance and repair.
- Long operating range.
- Compact and modular.
- Sealed against aggressive environmental conditions and external contamination.
- Least failure with minimum maintenance and manpower.
- Anti-corrosion components.
- Seismic resistant.
- Up to 800 kV.
- Small volume.
- Less maintenance and good technical performance.
- Being a type of advanced high voltage electrical distribution equipment that is developing rapidly.**noauthor_notitle_nodate-1**

#### SF6

SF6 gas is colorless, odorless, non-flammable and of unreactive behavior with excellent dielectric strength, which makes it commercially popular for GIS . SF6 shows extraordinary arc quenching properties due to its higher electron affinity and being unfavorable to the growth of discharges that may lead to breakdown.
Although decomposition of SF6 gas is minimal under normal operating conditions, it decomposes to some extent in events such as partial discharge, sparking, or overheating and produces SF4, SF3, SF2, S2F10, etc., which are reactive in nature and produce toxic byproducts .
Unfortunately, SF6 has its greenhouse impact 23500 times higher as compared to carbon dioxide (CO2) and remains among strongest influencers of the global warming potential.[11]

### 60/30 kV Transformers

High voltage transformers convert voltages from one level or phase configuration to another, in the current case from higher to lower(60/30KV). the figure (2.3)shows the characteristics of one of the two power transformers located in the PHT.

| CARACTÉRISTIQUES DU TRANSFORMATEUR/**CARATTERISTICHE TRASFORMATORE** : | | |
|---|---|---|
| **QUANTITE' / QUANTITA' :** | N° | 2 |
| TYPE / **TIPO** : | | PO |
| SYSTEME DE REFROIDISSEMENT / **RAFFREDDAMENTO** : | | ODAF |
| PUISSANCE / **POTENZA** : | MVA | 31,5 |
| TENSION / **TENSIONI** : | kV | 60 ± 13 x 1,23077 % / 31 |
| FREQUENCE / **FREQUENZA** : | Hz | 50 |
| SYMBOLE DE COUPLAGE / **GRUPPO** : | | YNyn0 |
| CLIENT / **CLIENTE** : SIEMENS TRANSMISSION & DISTRIBUTION S.A. METRO D'ALGER - ALGERIA | | |
| ORDRE / **ORDINE** : OA NO. 712985 AVT 1 | | |

| MASSE ET PEINTURE / **PESI E VERNICIATURA :** | | |
|---|---|---|
| MASSE TOTALE / **PESO TOTALE** : | kg | 52000 |
| MASSE PARTIE ACTIVE / **PESO PARTE ATTIVA :** | kg | |
| MASSE HUILE / **PESO OLIO :** | kg | 11700 |
| **CYCLE DU VERNISSAGE / VERNICIATURA :** | | MEGA 1032 - RAL 7031 |

Figure 2.3: 60/30 kV Transformer nameplate

### 30 KV High voltage cell bridges.

It consist of :

- Arrivial cell (figure2.4).
- Lighting bridge cell (figure2.5).
- Traction bridge 1 (figure2.4).
- Traction bridge 2 .

Figure 2.4: Arrivial and traction bridges.


Figure 2.5: Lighting bridge.

### High Voltage Cables

The network of 30 kV cables from the P.H.T. supplies On one hand, the 750 V direct current electrical traction installations via the rectifier stations (PR) with a nominal power of 3.3 MVA. On the other hand, the lighting and motive power installations via lighting and power transformer stations (PEF).[12]

These cables comply with the **IEC 502 standard** for a specified voltage of 18/30 (36) kV. They are radial field and insulated with PRC Chemically Crosslinked

Polyethylene(figure2.6)[12] . The dimensioning of all these links are presented in the third chapter.

Figure 2.6: High voltage(30KV) cable

### 2.2.2 Functioning of the high voltage substation (PHT)

The H diagram (figure2.7)of the shielded substation allows the supply of the two transformers to be done either by two or one of the two SONELGAZ feeders each transformer is sized so that the entire high voltage network can be supplied in the event of the loss of a 60kV source or the shutdown of a transformer. Downstream of the two transformers, a link of 30 kV supplies :

1. One half bridge Arrival.
2. Two half bridges (Traction Bridge 1 and Traction Bridge 2).
3. one lighting half-bridge.

Each half-bridge is coupled to the other half , so each bridge can be fully supplied from either 60 kV source HAMMA or KOUBA. the rectifier units are supplied by antenna from the traction bridge while the PEF arteries are distributed on both sides of the EL ANASSSERS substations. A bridge reserved for the supply of the lighting bridge from the Generating Sets completes the HTA equipment.
Interdictions protected by interlocks will have to be respected during the various possible reconfigurations of the network from the PHT.
These prohibitions are :

- Prohibition to close simultaneously the circuit breakers that can put in parallel the two SONELGAZ sources.
- Prohibition to operate the disconnectors under load.

- of closing operation of earthing switches in case of voltage presence.
- Prohibition on re-energising a circuit with a closed earthing switch.
- The transfer of energy from one source station to another through the 60kV link busbars is also prohibited.
  However, in exceptional situations and in agreement with the SONELGAZ network manager, it will be possible to couple the two feeders via the DC coupling circuit breaker after source selection through the SB1 to SB4 disconnectors of the GIS.

The 60kV/30kV transformers operate simultaneously to ensure:

- The distribution of the load on both transformers so as to reserve the maximum overload capacity.
- The permanent supply of each of the two half 30kV bridges.

Each 60 kV/30 kV power transformer in the PHT will supply a half bridge Arrival, 2 half bridges Traction and a half bridge Lighting. The coupling circuit breakers will allow the loads of each of the half bridges to be split, or in the event of an incident on an incoming feeder, to couple the de-energised half bridge to the half bridge in service. The complete bridge will then be supplied by a single feeder (valid for each bridge in this case). In general, the protections systematically ensure the isolation of a faulty element. Any incident detected on a transformer leads to the opening of 60 kV and 30 kV circuit breakers. Any damage detected on a bus-bar leads to the opening of the circuit breaker supplying the faulty bus-bar. The 30 kV voltage is controlled by self-regulating relays. If necessary, the PCE can take over the manual control of the regulators. The independence of the substation units allows the substation to be operated independently of the consignments without degrading its safety and functionality[12].

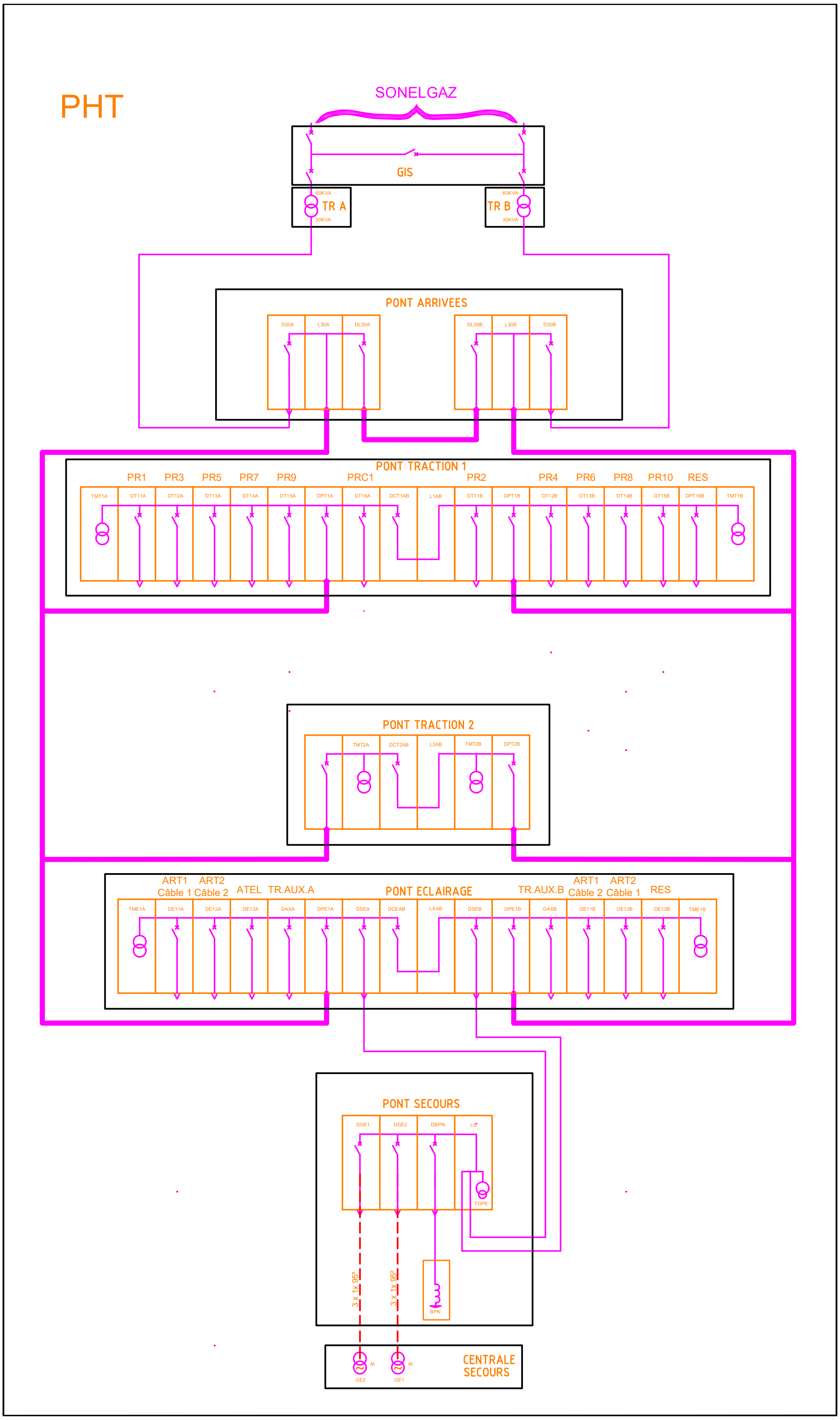



Figure 2.7: PHT diagramme.

### 2.2.3 High voltage network functioning

The high voltage network consisting of the PHT, PEF and PR(appendixA.1) has a ”Normal” operating mode, and degraded operating modes.
there 3 types of degraded mode:

1. Loss of a SONELGAZ source.
2. the stop or fault of a 60kV/30kV power transformer.
3. Minimal configuration during operation on the Backup Plant.

#### nominal operating

In normal operation (appendix A.3), all the coupling circuit breakers (DL30A or DL30B, DCT1A/B, DCT2A/B, DCEA/B, DSEA, and DSEB) on the PHT bridges are in the open position. The open-loop n°1 supplies energy to the PEFs of line 1 located at the North West of the El Anassers substation, the open-loop n°2 transports the electrical energy to the other PEFs of line 1 towards the PMA substation (Poste manoeuvre Atelier du Garage Atelier).[12]

#### Case of loss of a SONELGAZ arrival

In the event of the loss of a 60 kV source(appendix A.4), the H diagram of the G.I.S. will be reconfigured so that all bridges remain powered.
This arrangement allows all installations to remain energised and it allows checking the correct functioning of the whole metro installation in terms of electrical power, and to face the failure of any PR without affecting the line’s operation.
The loss of one of the two SONELGAZ feeders does not result in the automatic opening of the 60kV circuit breakers on the 60kV shortage. There are three possibilities for recovering nominal operation after this loss :

1. The first possibility is that in the event of the loss of a 60kV source, the circuit breaker of the 30kV lighting and traction bridges 1 and 2 close automatically due to the lack of 30kV voltage on the respectively deenergised half-bridges.
   The DT feeders of the traction bridge 1 and 2 trip instantly, whereas the DE and DAX feeders of the lighting bridge do not trip if the DCEAB coupling circuit breaker of the lighting bridge was able to close. This automatic system allows the PEFs and the PHT auxiliaries to be quickly re-supplied without the intervention of the PCE operator.
2. The second possibility is that the PCE operator closes the 60 kV (DC) circuit breaker after opening the DLA or DLB circuit breaker which has lost its 60kV supply. This solution makes it possible to supply the 2 60/30kV transformers from the same 60kV feeder.[12]

#### Failure of one of the 60 kV/30 kV power transformers

in this situation (appendix A.5) , the circuit breakers (D60A, D30A) or (D60B, D30B) are "open". The closing of the circuit breakers (DL30A, DL30B) for coupling the 30 kV incoming half-bridges must be carried out by the PCE operator.
This configuration is similar to configuration two when a SONELGAZ arrival is lost. All other circuit breakers remain in a state similar to the Nominal operating mode.[12]

#### failure of two 60 KV arrivals

in this case, a generator set is activated to fed the PEF (poste eclairage et force) only in order to ensure security.

## 2.3 Rectifier unit PR

### 2.3.1 The Traction Line Network Equipment

As mentioned previously , there are two types of rectifier units (appendix A.6) in the C' extension and they consist of :

1. **PR31 (T-shaped PR):**

- A rectifier.
- An Automatic Isolation disconnector : SIA.
- An Ultra Fast Circuit Breaker : DUR.
- A grounding contactor.[13]

1. **PR32 (PR in double $\pi$):**

- A rectifier.
- An automatic isolating disconnector: SIA .
- 3 Ultra Fast Circuit Breakers: DURAM1, DURAM2 and DURAV.
- 2 coupling circuit breakers: DUR-C1, DUR-C2 .
- One grounding contactors.
- 4 Coupon contactors CCP1, CCP2, CCP3 and CCP4.[13]

### 2.3.2 PR Power Supply

Each PR is supplied with 30kV three-phase current from a traction feeder of the High Voltage Substation (PHT). In each station, an auxiliary cabinet contains all the auxiliary distribution in 400Vac and 230Vac normal and rescued, 230Vac corrugated, 48Vdc and 24Vdc. There is also the security relay (NS1) and a PLC in charge of the station's automation and communications to the Multi Service Network (RMS). This auxiliary cabinet is supplied in redundancy via an automatic reverser:

- from the auxiliary transformer (50kVA) of the substation.
- in emergency, from a dedicated feeder of the TGBT of the nearest PEF.

In case of loss or switch over of the normal and emergency power supplies, a battery charger-inverter unit provides the autonomy necessary for the safety circuits (Emergency Switching Loop (RU) and High Voltage Authorization (AHT)) as well as for the maintenance control of certain equipment (DUR, CT, CCP).[13]

### 2.3.3 PR Equipment Description

The rectifier and distribution functions are performed in each substation by the following equipment:

#### 30kV High Voltage Panel

It consists of three cells( **figure2.8**):

- AR3 : An incoming line cell equipped with a disconnecting switch.
- PT3 (Departure Traction Unit ): A traction transformer protection cell equipped with a motorized circuit breaker and a protection relay.
- PT4(Auxiliary transformer departure cell) : A protection cell for the Low Voltage auxiliary services transformer, equipped with a fuse switch-disconnector.

Figure 2.8: 30KV Panel.

### Transformer-Rectifier unit

A dodeca-phase transformer rectifier with diodes, with a power of 3.3MVA, ensures the production of a DC traction energy from the 30kV network. The traction voltage produced by the rectifier transformers is 750Vdc nominal on the track( **figure2.9**) . it is complies with class VI of the IEC 146-1-1 / NW EN 60146-1-1 standard, or:

- In en permanence.
- 1,5 In for two hours.
- 3 In for one minute.[13]


Figure 2.9: Transformer rectifier.

### Automatic isolation switch (SIA)

An Automatic Isolation Switch, bipolar, is installed downstream of the transformer rectifier unit. The SIA isolates the transformer and the rectifier from the downstream part of the distribution. The negative pole of the SIA is connected to the running rail, the positive pole is connected to the +750Vdc bus-bar of the traction distribution board.[13]

### Ultra fast Circuit Breaker (DUR)

On the main bus-bar of the substation downstream of the SIA, there are single-pole Ultra fast Circuit Breaker for line feed. Each DUR feeds the two channels of the electrical section upstream or downstream of a protection coupon, and in parallel. The circuit breaker cell is equipped with digital protection.[13]

### Ultra fast coupling circuit breaker (DUR-C)

On the downstream side of the DURs, a coupling circuit breaker is installed to ensure the continuity of the upstream and downstream electrical sections in the event of the rectifier station being unavailable where the device can be remotely controlled. There is no digital protection, only the intrinsic trip unit of the circuit breaker is in its operational mode.

The coupling circuit breaker can only be closed if one or both of the Upstream and Downstream of PR are open, or their trolley is not in service. A voluntary command is possible either via the HMI from the TSA, or the button in front of the DURC cell or from the PCC.[13]

#### Protection Coupon Cell (CCP)

A protection coupon is supplied by a circuit breaker on the output side of the DUR (this circuit breaker is not equipped with digital protection, it is only equipped with its internal trip unit). A CCP closes by command generated by the PLC in case of voltage presence upstream AND downstream of the protection coupon. It opens while a command generated by the PLC if there is a voltage loss upstream OR/AND downstream of the protection coupon.
A switch on the front of the cell offers two modes, Local and Auto. In Auto mode, the protection coupon circuit breakers can be ordered according to four scenarios:

1. Effective voltage presence downstream and upstream of coupons

2. One of the two upstream and downstream DUR circuit breakers is closed or the coupling circuit breaker is closed.

3. Manual control by the operator from the TSA HMI. The so-called ”manual” feed is necessary in case of a train on a coupon (which has to be removed for safety reasons).

4. If the above conditions are not met, the devices will open. In Local mode the operator can open or close the circuit breaker using the push buttons on the front of the cubicle.[13]

#### Negative potential monitoring box (CSPN)

The ground reference of the vehicles is connected to the negative rails through the wheels. The running rails do not have a permanent ground connection. In stations, to avoid any electrical danger to users when this potential rises (negative rails), a Negative Potential Monitoring Box is installed in PR31and PR32( **figure2.10**). If the threshold of 120Vdc (in absolute value) is exceeded (standard NF EN 50 122-1), this device connects the running rails to the LV ground of the station. The equipment is fully automatic with alarm reports and tripping in case of failure. It is powered by the auxiliaries of the same station and directly supervised by the station’s PLC or the PR.[13]

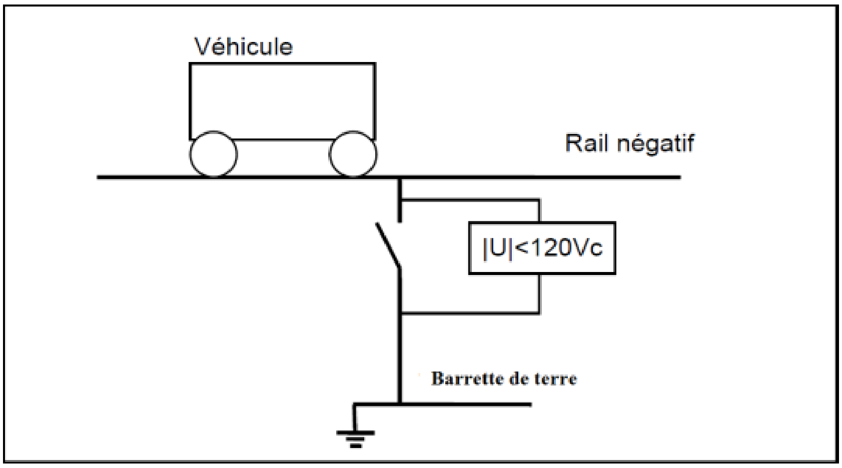



Figure 2.10: CSPN.

### Ground cell (CT)

Each traction zone that separates two PRs can be grounded via two switches/disconnectors. The first to ground the third rail of the positive, and the second to ground the two rails of the negative. The whole traction supply is short-circuited and grounded. This procedure is used during the teleconsignment phases.
The protection coupons are never grounded.[13]

### Voltage detector (DDT)

Connected to each end of a traction zone, a relay detects the presence of the 750Vdc traction voltage. This is the line voltage. Each PR supplies two traction zones, so there are two relays.[13]

### Negative return cell

Each PR is equipped with a negative return cell containing bar sets.[13]

## 2.3.4 12 Pulse rectifier simulation

figure2.11 illustrates the circuit diagram of a 12-pulse rectifier bridge.In general ,a twelve pulse rectifier is created by connecting in series or in parallel two six pulse bridges fed by two secondaries of a three-winding transformer.The first bridge,identified by the out put voltage vd1,is fed from the star-connected secondary,while the second bridge,which supplies the voltage vd2 at the out put,is driven by the delta-connected secondary.This implies that the voltages of the second secondary winding have a 30°phase shift with respect to those of the first secondary winding.[1]

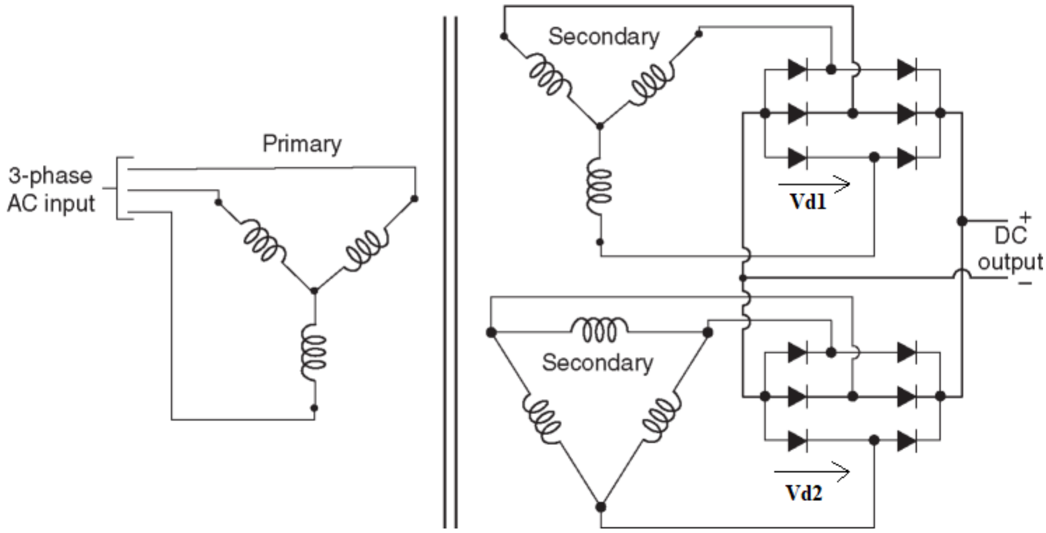



Figure 2.11: 12 Pulse rectifier.

To have better current capability with reduced low frequency harmonics and to minimize the output DC voltage ripple, parallel connection of two six pulse rectifier is further simulated and analyzed in **figure 2.13** which gives the signal shown in **figure 2.12**

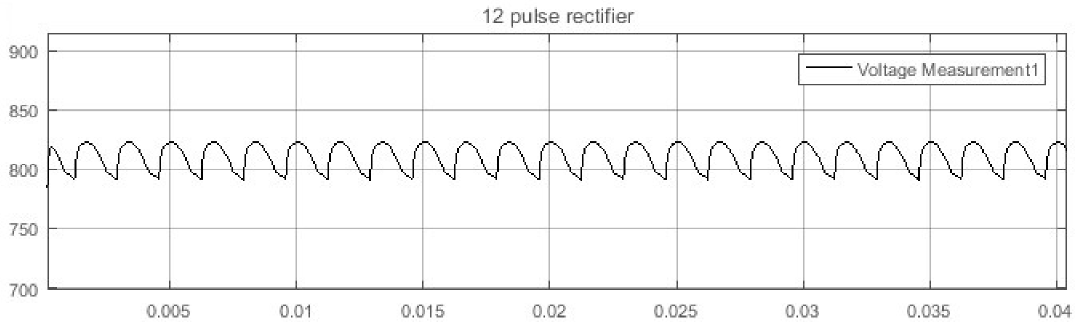



Figure 2.12: Twelve pulse rectifier output signal

As it is mentioned a 12 pulse rectifier is two six pulse rectifiers connecting in series or in palell. For a six-pulse rectifier, the input current will have harmonic components at the following multiples of the fundamental frequency. 5, 7, 11, 13, 17, 19, 23, 25, 29, 31.[14] but in the twelve-pulse system that is shown in **figure 2.13** , the input current will have theoretical harmonic components at the following multiples of the fundamental frequency: 11, 13, 23, 25, 35, 37 **(figure2.14)**

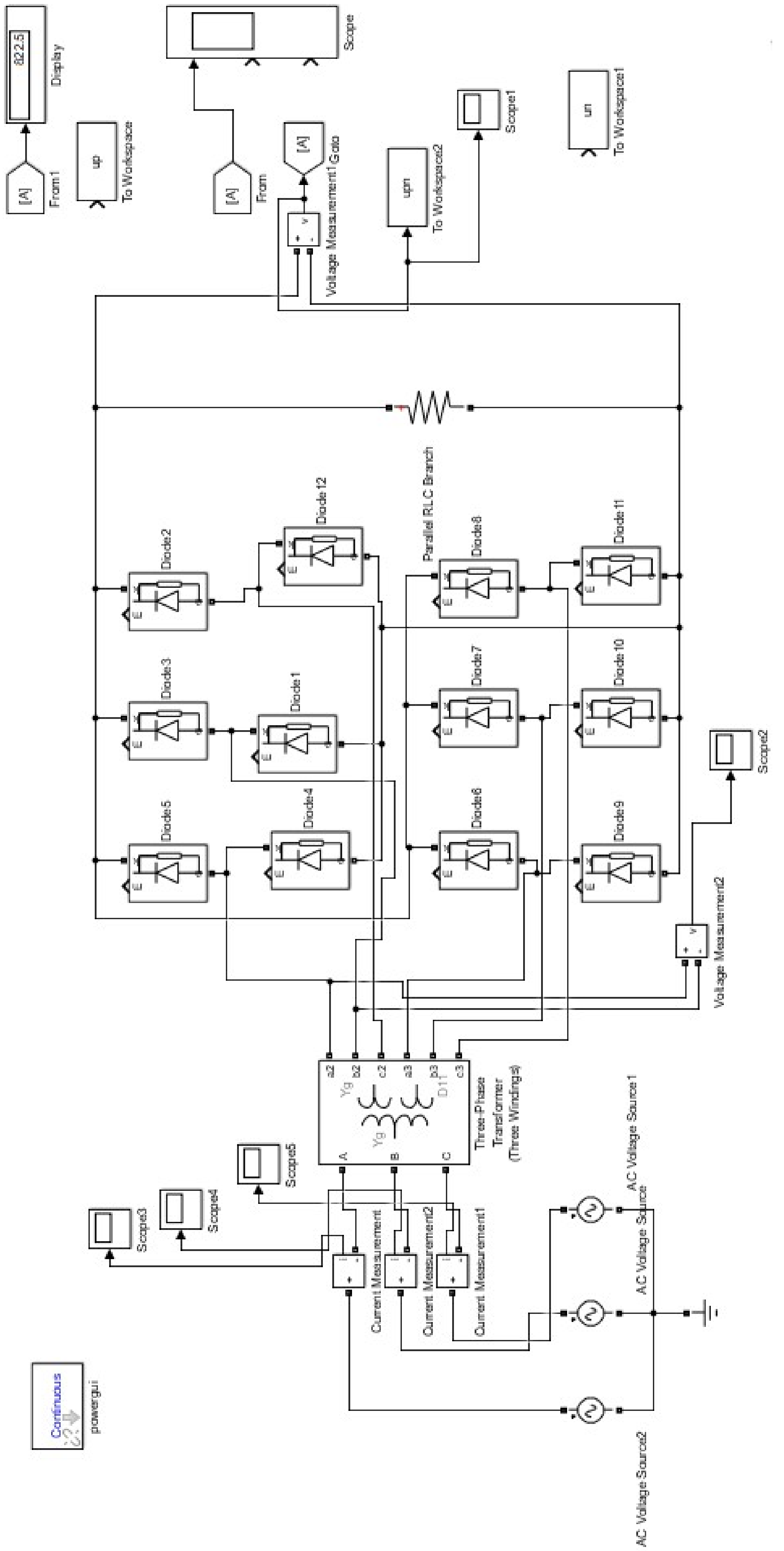



Figure 2.13: 12 Pulse rectifier simulation.

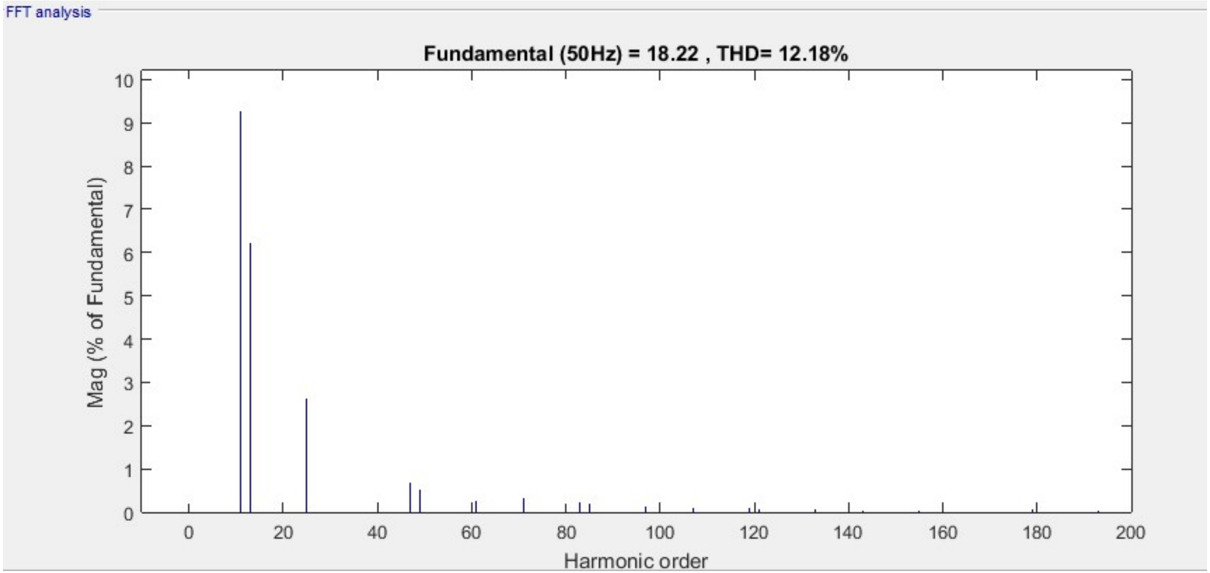



Figure 2.14: FFT analysis

```
Fundamental          = 18.22 peak (12.88 rms)
THD                  = 12.18%

       0 Hz  (DC):          0.00%    270.0°
16.6667 Hz                  0.00%     23.6°
33.3333 Hz                  0.00%    191.3°
      50 Hz  (Fnd):       100.00%     -5.1°
66.6667 Hz                  0.00%     35.6°
83.3333 Hz                  0.00%    161.1°
     100 Hz  (h2):          0.00%    -25.6°
116.667 Hz                  0.00%     52.6°
133.333 Hz                  0.00%    180.5°
     150 Hz  (h3):          0.00%    -59.2°
166.667 Hz                  0.00%     62.8°
183.333 Hz                  0.00%    187.4°
     200 Hz  (h4):          0.00%    -57.9°
216.667 Hz                  0.00%     74.1°
233.333 Hz                  0.00%    208.7°
     250 Hz  (h5):          0.00%    -38.8°
266.667 Hz                  0.00%     76.4°
283.333 Hz                  0.00%    206.6°
     300 Hz  (h6):          0.00%    -30.8°
316.667 Hz                  0.00%     94.4°
333.333 Hz                  0.00%    218.4°
     350 Hz  (h7):          0.00%    -17.8°
366.667 Hz                  0.00%     87.0°
383.333 Hz                  0.00%    226.2°
     400 Hz  (h8):          0.00%     -2.3°
416.667 Hz                  0.00%    106.9°
433.333 Hz                  0.00%    239.2°
     450 Hz  (h9):          0.00%     -2.2°
466.667 Hz                  0.00%    113.1°
483.333 Hz                  0.00%    251.3°
     500 Hz (h10):          0.00%    -32.7°
516.667 Hz                  0.00%    121.2°
533.333 Hz                  0.00%    -64.7°
     550 Hz (h11):          9.28%    131.4°
```

Figure 2.15: FFT list

### 2.3.5 Traction network configuration (EXTENSION C)

The manoeuvres described below will be carried out on the basis that :

- The rectifiers are energized.
- The SIAs are closed.

- No safety cut-off is activated.
- The traction network is accessible in " distance " mode.

#### Extension C Power Supply

The phases are as follow:

- Successive opening of all CTs in each electrical zone.
- Successive closing of all the DURs in the line.
- coupons are powered automatically.[13]

#### Powering off the line (extension C)

This is achieved by successively opening all the DURs in the line. The powering off of the coupons is automatic.

### 2.3.6 PR failure

The rectifier transformer unit can be isolated by opening the 30kV circuit breaker protecting the substation and by opening the SIA and closing the DUR-C of the substation. The 750VDC voltage is thus transmitted beyond the substation via the DUR-C and the substation busbar.
After opening the 30kV circuit breaker, opening the SIA and the line circuit breaker, the PR is fully isolated from the line. The coupling DUR can be closed to ensure continuity of feeding of the electrical sections of the PR.[13]

### 2.3.7 Control / command line configuration

The control / command in the PR is provided by a safety PLC and a HMI. Two types of PLCs are used in the PR, the protection PLCs and the control / command PLC.

#### Control protection PLC

They are the digital protections that equip the circuit breaker cubicles, the HV outgoing transformer and DUR for the 750Vdc traction feeders. This PLC provides several electrical protection functions and directly handles the switching of the circuit breaker.[13]

#### control / command PLC

The PR is equipped with an automatic control and command system, which is installed in the auxiliary services panel. This PLC manages the entire rectifier unit as an interface to the supervision of the control and command stations. Exchange tables are configured for each receiver such as the PCC. The PLC collects information from all the equipment in the substation and executes the commands to open or close the breaking devices. For this purpose, it communicates with the PLCs,by means of exchange tables. This ensures that TOR (toute ou rien) information can be passed between the different levels, the local equipment level, the local control level (HMI), and the remote level such as the PCC.[13]

## 2.4 Traction lock

There are different types of locks on the traction network:

### 2.4.1 Key interlocking

Interlocking devices with numbered and unique keys guarantee safety when working on equipment in the substation or when the tracks are manually energized.[13]

### 2.4.2 The consignment lock

It is associated with mechanical positioning controls and obtained by means of numbered and unique keys.It is done with or without interlocking with other mechanisms.The equipment affected by this consignment lockout are the following:

- CTs in closed position.
- SIAs in an open position.
- DURs in the unplugged position.[13]

### 2.4.3 programmed interlocking

The programmed interlock is a non-secure interlocking system performed by the PLC.Its purpose is to protect the equipment against dangerous maneuvers.[13]

## 2.5 Conclusion

A study of the third rail power supply was reviewed from the high voltage substation to the positive rail passing by a transformer rectifier unit which was simulated and analyzed, the simulation results confirm its performance in either input current quality and output voltage ripple. A description of high voltage and traction equipments were also carried out .
The **figure2.16**presented the traction line of the third rail power supply from the PHT to the main system.

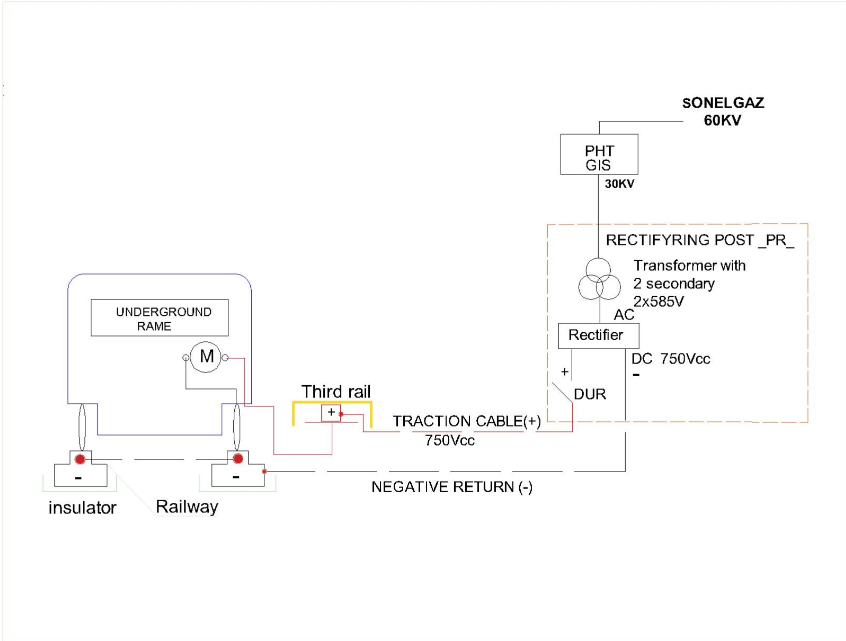



Figure 2.16: Third rail power supply.

# Chapter 3

# Cables Sizing Calculations

## 3.1 Introduction

Cables are used for the transmission and distribution of electrical energy in public and industrial power systems.The permissible loading of the cables is determined by different parameters such as environmental conditions,type of laying (in ground or in the air), type of insulation and operating conditions .Conductors are made of aluminum or copper. When installing circuits it is important that the correct size current carrying conductor is selected to carry the current required without causing the cable to overheat and that the voltage drop caused by the resistance of the cable is not greater than what is permissible. this chapter includes:

- 30 kV High voltage cable sizing that supplies PR32 and PR31.
- Traction network cables.
- Low voltage cables sizing of the rectifier unit (using CANECO BT ).

## 3.2 The network's general design

Before start the cables sizing,a general design of the Algiers metro's network is presented bellow as shown in figure **3.1**.

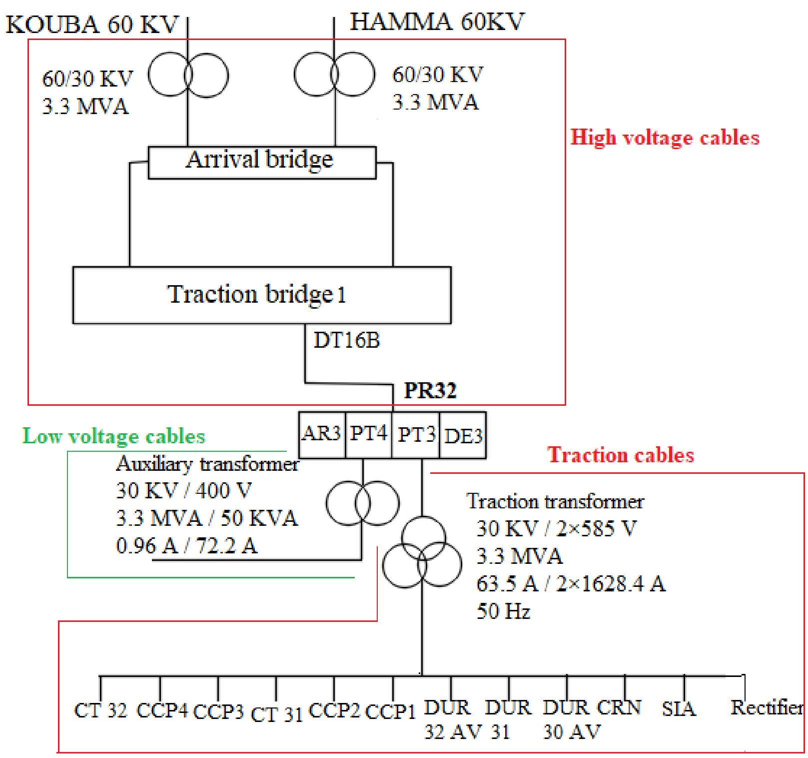



Figure 3.1: Algiers metro's general network.

## 3.3 30 kV High voltage cables sizing

these cable are used for Supplying PR31 and PR32. The following parameters are calculated to select the correct HV cable size:

- Current to be transmitted($I_b$).
- Admissible current ($I_z$).
- Short-Circuit Current.
- Voltage drop.[15]

### 3.3.1 Current to be transmitted($I_b$)

In accordance with the operating principle of the substations, the 30 kV links supplying the PRs will be sized for operation with a 50 % overload for 2 hours The cross-section of the HTA cables supplying the PRs of extension C (PR31 and PR32) must take into account the supply of the future PRs of the extension towards Baraki (PR33, PR34, PR35, and PR36). The future extensions will not be fed from the PHT like the PRs of the existing line but will be fed in series from PR31 (track 1) or PR32 (track 2)as shown in figure( **figure3.2**).
Requirements:

- For 2 PRs in series, we assume that the second PR operates with a 25% overload.
- For 3 PRs in series, we assume that the third PR has a 10% overload operation.[15]

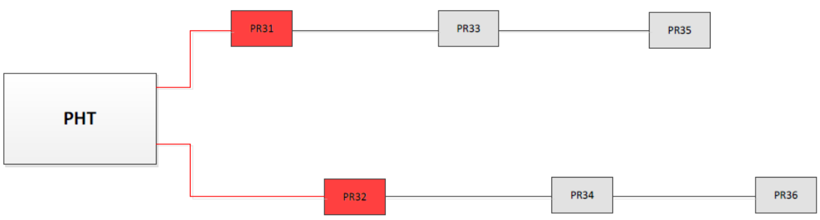



Figure 3.2: PRs feeding principle of extension c and the future extensions.

$$I_b = \frac{S(KVA)}{\sqrt{3}\times U(KV)} = \frac{3300(1.5+1.25+1.10)}{\sqrt{3}\times 30} = 245A \tag{3.1}$$

With the hypothesis of 3 PR in series, we find that the electrical current intended to be carried in an electrical circuit during normal operation $I_b$=245A.

### 3.3.2 Admissible current ($I_z$)

The admissible current $I_z$ is the maximum value of the electric current which can flow continuously through a conductor, device or apparatus without its steady-state temperature being exceeded.[16]

$$I_z(A) = \frac{I_b}{K} \tag{3.2}$$

K : The weighting coefficient.

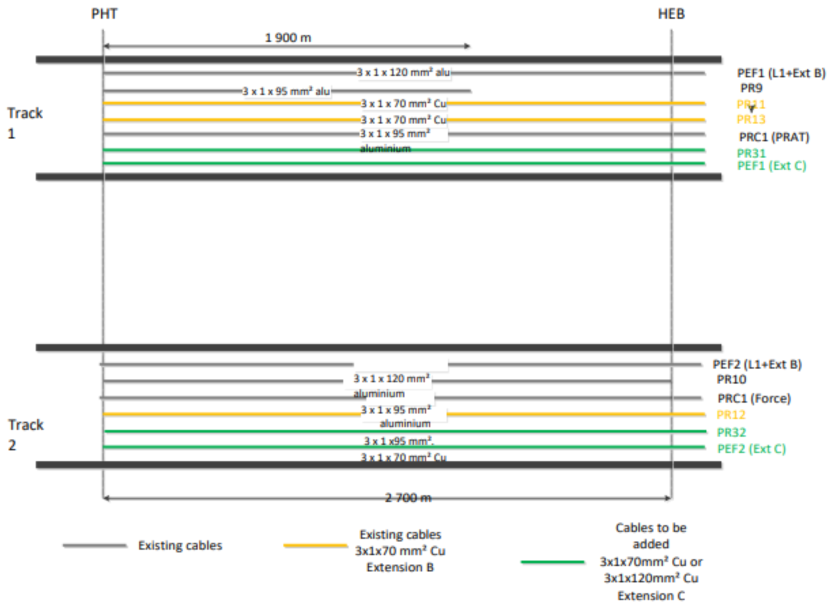



Figure 3.3: Mapping of the existing 30 kV cables and the C extension.

The **figure 3.3** shows the electrical circuits laid in the channels of tracks 1 and 2 between the high-voltage substation and Hai El Badr for line 1 and extension B as well as the cables that will be laid for extension C. **The table3.1** bellow shows the electrical circuits running in the existing channels of tracks 1 and 2 between the PHT and HEB, Each circuit consists of 3 single-pole cables.

Table 3.1: Summary table of single-core cables in the channels between the PHT and HEB

| | Existing circuits | Extension C | Total of Circuits |
|---|---|---|---|
| Circuits Track 1 | 5 | 2 | 7 |
| Circuits Track 2 | 4 | 2 | 6 |

#### Laying mode and weighting factor of high voltage cables

**The figure 3.4** shows the cable trench of the existing Line in which the cables of Extension C laid.

Figure 3.4: Cable trench of the existing line.

**The figure 3.5** shows the corridor installed on extension C with the supports for the 30 kV high voltage cables tray and the traction cables.

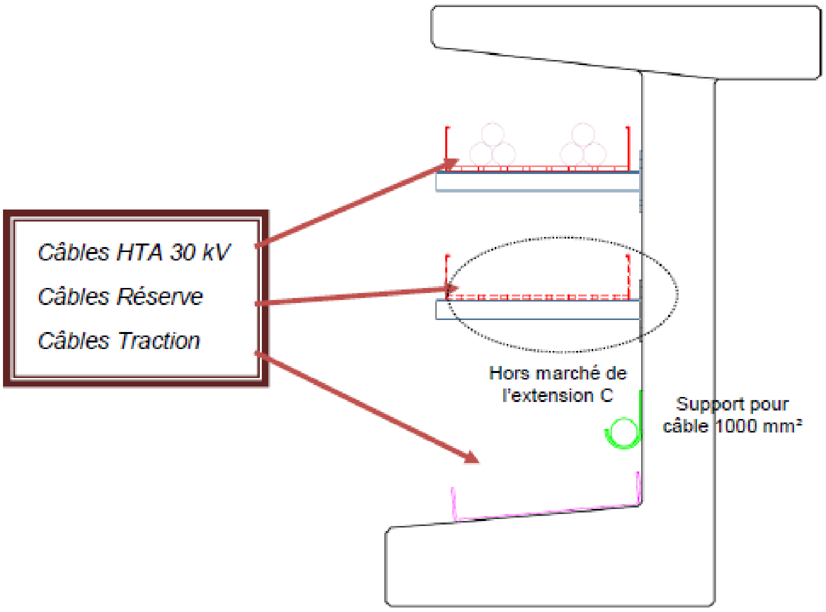



Figure 3.5: Cable tray installation diagram for extension C.

The laying method of the existing cables and added cables for extension C allows to calculate the weighting coefficient for calculating the cross-section of the high voltage cables.
According to **table 52 E of the NF C13-200 standard of September 2009 shown in figure3.6** , the laying mode is type A43.

So, The correction factors to be used are K1, K2, K3 and K7.

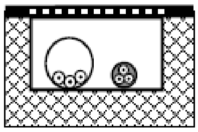
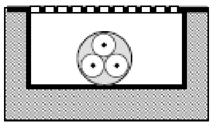
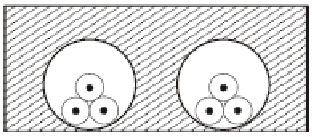
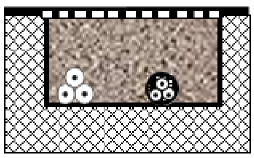
| Type de pose | Exemple | Description | Facteurs de correction concernés |
|---|---|---|---|
| 41 |  | Câbles monoconducteurs ou multiconducteurs dans des caniveaux ou blocs manufacturés non remplis de sable et fermés. | K1<br>K10 |
| 43 |  | Câbles monoconducteurs ou multiconducteurs dans des caniveaux ouverts ou ventilés. | K1<br>K2<br>K3<br>K7 |
| 45 |  | Câbles monoconducteurs ou multiconducteurs dans alvéoles ou blocs manufacturés, monolithes béton non enterrés et traversées de mur d'épaisseur supérieur à 1 m. | K1<br>K9 |
| 60 |  | Câbles monoconducteurs ou multiconducteurs dans des caniveaux remplis de sable. | K12<br>K13<br>K15 |

Figure 3.6: Table 52E - Examples of laying modes(extracted from the NF C13-200 standard).[16]

from **figure 3.7** K1=0.96 (Ambient temperature: 35°C )

| Isolant | Température de l'air ambiant (°C) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| PVC | 1,22 | 1,17 | 1,12 | 1,06 | 1 | 0,94 | 0,87 | 0,79 | 0,71 | 0,61 |
| PR / EPR | 1,15 | 1,12 | 1,08 | 1,04 | 1 | 0,96 | 0,91 | 0,87 | 0,82 | 0,76 |

Figure 3.7: Tableau 52K1 – Influence de la température ambiante – k1(extracted from the NF C13-200 standard).[16]

Cables are laid in a single layer. So from **figure 3.8** K3=0.72.

| Nombre de câbles ou groupements | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 0,85 | 0,79 | 0,75 | 0,73 | 0,72 | 0,72 | 0,71 | 0,70 |

Figure 3.8: Table 52K3 - Cables laid in a single layer on walls, floors or unperforated shelves - k3 (extracted from the NF C13-200 standard).[16]

Cables are in one layer.So from **figure 3.9** K7= 1 .

| Nombre de couches | | | |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 1 | 0,80 | 0,73 | 0,70 |

Figure 3.9: Table 52K7 - Laying in several layers - k7(extracted from the NF C13-200 standard).[16]

Exposure to direct sunlight (cables away from the sun)K2=1.
So:

$$K(Ventilatedtrench) = K1 \times K2 \times K3 \times K7 = 0.96 \times 1 \times 0.72 \times 1 = 0.69 \qquad (3.3)$$

The weighting coefficient for the calculation of the section of the high voltage cables of the extension C, installed between the PHT and Ain Naadja is K=0.69.

$$I_z(A) = \frac{245}{0.69} = 355A \qquad (3.4)$$

According to table 52J of the C13-200/2009 standard, single-core Cu cables with a cross-section of 120 mm$^2$laid in a trefoil for the extension C can carry a current of 355 A.

| Ames en cuivre | | | | Section nominale (mm²) | Ames en aluminium | | | |
|---|---|---|---|---|---|---|---|---|
| Air | | Enterré | | | Air | | Enterré | |
| Trèfle(1) | Nappe(2) | Trèfle(1) | Nappe(2) | | Trèfle(1) | Nappe(2) | Trèfle(1) | Nappe(2) |
| 120 | 123 | 126 | 129 | 16 | 94 | 96 | 98 | 101 |
| 157 | 161 | 161 | 165 | 25 | 122 | 125 | 125 | 128 |
| 190 | 195 | 192 | 197 | 35 | 147 | 151 | 149 | 153 |
| 233 | 244 | 225 | 231 | 50 | 185 | 189 | 175 | 179 |
| 292 | 304 | 276 | 283 | 70 | 226 | 236 | 214 | 220 |
| 356 | 369 | 330 | 338 | 95 | 266 | 285 | 252 | 262 |
| 409 | 423 | 375 | 383 | 120 | 318 | 330 | 291 | 299 |
| 465 | 478 | 420 | 430 | 150 | 360 | 370 | 325 | 334 |
| 533 | 549 | 474 | 484 | 185 | 417 | 430 | 370 | 379 |
| 630 | 646 | 549 | 559 | 240 | 490 | 504 | 428 | 439 |
| 724 | 735 | 619 | 623 | 300 | 567 | 579 | 485 | 492 |
| 836 | 838 | 698 | 703 | 400 | 662 | 669 | 554 | 562 |
| 959 | 958 | 786 | 785 | 500 | 771 | 776 | 631 | 637 |
| 1 108 | 1 108 | 887 | 886 | 630 | 897 | 905 | 720 | 727 |
| 1 255 | 1 244 | 980 | 970 | 800 | 1 037 | 1 040 | 810 | 812 |
| 1 390 | 1 366 | 1 063 | 1 042 | 1 000 | 1 165 | 1 160 | 895 | 890 |
| 1 480 | 1 445 | 1 117 | 1 087 | 1 200 | 1 264 | 1 252 | 957 | 945 |

(1) Pose en trèfle jointif.
(2) Pose en nappe jointive.
*La pose en trèfle est toujours recommandée pour un meilleur équilibrage des phases.*

Figure 3.10: Table 52J - Admissible currents in circuits consisting of three single-core radial field cables of rated voltage 3.6/6 (7.2) kV to 18/30 (36) kV(extracted from the NF C13-200 standard).[16]

### 3.3.3 Calculation of Short-Circuit Current

On the 60 kV busbar of both KOUBA and HAMMA substations , a values of the short-circuit current given by SONELGAZ equal to 8.7 kA in operating mode with a SONELGAZ supply and generator operation.[15]

#### Verification of the section according to thermal stress

The thermal stress check is to ensure that the operating time of the protection device (the fuse melting time) is not greater than the time t that is equal to (in seconds)[16] :

$$t \leq \frac{I^2 t}{I_{cc}^2} \tag{3.5}$$

$I^2t$ being the permissible thermal stress in the conductors:

$$I^2 t = k^2 S^2 \tag{3.6}$$

for conductors and cables where, k is a factor whose value is given in the EA table of the **NF 13 205 standard** according to the nature of the conductor core and insulation.

$$k = 143 for copper$$

S : is the conductor cross-sectional area, in mm$^2$.
Icc : is the short-circuit current. taken to be equal to :

$$I_{cc} = 8.7KA$$

t=1s : is the circuit breaker tripping time.

$$S = \frac{I_{cc} \times \sqrt{t}}{K} \tag{3.7}$$

$$S = 60mm^2$$

### 3.3.4 voltage drop

The voltage drop limits are given in the **the table 3.2** :

Table 3.2: Voltage Drop[17]

| Type of connection | Lighting | Other uses |
|---|---|---|
| Supply from the low-voltage network public distribution network | 3% | 5% |
| Supply by private substation HIGH VOLTAGE/LOW VOLTAGE | 6% | 8% |

Cables length between the PHT and the PR of the extension C shown **the table 3.3**

Table 3.3: Cables length between the PHT and the PR of the extension C.[17]

| Designation of the departure or link | Length (m) |
|---|---|
| PHT substation - PR31 | 5512 |
| PHT substation - PR32 | 6365 |

The voltage drop is calculated by the following formula [17]:

$$\Delta U = \frac{Z(\Omega/km) \times I_b(A) \times l(m)}{1000} \tag{3.8}$$

Or:

1. $$Z(\Omega/km) = \sqrt{(R2 + X2)} \tag{3.9}$$

   Z(Ω/km) is the cable impedance in Ω/km such that:

- for copper R = 22.5 (Ωmm$^2$/km) / S (Section in mm$^2$).
- for copper X= 0.13 Ω/km for HVA cables.

2. $I_b$(A) is the current to be transmitted .
3. l(m) is the cable length in m.

The voltage drop in (%) is given by [17]:

$$\Delta U(\%) = \frac{\Delta U(V)\times\sqrt{3}\times 1000}{U_n(KV)} \tag{3.10}$$

**For the PR31 30 kV link:**

$$\Delta U = \frac{\sqrt{(\frac{22.5}{120})^2 + 0.13^2}\times 355\times 5512}{1000} = 447V \tag{3.11}$$

$$\Delta U(\%) = \frac{447\times\sqrt{3}\times 1000}{30000} = 2.58\% \leq 8\% \tag{3.12}$$

The voltage drop is well below the recommended values.

**For the PR32 30 kV link:**

$$\Delta U = \frac{\sqrt{(\frac{22.5}{120})^2 + 0.13^2}\times 355\times 6365}{1000} = 515.5V \tag{3.13}$$

$$\Delta U(\%) = \frac{515.\times\sqrt{3}\times 1000}{30000} = 2.97\% \leq 8\% \tag{3.14}$$

The voltage drop is well below the recommended values.

## 3.4 Tration cable calculation note

The sketch below **figure 3.11** shows the equivalent simplified diagram for dimensioning of the DC traction cables .

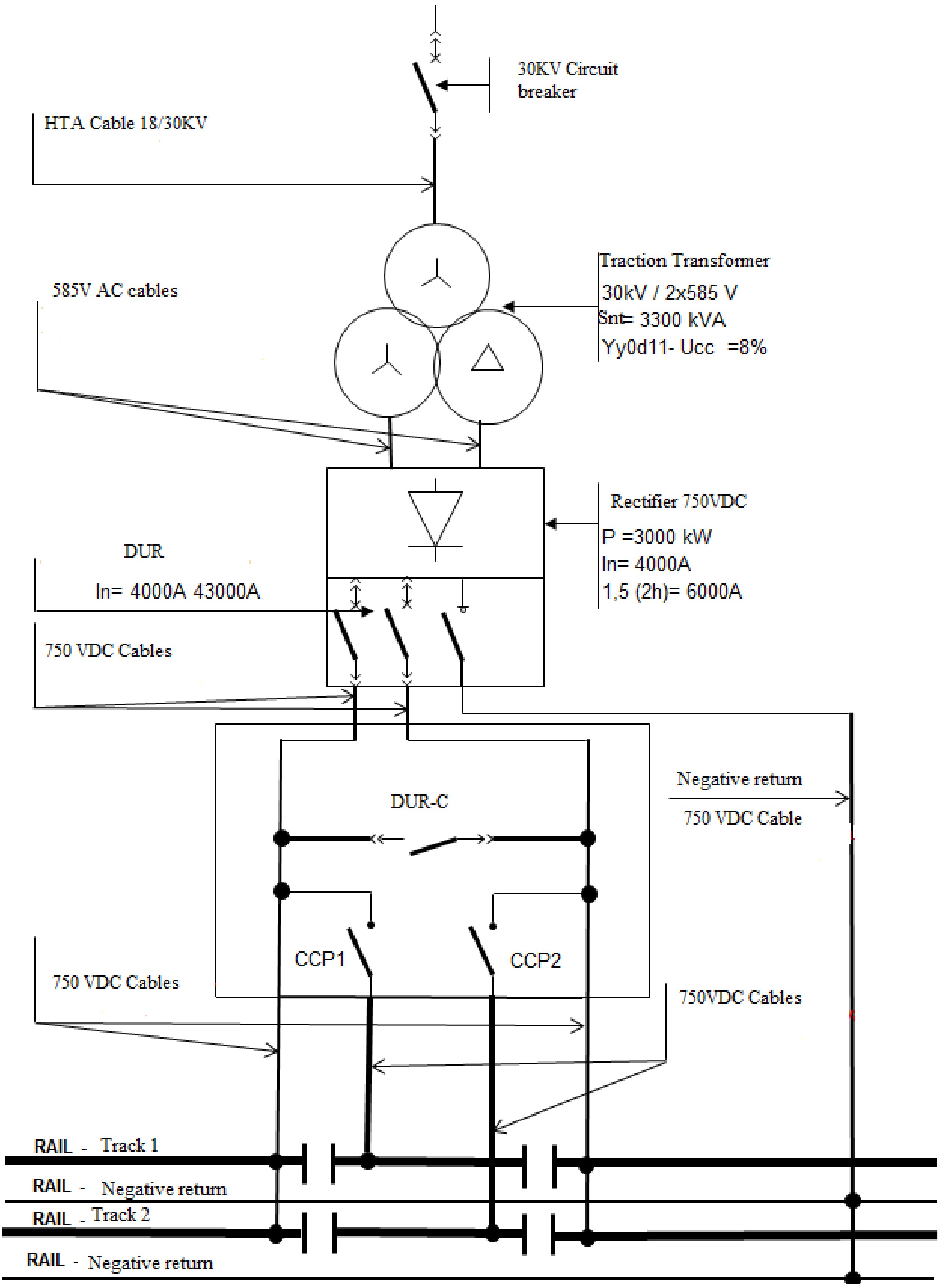



Figure 3.11: Traction line synoptic presentation.

### 3.4.1 Input data

the following data are extracted from [18]

1. Upstream network:
   - Upstream network :$S_{kq}$=313000 KVA
   - unloading load factor m=1.05.
   - voltage factor C=1.05.
   - $U_n$=30 KV.
2. Traction transformer(corresponds to 2×1650 KVA)
   - apparent power $S_{nt}$=3300KVA.
   - short circuit voltage $U_{cc}$=8%.
   - no-load secondary voltage $U_n$=585 V.
   - copper loss $W_c$=21000 W.
   - no-load loss $W_v$=6400 W.
3. connection cable traction transformer-rectifier
   - cable cross-section S=400mm$^2$.
   - copper resistivity 18.5 m$\Omega$.mm$^2$/m.
   - cable length L=50m.
4. rectifier-SIA
   - power $S_{nt}$=3000KW.
   - no-load secondary voltage $U_n$=750V.
   - $W_{rt}$=7000W.

### 3.4.2 Short circuit current

Before the calculation of the short circuit current , an upstream network , traction transformer and the cable link between the traction transformer and the rectifier impedances should be calculated .

**Upstream network**

When the installation is powered by a high voltage network, the impedances of the HV network and the HV/LV transformer must be taken into account for the calculation of fault and short circuit currents. From the **NFC 15-105 standard** the high voltage network impedance , resistance and reactance are [17]:

$$Z_q = \frac{(m\times U_n)^2}{S_{kq}} = \frac{(1.05\times 585)^2}{313000} = 1.21\Omega \tag{3.15}$$

$$R_1 = 0.1 \times X_1 = 0.12 m\Omega \tag{3.16}$$

$$X_1 = 0.995 \times Z_q = 1.20 m\Omega \tag{3.17}$$

$U_n$:The low compound voltage

**Traction transformer**

From the **NFC 15-105 standard** the transformer impedance , resistance and reactance are [19]:

$$Z_q = \frac{(U_n)^2}{S_{nt}} \times \frac{U_{cc}}{100} = \frac{585^2}{3300} \times \frac{8}{100} = 8.3 m\Omega \tag{3.18}$$

$$R_2 = \frac{W_c (U_n)^2 \times 10^{-3}}{S_{nt}^2} = \frac{21000 \times 585^2 \times 10^{-3}}{3300^2} = 0.66 m\Omega \tag{3.19}$$

$$X_2 = \sqrt{Z_2^2 - R_2^2} = \sqrt{8.3^2 - 0.66^2} = 8.27 m\Omega \tag{3.20}$$

**Traction transformer-Rectifier cable link**

from the **NFC 15-105 standard** the resistance and the reactance of the link cable between the traction transformer and the rectifier are [19]:

$$R_3 = \rho \times \frac{L}{S} = 0.58 m\Omega \tag{3.21}$$

$$X_3 = 0.09 \times L = 1.13 m\Omega \tag{3.22}$$

**Traction transformer short circuit current**

from the **NFC 15-105 standard** the short circuit current of the traction transformer is

$$R_t = R_1 + R_1 = 0.78 \Omega \tag{3.23}$$

$$X_t = X_1 + X_2 = 9.47 \Omega \tag{3.24}$$

$$Z_t = \sqrt{R_t^2 + X_t^2} = 9.50 \Omega \tag{3.25}$$

$$I_{cc} = \frac{m \times c \times U_n}{\sqrt{3} \times Z_t} = 39 KA \tag{3.26}$$

**Short circuit current at the rectifier input**

from the **NFC 15-105 standard** the short circuit current of the traction transformer is

$$R_t = R_1 + R_2 + R_3 = 1.36 \Omega \tag{3.27}$$

$$X_t = X_1 + X_2 + X_3 = 10.59 \Omega \tag{3.28}$$

$$Z_t = \sqrt{R_t^2 + X_t^2} = 10.6 \Omega \tag{3.29}$$

$$I_{cc} = \frac{m \times c \times U_n}{\sqrt{3} \times Z_t} = 35 KA \tag{3.30}$$

### 3.4.3 30KV Cables between HTA circuit breaker and traction transformer

The method of traction cables sizing consist of the proposition of a cable size than a thermal stress,short circuit and voltage drop studies should be calculated.
**The table 4.1** bellow present theCharacteristic of the proposed cable between HTA circuit breaker and traction transformer.[18]

Table 3.4: Characteristic of the proposed cable between HTA circuit breaker and traction transformer

| | |
|---|---|
| Section | $1 \times 70$ mm$^2$ |
| r(Ω/Km) | 0.51 |
| Admissible current at 30°C | 207 |
| $\rho$(Ωmm$^2$ /m) | 0.036 |
| T in a short circuit(°C) $\theta_f$ | 250 |
| T Admissible(°C) $\theta_d$ | 90 |
| $I_n$2h(A) | 96 |
| $U_n$(V) | 3000 |
| max ambiante temperature(°C) | 35 |

**Conductor thermal stress**

The thermal stress allows to calculate the number of cables required laying condition:cable tray on non perforated shelf .So,from the table that is extracted from the NFC 13 200

$$K = K_1 \times K_2 \times K_3 \times K_7 \tag{3.31}$$

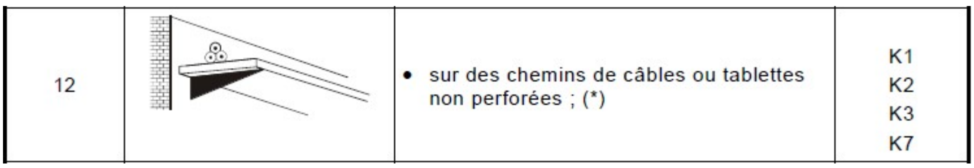



Figure 3.12: :cable tray on non perforated shelf laying mode(extracted from the NF C13-200 standard).

- Ambient temperature Coefficient at: 35°C : $K_1$=0.96 (figure 3.7)
- Coefficient of exposure to direct sunlight: $K_2$=1.00 (cables away from the sun)
- Coefficient of cables laid in several layers $K_7$=0.75(figure 3.9)
- Cables laid in a single layer $K_3$=0.73 (figure 3.8).

$$I_{admissible} = \frac{I_n 2h}{k} = \frac{96}{0.96{\times}1{\times}0.73{\times}0.75} = 182.65A \tag{3.32}$$

$$numberofcables = \frac{I_{admissible}}{I_{admissible}(cable)} = \frac{182.65}{207} = 0.88 \tag{3.33}$$

the number of cables required=1.

#### short circuit

This study allows to calculate the cable cross section using the following formula from **NFC 13 200 standard**

$$S = \frac{I_{cc}}{k}\sqrt{\frac{t}{\theta f - \theta d}} = 27.96mm^2 \tag{3.34}$$

- short circuit current on the 30KV network $I_{cc}$=8.7KA.
- breaking time of the high voltage circuit breaker 0.2s.
- k=11 (coefficient depending on the nature of core 7 for aluminium and 11 for copper) .

S=27.96mm$^2$ < proposed section.

#### Voltage drop

$$\Delta U_V = \frac{\rho{\times}L{\times}\sqrt{3}}{S}{\times}I_n 2h = 1.28V \tag{3.35}$$

which corresponds to 0.00426% of 30000V.
So, the cable proposed is a correct choice (1 x 70 mm$^2$ Cu cable per phase).

### 3.4.4 Cables Between traction transformer and the rectifier

**The table 3.5** bellow present the Characteristic of the proposed Cables Between traction transformer and the rectifier.

Table 3.5: Characteristic of the proposed Cables Between traction transformer and the rectifier.

| Section | $1 \times 400$ mm$^2$ |
|---|---|
| r($\Omega$/Km) | 0.056 |
| Admissible current at 30°C | 940 |
| $\rho$($\Omega$mm$^2$/m) | 0.023 |
| T in a short circuit(°C) $\theta_f$ | 250 |
| T Admissible(°C) $\theta_d$ | 90 |
| $I_n$2h(A) | 96 |
| $U_n$(V) | 3000 |
| max ambiante temperature(°C) | 35 |
| secondary $U_n$(V) | 585 |

#### Conductor thermal stress

The laying condition between the traction transformer and the rectifier is on jointed cable ladders. from **NFC 13 200 standard** the weighting factor of an jointed cable ladders condition pose is

$$K = K_1 \times K_2 = 0.76$$

- Ambient temperature Coefficient at: 35°C : $K_1$=0.96
- $K_2$=0.80 coefficient quantity of joined link (extracted from the table 52N of NF C 15-100)
- secondary power rating:1650KVA.
- secondary current rating(2h)1.5 × In : 2442A.

$$I_{admissible} = \frac{In_{2h}}{K} = \frac{2442}{0.76} = 3179.68A \tag{3.36}$$

$$numberofcables = \frac{I_{admissible}}{I_{admissible}(cable)} = \frac{3179.68}{940} = 3.38 \tag{3.37}$$

So,the number of cables required=4.

#### short circuit

- short circuit current $I_{cc}$=39KA.
- breaking time of the high voltage circuit breaker 0.2S.
- k = 11 (coefficient depending on the nature of core 7 for aluminum and 11 for copper).

$$S = \frac{I_{cc}}{k}\sqrt{\frac{t}{\theta f - \theta d}} \tag{3.38}$$

S=125.35mm$^2$ < proposed section.

#### Voltage drop

$$\Delta U_V = \frac{\rho \times L \times \sqrt{3}}{S} \times In_{2h} = 3.64V \tag{3.39}$$

L=15m
which corresponds to 0.62% of 585V So, 4×400mm$^2$Cu cables per phase are a correct choice .

### 3.4.5 Calculation of 750V cables between rectifier/DUR and the third rail

**the table 3.6** bellow present the Characteristic of proposed cable between rectifier/DUR and the third rail.

Table 3.6: Characteristic of proposed cable between rectifier/DUR and the third rail

| Section | 1 × 400 mm$^2$ |
|---|---|
| r(Ω/Km) | 0.056 |
| Admissible current at 30°C | 940 |
| $\rho$(Ωmm$^2$/m) | 0.023 |
| T in a short circuit(°C) $\theta_f$ | 250 |
| T Admissible(°C) $\theta_d$ | 90 |
| I$_n$(A) | 3900 |
| U$_n$(V) | 750 |
| Max ambiante temperature(C°) | 35 |

#### thermal stress

The laying condition between rectifier/DUR and the third rail is on a jointed cable ledder.

- Ambient temperature Coefficient at: 35°C : $K_1$=0.96
- $K_2$=0.79 coefficient quantity of joined link (extracted from the table 52N of NF C 15-100).

$$K = K_1 \times K_2 = 0.7584$$

$$I_{admissible} = \frac{In_{2h}}{K} = 5.47A \tag{3.40}$$

$$numberofcables = \frac{I_{admissible}}{I_{admissible}(cable)} \tag{3.41}$$

the number of cables required=6.

#### short circuit

- short circuit current $I_{cc}$=39KA.
- breaking time of the high voltage circuit breaker 0.2S.
- k = 11 (coefficient depending on the nature of core 7 for aluminum and 11 for copper).

$$S = \frac{I_{cc}}{k}\sqrt{\frac{t}{\theta f - \theta d}} \tag{3.42}$$

S=140.15mm$^2$ < proposed section.

#### Voltage drop

$$\Delta U_V = \frac{\rho \times L \times 2}{S} \times I_n 2h = 11.5V \tag{3.43}$$

L=100m
which corresponds to 1.53%of 750V So, from the previous study a 6×400mm$^2$Cu cables are used to supply the third rail.

### 3.4.6 Calculation of 750V cables between Rectifier unit /SIA and negative rails

**the table 3.7**bellow present the Characteristic of proposed cable between Rectifier unit /SIA and negative rails.

#### Conductor thermal stress

The laying condition between Rectifier unit /SIA and negative rails is on the floor jointed cables.

- Ambient temperature Coefficient at: 35°C : $K_1$=0.96
- $K_2$=0.72 coefficient quantity of joined link (extracted from table 52N of NF C 15-100)

Table 3.7: Characteristic of proposed cable between Rectifier unit /SIA and negative rails

| Section | 1 × 400 $mm^2$ |
|---|---|
| r(Ω/Km) | 0.056 |
| Admissible current at 30°C | 940 |
| $\rho$(Ω$mm^2$/m) | 0.023 |
| T in a short circuit(°C) $\theta_f$ | 250 |
| T Admissible(°C) $\theta_d$ | 90 |
| 1.5$I_n$(A) | 6000 |
| $U_n$(V) | 750 |
| max ambiante temperature(°C) | 35 |

$$K = K_1 \times K_2 = 0.70$$

$$I_{admissible} = \frac{In_{2h}}{K} = 8571.4A \tag{3.44}$$

$$numberofcables = \frac{I_{admissible}}{I_{admissible}(cable)} = 9.11 \tag{3.45}$$

the number of cables required=10.

### short circuit

- short circuit current $I_{cc}$=39KA.
- breaking time of the high voltage circuit breaker 0.2S.
- k=11.

$$S = \frac{I_{cc}}{k}\sqrt{\frac{t}{\theta f - \theta d}} = 140.15mm^2 \tag{3.46}$$

S=140.15$mm^2$ < proposed section.

### Voltage drop

$$\Delta U_V = \frac{\rho \times L \times 2}{S} \times I_n 2h = 6.9V \tag{3.47}$$

L=100m
which corresponds to 0.92%of 750V. So, 10 cable of 1×400$mm^2$Cu cables per phase to supply the negative return.

### 3.4.7 750V cables for coupon power supply

**The table 3.8** present the Characteristic of the proposed cable for coupon power supply

Table 3.8: Characteristic of the proposed cable for coupon power supply

| Section | 1 × 400 $mm^2$ |
|---|---|
| r(Ω/Km) | 0.056 |
| Admissible current at 30°C | 940 |
| $\rho$($\Omega mm^2$/m) | 0.023 |
| T in a short circuit(°C) $\theta_f$ | 250 |
| T Admissible(°C) $\theta_d$ | 90 |
| $I_n$(A) | 850 |
| $U_n$(V) | 750 |
| max ambiante temperature(°C) | 35 |

**conductor thermal stress**

laying condition of coupon's power supply cables is on a cable tray.

- Ambient temperature Coefficient at: 35°C : $K_1$=0.96
- $K_2$=1 coefficient quantity of joined link (extracted from the table 52N of NF C 15-100)

$$K = K_1 \times K_2 = 0.96$$

$$I_{admissible} = \frac{I_n 2h}{K} = 885.41A \tag{3.48}$$

$$numberofcables = \frac{I_{admissible}}{I_{admissible}(cable)} = \frac{885.41}{940} = 0.94 \tag{3.49}$$

the number of cables required=1.

**short circuit**

- short circuit current $I_{cc}$=39KA.
- breaking time of the high voltage circuit breaker 0.2S.
- k=11.

$$S = \frac{I_{cc}}{k}\sqrt{\frac{t}{\theta f - \theta d}} = 140.15mm^2 \tag{3.50}$$

S=140.15$mm^2$ < proposed section.

**Voltage drop**

$$\Delta U_V = \frac{\rho \times L \times 2}{S} \times I_n 2h = 9.56V \tag{3.51}$$

L=100m
which corresponds to 1.27% of 750V So, 1 cable of 1×400mm²Cu cables per phase for the positive supply of the coupons.

### 3.4.8 The result of the traction cables sizing

**The figure3.13** bellow present all the traction cable sizing

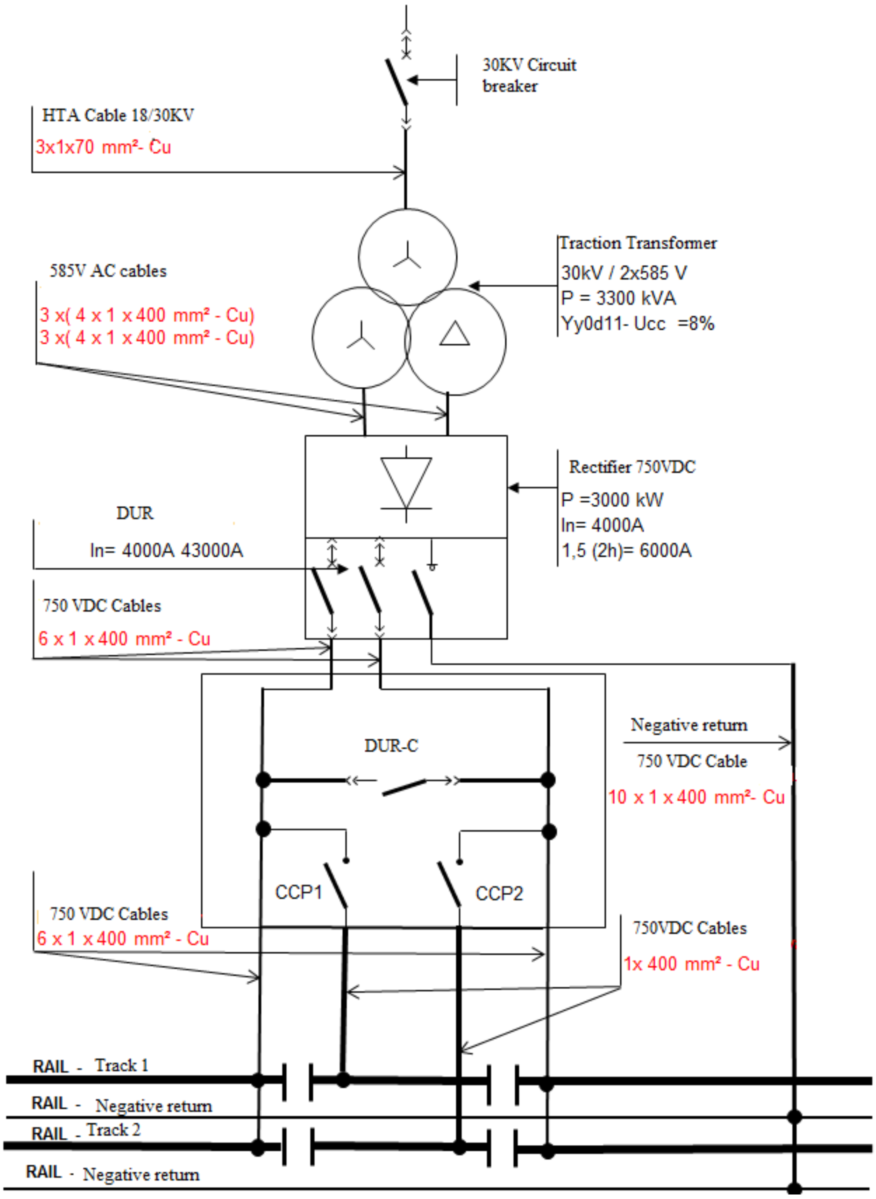



Figure 3.13: Traction cable sizing.

## 3.5 Low voltage cable sizing(PR31 and PR32)

### 3.5.1 Presentation of CANECO BT

CANECO BT is a software for automated calculations, sizing,Protection against electrical arc, and diagrams of low voltage electrical installations. Its functionalities are: Calculation and economic dimensioning of circuits, Conformity of electrical installations, Automated production of electrical diagrams, Automated design of prefabricated cabinets, Multi-manufacturer technical and tariff database, installation costing , Neutrality in calls for tender.
For the calculation using CANECO BT a necessary data should be entered such as the properties of the source ,the equipment and the appropriate circuit breakers.

### 3.5.2 Load schedule

Before the dimensioning simulation , a load schedule must be calculated to size the transformer , cables and protections devices. **the tables 3.9,3.10 and 3.11** present the Load schedule of auxiliary 400V -normal feeding ,Auxiliary 400V - rescued feeding and 230 VAC corrugated feeding .

Table 3.9: Auxiliary table 400V -normal feeding

| Auxiliary table 400V -normal feeding | | | | |
|---|---|---|---|---|
| Circuit | Designation | Single-phase/Threephase | Installed power(kVA) | Operating power(KVA) |
| Q1.3 | Coffret de ventilation PR32 | Triphasé | 22 | 22 |
| Q1.4 | Controle-commande- coffret de ventilation | Monophasé | 0.3 | 0.3 |
| Q1.5 | Eclairage sale PR-normal | Monophasé | 0.76 | 0.76 |
| Q1.6 | Eclairage et chauffage cellule de traction | Monophasé | 0.66 | 0.66 |
| Q1.7 | Eclairage sale a cable | Monophasé | 1.19 | 1.19 |
| Q1.19 | Eclairage et chauffage cellule HTA | Monophasé | 0.65 | 0.65 |
| Q1.12 | Eclairage et chauffage CSPN | Monophasé | 0.3 | 0.3 |

Table 3.10: Auxiliary table 400V - rescued feeding

| Auxiliary table 400V - rescued feeding | | | | |
|---|---|---|---|---|
| Circuit | Designation | Single-phase/threephase | Installed power(KVA) | Operating power(KVA) |
| Q2.2 | Eclairage armoire TSA | Monophasé | 0.1 | 0.10 |
| Q2.3 | Eclairage salle PR | Triphasé | 0.66 | 0.66 |
| Q12.4 | Eclairage sale PR secouru | Monophasé | 0.66 | 0.66 |
| Q2.5 | Eclairage locaux transformateur et UPS-secouru | Monophasé | 3.68 | 0.74 |
| Q2.6 | Prise de courant monophasé | Triphasé | 6.25 | 1.25 |
| Q2.7 | Prise de courant triphasé | Triphasé | 10 | 5 |
| Q2.8 | By pass UPS | Triphasé | 10 | 5 |
| Q2.10 | Eclairage locaux et ventilation | Triphasé | 0.66 | 0.66 |
| Q2.12 | Eclairage salle a cable secouru | Monophasé | 1.3 | 1.30 |

Table 3.11: 230 VAC corrugated feeding table

| 230 VAC corrugated feeding | | | | |
|---|---|---|---|---|
| Circuit | Designation | Single-phase/threephase | Installed power(KVA) | Operating power(KVA) |
| Q3.1 | Motorisation cellules HTA | Monophasé | 0.5 | 0.15 |
| Q3.2 | Motorisation cellules traction | Monophasé | 0.5 | 0.10 |
| Q3.3 | Motorisation cellules CSPN | Monophasé | 0.5 | 0.10 |
| Q3.4 | Coffret CFA | Monophasé | 0.1 | 0.10 |
| Q3.5 | Coffret AES | Monophasé | 0.2 | 0.10 |
| Q3.6 | Relais tsx1 TRT | Monophasé | 0.1 | 0.10 |
| Q3.7 | Relai TSX1 TRSA | Monophasé | 0.1 | 0.10 |
| Q3.8 | Alimentation redressé 230 VAC/24VCC | Monophasé | 0.48 | 0.48 |
| Q3.9 | Alimentation redressé 230 VAC/24VCC | Monophasé | 0.48 | 0.48 |
| Q3.10 | Alimentation redressé 230 VAC/48VCC | Monophasé | 0.24 | 0.24 |
| Q3.11 | Alimentation redressé 230 VAC/48VCC | Monophasé | 0.24 | 0.24 |
| Q3.13 | LSC salle PR | Monophasé | 0.12 | 0.12 |
| Q3.14 | LSC salle a câbles PR | Monophasé | 0.12 | 0.12 |

### 3.5.3 Simulation steps

for dimensioning Low Voltage cables and protections using the software CANECO BT, the steps below should be follow:

1. Adding the source and TGBT data and select the types of cables and circuit breakers used.

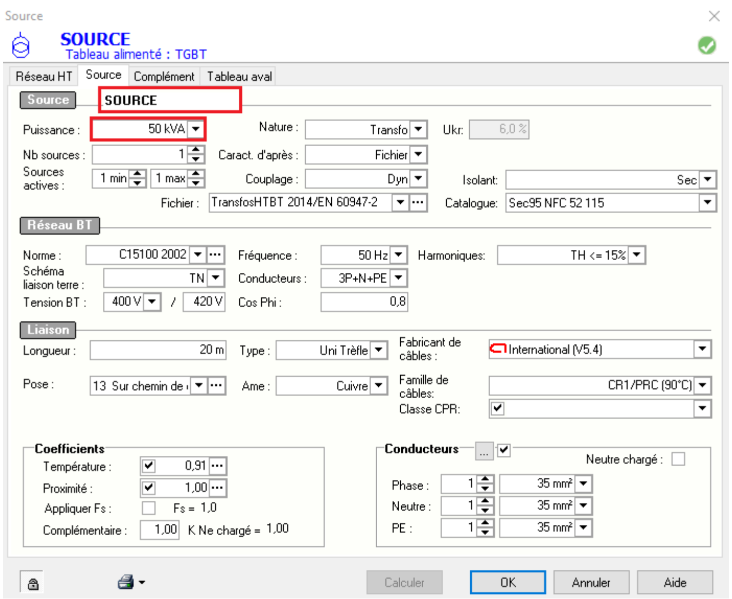



Figure 3.14: Source characteristics.

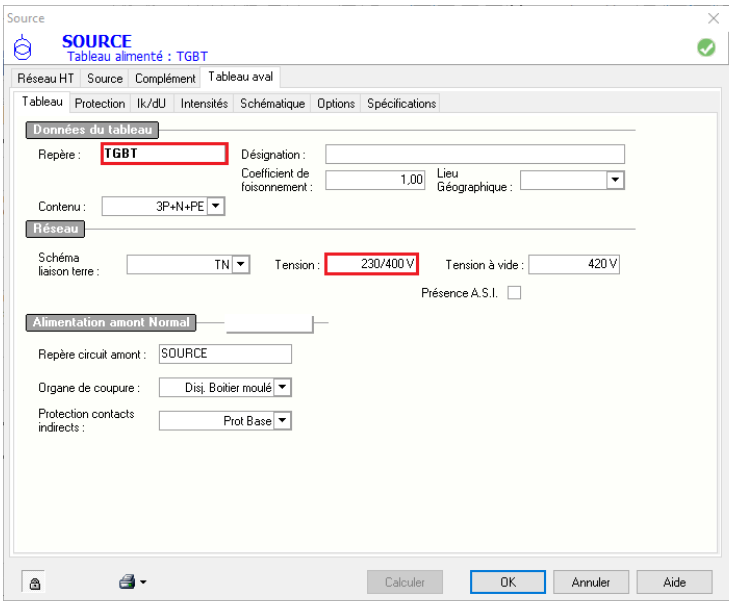



Figure 3.15: TGBT characteristics

2. Adding loads characteristics to Construct the single line diagram .

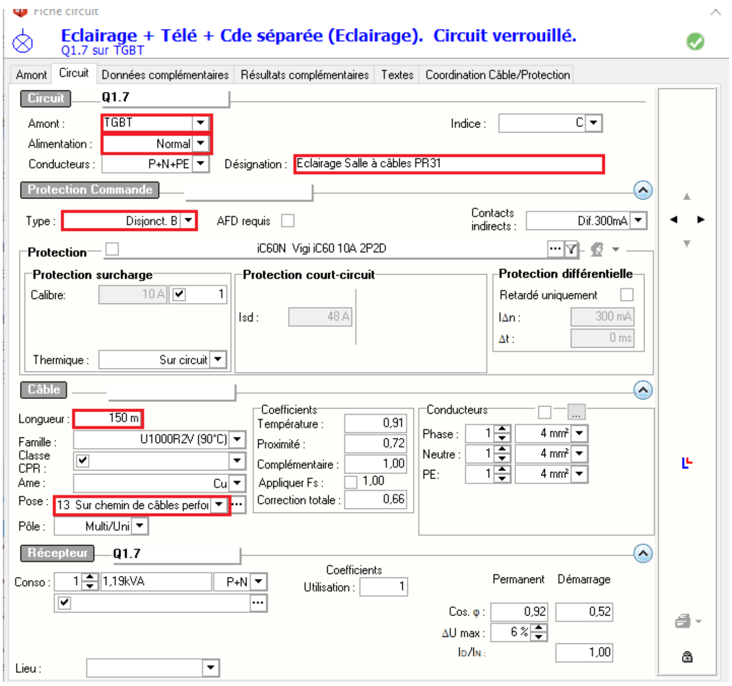



Figure 3.16: Load parameters

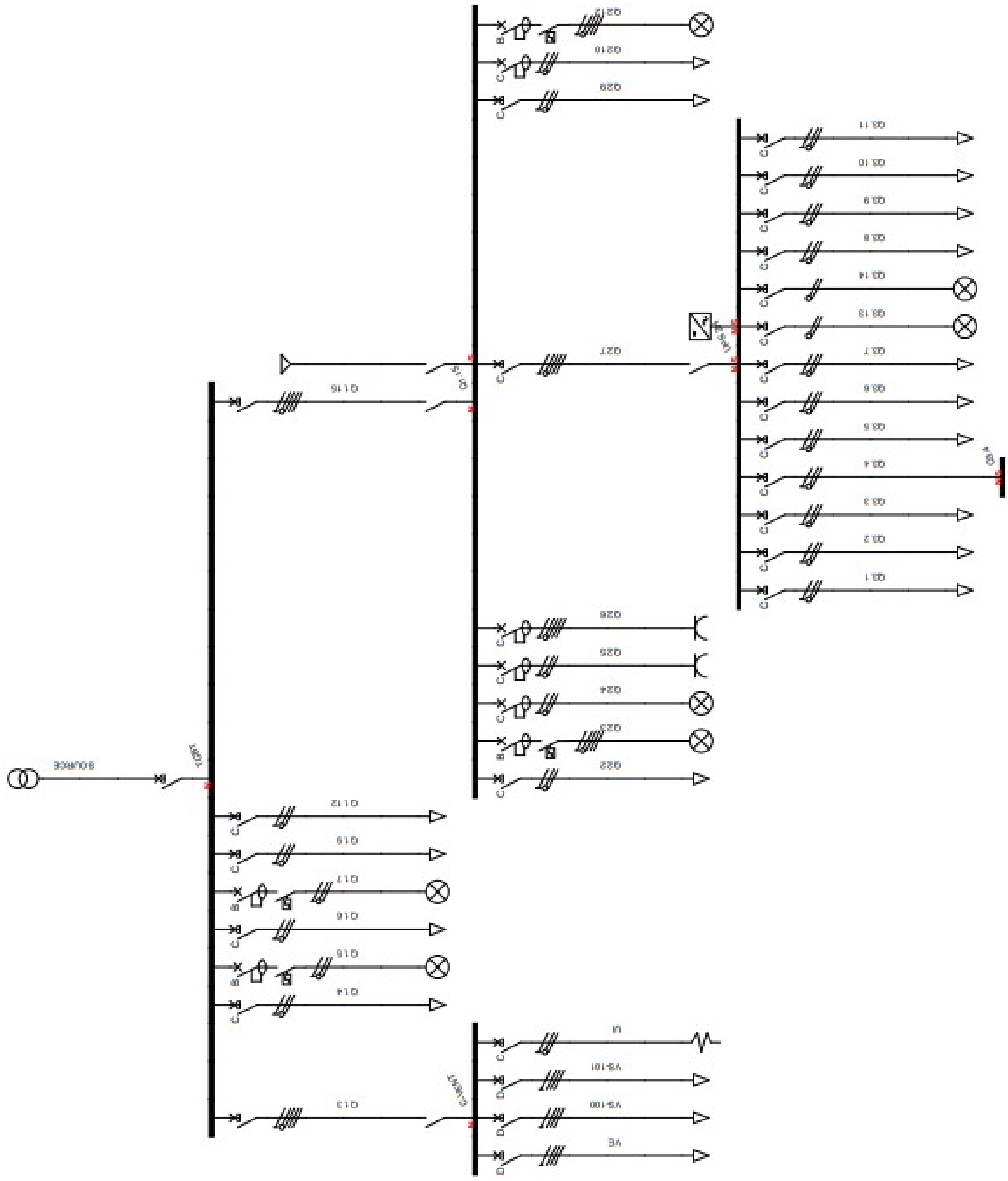


Figure 3.17: Single line diagramme.

3. Simulate and display the results.

Carnet de câbles SOURCE/SECOURS

| Amont | Repère | Longueur | Type de câble | Ame | Nb câbles multi | Câble | Neutre | PE ou PEN |
|---|---|---|---|---|---|---|---|---|
| | SOURCE | 20 m | CR1/PRC (90°C) | Cu | | | | |
| | SECOURS | 0 m | | | | | | |

Carnet de câbles TGBT

| Amont | Repère | Longueur | Type de câble | Ame | Nb câbles multi | Câble | Neutre | PE ou PEN |
|---|---|---|---|---|---|---|---|---|
| TGBT | Q1.3 | 40 m | PR (90°C) | Cu | 1 | 5G16 | | |
| TGBT | Q1.4 | 40 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| TGBT | Q1.5 | 150 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| TGBT | Q1.6 | 50 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| TGBT | Q1.7 | 150 m | U1000R2V (90°C) | Cu | 1 | 3G4 | | |
| TGBT | Q1.9 | 50 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| TGBT | Q1.12 | 50 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| TGBT | Q1.15 | 5 m | PR (90°C) | Cu | 1 | 5G16 | | |
| TGBT | BP2 | 0 m | | | | | | |
| TGBT | BP Q1.5 | 0 m | | | | | | |

Carnet de câbles C-VENT

| Amont | Repère | Longueur | Type de câble | Ame | Nb câbles multi | Câble | Neutre | PE ou PEN |
|---|---|---|---|---|---|---|---|---|
| C-VENT | VE | 30 m | PR (90°C) | Cu | 1 | 4G6 | | |
| C-VENT | VS-100 | 30 m | PR (90°C) | Cu | 1 | 4G6 | | |
| C-VENT | VS-101 | 30 m | PR (90°C) | Cu | 1 | 4G6 | | |
| C-VENT | UI | 50 m | PR (90°C) | Cu | 1 | 3G2,5 | | |

Carnet de câbles Q1.15

| Amont | Repère | Longueur | Type de câble | Ame | Nb câbles multi | Câble | Neutre | PE ou PEN |
|---|---|---|---|---|---|---|---|---|
| Q1.15 | Q2.2 | 5 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| Q1.15 | Q2.3 | 150 m | PR (90°C) | Cu | 1 | 5G2,5 | | |
| Q1.15 | Q2.4 | 60 m | PR (90°C) | Cu | 1 | 3G1,5 | | |
| Q1.15 | Q2.5 | 150 m | PR (90°C) | Cu | 1 | 3G6 | | |
| Q1.15 | Q2.6 | 150 m | U1000R2V (90°C) | Cu | 1 | 5G10 | | |
| Q1.15 | Q2.7 | 30 m | CR1/PRC (90°C) | Cu | 1 | 5G16 | | |
| Q1.15 | Q2.9 | 5 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| Q1.15 | Q2.10 | 50 m | U1000R2V (90°C) | Cu | 1 | 3G2,5 | | |
| Q1.15 | Q2.12 | 150 m | PR (90°C) | Cu | 1 | 5G2,5 | | |
| Q1.15 | BY-PASS STAT | 0 m | | | | | | |
| Q1.15 | BY-PASS M | 0 m | | | | | | |
| Q1.15 | BP Q2.3 | 0 m | | | | | | |
| Q1.15 | BP Q2.12 | 0 m | | | | | | |

Carnet de câbles UPS 2H

| Amont | Repère | Longueur | Type de câble | Ame | Nb câbles multi | Câble | Neutre | PE ou PEN |
|---|---|---|---|---|---|---|---|---|
| UPS 2H | Q3.1 | 50 m | CR1/PRC (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.2 | 50 m | CR1/PRC (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.3 | 50 m | CR1/PRC (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.4 | 50 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.5 | 50 m | CR1/PRC (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.6 | 5 m | U1000R2V (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.7 | 5 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.13 | 100 m | CR1/PRC (90°C) | Cu | 1 | 2X2,5 | | |
| UPS 2H | Q3.14 | 100 m | CR1/PRC (90°C) | Cu | 1 | 2X2,5 | | |
| UPS 2H | Q3.8 | 5 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.9 | 5 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.10 | 5 m | PR (90°C) | Cu | 1 | 3G2,5 | | |
| UPS 2H | Q3.11 | 5 m | PR (90°C) | Cu | 1 | 3G2,5 | | |

Figure 3.18: Result of low voltage cable sizing.

Table 3.12: Protection sizing devices

| Repère | Type Protection | IB | Bloc de coupure | Bloc déclencheur | Bloc différentiel | Calibre | IrTh / IN | IZ | IrMg / IN | IInstant | Tempo | IInstantOnOff | Ir Mg Max | Ir Diff | Tempo Diff |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q1.3 | Disj. Boitier moulé | 31,75 A | NSX100F | Micrologic 2.2 | | 100 A | 36 A | 65,82 A | 360 A | 1500 A | 20 ms | | 699 A | | |
| Q1.4 | Disjonct. C | 1,30 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q1.5 | Disjonct. B | 3,29 A | iC60N | | Vigi iC60 | 10 A | | 23,85 A | 48 A | | | | | 300 mA | 0 ms |
| Q1.6 | Disjonct. C | 2,86 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |
| Q1.7 | Disjonct. B | 5,15 A | iC60N | | Vigi iC60 | 10 A | | 31,96 A | 48 A | | | | | 300 mA | 0 ms |
| Q1.9 | Disjonct. C | 2,81 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |
| Q1.12 | Disjonct. C | 1,30 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |
| Q1.15 | Disj. Boitier moulé | 14,43 A | NSX100F | Micrologic 2.2 | | 100 A | 36 A | 65,82 A | 360 A | 1500 A | 20 ms | | 817 A | | |
| VE | Disjonct. D | 20,75 A | iC60N | | | 32 A | | 35,72 A | 460,8 A | | | | | | |
| VS-100 | Disjonct. D | 7,51 A | iC60N | | | 16 A | | 35,72 A | 230,4 A | | | | | | |
| VS-101 | Disjonct. D | 7,51 A | DT40 | | | 16 A | | 35,72 A | 224 A | | | | | | |
| UI | Disjonct. C | 9,74 A | DT40 | | | 16 A | | 23,85 A | 160 A | | | | | | |
| Q2.2 | Disjonct. C | 0,43 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |
| Q2.3 | Disjonct. B | 0,95 A | iC60N | | Vigi iC60 | 10 A | | 20,71 A | 48 A | | | | | 300 mA | 0 ms |
| Q2.4 | Disjonct. C | 2,86 A | iC60N | | Vigi iC60 | 10 A | | 17,35 A | 96 A | | | | | 300 mA | 0 ms |
| Q2.5 | Disjonct. C | 3,20 A | iC60N | | Vigi iC60 | 16 A | | 41,14 A | 153,6 A | | | | | 30 mA | 0 ms |
| Q2.6 | Disjonct. C | 9,02 A | iC60N | | Vigi iC60 | 20 A | | 49,11 A | 192 A | | | | | 30 mA | 0 ms |
| Q2.7 | Disjonct. C | 7,22 A | iC60N | | | 25 A | | 65,82 A | 240 A | | | | | | |
| Q2.9 | Disjonct. C | 0,43 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q2.10 | Disjonct. C | 2,86 A | iC60N | | Vigi iC60 | 10 A | | 23,85 A | 96 A | | | | | 300 mA | 0 ms |
| Q2.12 | Disjonct. B | 1,88 A | iC60N | | Vigi iC60 | 10 A | | 20,71 A | 48 A | | | | | 300 mA | 0 ms |
| Q3.1 | Disjonct. C | 2,17 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q3.2 | Disjonct. C | 2,17 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |
| Q3.3 | Disjonct. C | 2,17 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q3.4 | Disjonct. C | 0,43 A | iC60N | | | 16 A | | 23,85 A | 153,6 A | | | | | | |
| Q3.5 | Disjonct. C | 0,87 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q3.6 | Disjonct. C | 0,43 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q3.7 | Disjonct. C | 0,43 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q3.13 | Disjonct. C | 0,52 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q3.14 | Disjonct. C | 0,52 A | iC60N | | | 6 A | | 23,85 A | 57,6 A | | | | | | |
| Q3.8 | Disjonct. C | 2,08 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |
| Q3.9 | Disjonct. C | 2,08 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |
| Q3.10 | Disjonct. C | 1,04 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |
| Q3.11 | Disjonct. C | 1,04 A | iC60N | | | 10 A | | 23,85 A | 96 A | | | | | | |

## 3.6 Conclusion

As the third rail is supplied from the rectifier unit that is fed from the high voltage substation ,sizing study of the high voltage cables between PHT and PR ,traction line cables and the low voltage cables is treated in this chapter.

Based on the table 52J of the NFC13-200/2009 standard and after calculation using the input data we found that a high voltage single-core Cu cables with a cross-section of 120 mm $^2$ laid in a trefoil between the PHT and extension C can carried out the power supply of the PRs.

The synthesis of the results by measuring the type, section and quantities of cables to be applied for the traction line of the extension c's project are calculated then presented in **figure3.13** .

Low voltage cables and protection devices sizing using CANECO BT are listed in appendix B.1.

# Chapter 4

# Stray Current Corrosion

## 4.1 Introduction

Corrosion, from the Latin “corrodere”, means “to chew away” or “to attack” a material as a result of chemical interaction between this material and its environment. Corrosion is not limited to metals only but affects other materials as well ( wood, polymers, ceramics, etc), which also corrode or degrade during their service life .
The corrosion problem caused by stray current was noticed within ten years of the first dc-powered rail line in the United States in 1888 in Richmond, Virginia, and ever since, the control of stray current has been a critical issue. Similarly, the effects of rail and utility-pipe corrosion caused by stray current had been observed in Europe. However, the most relevant source of stray current both in terms of intensity and physical extension are electric transportation systems, such as railway, metro and tram lines.
This chapter includes the problem description of stray current caused by the DC traction system and its solution .

## 4.2 stray current definition

Is part of the current from a DC traction network that follows paths other than the return circuit(**figure 4.1**).[20]

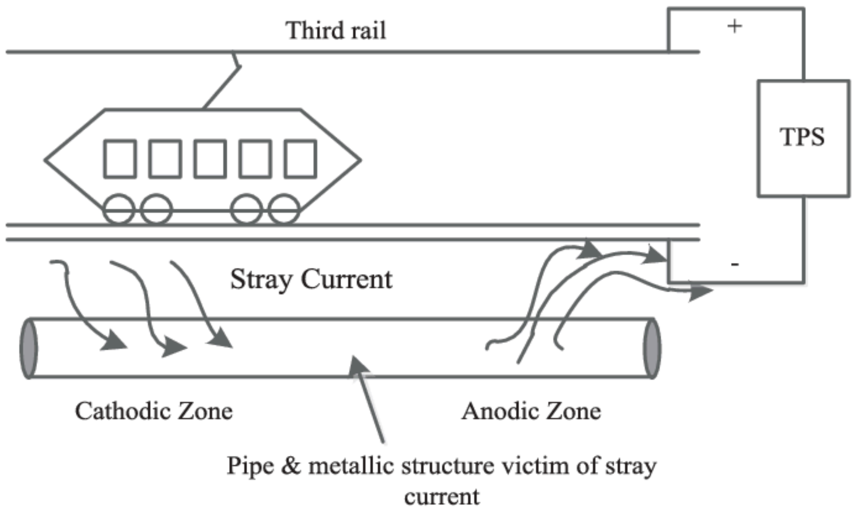



Figure 4.1: Schematic of stray current generated in an electric traction system flowing through the underground metallic structures.

## 4.3 Consequences

The major effects of stray currents can be corrosion and subsequent damage of metallic structures(**figure4.2**). There is also the risk of overheating, arcing , fire and subsequent danger to persons and equipment both inside and outside the railway system.
All components and systems which can be affected by stray currents shall be considered such as:

- Running rails.
- Metallic pipe work.
- Cables with metal armour and/or metal shield.
- Metallic tanks and vessels.
- Earthing installations.
- Reinforced concrete structures.
- Buried metallic structures.
- Signalling and telecommunication installations.
- Cathodic protection installations.[20]


Figure 4.2: Stray current corrosion.

circulation of a current of 1 Ampere entraine per year the dissolution of

- 3.5 Kg of Aluminum
- 9 Kg of iron
- 23Kg of Plumb[21]

## 4.4 Principles of stray current and corrosion

### 4.4.1 Corrosion cell

For corrosion to occur, the formation of a corrosion cell is a necessity. It is composed of typically four components: anode, cathode, electrolyte and metallic path. Anode is where oxidation (removal of electrons) takes place. Cathode is where reduction (gain of electrons) takes place. Electrolyte is an electrically conductive solution, through which positively charged ions (cations) can flow. Conversely, a metallic path is necessary for the flow of electrons. Conventional current flows from anode to cathode in form of positively charged ions through the electrolyte, metallic path is necessary for the flow of electrons flow. The best way to stop corrosion is opening this circuit by removing one (or more than one) of the aforementioned components of the corrosion cell.[22]

Anodic reaction: $Fe \rightarrow Fe^{2+} + 2e^-$

Cathodic reaction:

$$\frac{1}{2}O^2 + H_2O + 2e^- \rightarrow 2OH^- \qquad pH>7$$

$$2H^+ + 2e^- \rightarrow H_2 \qquad pH<7$$

### 4.4.2 DC traction stray current

The traction current, which in conjunction with the voltage applied to the collectors, supplies power to the railway traction vehicle through positive conductor (third rail or overhead contact system) must have a return path. As the current path must be considered to constitute a closed loop, the total return current must be equal to the current flowing through the positive conductor.

The train current collection devices receive the DC supply required to operate the train and the current then returns to traction substations via the wheels of the train and the unearthed rail track system. Ideally, all the current should return through the rails. But due to the resistances of running rails and insulation deterioration between running rails and track plinth/slab, there will be a portion of the return traction current that deviates from the intended path (i.e. running rails) called stray current. This current leaks from the rails to the structure (track plinth, deck and surrounding ground), and flows back into the rectifier negative bus through the running rails. Since the rectifier is insulated from the earth, so there is no other path for stray current to enter the negative bus of the rectifier.

The return traction current causes a longitudinal voltage drop along the rails. Although the rails are isolated from the main mass of earth, there is inevitably distributed leakage resistance causing a varying potential difference with respect to earth. Thus, the region where current leaving the metallic object (running rails, structure reinforcement, etc.) is the anodic region. The below reaction indicates the oxidation of iron which leads to corrosion. At the point where the stray current leaves the metal surfaces, an anodic reaction takes place at the metal/electrolyte, resulting in oxidation (dissolution) of the metal. The anodic reaction results in positive polarisation (positive potential shift) of the metal surface, and thus stray current can be identified by potential measurements. At the point where the stray current enters the metal surface the cathodic part of the reaction takes place at the metal/electrolyte interface.[22]

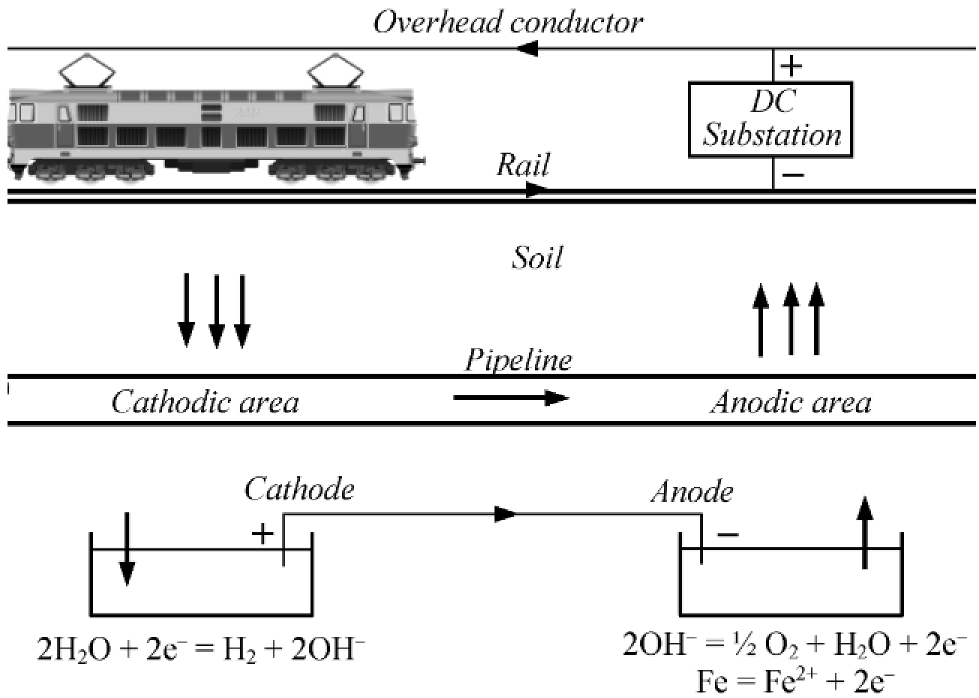



Figure 4.3: Railway stray-current schematic diagram( real railway system and equivalent ground-return circuit model).

## 4.5 Design criteria to reduce stray current

Beside to the operating currents, the most important parameters for the amount of stray current are:

- The conductance per length of the tracks and the other parts of the return circuit.
- The distance of the substations.
- The longitudinal resistance of the running rails.
- Spacing of cross bonds.[20]

If the railway system meets the requirements and measures of **EN 50122-2** Standard, the system is assumed to be acceptable from the stray current point of view. As per **EN 50122-2**, there are two important criteria in order to reduce corrosion and assess protection against it.

### 4.5.1 Criteria 1: rail to earth conductance

The most influencing variable that is a direct cause of stray current is the rail-to-earth conductance $G'_{RE}$(**figure 4.4**).$U_s$, $I_l$, $I_s$, $I_n$, $R_n$, $R_p$, $R_{in1}$ and $R_{in2}$ are defined as the traction substation voltage, train operating current, stray current, return current through rails, resistance of negative return circuit, resistance of positive circuit, rail-to-earth resistance at source end and rail-to-earth resistance at load end respectively.[22]

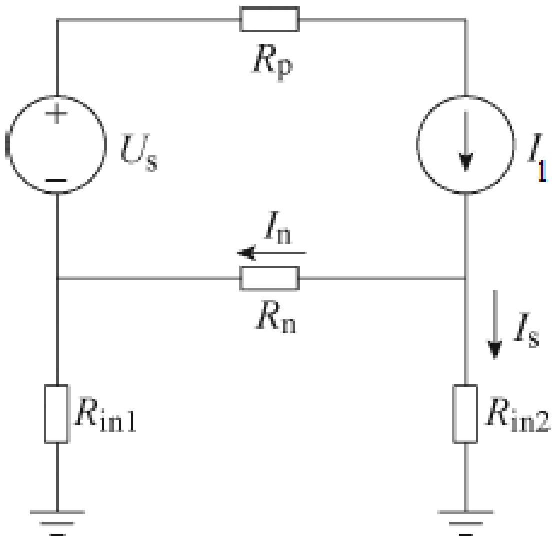



Figure 4.4: Basic stray current model.

$$U_{RE} = I_n R_n \tag{4.1}$$

$$I_s = \frac{U_{RE}}{R_{in1} + R_{in2}} \tag{4.2}$$

Equation4.1 indicates that the stray current is related to average rail potential $U_{RE}$ and rail-to-earth conductance $G'_{RE}$ . Therefore, low value of rail potential and good insulation of the running rails with respect to earth can limit stray currents considerably. Experience proves that there is no damage in the tracks over a period of 25 years, if the average stray current per unit length does not exceed the following value:[20]

$$I_{smax} = 2,5mA/m$$

### 4.5.2 Criteria for systems with metal reinforced concrete or metallic structures

Besides conductance, the other relevant quantity subject to limit is the average potential shift between the structure and earth in the hour of highest traffic, not to exceed +200mV for steel in concrete structures. This is illustrated in **figure4.5**.[22], [20]

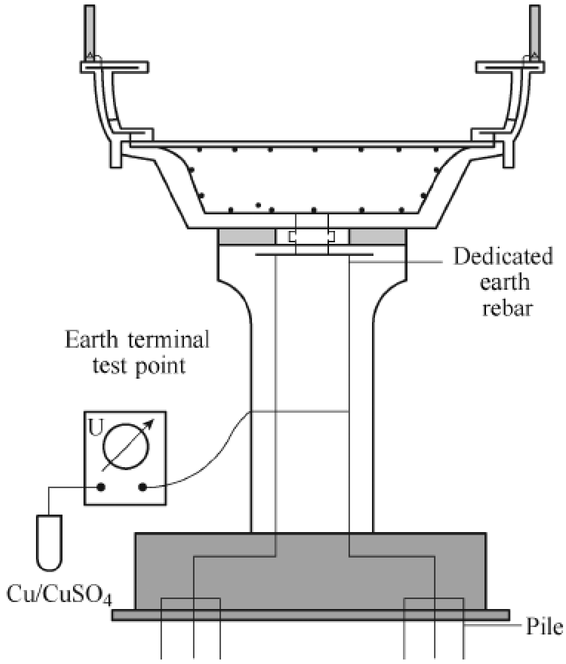



Figure 4.5: Average potential shift of structure.

A similar criterion may be applied to the longitudinal voltage drop between any two points of the through connected metal reinforced structure, such as viaducts or tunnels. Although a slightly different case from the potential shift previously considered, it is generally agreed the limit to be 200mV ( **Figure 4.6**).[20]

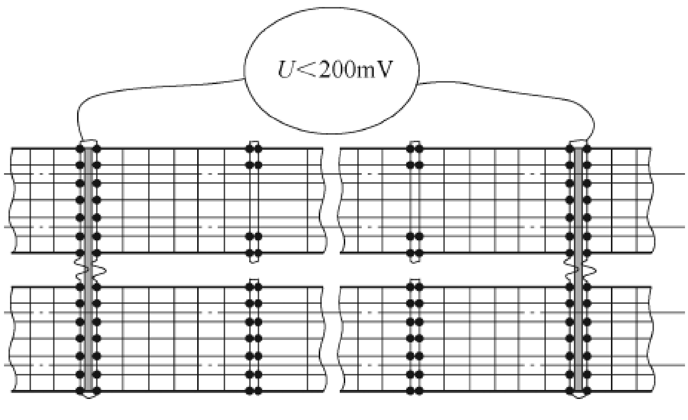



Figure 4.6: Longitudinal voltage drop of structure along line section.

## 4.6 Mitigations and control measures

### 4.6.1 Reducing the rail-return circuit resistance

Three specific measures are used to decrease the resistance of the rail-return circuit.

#### Increase rail size or cross-sectional area

Stray current leakage is a result of the resistance relationship between the rail-to-earth return path and the running rail return path.A high resistance of the running rail negative return increases the voltage drop along the rails and, therefore, makes the rail-to-earth return circuit a more favorable path for the return current, thus causing stray current leakage. The size of the rail is internationally standardized and increasing the cross-sectional area for reducing stray currents is not an available option.[22]

#### Improve track and rail cross bonding

The second important measure to decrease the running rail resistance is to maintain a continuous electrical path for the negative current return. This is accomplished by using continuously welded rails, or by using welded cable bonds between discontinuous sections of the track. The objective must be to ensure that the longitudinal rail resistance is not increased by more than 5% by the rail joints.[20]

#### Reduce distance between traction substations

Short distance between two substations decreases the length of positive feeder and the negative return circuit, and thereby reducing the voltage drop and making stray current paths less favorable. Traction substations typically will coincide with a passenger station, which provides added benefit in reducing stray current, since the current requirements of the trains are highest during acceleration, but the running rails return circuit voltage drops are the smallest due to the short length of track.[20]

### 4.6.2 Increasing resistance of leakage path to earth

Specific measures used to increase the leakage path resistance are discussed below.

#### Maintaining an ungrounded negative return circuit

First and foremost, to increase the resistance of leakage paths to earth an ungrounded traction power system must be used. Let us consider the case of insulated track, having a small uniform electrical conductance with the earth. In the case of a traction substation at one end and a train at the other, the major portion of traction current will flow through the running rails, and part will leak into the earth where rail potential is positive and will return to the rails where rail potential is negative. At equilibrium, the current entering will be equal to the current leaving and somewhere near the mid-point between train and traction substation the potential will be zero ("Pseudo earth"), ( **Figure4.7**) in case, the negative bus-bar is earthed at the traction sub-station end, while maintaining the remaining track floating. It is observed that the running rail potential will increase to double the value as the curve will shift to the origin, where the traction substation is connected to earth, as shown in **figure 4.8**. This will lead to more current leakage. thus, it is advisable to keep the system ungrounded However, to avoid impermissible touch voltage, voltage limiting devices shall be installed. Typically, they are installed at passenger stations where the probability of passenger entering the tracks is higher, including the contact with Platform Screen Doors.[22]

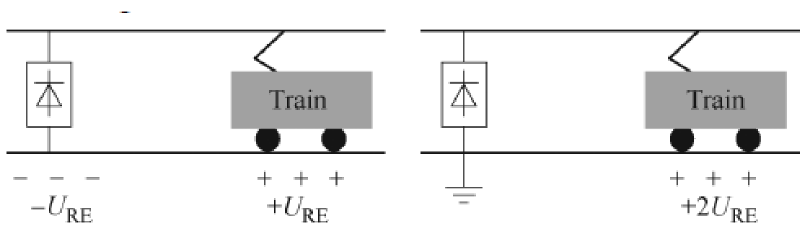



Figure 4.7: Floating and earthed tracks.

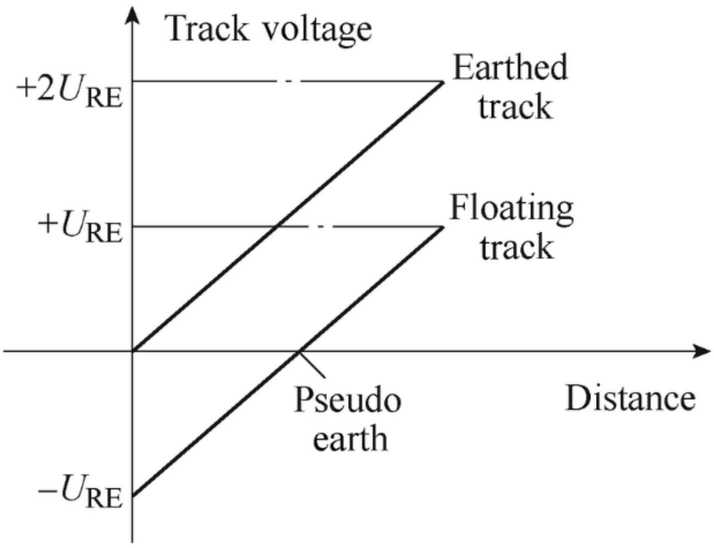



Figure 4.8: Ideal track voltage profile.

**Increasing the rail-to-earth resistance**

This is the most influencing variable for stray current leaving the tracks. Rail fastener insulation is important, so that, high rail-to-earth resistance is maintained. In theory, stray currents from an ungrounded system should be low, as long as rail is not earthed along the line. By increasing this resistance, the stray current path is less favorable than the running rail return path, resulting in less stray current. Track design shall utilize insulated track fasteners on concrete track plinths or track slabs.[22]

### 4.6.3 Stray current collection system

Stray current collection system (SCCS) is aimed at catching as much stray current as possible to limit their propagation to the surrounding environment. All reinforced track sections shall meet the corrosion criteria of 200mV maximum as per EN 50122-2 and EN 50162. This criterion is intended for the voltage taken between any two points of the track or structure reinforcement. If the total stray current for a given system design is high, a considerable corrosion of the supporting infrastructure and of a third-party infrastructure may occur. In this situation, a stray current collection system (current collection mat or cable) may be needed to control the path through which the stray current returns to the substation.[22] As shown in **Figure 4.9** , a stray current collection system can be constructed under the rails to "capture" the stray current and avoid damage to the segments. Such collection systems usually take the form of reinforcement in the concrete track bed of a traction system. This reinforcement is bonded along its length to provide a continuous and relatively low resistance path. The stray current leaking from the running rails is intended to flow into this collection system and be captured upon it, as opposed to flowing through the surrounding construction or other local conductors such as utility pipes/cables. The performance of a stray current collection system is highly dependent on the conductivity of the system itself and of the neighboring soil.[23]

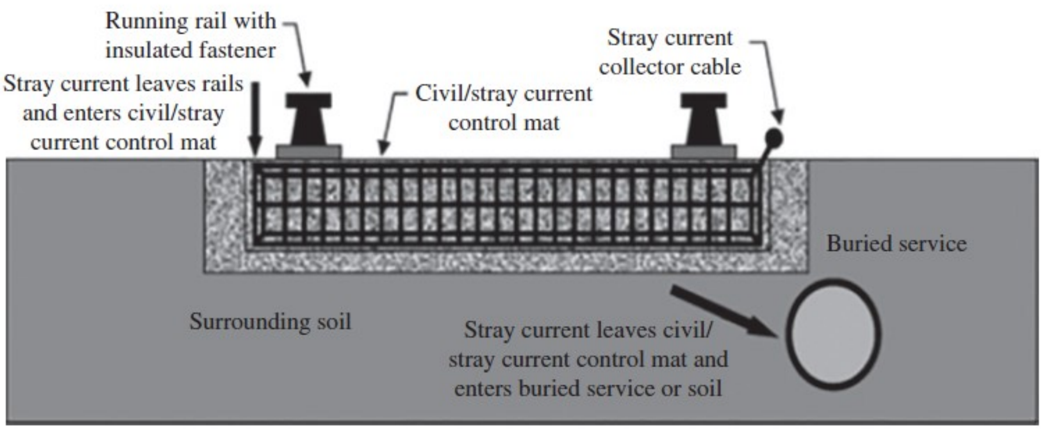



Figure 4.9: Stray current collection system under the rail

### 4.6.4 Drainage

A stray current cubicle is located in traction substation (TSS) to connect the reinforcement to the traction system negative bus through a diode and switch system. The so-called drainage function is aimed to collect stray current that flows along the SCCS when the latter is under corrosion risk (appendix C.1). To achieve this drainage function, a dedicated manual switch must be closed: this operation should be taken as the last resort only, since it brings the potential of the traction return circuit to earth (in turn increasing the overall amount of stray current).[23]

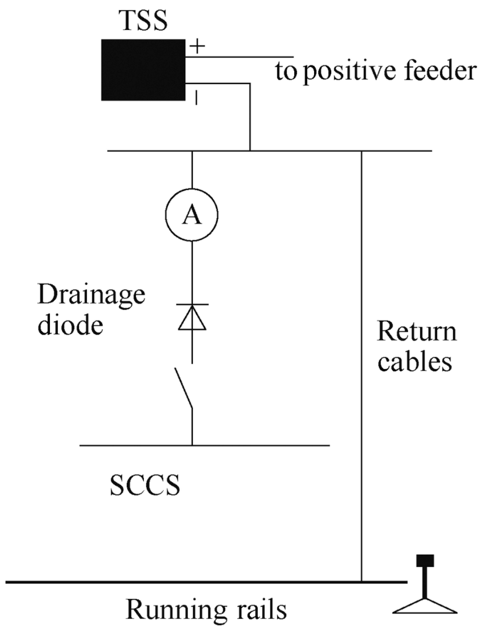



Figure 4.10: Drainage diode connection

## 4.7 Algiers metro solution for draining stray currents

### 4.7.1 Paralleling the tracks and installation of the 1000mm$^2$ feeder

Two feeder cables are unrolled on each side of the track, every 400 to 500 meters is placed a Parallel Setting Box (CMP), this box allows to realize the equipotential between the 4 rail wires and the two Feeders. Each feeder is a 1000 mm$^2$ insulated aluminium cable. These cables are at the bottom of the tunnel walkways. The equipotential between the 4 running rails and the two CMP boxes are made of two flexible copper cables with a cross section of 240 mm$^2$ each and insulated **(figure4.11)**. The CMP is composed of an insulating enclosure, a set of copper bus-bars or the equipotential rail connections can be disconnected. The connection of the 1000 mm$^2$ feeder to the CMP is Using bimetal terminals, the 240 mm$^2$ equipotentials are connected using copper terminals. The 4 running rails are connected to the substation via low-voltage cables with a cross-section of 400 mm$^2$. At each substation we have 10 cables of 400 mm$^2$ for the return of the currents.[24]

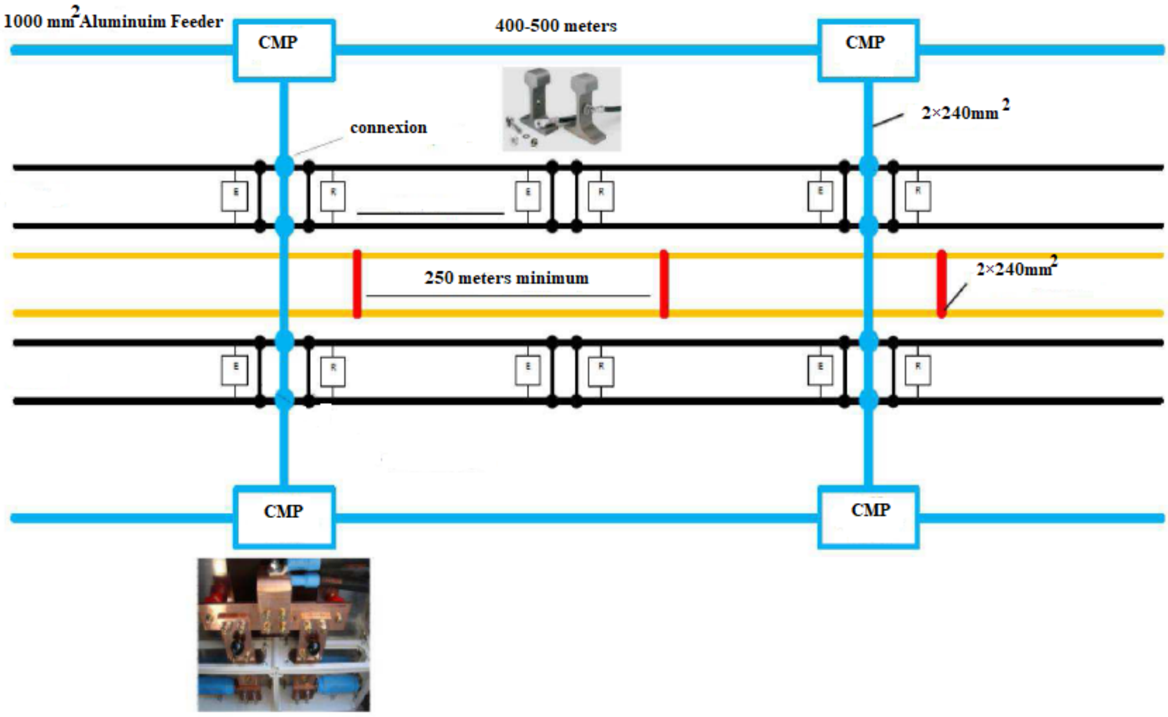



Figure 4.11: Track Paralleling and feeder 1000mm$^2$.

### 4.7.2 Iron bar under the track

A flat iron sheet is laid under the track to collect stray currents. An insulated cable cable connects this flat iron with the rectifier unit for the current returning ( **the same thing with the stray current collection system mentioned in 4.6.3)**.[25]

### 4.7.3 Feeder 70mm$^2$

As the tracks are built in a tunnel with a reinforced concrete structure, and to negate the possibility of stray currents flowing through the structure,according to the recommendations of §7.2.2 of the 50122-2 standard, the chosen solutions are :

- The installation of a 70mm$^2$feeder along the tunnel wall, connected to each equipotential bond in the tunnel ( connected to the reinforcement of the elements). Its purpose is to guide the stray currents to a drainage cabinet.
- The installation of polarised drainage cabinets that collect stray currents from the tunnel feeder and force the direction of stray currents towards the negative return of the substation.[25]

### 4.7.4 Stray current drainage cabinet

The drainage cabinet consists of :

- A collector diode to connect the 70$^2$ cables coming from the tunnel.

- A negative bar that will be connected to the negative busbar of the PR (CRN/SIA).
- An earthing bar diode which is connected to the grounding bar of the PR.
- A motorised disconnector.
- A SEPCOS PRISME PLC for the protection and remote control of the disconnector.[25]

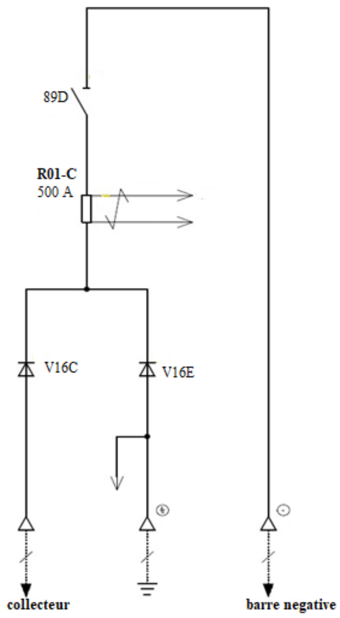



Figure 4.12: Drainage cabinet diagramme.

## 4.8 Functional analysis of drainage cabinets

The drainage cabinets are located in all the PR of the two A and C extensions and line 1 of the Algiers metro, namely 13 drainage cabinets.

### 4.8.1 Automatic functioning of the drainage cabinets

For the C extension the functional chronograph is as below:[25]

Table 4.1: Functional chronograph.

| PRs | $1^{st}$ week | $2^{nd}$ week | $3^{rd}$ week | $4^{th}$ week |
|---|---|---|---|---|
| PR31 | 0 | 1 | 1 | 1 |
| PR32 | 1 | 0 | 1 | 1 |

## 4.9 stray current measurement

In order to estimate the risk of corrosion caused by stray currents to which any metal structure is exposed, the positive potential shift of the affected structure must be taken into account. If cathodic corrosion of the metal structure is expected to occur, the risk of corrosion should also be estimated by reference to the negative potential shift of the structure . It is recommended to measure the potential between the structure and the ground with a reference electrode which is placed directly above the affected structure. Measurement techniques, sampling periods and the number of readings must be chosen in order to provide representative data. To ensure accurate measurements it is recommended to carefully choose an adequate voltage recording device and to consider fully (impedance of the input circuit, sampling period (or trace speed) conditioning and filtering of the signal.[26]

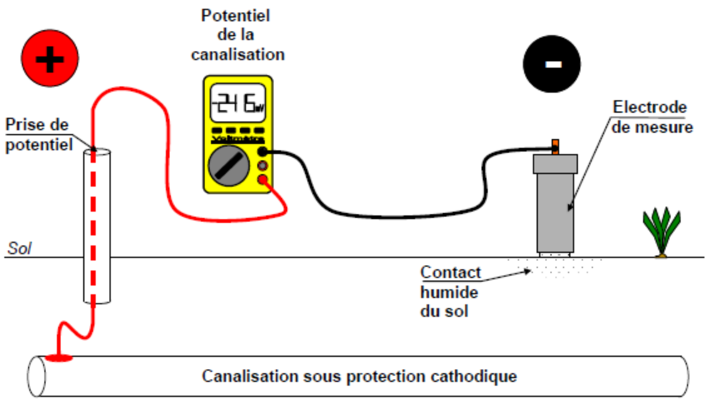



Figure 4.13: Potential measurement.

## 4.10 Drained stray current measurement

To measure drained stray current the following materials list is used :

- Calibrated ramlog recorder.
- Calibrated correal recorder.
- Cu/CuSo4 reference electrode.
- Multimeter.

- Cables and connector.
- Diode 3000 amp.
- 400 amp /100 AMP measuring shunt.
- Temporary drainage station with 100 amp diode.

**measuring results**

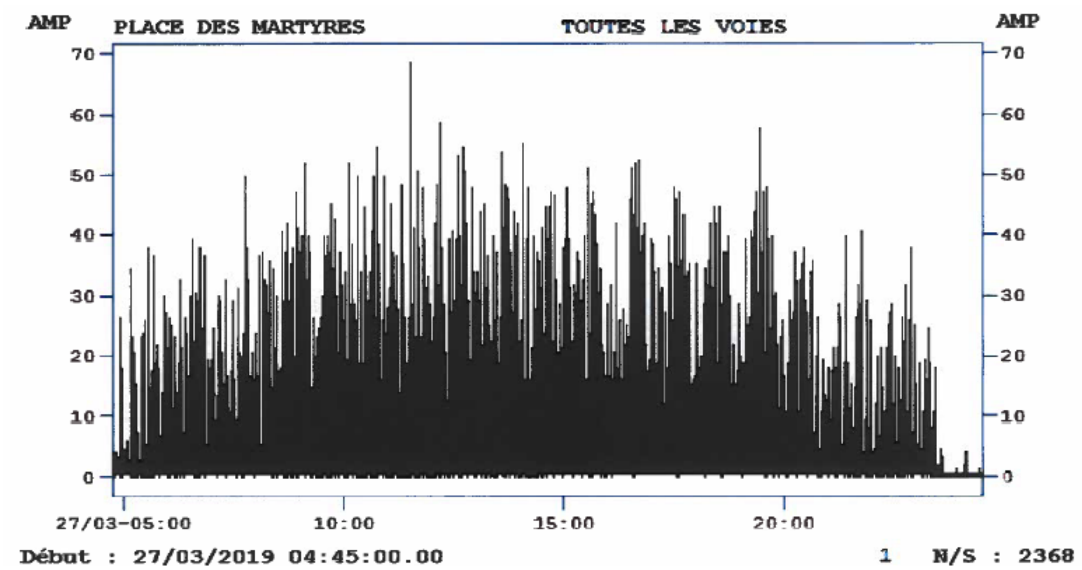



Figure 4.14: Measurement of the drained current from all channels.

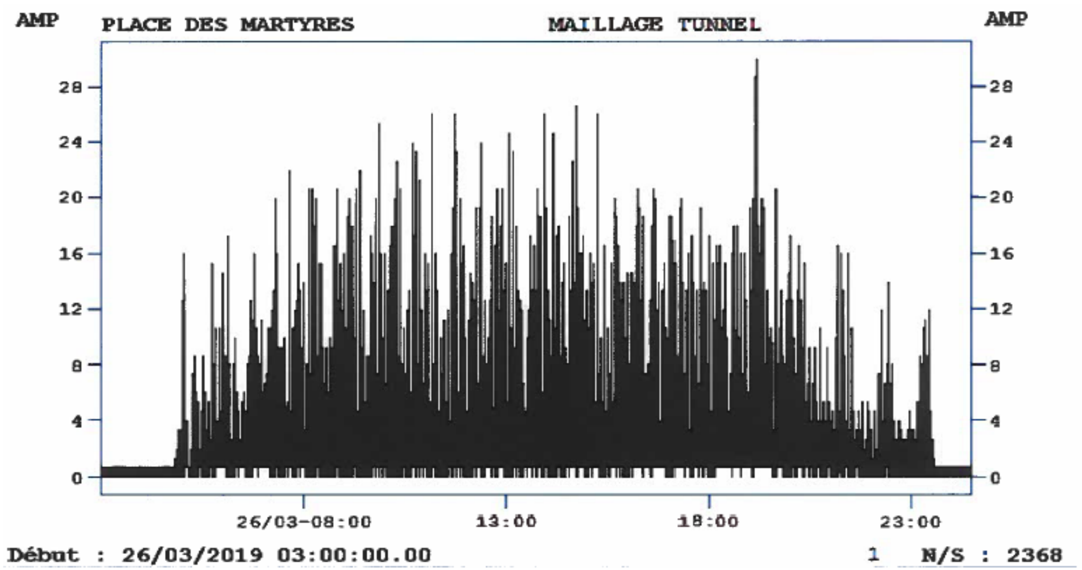



Figure 4.15: The drained current measurement of tunnel mesh.

**figures 4.14** and **4.15** shows that The current drained from the flat bars installed under the track is 70 Amp with the addition of 30 Amp of tunnel mesh which is considerable if a steel pipe with a stray current of 1 Amp loses 9 kg of its mass per year. Without this facility, these measured stray currents will not be drained and will pass through any buried metal structure causing accelerated degradation due to corrosion.

## 4.11 conclusion

Stray current arising from different power sources and then circulating in metal structures may initiate corrosion or even accelerate existing corrosion processes. Nevertheless, stray current-induced corrosion is still not sufficiently recognized in practice despite the far-reaching range and scale of dangerous or unwanted interactions of stray currents under favorable conditions and environment.

The aim of this chapter was to outline and bring the main aspects with regard to stray current corrosion, namely, the source , characteristics and consequences in view of electrochemical aspects, methods and techniques for reducing, monitoring and control of stray current induced corrosion for steel in infrastructure(all these are based on the NFC 50122-1 NFC 50122-2 and NFC 50162 standards). methods of reducing and mitigating stray current are applied in the algeirs metro extension c ,as a result the stray current drained under the track is about 70 amp under and 30 amp in tunnels which explain the importance of the current drainage .

# General Conclusion

The aim goal of this project is to study and size the third rail power supply of the Algiers metro exactly the extension C between HAI EL BADR and AIN NAAJA . the project's study is considred to be the responsibility of colas rail Algeria.

First this work described the traction system , advantages and disadvantages , electrification systems, then a third rail description , history and comparison between the other contact system were presented.

Second a study of a third rail power supply had montionned with a presentation of a high voltage substation also the rectifier unit which is a twelve pulse rectifier , a simulation with matlab simulink has developed to ensure its output performance.

Third a cable sizing study has developed which is based on NF 15-100 NF 15-105 NF 13-200 NF 13-205 to size the HV and the traction cables then a caneco bt software was used to dimensioning the low voltage cables of each PR.

Finally, the problem of stray current corrosion ,consequences , mitigation and measurement have been treated .

As perspective a new line extend to baraki will be constracted in the near future also new drainage cabinets will be in service.

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# Appendices

# Appendix A

# Study of a 3rd Rail Power Supply

## A.1 General architecture of High voltage network

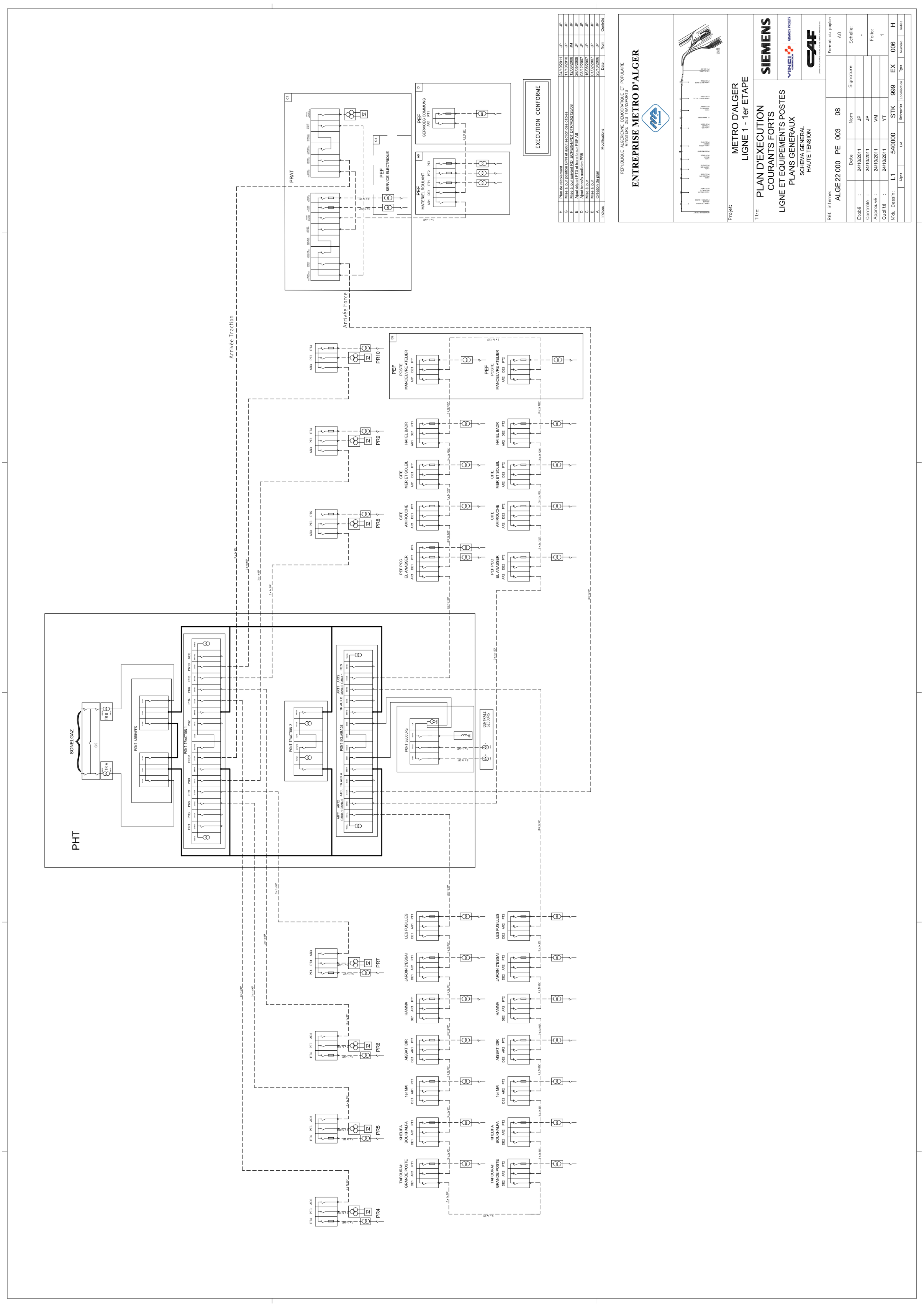



Figure A.1: General architecture of High voltage network.

## A.2 Gas insulated switchgear

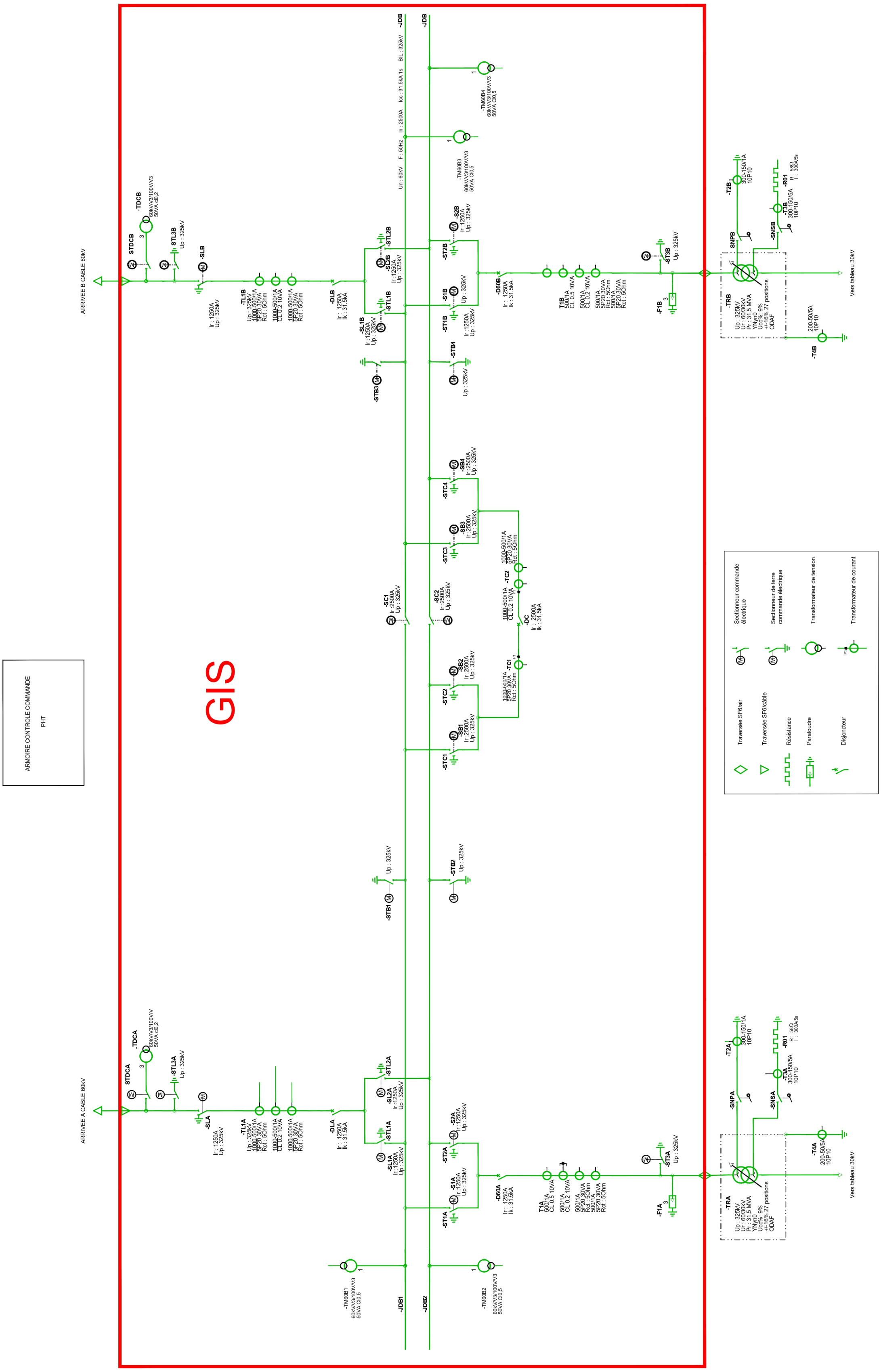



Figure A.2: Gas insulated switchgear equipments

## A.3 Functioning of the high voltage substation (PHT) 'Nominal mode'

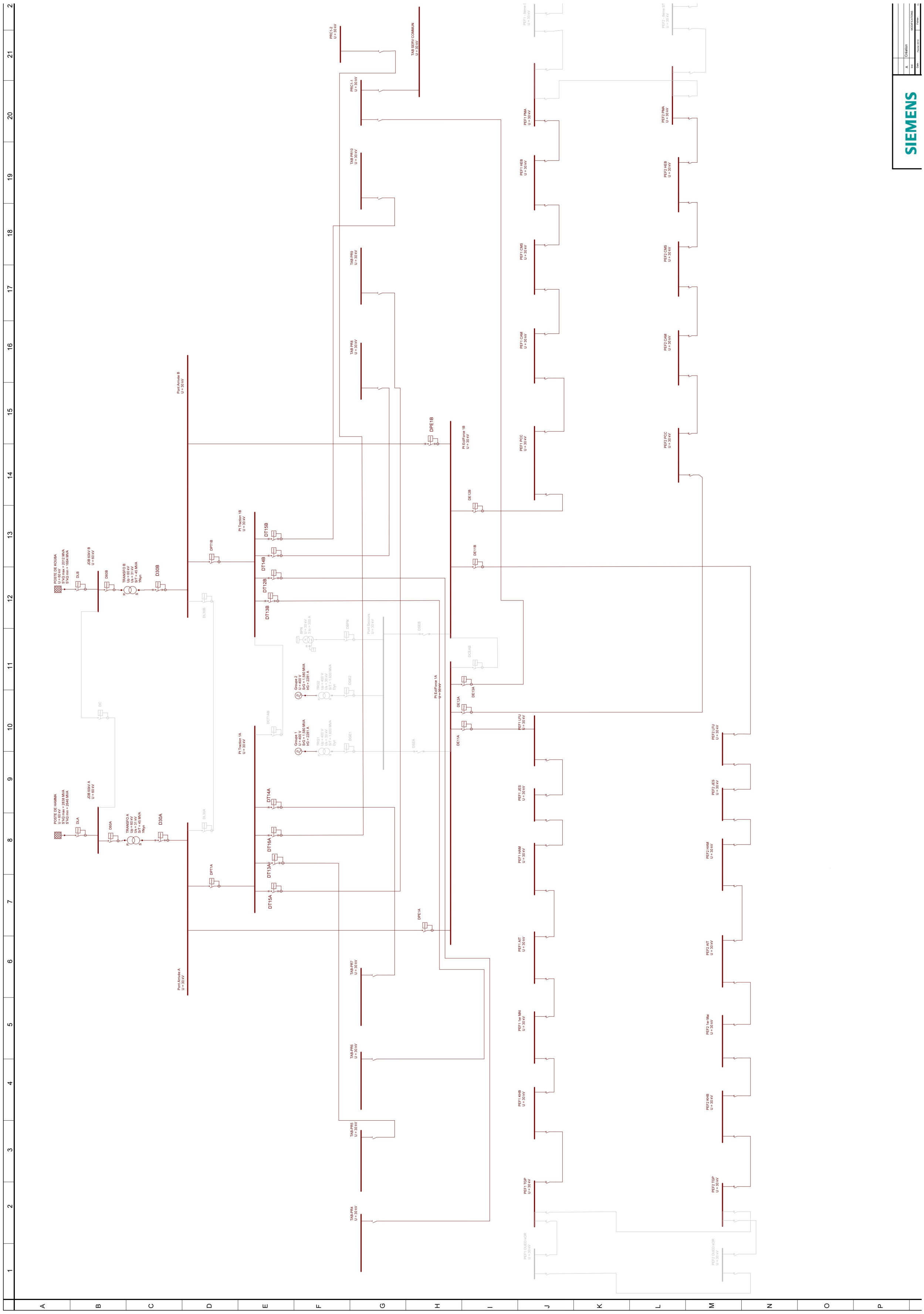


Figure A.3: Nominal mode

## A.4 Case of loss of a SONELGAZ arrival

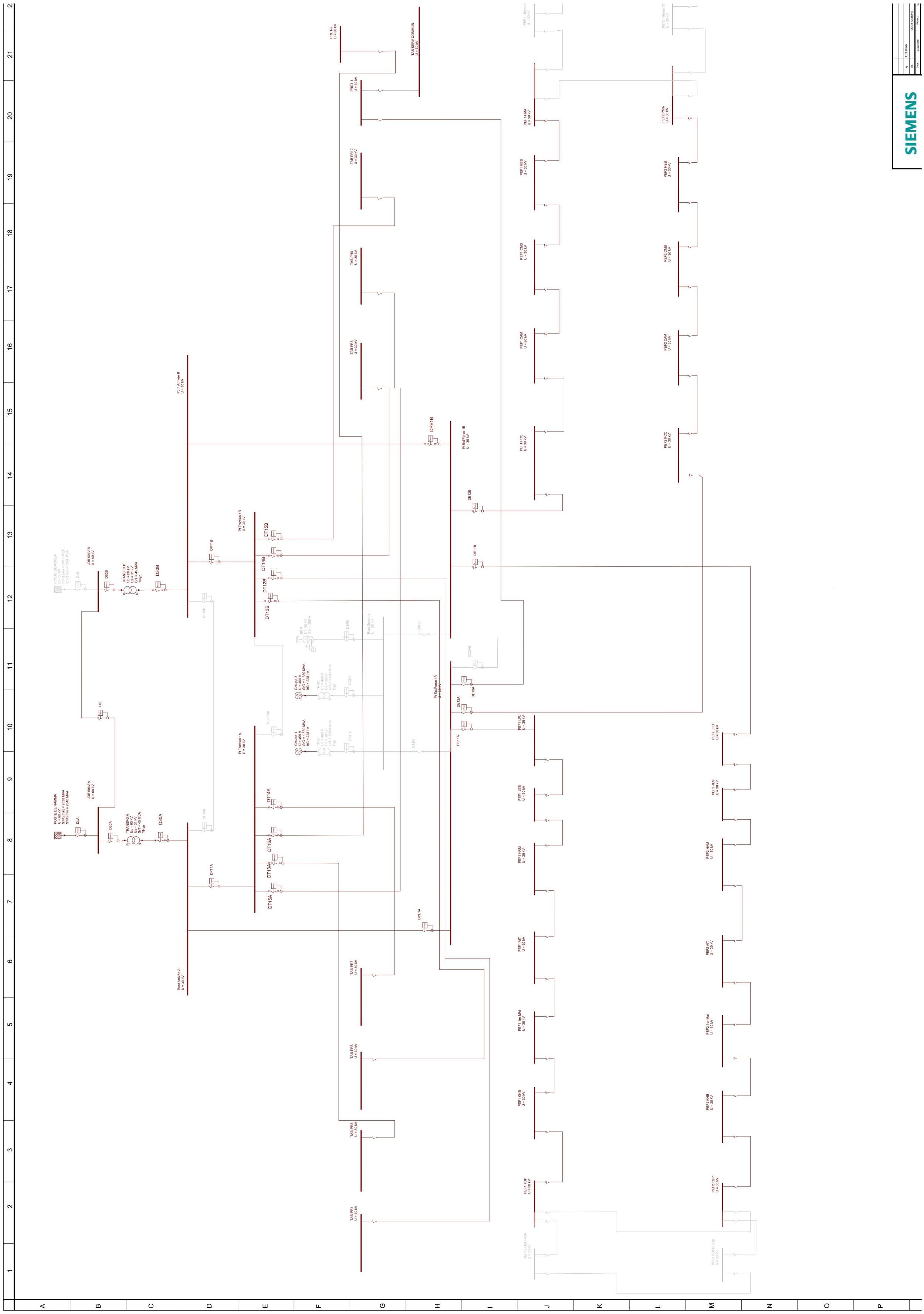


Figure A.4: Case of loss of a SONELGAZ arrival

## A.5 Failure of one of the 60 kV/30 kV power transformers

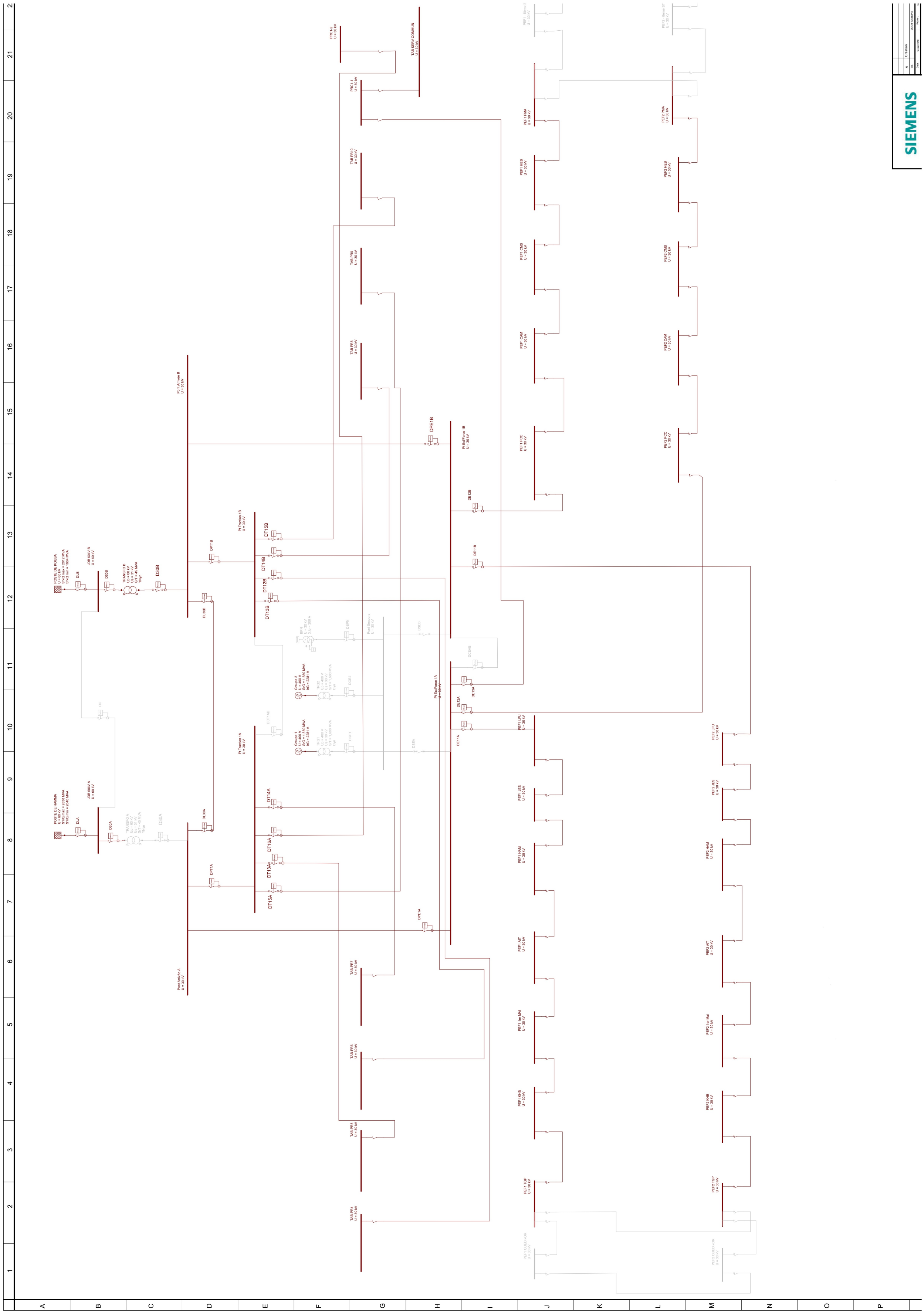
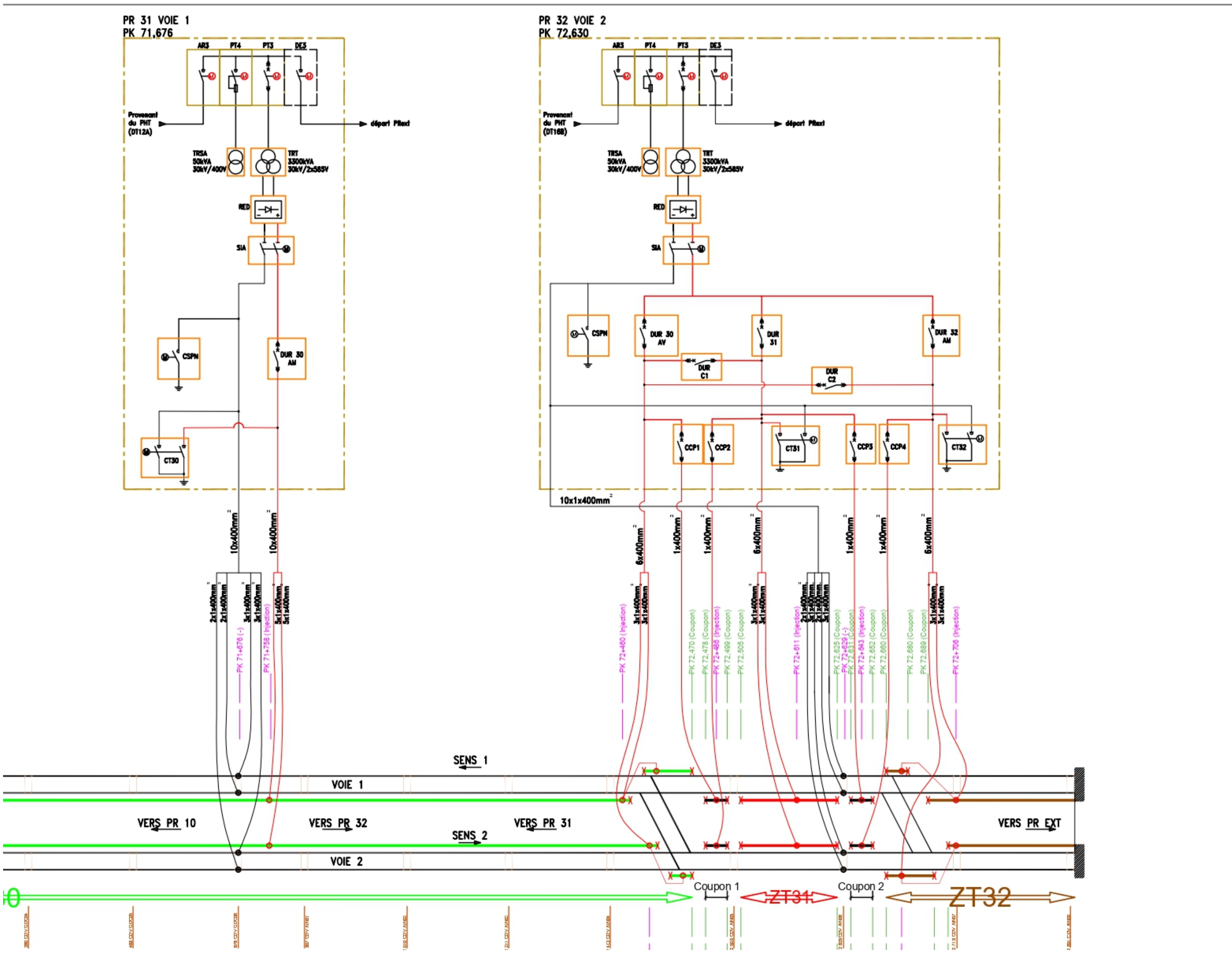


Figure A.5: Failure of one of the 60 kV/30 kV power transformers

## A.6 PR31 and PR32 general architecture


PR 31 VOIE 1
PK 71,676
PR 32 VOIE 2
PK 72,630
SENS 1
SENS 2
VOIE 1
VOIE 2
VERS PR 10
VERS PR 32
VERS PR 31
VERS PR EXT
Coupon 1
Coupon 2
ZT31
ZT32

# Appendix B

# Cable sizing

## B.1 CANECO BT results

| Révision | | C | A | | A | A | | A |
|---|---|---|---|---|---|---|---|---|

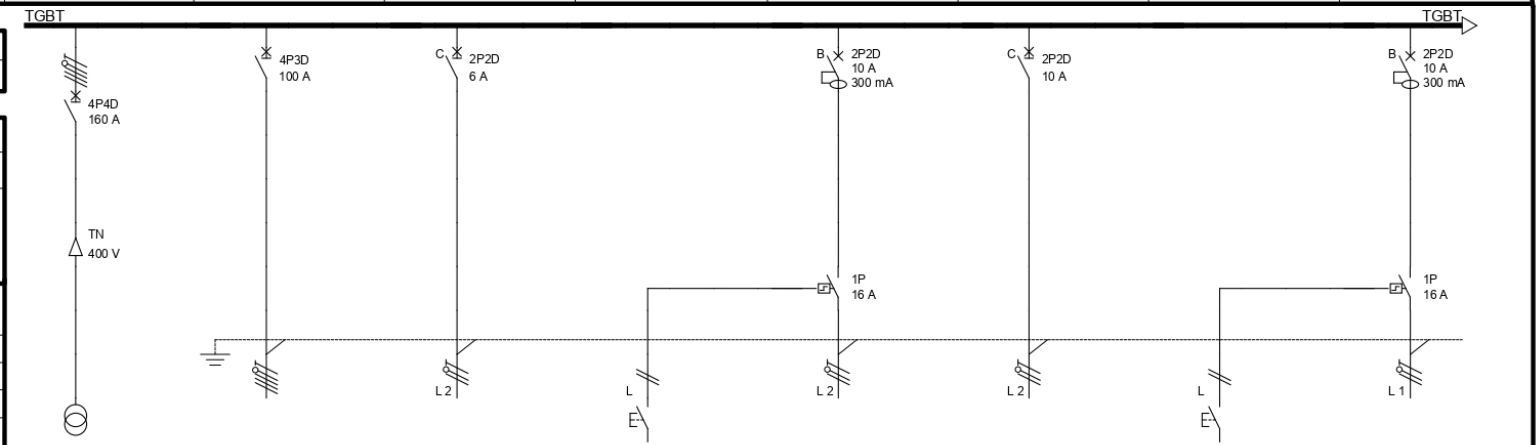
**RESEAU**

| | |
|---|---|
| Rég.de N | TN |
| Tension | 400 V |

**DISTRIBUTION**

| | |
|---|---|
| Amont Normal | SOURCE |
| Amont Secours | |
| Désignation | |

| | Normal | Secours |
|---|---|---|
| I installée | 72,17 A | |
| I Totale | 51,69 A | |
| Ik3 max | 1179 A | |
| Ik1 max | 1148 A | |
| ΔU max | 0,37 % | |




| | | SOURCE | Q1.3 | Q1.4 | BP Q1.5 | Q1.5 | Q1.6 | BP2 | Q1.7 |
|---|---|---|---|---|---|---|---|---|---|
| CIRCUIT | Repère Circuit | SOURCE | Q1.3 | Q1.4 | BP Q1.5 | Q1.5 | Q1.6 | BP2 | Q1.7 |
| | Repère Câble | | | | | | | | |
| | Repère Récepteur | TGBT | C-VENT | Q1.4 | | Q1.5 | Q1.6 | | Q1.7 |
| | Désignation | | Coffret Ventilation PR31 | Commande C-VENT-PR31 | BP commande | Eclairage Normal salle PR31 | Cellule Traction chauffage et éclairage | BP commande | Eclairage Salle à câbles PR31 |
| | Nb / Consommation | 1 / 50KVA | 1 / 22kVA | 1 / 0.3kVA | 0 | 1 / 0.76kVA | 1 / 0.66kVA | 0 | 1 / 1.19kVA |
| | Alimentation | Normal | Normal | Normal | | Normal | Normal | | Normal |
| LIAISON | JdB Amont | | | | | | | | |
| | Type | CR1/PRC (90°C) | PRC (90°C) | PRC (90°C) | | PRC (90°C) | PRC (90°C) | | U1000R2V (90°C) |
| | Pose / Ame | 13 / Cu | 13 / Cu | 13 / Cu | | 13 / Cu | 13 / Cu | | 13 / Cu |
| | Longueur / L.Max prot. | 20 m | 40 m / 149 m (CI) | 40 m / 206 m (CI) | 0 m | 150 m / 225 m (DU) | 50 m / 121 m (CI) | 0 m | 150 m / 230 m (DU) |
| | ΔU Totale | 0,37 % | 1,05 % | 0,71 % | | 4,11 % | 1,31 % | | 4,04 % |
| | Câble | 3X(1x35) | 5G16 | 3G2.5 | | 3G2.5 | 3G2.5 | | 3G4 |
| | Neutre / Séparé | 1x35 | | | | | | | |
| | PE/PEN | 1x35 | | | | | | | |
| | Taux d'Harmonique | TH <= 15% | TH <= 15% | | | | | | |
| | IB / Iz | 72,17 A | 31,80 A / 65,82 A | 1,30 A / 23,85 A | | 3,29 A / 23,85 A | 2,86 A / 23,85 A | | 5,15 A / 31,96 A |
| | Ik3 Max / Ik2 Min | 1179 A / 906 A | 1067 A / 802 A | | | | | | |
| | Ik1 Min / If | 1003 A / 1003 A | 769 A / 769 A | 263 A / 263 A | | 78 A / 78 A | 217 A / 217 A | | 122 A / 122 A |
| | Sélectivité | | Totale | Totale | | Totale | Totale | | Totale |
| PROT. | Protection | NSX160F | NSX100F | iC60N | | iC60N / Vigi iC60 | iC60N | | iC60N / Vigi iC60 |
| | Icu Disj. Vérifié | Micrologic 2.2 ☐ | Micrologic 2.2 ☒ | ☒ | ☐ | ☒ | ☒ | ☐ | ☒ |
| | Calibre / Ir | 160 A / 72,2 A | 100 A / 36 A | 6 A | | 10 A | 10 A | | 10 A |
| | Im / Isd | 722 A | 360 A | 57,6 A | | 48 A | 96 A | | 48 A |
| | Tempo / Im/Isd max. | 20 ms | 20 ms / 699 A | | | | | | |
| | Cont. Ind. | Prot Base | Prot Base | Prot Base | | Dif.300mA | Prot Base | | Dif.300mA |
| | IΔn / Δt | | | | | 300 mA / 0 ms | | | 300 mA / 0 ms |

Note de calcul CANECO PR 31

Unif. Exploitant 8 circuits TGBT

| Ind. | MODIFICATIONS |
|---|---|
| C | Note de calcul CANECO PR 31 TQC |
| B | Note de calcul CANECO PR 31 |
| A | Note de calcul CANECO PR 31 |

Date : 17/05/2022 Norme : C1510002

**Avis Technique 15L-601** ELIE BT

**AFFAIRE:**

**PLAN:**

Folio 3/10

Fichier : Note de calcul CANECO PR 31 TQC - C.afr

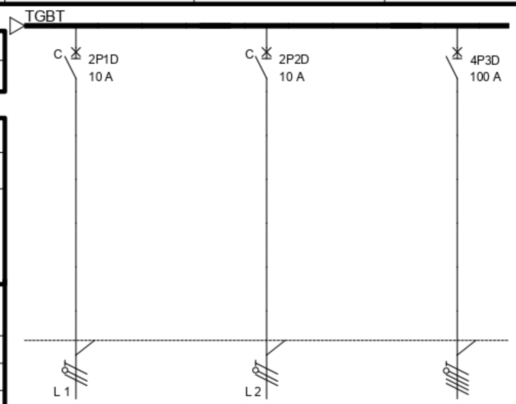
| Révision | A | A | A |
|---|---|---|---|

| RESEAU | |
|---|---|
| Rég.de N | TN |
| Tension | 400 V |

DISTRIBUTION

| Amont | |
|---|---|
| Normal | SOURCE |
| Secours | |
| Désignation | |

| | Normal | Secours |
|---|---|---|
| I installée | 72,17 A | |
| I Totale | 51,69 A | |
| Ik3 max | 1179 A | |
| Ik1 max | 1148 A | |
| ΔU max | 0,37 % | |




| | | Q1.9 | Q1.12 | Q1.15 |
|---|---|---|---|---|
| CIRCUIT | Repère Circuit | Q1.9 | Q1.12 | Q1.15 |
| | Repère Câble | | | |
| | Repère Récepteur | CELLULE-HTA | Q1.12 | Q1.15 |
| | Désignation | cellule HTA chauffage | Eclairage Chauffage CSPN | Almentation secourue depuis PEF |
| | Nb / Consommation | 1 / 0.65kVA | 1 / 0.3kVA | 1 / 10kVA |
| | Alimentation | Normal | Normal | Normal |
| LIAISON | JdB Amont | | | |
| | Type | PRC (90°C) | PRC (90°C) | PRC (90°C) |
| | Pose / Ame | 13 / Cu | 13 / Cu | 13 / Cu |
| | Longueur / L.Max prot. | 50 m / 121 m (CI) | 50 m / 121 m (CI) | 5 m / 149 m (CI) |
| | ΔU Totale | 1,30 % | 0,80 % | 0,41 % |
| | Câble | 3G2.5 | 3G2.5 | 5G16 |
| | Neutre / PE/PEN (Séparé) | | | |
| | Taux d'Harmonique | | | TH <= 15% |
| | IB / Iz | 2,81 A / 23,85 A | 1,30 A / 23,85 A | 14,40 A / 65,82 A |
| | Ik3 Max / Ik2 Min | | | 1166 A / 899 A |
| | Ik1 Min / If | 217 A / 217 A | 217 A / 217 A | 985 A / 985 A |
| | Sélectivité | Totale | Totale | Totale |
| PROT. | Protection | iC60N | iC60N | NSX100F |
| | Icu Disj. Vérifié | X | X | Micrologic 2.2 X |
| | Calibre / Ir | 10 A | 10 A | 100 A / 36 A |
| | Im / Isd | 96 A | 96 A | 360 A |
| | Tempo / Im/Isd max. | | | 20 ms / 817 A |
| | Cont. Ind. | Prot Base | Prot Base | Prot Base |
| | IΔn / Δt | | | |

Note de calcul CANECO PR 31

Unif. Exploitant 8 circuits TGBT

| Ind. | MODIFICATIONS |
|---|---|
| C | Note de calcul CANECO PR 31 TQC |
| B | Note de calcul CANECO PR 31 |
| A | Note de calcul CANECO PR 31 |

Date : 17/05/2022 Norme : C1510002

Avis Technique 15L-601 ELIE BT

AFFAIRE:

PLAN:

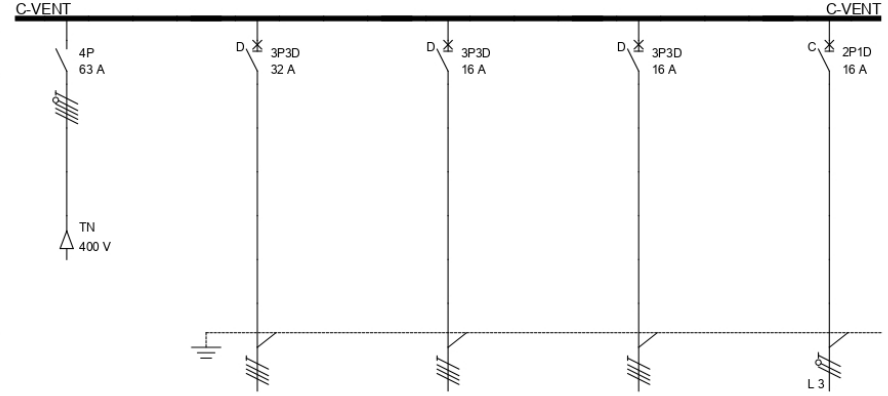
Folio 4/10

Fichier : Note de calcul CANECO PR 31 TQC - C.afr

| Révision | C | C | C | C | C |
|---|---|---|---|---|---|
| RESEAU | C-VENT | | | | C-VENT |

| | |
|---|---|
| Rég.de N | TN |
| Tension | 400 V |
| **DISTRIBUTION** | |
| Amont Normal | Q1.3 |
| Amont Secours | |
| Désignation | |

| | Normal | Secours |
|---|---|---|
| I installée | 31,80 A | |
| I Totale | 29,45 A | |
| Ik3 max | 1067 A | |
| Ik1 max | 924 A | |
| ΔU max | 1,05 % | |




| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **CIRCUIT** Repère Circuit | Q1.3 | | VE | | VS-100 | | VS-101 | | UI | |
| Repère Câble | | | | | | | | | | |
| Repère Récepteur | C-VENT | | VE | | VS-100 | | VS-101 | | UI | |
| Désignation | | | Ventilateur Petite vitesse | | Ventilateur Petite vitesse | | Ventilateur Petite vitesse | | Climatiseur - Unité Extérieure | |
| Nb / Consommation | 1 | 22KVA | 1 | 11.5kW | 1 | 4.16kW | 1 | 4.16kW | 1 | 2.25kW |
| Alimentation | Normal | | Normal | | Normal | | Normal | | Normal | |
| **LIAISON** JdB Amont | | | | | | | | | | |
| Type | PRC (90°C) | | PRC (90°C) | | PRC (90°C) | | PRC (90°C) | | PRC (90°C) | |
| Pose / Ame | 13 | Cu | 13 | Cu | 13 | Cu | 13 | Cu | 13 | Cu |
| Longueur / L.Max prot. | 40 m | 149 m (Cl) | 30 m | 30 m (Cl) | 30 m | 96 m (Cl) | 30 m | 100 m (Cl) | 50 m | 64 m (Cl) |
| ΔU Totale | 1,05 % | | 1,91 % | | 1,36 % | | 1,36 % | | 5,04 % | |
| Câble | 5G16 | | 4G6 | | 4G6 | | 4G6 | | 3G2.5 | |
| Neutre / PE/PEN (Séparé) | | | | | | | | | | |
| Taux d'Harmonique | TH <= 15% | | | | | | | | | |
| IB / Iz | 31,80 A | 65,82 A | 20,70 A | 35,72 A | 7,51 A | 35,72 A | 7,51 A | 35,72 A | 9,74 A | 23,85 A |
| Ik3 Max / Ik2 Min | 1067 A | 802 A | 852 A | 603 A | 852 A | 603 A | 852 A | 603 A | | |
| Ik1 Min / If | 769 A | 769 A | | 463 A | | 463 A | | 463 A | 196 A | 196 A |
| Sélectivité | | | Nulle | | Totale | | Totale | | Totale | |
| **PROT.** Protection | INS63 | | iC60N | | iC60N | | DT40 | | DT40 | |
| Icu Disj. Vérifié | | X | | X | | X | | X | | X |
| Calibre Ir | 63 A | | 32 A | | 16 A | | 16 A | | 16 A | |
| Im / Isd | | | | 460,8 A | | 230,4 A | | 224 A | | 160 A |
| Tempo Im/Isd max. | | | | | | | | | | |
| Cont. Ind. | Prot Base | | Prot Base | | Prot Base | | Prot Base | | Prot Base | |
| IΔn / Δt | | | | | | | | | | |

Note de calcul CANECO PR 31

Unif. Exploitant 8 circuits C-VENT

| Ind. | MODIFICATIONS |
|---|---|
| C | Note de calcul CANECO PR 31 TQC |
| B | Note de calcul CANECO PR 31 |
| A | Note de calcul CANECO PR 31 |
| Date : 17/05/2022 | Norme : C1510002 |

**Avis Technique 15L-601** ELIE BT

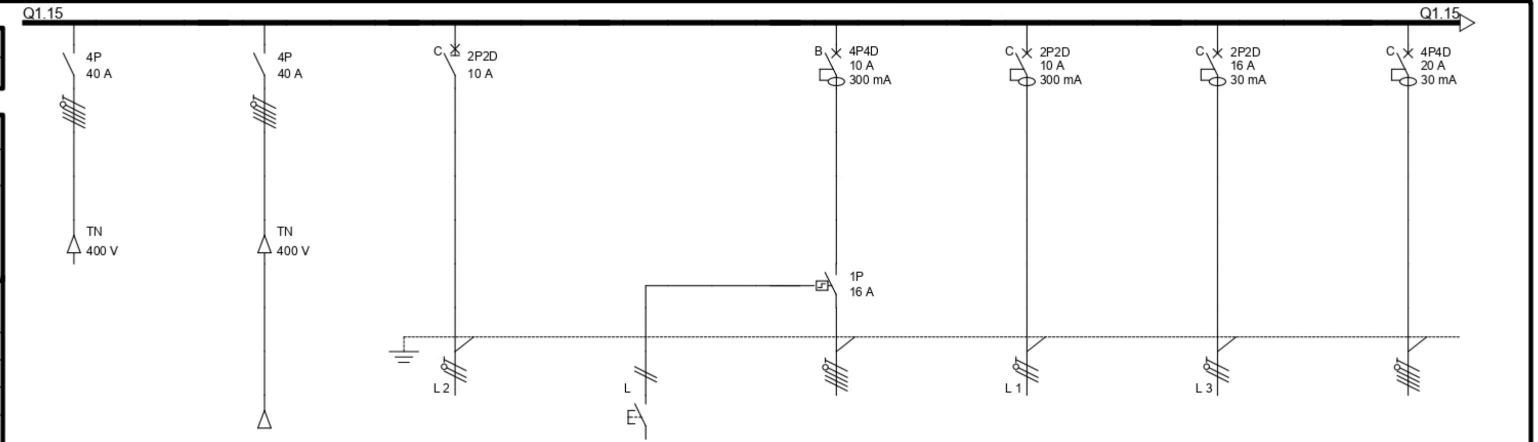
**AFFAIRE:**

**PLAN:**

Folio 5/10

Fichier : Note de calcul CANECO PR 31 TQC - C.afr

| Révision | A | | C | | A | A | A | A |
|---|---|---|---|---|---|---|---|---|




| RESEAU | |
|---|---|
| Rég.de N | TN |
| Tension | 400 V |
| **DISTRIBUTION** | |
| Amont – Normal | Q1.15 |
| Amont – Secours | SECOURS |
| Désignation | Alimentation permanente depuis PEF |

| | Normal | Secours |
|---|---|---|
| I installée | 14,40 A | 40,00 A |
| I Totale | 22,24 A | 22,24 A |
| Ik3 max | 1166 A | 6000 A |
| Ik1 max | 1121 A | 4800 A |
| ΔU max | 0,41 % | 2,00 % |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CIRCUIT** – Repère Circuit | Q1.15 | SECOURS | Q2.2 | BP Q2.3 | Q2.3 | Q2.4 | Q2.5 | Q2.6 |
| Repère Câble | | | | | | | | |
| Repère Récepteur | Q1.15 | Q1.15 | Q2.2 | | Q2.3 | Q2.4 | Q2.5 | Q2.6 |
| Désignation | Alimentation permanente depuis PEF | Alimentation permanente depuis PEF | Eclairage TSA | BP commande | Eclairage Salle PR31 Secouru | Eclairage locaux transfo | PDC monophasées PR31 | PDC triphasées PR31 |
| Nb / Consommation | 1 / 10kVA | 1 / 40A | 1 / 0.1kVA | 0 | 1 / 0.66kVA | 1 / 0.66kVA | 1 / 0.74kVA | 1 / 6.25kVA |
| Alimentation | Normal | Secours | N et S | | N et S | N et S | N et S | N et S |
| **LIAISON** – JdB Amont | | | | | | | | |
| Type | PRC (90°C) | | PRC (90°C) | | PRC (90°C) | PRC (90°C) | PRC (90°C) | U1000R2V (90°C) |
| Pose / Ame | 13 / Cu | | 13 / Cu | | 13 / Cu | 13 / Cu | 13 / Cu | 13 / Cu |
| Longueur / L.Max prot. | 5 m / 149 m (CI) | 0 m | 5 m / 121 m (CI) | 0 m | 150 m / 249 m (CC) | 60 m / 72 m (CC) | 150 m / 174 m (CC) | 150 m / 226 m (CC) |
| ΔU Totale | 0,41 % | 2,00 % | 2,01 % | | 2,54 % | 4,16 % | 3,33 % | 3,14 % |
| Câble | 5G16 | | 3G2.5 | | 5G2.5 | 3G1.5 | 3G6 | 5G10 |
| Neutre / PE/PEN – Séparé | | | | | | | | |
| Taux d'Harmonique | TH <= 15% | TH <= 15% | | | TH <= 15% | | | TH <= 15% |
| IB / Iz | 14,40 A / 65,82 A | 40,00 A | 0,43 A / 23,85 A | | 0,95 A / 20,71 A | 2,86 A / 17,35 A | 3,20 A / 41,14 A | 9,02 A / 49,11 A |
| Ik3 Max / Ik2 Min | 1166 A / 899 A | 6000 A / 4000 A | | | 223 A / 131 A | | | 821 A / 407 A |
| Ik1 Min / If | 985 A / 985 A | 4000 A / 4000 A | 794 A / 794 A | | 78 A / 78 A | 114 A / 114 A | 176 A / 176 A | 271 A / 271 A |
| Sélectivité | | | Totale | | Totale | Totale | Totale | Totale |
| **PROT.** – Protection | INS40 | INS40 | iC60N | | iC60N / Vigi iC60 | iC60N / Vigi iC60 | iC60N / Vigi iC60 | iC60N / Vigi iC60 |
| Icu Disj. Vérifié | ☒ | ☐ | ☒ | ☐ | ☒ | ☒ | ☒ | ☒ |
| Calibre – Ir | 40 A | 40 A | 10 A | | 10 A | 10 A | 16 A | 20 A |
| Im / Isd | | | 96 A | | 48 A | 96 A | 153,6 A | 192 A |
| Tempo – Im/Isd max. | | | | | | | | |
| Cont. Ind. | Prot Base | Prot Base | Prot Base | | Dif.300mA | Dif.300mA | Dif.30mA | Dif.30mA |
| IΔn / Δt | | | | | 300 mA / 0 ms | 300 mA / 0 ms | 30 mA / 0 ms | 30 mA / 0 ms |

Note de calcul CANECO PR 31

Unif. Exploitant 8 circuits Q1.15

| Ind. | MODIFICATIONS |
|---|---|
| C | Note de calcul CANECO PR 31 TQC |
| B | Note de calcul CANECO PR 31 |
| A | Note de calcul CANECO PR 31 |
| Date : 17/05/2022 | Norme : C1510002 |

**Avis Technique 15L-601** ELIE BT

**AFFAIRE:**

**PLAN:**

Folio 6/10

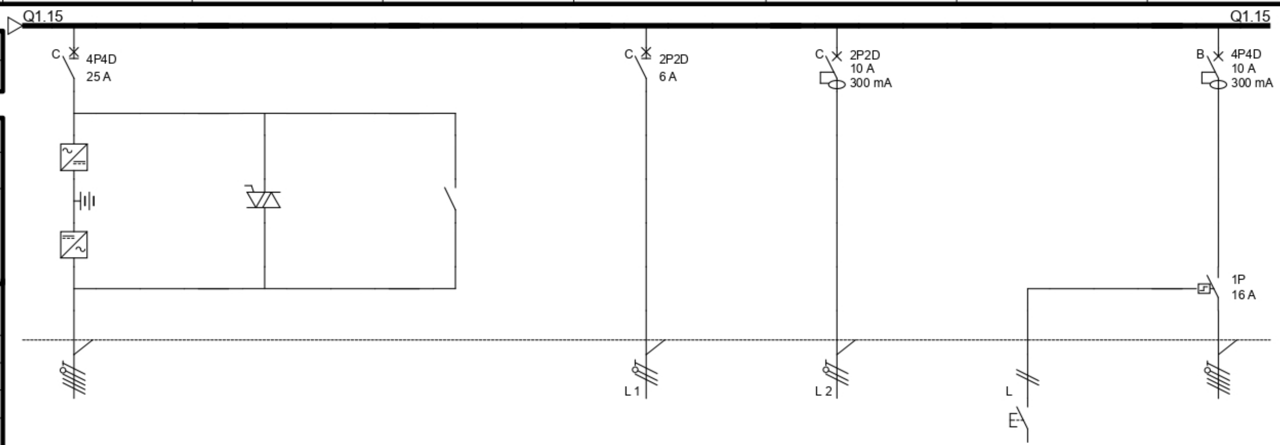
Fichier : Note de calcul CANECO PR 31 TQC - C.afr

©ALPI Caneco BT 5.80 Cracked by gta126

| Révision | A | | | A | A | | A | |
|---|---|---|---|---|---|---|---|---|

| RESEAU | |
|---|---|
| Rég.de N | TN |
| Tension | 400 V |
| **DISTRIBUTION** | |
| Amont – Normal | Q1.15 |
| Amont – Secours | SECOURS |
| Désignation | Alimentation permanente depuis PEF |

| | Normal | Secours |
|---|---|---|
| I installée | 14,40 A | 40,00 A |
| I Totale | 22,24 A | 22,24 A |
| Ik3 max | 1166 A | 6000 A |
| Ik1 max | 1121 A | 4800 A |
| ΔU max | 0,41 % | 2,00 % |




| | | Q2.7 | BY-PASS STAT | BY-PASS M | Q2.9 | Q2.10 | BP Q2.12 | Q2.12 | |
|---|---|---|---|---|---|---|---|---|---|
| CIRCUIT | Repère Circuit | Q2.7 | BY-PASS STAT | BY-PASS M | Q2.9 | Q2.10 | BP Q2.12 | Q2.12 | |
| | Repère Câble | | | | | | | | |
| | Repère Récepteur | UPS 2H | | | Q2.9 | Q2.10 | | Q2.12 | |
| | Désignation | UPS 2H PR31 | | | Alimentation Bobine KM3 | Eclairage Locaux Ventilation- Secouru | BP commande | Eclairage Salle à câbles PR31 Secouru | |
| | Nb / Consommation | 1 / 5kVA | 0 | 0 | 1 / 100VA | 1 / 0.66kVA | 0 | 1 / 1.30kVA | |
| | Alimentation | N et S | | | N et S | N et S | | N et S | |
| LIAISON | JdB Amont | | | | | | | | |
| | Type | CR1/PRC (90°C) | | | PRC (90°C) | U1000R2V (90°C) | | PRC (90°C) | |
| | Pose / Ame | 13 / Cu | | | 13 / Cu | 13 / Cu | | 13 / Cu | |
| | Longueur / L.Max prot. | 30 m / 277 m (CI) | 0 m | 0 m | 5 m / 205 m (CI) | 50 m / 121 m (CC) | 0 m | 150 m / 249 m (CC) | |
| | ΔU Totale | 2,12 % | | | 2,01 % | 2,94 % | | 3,07 % | |
| | Câble | 5G16 | | | 3G2.5 | 3G2.5 | | 5G2.5 | |
| | Neutre / PE/PEN – Séparé | | | | | | | | |
| | Taux d'Harmonique | TH <= 15% | | | | | | TH <= 15% | |
| | IB / Iz | 7,22 A / 65,82 A | | | 0,43 A / 23,85 A | 2,86 A / 23,85 A | | 1,88 A / 20,71 A | |
| | Ik3 Max / Ik2 Min | 3525 A / 816 A | | | | | | 223 A / 131 A | |
| | Ik1 Min / If | 798 A / 798 A | | | 794 A / 794 A | 214 A / 214 A | | 78 A / 78 A | |
| | Sélectivité | Totale | | | Totale | Totale | | Totale | |
| PROT. | Protection | iC60N | | | iC60N | iC60N / Vigi iC60 | | iC60N / Vigi iC60 | |
| | Icu Disj. Vérifié | X | ☐ | ☐ | X | X | ☐ | X | ☐ |
| | Calibre / Ir | 25 A | | | 6 A | 10 A | | 10 A | |
| | Im / Isd | 240 A | | | 57,6 A | 96 A | | 48 A | |
| | Tempo / Im/Isd max. | | | | | | | | |
| | Cont. Ind. | Prot Base | | | Prot Base | Dif.300mA | | Dif.300mA | |
| | IΔn / Δt | | | | | 300 mA / 0 ms | | 300 mA / 0 ms | |

Note de calcul CANECO PR 31

Unif. Exploitant 8 circuits Q1.15

| Ind. | MODIFICATIONS |
|---|---|
| C | Note de calcul CANECO PR 31 TQC |
| B | Note de calcul CANECO PR 31 |
| A | Note de calcul CANECO PR 31 |
| Date : 17/05/2022 | Norme : C1510002 |

**Avis Technique 15L-601** ELIE BT

**AFFAIRE:**

**PLAN:**

Folio 7/10

Fichier : Note de calcul CANECO PR 31 TQC - C.afr

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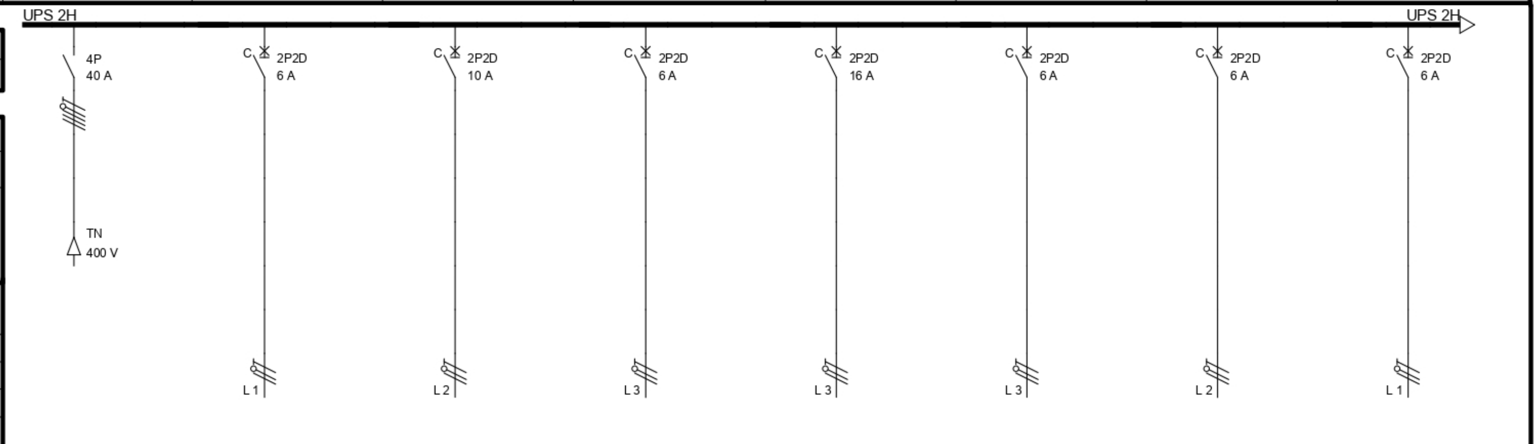
| Révision | | | | |
|---|---|---|---|---|
| **RESEAU** | | | | |
| **Rég.de N** | TN | | | |
| **Tension** | 400 V | | | |
| **DISTRIBUTION** | | | | |
| **Amont** | Normal | Q2.7 | | |
| | Secours | Q2.7 | | |
| **Désignation** | | | | |
| | Normal | Secours | | |
| **I installée** | 7,22 A | 7,22 A | | |
| **I Totale** | 5,31 A | 5,31 A | | |
| **Ik3 max** | 1081 A | 3525 A | | |
| **Ik1 max** | 951 A | 2218 A | | |
| **ΔU max** | 0,52 % | 2,12 % | | |




| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Révision | | A | | A | | A | | A | | A | | A | | A | | A | |
| **CIRCUIT** | Repère Circuit | Q2.7 | | Q3.1 | | Q3.2 | | Q3.3 | | Q3.4 | | Q3.5 | | Q3.6 | | Q3.7 | |
| | Repère Câble | | | | | | | | | | | | | | | | |
| | Repère Récepteur | UPS 2H | | Q3.1 | | Q3.2 | | Q3.3 | | Q3.4 | | Q3.5 | | Q3.6 | | Q3.7 | |
| | Désignation | | | Motorisation HTA | | Motorisation Traction | | Motorisation CSPN | | Coffret CFA | | Alimentation AES | | Relais TSX1 TRT | | Relais TSX1 TRSA | |
| | Nb / Consommation | 1 | 5kVA | 1 | 0.5kVA | 1 | 0.5kVA | 1 | 0.5kVA | 1 | 0.1kVA | 1 | 0.2kVA | 1 | 100VA | 1 | 100VA |
| | Alimentation | N et S | | N et S | | N et S | | N et S | | N et S | | N et S | | N et S | | N et S | |
| **LIAISON** | JdB Amont | | | | | | | | | | | | | | | | |
| | Type | CR1/PRC (90°C) | | CR1/PRC (90°C) | | CR1/PRC (90°C) | | CR1/PRC (90°C) | | PRC (90°C) | | CR1/PRC (90°C) | | U1000R2V (90°C) | | PRC (90°C) | |
| | Pose / Ame | 13 | Cu | 13 | Cu | 13 | Cu | 13 | Cu | 13 | Cu | 13 | Cu | 13 | Cu | 13 | Cu |
| | Longueur / L.Max prot. | 30 m | 277 m (CI) | 50 m | 200 m (CI) | 50 m | 116 m (CI) | 50 m | 200 m (CI) | 50 m | 68 m (CI) | 50 m | 200 m (CI) | 5 m | 200 m (CI) | 5 m | 200 m (CI) |
| | ΔU Totale | 2,12 % | | 2,83 % | | 2,83 % | | 2,83 % | | 2,26 % | | 2,40 % | | 2,13 % | | 2,13 % | |
| | Câble | 5G16 | | 3G2.5 | | 3G2.5 | | 3G2.5 | | 3G2.5 | | 3G2.5 | | 3G2.5 | | 3G2.5 | |
| | Neutre / Séparé | | | | | | | | | | | | | | | | |
| | PE/PEN | | | | | | | | | | | | | | | | |
| | Taux d'Harmonique | TH <= 15% | | | | | | | | | | | | | | | |
| | IB / Iz | 7,22 A | 65,82 A | 2,17 A | 23,85 A | 2,17 A | 23,85 A | 2,17 A | 23,85 A | 0,43 A | 23,85 A | 0,87 A | 23,85 A | 0,43 A | 23,85 A | 0,43 A | 23,85 A |
| | Ik3 Max / Ik2 Min | 3525 A | 816 A | | | | | | | | | | | | | | |
| | Ik1 Min / If | 798 A | 798 A | 198 A | 198 A | 198 A | 198 A | 198 A | 198 A | 198 A | 198 A | 198 A | 198 A | 640 A | 640 A | 640 A | 640 A |
| | Sélectivité | | | I<0,20kA | | I<0,20kA | | I<0,20kA | | I<0,20kA | | I<0,20kA | | I<0,20kA | | I<0,20kA | |
| **PROT.** | Protection | iSW-NA | | iC60N | | iC60N | | iC60N | | iC60N | | iC60N | | iC60N | | iC60N | |
| | Icu Disj. Vérifié | | X | | X | | X | | X | | X | | X | | X | | X |
| | Calibre / Ir | 40 A | | 6 A | | 10 A | | 6 A | | 16 A | | 6 A | | 6 A | | 6 A | |
| | Im / Isd | | | | 57,6 A | | 96 A | | 57,6 A | | 153,6 A | | 57,6 A | | 57,6 A | | 57,6 A |
| | Tempo / Im/Isd max. | | | | | | | | | | | | | | | | |
| | Cont. Ind. | Prot Base | | Prot Base | | Prot Base | | Prot Base | | Prot Base | | Prot Base | | Prot Base | | Prot Base | |
| | IΔn / Δt | | | | | | | | | | | | | | | | |

Note de calcul CANECO PR 31

Unif. Exploitant 8 circuits UPS 2H

| Ind. | MODIFICATIONS |
|---|---|
| C | Note de calcul CANECO PR 31 TQC |
| B | Note de calcul CANECO PR 31 |
| A | Note de calcul CANECO PR 31 |

Date : 17/05/2022 Norme : C1510002

**Avis Technique 15L-601** ELIE BT

**AFFAIRE:**

**PLAN:**

Folio 8/10

Fichier : Note de calcul CANECO PR 31 TQC - C.afr

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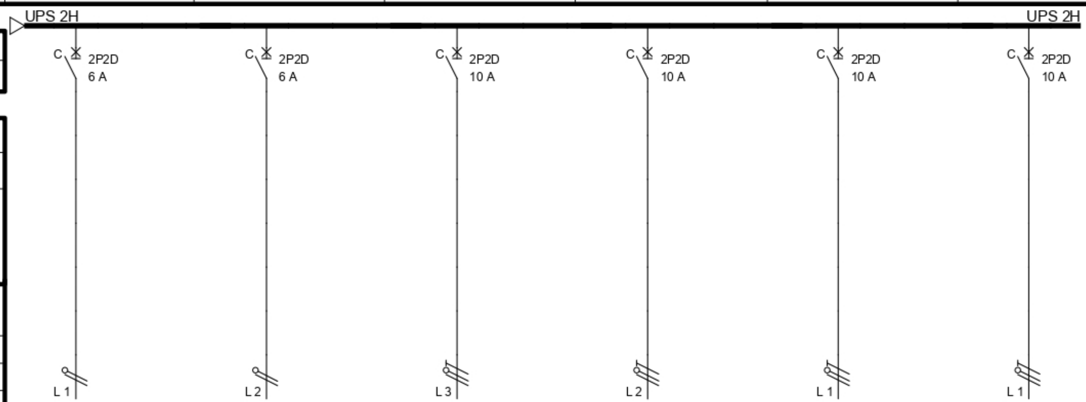
| Révision | A | A | A | A | C | C |
|---|---|---|---|---|---|---|

| RESEAU | |
|---|---|
| Rég.de N | TN |
| Tension | 400 V |
| DISTRIBUTION | |
| Amont Normal | Q2.7 |
| Amont Secours | Q2.7 |
| Désignation | |

| | Normal | Secours |
|---|---|---|
| I installée | 7,22 A | 7,22 A |
| I Totale | 5,31 A | 5,31 A |
| Ik3 max | 1081 A | 3525 A |
| Ik1 max | 951 A | 2218 A |
| ΔU max | 0,52 % | 2,12 % |




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CIRCUIT | Repère Circuit | Q3.13 | Q3.14 | Q3.8 | Q3.9 | Q3.10 | Q3.11 |
| | Repère Câble | | | | | | |
| | Repère Récepteur | Q3.13 | Q3.14 | Q3.8 | Q3.9 | Q3.10 | Q3.11 |
| | Désignation | LSC Salle PR31 | LSC Salle à câbles PR31 | Alimentation 1 24VCC | Alimentation 2 24VCC | Alimentation 1 48VCC | Alimentation 2 48VCC |
| | Nb / Consommation | 1 / 0.12kVA | 1 / 0.12kVA | 1 / 0.48kVA | 1 / 0.48kVA | 1 / 0.24kVA | 1 / 0.24kVA |
| | Alimentation | N et S | N et S | N et S | N et S | N et S | N et S |
| LIAISON | JdB Amont | | | | | | |
| | Type | CR1/PRC (90°C) | CR1/PRC (90°C) | PRC (90°C) | PRC (90°C) | PRC (90°C) | PRC (90°C) |
| | Pose / Ame | 13 / Cu | 13 / Cu | 13 / Cu | 13 / Cu | 13 / Cu | 13 / Cu |
| | Longueur / L.Max prot. | 100 m / 200 m (CC) | 100 m / 200 m (CC) | 5 m / 116 m (CI) | 5 m / 116 m (CI) | 5 m / 116 m (CI) | 5 m / 116 m (CI) |
| | ΔU Totale | 2,51 % | 2,51 % | 2,18 % | 2,18 % | 2,15 % | 2,15 % |
| | Câble | 2X2.5 | 2X2.5 | 3G2.5 | 3G2.5 | 3G2.5 | 3G2.5 |
| | Neutre / Séparé | | | | | | |
| | PE/PEN | | | | | | |
| | Taux d'Harmonique | | | | | | |
| | IB / Iz | 0,52 A / 23,85 A | 0,52 A / 23,85 A | 2,08 A / 23,85 A | 2,08 A / 23,85 A | 1,04 A / 23,85 A | 1,04 A / 23,85 A |
| | Ik3 Max / Ik2 Min | | | | | | |
| | Ik1 Min / If | 110 A | 110 A | 640 A / 640 A | 640 A / 640 A | 640 A / 640 A | 640 A / 640 A |
| | Sélectivité | I<0,20kA | I<0,20kA | I<0,20kA | I<0,20kA | I<0,20kA | I<0,20kA |
| PROT. | Protection | iC60N | iC60N | iC60N | iC60N | iC60N | iC60N |
| | Icu Disj. Vérifié | X | X | X | X | X | X |
| | Calibre / Ir | 6 A | 6 A | 10 A | 10 A | 10 A | 10 A |
| | Im / Isd | 57,6 A | 57,6 A | 96 A | 96 A | 96 A | 96 A |
| | Tempo / Im/Isd max. | | | | | | |
| | Cont. Ind. | Equipot | Equipot | Prot Base | Prot Base | Prot Base | Prot Base |
| | IΔn / Δt | | | | | | |

Note de calcul CANECO PR 31

Unif. Exploitant 8 circuits UPS 2H

| Ind. | MODIFICATIONS |
|---|---|
| C | Note de calcul CANECO PR 31 TQC |
| B | Note de calcul CANECO PR 31 |
| A | Note de calcul CANECO PR 31 |
| Date : 17/05/2022 | Norme : C1510002 |

**Avis Technique 15L-601**

ELIE BT

**AFFAIRE:**

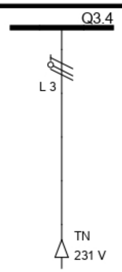
**PLAN:**

Folio 9/10

Fichier : Note de calcul CANECO PR 31 TQC - C.afr

©ALPI Caneco BT 5.80 Cracked by gta126

| Révision | A |
|---|---|
| **RESEAU** | |
| **Rég.de N** | TN |
| **Tension** | 231 V |
| **DISTRIBUTION** | |
| **Amont** Normal | Q3.4 |
| **Amont** Secours | Q3.4 |
| **Désignation** | |




| | Normal | Secours |
|---|---|---|
| **I installée** | 0,43 A | 0,43 A |
| **I Totale** | 0,00 A | 0,00 A |
| **Ik3 max** | | |
| **Ik1 max** | 6000 A | 6000 A |
| **ΔU max** | 0,67 % | 2,26 % |

| | | | | |
|---|---|---|---|---|
| **CIRCUIT** | Repère Circuit | | Q3.4 | |
| | Repère Câble | | | |
| | Repère Récepteur | | Q3.4 | |
| | Désignation | | | |
| | Nb | Consommation | 1 | 0.1kVA |
| | Alimentation | | N et S | |
| **LIAISON** | JdB Amont | | | |
| | Type | | PRC (90°C) | |
| | Pose | Ame | 13 | Cu |
| | Longueur | L.Max prot. | 50 m | 68 m (CI) |
| | ΔU Totale | | 2,26 % | |
| | Câble | | 3G2.5 | |
| | Neutre | Séparé | | |
| | PE/PEN | | | |
| | Taux d'Harmonique | | | |
| | IB | Iz | 0,43 A | 23,85 A |
| | Ik3 Max | Ik2 Min | | |
| | Ik1 Min | If | 198 A | 198 A |
| | Sélectivité | | | |
| **PROT.** | Protection | Icu Disj. Vérifié | ☐ | |
| | Calibre | Ir | | |
| | | Im / Isd | | |
| | Tempo | Im/Isd max. | | |
| | Cont. Ind. | | Prot Base | |
| | IΔn | Δt | | |

Note de calcul CANECO PR 31

Unif. Exploitant 8 circuits Q3.4

| Ind. | MODIFICATIONS |
|---|---|
| C | Note de calcul CANECO PR 31 TQC |
| B | Note de calcul CANECO PR 31 |
| A | Note de calcul CANECO PR 31 |

Date : 17/05/2022 Norme : C1510002

**Avis Technique 15L-601** ELIE BT

**AFFAIRE:**

**PLAN:**

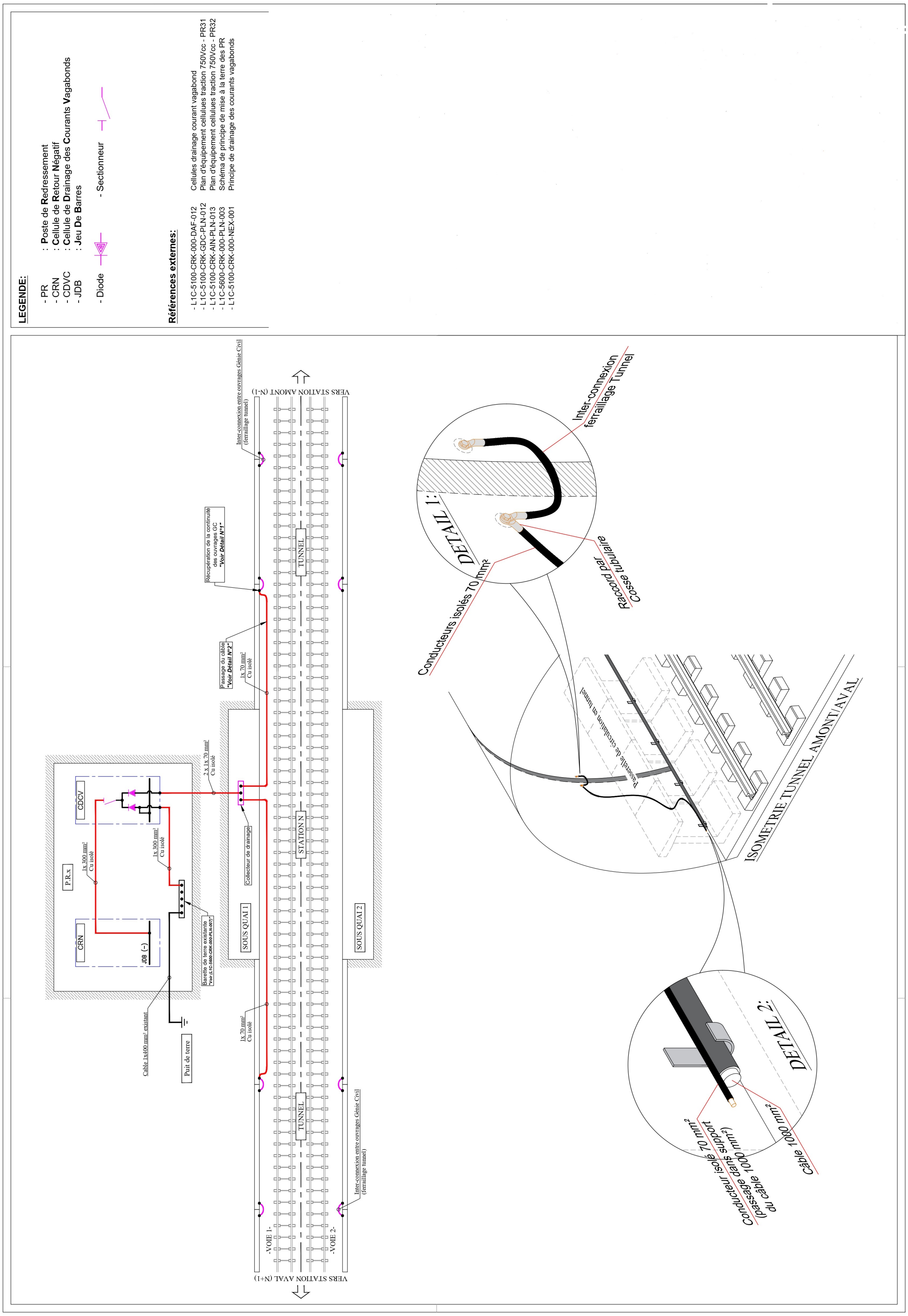
Folio 10/10

Fichier : Note de calcul CANECO PR 31 TQC - C.afr

# Appendix C

# stray current corrosion

## C.1 stray current drainage


LEGENDE:
- PR : Poste de Redressement
- CRN : Cellule de Retour Négatif
- CDVC : Cellule de Drainage des Courants Vagabonds
- JDB : Jeu De Barres
- Diode
- Sectionneur
Références externes:
- L1C-5100-CRK-000-DAF-012 Cellules drainage courant vagabond
- L1C-5100-CRK-GDC-PLN-012 Plan d'équipement cellules traction 750Vcc - PR31
- L1C-5100-CRK-AIN-PLN-013 Plan d'équipement cellules traction 750Vcc - PR32
- L1C-5600-CRK-000-PLN-003 Schéma de principe de mise à la terre des PR
- L1C-5100-CRK-000-NEX-001 Principe de drainage des courants vagabonds
VERS STATION AMONT (N-1)
VERS STATION AVAL (N+1)
TUNNEL
STATION N
SOUS QUAI 1
SOUS QUAI 2
-VOIE 1-
-VOIE 2-
CDCV
CRN
P.R.x
Puit de terre
Collecteur de drainage
DETAIL 1:
Inter-connexion ferraillage Tunnel
Raccord par Cosse tubulaire
Conducteurs isolés 70 mm²
ISOMETRIE TUNNEL AMONT/AVAL
DETAIL 2:
Conducteur isolé 70 mm² (passage dans support du câble 1000 mm²)
Câble 1000 mm²