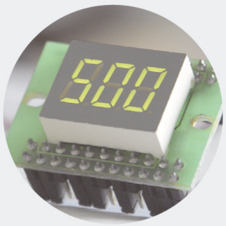
INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO
MESTRADO EM ENGENHARIA ELECTROTÉCNICA - SISTEMAS ELÉCTRICOS DE ENERGIA






Intervenções básicas do sistema de tração.

AJIN SUSAN KURIAN
novembro de 2017

POLITÉCNICO
DO PORTO

Intervention of Traction System

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Master’s in Electrical Engineering – Power Systems

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ABSTRACT

Trains and railways are influence our lives in a variety of ways we may not always realize. Passengers traveling across country get their destination safely and quickly with the use of trains and railway systems. Urban cities came up with importance of railways and railway stations in particular.

Moreover, unlike other industries which become modern over a period of time, railways changed technology at a much faster scale. It bought distant towns closer to mainstream cities and helped big time in commerce. Railways were the first form of rapid land transportation and had an effective monopoly on passenger traffic until the development of the motor car and airliners in the early-mid 20th century. In addition to that, mankind nowadays largely depending on railways mainly because it offers more safe, comfortable and cheaper transportation.

The main aim of this project is, to give detailed information about present-day railway systems as well as the reason behind the paradigm shift from Diesel Locomotive to Energy Traction system. Along with, the involvement of power equipment for transferring energy from the National Grid to the Pantograph (Mechanical Part of Train, which ensures the connection between Contact Wire and the Train), followed by, the Maintenance actions taking to account to keep Portugal Railway system more functional, then describes the main case studies associated with this electrically operated railway system and the developed solutions based on the requirements of the company.

Keywords:

Electric Traction System (ETN), High Tension Equipment, Overhead Catenary System (OCS), Maintenance Actions, Pantograph, Gas Insulated Substations (GIS) and Grounding Systems.

"Nothing Great is Ever Achieved Without Enthusiasm"

-Ralph Waldo Emerson

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LIST OF ABBREVIATIONS & ACRONYMS

IP –Infraestruturas de Portugal

PC – Post of Catenary

SST – Substations

CT – Current Transformers

VT – Voltage Transformers

OCS – Overhead Catenary Syatem

ETN – Energy Traction

ACSR – Aluminum Core Steel Reinforced

SA – Surge Arresters

MPS - Systematic Periodic Preventive Maintenance

MPC – Preventive Maintenance Conditioned

MC – Corrective Maintenance

O&M – Operation & Maintenance

CP – Contact Point

IL – Interrupter for Line

GIS – Gas Insulated Substation

CB – Circuit Breaker

Tc – Tension on catenary

Ts – Tension on Support Cable

MV- Medium Voltage

LV - Low Voltage

R - Radius of curvature

tF – Tension on the feeder

tT – Tension on the earth cable

PC – Weight of the catenary

PF – Weight of the feeder

Pi – Weight of the isolator

PT – Weight of the earth cable

PA – Weight of the console

MA – Force on the console and the connectors

H – Total height of the beam

h1 – Height of the post

h1' – Total height of the beam

h2 – Height from Contact wire, track and catenary

h3 – Height from contact cable and ground level

h4 – Height of the earth cable

h5 – Height till console

hF – Height till feeder

b – Horizontal distance of support cable to beam

d – Horizontal distance of feeder to beam

VF – Force of the wind to the feeder

VT – Force of the wind to the earth cable

VS – Force of wind to the support cable and droppers

VC – Force of wind to the contact wire and droppers

RF – Force of wind on the console of the feeder

Ri – Force of wind on isolator of the feeder

RC – Force of the wind on console

TRV – Transient Recovery Voltage

1. INTRODUCTION

The electric locomotive and electric motor coach may be regarded as natural developments that have followed steam traction. New conditions have set new standards in railway travel. This is exemplified in the rapid development of electric suburban train services for the new built-up areas spreading in all directions round large cities.

There can be no question that for comparatively short distances where stops are numerous, and fast and frequent trains are essential, the electric locomotive or electric motor coach has an enormous advantage over the steam engine. With their remarkable acceleration and efficiency in service, electric trains have solved the problem of transporting vast numbers of people over the great network of railway lines of the world's suburban systems.

The use of electricity for traction purposes has made possible the tube railways of great cities, and has contributed in no small measure to the successful operation of the longest tunnels, such as those under the mountain ranges of North America and the continent of Europe. The first experimental electric railway in the world is attributed to Thomas Davenport, a blacksmith of Vermont, U.S.A., who exhibited a small railway operated by a miniature electric motor in 1835. A Scotsman named Robert Davidson built in 1838 an electric locomotive that attained a speed of four miles an hour. In England, a patent was granted in 1840 for the use of rails as conductors of electric current, and similar American patents were issued to Lilley and Colten in 1847.

In 1858, however, an unknown inventor discovered that the field magnets of a dynamo could be electrically energized by the rotation of its own armature. The next step forward in the development of electric traction was the invention, by Pacinotte, of the continuous current dynamo. This discovery was followed by the development of self-energizing field magnets by three Englishmen—Wheatstone, Varley, and Ladd, by the German engineer Siemens, and also by the American inventor, Professor Farmer.

The principle of the dynamo is, briefly, that if a wire be moved in the "field of force" of a magnet, an electric current will be "induced" or caused to flow in such wire. When the wires, wound on the drum armature, are made to revolve by mechanical means an electric current is produced. In non-technical language, then, it is only necessary to connect the terminals of a dynamo (with its armature revolving) to the terminals of an electric motor, to cause the armature of the latter to revolve. The motor armature can be coupled by gearing to the wheels of a rail-car. All that is needed to cause the car to move along the running rails is to supply current through an overhead wire or third "conductor rail." This wire or track will serve as a "return" for the electric current to the dynamo in the power station. Electricity for this line is generated by water power, as in Europe. Owing to the "switchback" nature of the route the effect of "regenerative braking" is used to the best advantage. The regenerative system of braking makes use of the power developed by an electric train on a falling gradient to produce electric current (the driving motors serving as generators), which is returned to the power station. Thus, the power that is usually lost in braking a train is turned to useful account and economies are affected in operation.

1.1 Portugal railway

In 1856, on October 28, [10] the first railway section was inaugurated in Portugal territory. It connected Lisbon to the town of Carregado, scarce 36 km away, initially built in 1.44 m gauge. The Portuguese tracks changed, in 1861, to the 1.67 m gauge in order to adjust to the Spanish network which, for political reasons - the too-fresh memory of Napoleonic invasions - was built in later which was wider than the initial model.

In 1863 the Eastern Line, of which the inaugural section of Lisbon to Carregado was part, finally arrived at the border. Lisbon was linked to the world through a modern and technological means of transport. To the north the trains have arrived slightly later. It was only in 1875 that the Linhas do Minho (from Porto to Nine and Braga) and from the Douro (from Porto to Penafiel). Also, in the same year was inaugurated the Porto Line to Póvoa. After 127 years, on the day 7 December 2002, Porto rail system had inaugurated.

In 1877 the Ponte Maria Pia on the Douro was finished. Built by the famous Eiffel Tower, launched between Porto and Vila Nova de Gaia, finally establishes the physical link between Lisbon and Porto by rail. This work of art is undoubtedly the most emblematic work of engineering built in Portugal.

Over the next three decades some progress had been made, of diesel traction and then electric traction at 25,000 volts. Electric railway started first, in 1956, at the Sintra and the Lisbon - Carregado section. In 1966 the electrification of Lisbon got expanded and finally reached to Porto. In 1975, CP, which was already the holder of the single concession, is nationalized by the government revolutionary.

However, from the last two decades, we can extract positive effects on rail transport in Portugal. At the forefront of modernization and optimization achieved in the aforementioned rail systems of the metropolises of Lisbon and Porto. Rail tracks, some four-fold axles were renewed, and new trains were purchased. In 1991 Ponte de S. João on the Douro was inaugurated, and finally, on July 1999, the train succeeds the Tagus River crossing it in Lisbon on the 25 of April. The complete renewal of the from Beira Baixa to Braga, from Douro to Caíde and from the South Line towards the Algarve, as well as the introduction of new traffic control and command, communications driving safety and support should also be accounted for as positive. Finally, introduce a new era of in the Portugal rail service. Today the discussion is still heated about the introduction of high-speed trains and the costs of this project are anything but consensual in Portuguese society.

Figure 1: Portugal Rail Lines (1850)

In this section, an introduction is based on the electric traction followed by its origin and the evolution of Portugal railway. In addition to that, it’s very important to know about electric traction system, equipment functionality and operations associated with the current railway system. Now, this report specifically focuses on three important factors behind the present traction system. They are Energy substation and traction equipment, overhead catenary system (OCS) and Maintenance associated with energy traction system.

Traction substations are carefully located installations that guarantee the power supply to the catenary from the network of the public distributor (REN and EDP). They consist of a set of equipment for disconnecting, measuring, controlling, protecting and central elements such as power transformers.

The overhead catenary system is a high voltage system consisting of contact wire and catenary wire suspended via supports primarily on poles placed along the railway. The overhead catenary supplies current to the electrical trains. The overhead catenary, is set up in a zig-zag course above the railway and mounted in a height of 5,3 m from the top of rail to the contact wire. The catenary wire is normally placed an extra 1,1 m above the contact wire at the supports. Contact wire and catenary wire are set up with a force of 15 kN, which among other things is to minimize the blowout of the contact wire measured horizontally from the Centre of the tracks.

To provide a safe and reliable service, all elements of the traction system must be effectively maintained. In this project mainly observe the maintenance works associated with, substations, post of catenary, tracks and the structures, and the preventive actions to take to avoid these problems based on the seriousness, cost involved and time to solve, in six locations of north zone at Portugal.

1.2 Structure of the Dissertation

- The structure of this dissertation has divided into five chapters, in which the objective, history about the railway in world as well as in Portugal, are explained in the introduction. Followed by, the literature review is about the comprehensive study about the energy traction equipment, which keeps the traction system active explained in Chapter 2.
- Chapter 2, describes a detailed literature review about the energy traction equipment, which keeps the traction system active. Along with that, explains operation behind the energy transmission from the power production unit to catenary.
- Chapter 3, mainly explains the developed solutions for the case studies associated with the traction system and the entities of the IP.
- In Chapter4, provides the information about the thorough study behind the selection process and the comparisons between the solutions, before reaching to the best resolutions.
- This dissertation ends up, after an elaborated analysis about the Power traction system, the behavior of the devices associated, and the criteria should be considered before implementing a solution.

2. Background and Literature Review

2.1 Electric Traction

Electric traction is not the simple substitution of the machine that tows vehicles under rails for a machine equipped with electric motors. It is not just the replacement of the steam engine or an internal combustion engine with the diesel engine by an electric motor. Remember that for some years now, diesel locomotives are equipped with electric traction motors. The diesel engine was being only the actuator of a power plant installed on board the locomotive.

Traction electric associated with subsystems, such as:

- Power Source;
- Load Transmission Line;
- Source -to- Load Transmission Line;
- Load: The Motor Unit [Locomotive or Automotive] - which will have to make the connection between the referred lines of transmission and that will use the electric power to drive the engines.

The power source is a set of plants, substations, transformer substations and power receivers, connected by grid lines. Electric power system that includes facilities for producing electricity (generators), processing plants, to a voltage to another (and transformer stations), transmission facilities and distribution of electricity (network high, medium and low voltage) and uses its facilities. The electricity produced from power plants suffer more changes in line to be transported with low losses as large as distances and then used by consumers. The higher voltage is much lower current and therefore losses (own consumption) for transmission of electricity, much lower because they are proportional to the square of current. Conversion voltage levels (the transportation of electricity as low loss with power lines), taking place in the stations and substations, which are nodes of the power system and power lines are connected.

2.1.1 Characteristics of electric traction

The main advantage of electric traction is a higher power-to-weight ratio than forms of traction such as diesel or steam that generate power on board. Electricity enables faster acceleration and higher tractive effort on steep gradients. On locomotives equipped with regenerative brakes, descending gradients require very little use of air brakes as the locomotive's traction motors become generators sending current back into the supply system and/or on-board resistors, which convert the excess energy to heat. Also, if the overhead wiring breaks down in some way, all trains can be brought to a standstill.

Electrification systems are classified by three main parameters:

- Voltage
- Current:
    - Direct current (DC);
    - Alternating current (AC).
- Contact System:
    - Third rail;
    - Overhead line (catenary).

2.1.2 Direct and Alternating Current (DC and AC)

The most fundamental difference lies in the choice of direct (DC) or alternating current (AC). The earliest systems used direct current as, initially, alternating current was not well understood and insulation material for high voltage lines was not available. Direct current locomotives typically run at relatively low voltage (600 to 3,000 volts); the equipment is therefore relatively massive because the currents involved are large to transmit sufficient power. Power must be supplied at frequent intervals as the high currents result in large transmission system losses.

As alternating current motors were developed, they became the predominant type, particularly on longer routes. High voltages (tens of thousands of volts) are used because this allows the use of low currents; transmission losses are proportional to the square of the current (e.g. twice the current means four times the loss). Thus, high power can be conducted over long distances on lighter wires. Transformers in the locomotives transform this power to a low voltage and high current for the motors.

A similar high voltage, low current system could not be employed with direct current locomotives because there is no easy way to do the voltage/current transformation for DC so efficiently as achieved by AC transformers.

2.1.3 Advantages and disadvantages of Electric Traction

Advantages

- Lower running cost of locomotives and multiple units:
    - Lower maintenance cost of locomotives and multiple units.
- Higher power-to-weight ratio, resulting in:

    - Fewer locomotives;
    - Faster acceleration;
    - Higher practical limit of power;
    - Higher limit of speed.
- Reduced power loss at higher altitudes;
- Lack of dependence on crude oil as fuel;
- Less environmental pollution, even if electricity is produced by fossil fuels.

Disadvantages:

- Upgrading brings significant cost:
    - Especially where tunnels and bridges and other obstructions have to be altered for clearance;
    - Alterations or upgrades will be needed on the railway signaling to take advantage of the new traffic characteristics.

2.2 Electric traction equipment

The natural phenomena were there, just waiting to be tamed by geniuses of the kind of Michael Faraday, the Father of Electricity. "If I have seen further it is by standing on the shoulders of giants". He started experimenting with electricity and may rightly be regarded as the inventor of the main principles that form the basis of the generation, transmission and utilization of electricity: the generator, the transformer and the electric motor. His major contribution was Faraday's Law, which states that, when a piece of copper wire moves past a magnetic pole, the electrons in the wire tend to move. The amazing fact is that this principle is still responsible for the generation of the bulk of the electric power being generated today.

In power stations, other forms of energy, such as that in fossil fuel, nuclear fuel, hydraulic head or wind, are first converted into mechanical energy and then into three-phase electrical energy when the magnetic field of the rotor "cuts" the copper phase conductors.

One of the main advantages of electrical power is the ease whereby it can be transmitted over long distances to remote parts of a country. It was soon realized that a low voltage power lines such as those run by Edison are limited in their length due to voltage drop constraints. Nikola Tesla (1856 – 1943) conceived the concept of alternating current in 1886, together with the concept of using transformers to step up the voltage, causing a proportional reduction in current. The use of higher voltages therefore permitted the construction of longer lines to supply power to remote areas.

The use of the higher voltages, however, uncovered the problems associated with high voltage insulation. The effects of the environment such as lightning on the overhead power lines necessitated research and development, leading to the necessary of High Voltage Engineering. The continued efforts of electrical power engineers during the past century in various countries of the world resulted in the development of sophisticated and surprisingly reliable power grids, considering the size of the networks and the severity of the environmental conditions. In the following sections an overview will be given of the major aspects of such power systems and role of energy equipment for the effective operation.

2.2.1 Power lines and cables

High voltage feeders in the form of overhead power lines or underground cables interconnect high voltage substations. Typical high voltage overhead power lines are shown in the following figures:

Figure 2: 400 kV double circuit strain tower

When a new power line is planned, it is necessary to negotiate a servitude or “right of way”. Due to environmental considerations, it is becoming increasingly difficult to obtain servitudes for overhead lines. In urban areas, it is often necessary to use underground cables at voltages of 66 kV and below. The cost of underground cables is typically three times that of comparable overhead lines. At higher voltages cables are used only in special circumstances as the cost thereof are prohibitive.

Typically, conductors are aluminum core steel reinforced (ACSR). These conductors are often used as bundle conductors where two or more conductors are used in parallel as shown in the Figure 3.

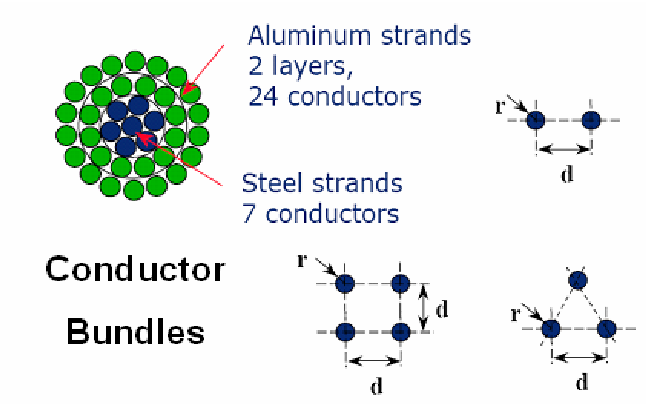


Figure 3: Detail of ACSR conductor

Figure 4: Bare ASCR multi-strand conductor.

The line conductors are bare and the air clearances surrounding the conductors form the main insulation. Where the conductors are supported by the towers, insulators are used. Obviously, the insulators must be manufactured from a good insulating material and must be of sufficient length to provide the necessary air clearance. The interface between the insulator and the air is very important, especially when the surface is contaminated. Traditionally the ceramic materials; glass and porcelain were the main insulator materials, but nowadays various non-ceramic materials are available.

A number of different insulator and materials are shown in the following figures:

Figure 5: Airline flexible insulator | Material: Glass

Figure 6: Rigid insulators | Material: Synthetic and Ceramic.

Performance

- The insulation material must be able to withstand the system voltages;
- The leakage line must be sufficient to avoid leakage of the insulator.

Breakdowns

- Perforation: disturbances of the dielectric material that constitutes the insulator (Non-reversible fault);
- Contouring: disturbances of the gaseous dielectric surrounding of the insulator (Reversible failure).

Main electrical characteristics

- Service voltage and dielectric strength;
- Mechanical Stiffness.

2.2.2 Switch-disconnectors

Switch-disconnectors combine the functions of a [9] switch with those of a disconnector and are therefore used for breaking load currents up to their rated normal current. While connecting consumers, taking on an existing short-circuit cannot be excluded. That is why, today, switch-disconnectors are generally feature short-circuit making capacity. In combination with fuses, switches (switch-disconnectors) can also be used to break short-circuit currents. The short-circuit current is interrupted by the fuses. Subsequently, the fuses trip the three poles of the switch-disconnectors, disconnecting the faulty feeder from the power system.

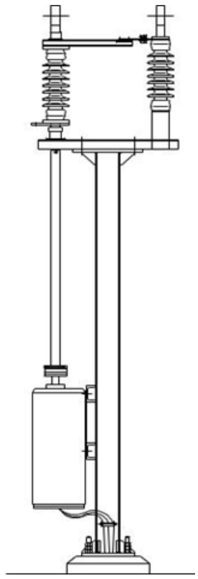


Figure 7: Mounting of disconnector

Types of Switch:

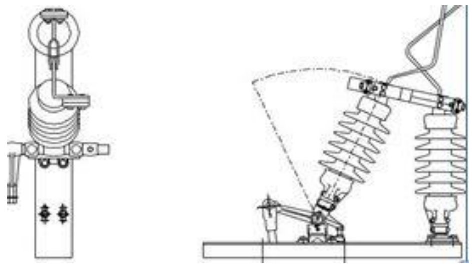


Figure 8:- Switch with a support isolator, one is movable and other fixed.

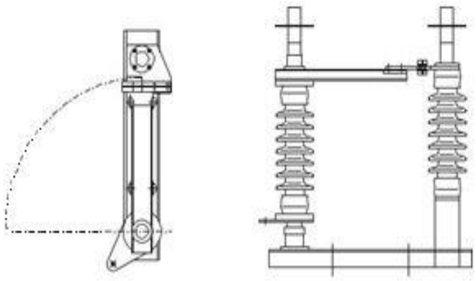


Figure 9: Switch with a fixed isolator which makes contact by a rotating conductor.

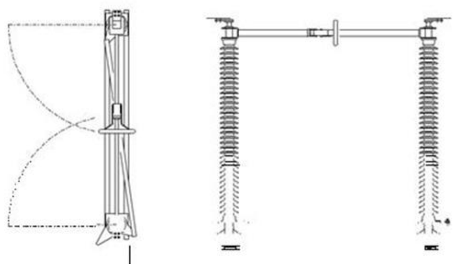


Figure 10: Switch with two rotating support isolators.

Function

- This device intended to interrupt or establish the continuity of an electric circuit;
- It can only be operated in vacuum (except switch associated with TT and TA);
- Main components:
  - Articulated pole;
  - Control panel;
  - Transmission shaft or control rod.

2.2.3 Interrupters

In Portugal, high-voltage circuit interrupters with SF6 gas as the insulation and quenching medium have been in use and throughout the world for more than 30 years. This gas is exactly suitable because of its high dielectric strength and thermal conductivity. The current interruption process in a high-voltage interrupter is a complex matter due to simultaneous interaction of several phenomena. When a circuit breaker contacts separate, an electric arc will be established, and current will continue to flow through the arc. Interruption will take place at an instant when the alternating current reaches zero. When a circuit breaker is tripped in order to interrupt a short-circuit current, the contact parting can start anywhere in the current loop. After the contacts have parted mechanically, the current will flow between the contacts through an electric arc, which consists of a core of extremely hot gas with a temperature of 5,000 to 20,000 K. This column of gas is fully ionized (plasma) and has an electrical conductivity comparable to that of carbon. When the current approaches zero, the arc diameter will decrease, with the cross-section approximately proportional to the current. In the vicinity of zero passage of current, the gas has been cooled down to around 2,000 K and will no longer be ionized plasma, nor will it be electrically conducting.

Two physical requirements (regimes) are involved:

- Thermal regime: The hot arc channel must be cooled down to a temperature low enough that it ceases to be electrically conducting;
- Dielectric regime: After the arc extinction, the insulating medium between the contacts must withstand the rapidly-increasing recovery voltage. This recovery voltage has a transient component (transient recovery voltage, TRV) caused by the system when current is interrupted.

If, either of these two requirements is not met, the current will continue to flow for another half cycle, until the next current zero is reached. It is quite normal for a circuit breaker to interrupt the short-circuit current at the second or even third current zero after contact separation.

Main components

- Pole with disconnecting chamber;
- Remote and manual control unit;
- Electrical or mechanical connection between the control unit and the pole.

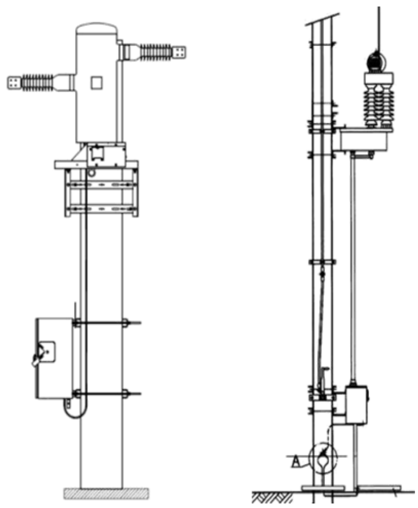


Figure 11: Interrupters

Functions

- This device designed to interrupt or establish the continuity of an electrical circuit;
- Can interrupt circuits up to rated current.

Operations

- The switch only operates as per operator order.

Main electrical characteristics

- Operates in nominal current limit.

2.2.4 Circuit breakers & fuses

The duty of circuit breakers and fuses is to rapidly interrupt fault current. A fault on the power system is usually caused by failure or breakdown of the insulation of some equipment on the power system. Often the fault current is caused by air breakdown due to overvoltage, typically caused by system disturbances by factors such as lightning. These discharges develop into arcs, providing a path for the power frequency follow current.

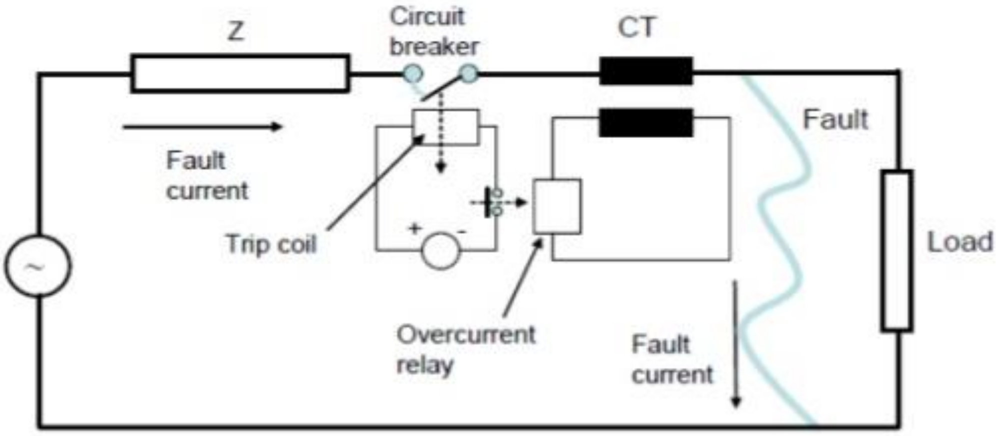


Figure 12: Schematic representation of the interruption of fault current by a circuit breaker and associated protection relays.

The presence of these power frequency fault currents is detected by the protection relays and the output contacts of the relays energize the circuit breaker trip coils, as shown in Figure: 12. The trip coils activate mechanisms that release stored energy (usually a charged spring) to force the contacts apart to interrupt the current. This is an onerous task and the arc quenching is assisted in various ways, depending on the type of circuit breaker. With AC circuit breakers arc interruption is assisted by the presence of current zero crossings. The interruption of DC arcs is more difficult.

In the case of AC transmission lines, many of the faults (especially earth faults) are not permanent and after a trip the circuit breaker recloses automatically. Ionization in the arc path has dispersed by the time the circuit breaker recloses and the circuit breaker remains closed.

In air-break circuit breakers, such as used in LV (< 100 V) and MV (up to 11 kV) systems, the contacts are in air at atmospheric pressure and the arc is quenched by the elongation, often assisted by magnetic blow-out coils, the short circuit current creating the magnetic field. The arc is forced against arc chutes that cool and subdivide the arc. Nowadays, this type of breaker is rarely used at higher voltages. In air blast circuit breakers compressed air at pressures as high as 1 MPa is used to blow out the arc as the contacts are separated. The movement of the contacts is also affected by the compressed air. While the contacts are open, full system voltage appears across the contacts and the required insulation is provided by the pressurized gas. Several (up to six) interrupting chambers, each housing a pair of contacts, are connected in series to share the voltage among the various interrupter heads. To ensure that this division is evenly, grading capacitors are provided over the contacts. Air blast circuit breakers have been used at 400 kV, but have been superseded by SF6 circuit breakers for new projects. In SF6 (Sulphur hexafluoride) circuit breakers the insulation and arc quenching functions are both performed by the SF6 gas. SF6 is an electronegative gas with superior insulation characteristics. The gas also can assist arc quenching, due to its thermal and electronegative properties. The gas is kept in a closed cycle, i.e. not released to the atmosphere. The circuit breakers are usually spring operated. SF6 circuit breakers are available for all voltages.

Figure 13:SF6 Circuit Breakers

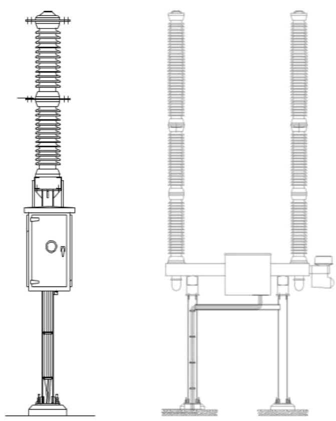


Figure 14: FXT9 da EFACEC 72 kV and SIEMENS 3AQ1 EB da 245 kV

Function

- This device designed to interrupt or establish the continuity of an electrical circuit;
- Can interrupt circuits with short-circuit currents (fault).

Main components

- Pole with cutting chamber;
- Electric control unit;
- Electrical or mechanical connection between the control unit and the pole.

2.2.5 Surge arrester or lightning arresters (LA)

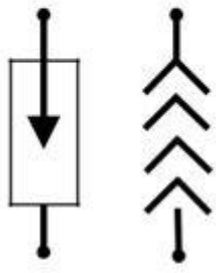
The power system is subject to transient overvoltage due to lightning and switching. Lightning arresters (also called surge diverters) are applied to limit the peak voltages to values that cannot damage the equipment. These over voltages are limited by the use of nonlinear resistive elements. In conventional lightning arrestors silicon carbide elements were used. To prevent the continuous flow of leakage currents, spark gaps are required. Modern metal oxide elements low leakage currents that gaps are not necessary. Lightning arresters are usually fitted with grading rings to ensure a more uniform voltage distribution over the height of the arrester. This ensures that some internal elements are not more severely stressed than others.

Figure 15: Lightning arrester

Function

- The function of this device is to protect electrical equipment from surges with external, such as lightning or internal origin, such as short circuit problems, to the system ensuring voltage within values and allow the continuity of service.

Symbolic representation of Lightening arrester



Functional characteristics

- Surge arresters should be connected between the conductor of the system to be protected and the earth;
- It is necessary to apply an SA for each phase of the system to be protected;
- It can discharge multiple discharges during their life cycle as long as they do not exceed their operating values.

Main electrical Characteristics

- Maximum continuous voltage;
- Specified Voltage.

2.2.6 Power transformers

The power transformers transform the voltage from one level to another and must be able to handle the full power to be transformed, i.e. the copper windings must be rated to handle the full load current and short time overcurrent and the magnetic circuit and insulation must be able to cope with the rated system voltage, allowing for overvoltage. The copper winding must be adequately insulated to prevent insulation failure to the earthed iron core. Traditionally paper and linen tape around the windings, inside the tank, filled with oil, is used. The oil fills possible voids, while also serving as coolant that can circulate by natural convection or being pumped. Hard paper cylinders are used as part of the insulation system to prevent fibre-bridge flashover of the oil. A transformer is equipped with a conservator to serve as an expansion tank to allow for the expansion of the oil when the transformer temperature increases. A silica gel breather sees to it that air entering from the atmosphere is dried.

Figure 16: Power transformers

Function

- Static electric machine that has the function of transferring electrical energy from one circuit to another, allowing the voltage amplitude to be changed as per the requirement.

Main components

- Primary winding;
- Secondary winding;
- Core (usually in iron) that guarantees the inductive coupling of the windings.

Main characteristics

- The transformation ratio is given by the ratio of the number of turns of the primary and secondary windings;
- Only works on AC systems;
- The primary and secondary voltage has the same phase.

2.2.7 Instrument transformers

In an operating power system, it is necessary to know the system voltages and currents as accurately as possible. Current transformers (CT's), voltage transformers (VT's) and capacitive voltage transformers (CVT's) are used for this purpose.

A VT is a high impedance shunt device, like a normal power transformer, whereas a CT is a low impedance device in series with the main current, as is shown in Figure 17.

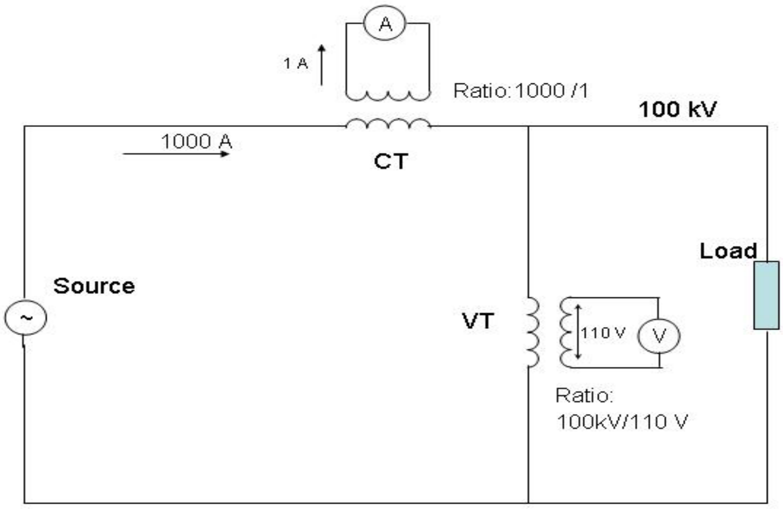


Figure 17: Schematic diagram showing a typical application of current and voltage transformers to a single-phase circuit

The active parts of both voltage and current transformers are similar, consisting of an iron core and two windings: a primary and a secondary. A VT is in fact identical to a power transformer with the primary connected to and rated for the high voltage, but has a very large ratio with the secondary voltage usually 110 V. A typical rating for a VT is 100 VA. A CT on the other hand is applied in series with the main circuit.

The primary usually consists of only one turn, carrying the current that has to be measured. The secondary winding is usually rated for 1 A. A typical rating for a CT is 10 VA. Based on this for a 1000/ 1 ratio the voltage across the secondary winding is 10 VA/ 1 A = 10 V and on the primary side 10 VA/ 1000 A, i.e. only 0.01 V, a negligible voltage compared to the supply voltage.

2.2.8 Current transformers (CT's)

A typical design of a high voltage current transformer, such as is encountered in transmission substations, is shown in Figure 18.

Figure 18: Current Transformer

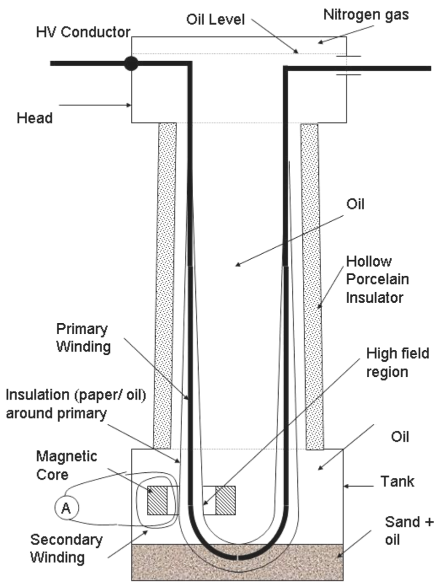


Figure 19: Showing the construction of a high voltage current transformer.

At medium voltages, such as those encountered in indoor distribution switchgear, the bar primary winding, the magnetic core and secondary winding are cast in epoxy under vacuum to remove all gas bubbles that may cause partial discharges. An important aspect relating to current transformers is that the lower the secondary impedance the better its performance. The secondary winding should always not be open circuited while the primary winding carries current. If this happens, high voltage spikes develop across its secondary terminals.

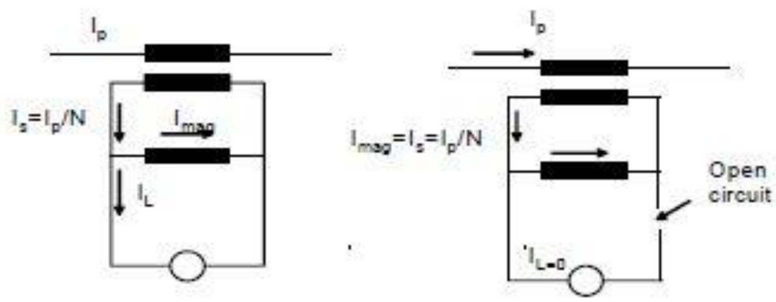


Figure 20: Equivalent circuit of current transformers

Since the CT is in series with the main circuit, a current source of Ip/N feeds the equivalent circuit, Ip being the primary current and N the CT ratio. Open circuiting the secondary circuit forces this full current through the magnetizing impedance as the change in impedance presented by the open circuit of the CT secondary is too small relative to that of the load as to affect the primary current. In accordance with Faraday's Law, large voltage spikes appear across the secondary terminals of the CT. Ironically a current measuring device can produce very high voltages that do not originate from the system high voltage. These pulses may cause serious shocks to workers and may damage the insulation of the secondary winding and of equipment connected to it.

Function

- The function current transformer is to produce electric current in the secondary side as per applied to the primary side and that can be treated by a measuring device.

Symbolic representation of Current transform

Functional characteristics

- Current transformer connected between the observing system conductor and the earth (parallel connection);
- It is necessary to apply a current transformer for each phase of a system to observe the current.

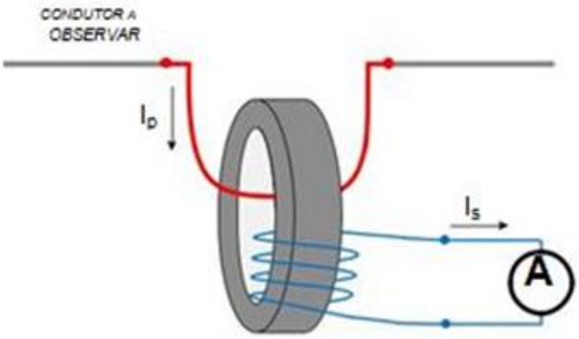


Figure 21: Diagram of current transformer

Main electrical characteristics

- Transformation ratio (primary and secondary current);
- Accuracy rate.

2.2.9 Voltage Transformers (VT's)

As already mentioned, VT's are similar to power transformers, except that the ratio is so large as to produce a secondary voltage of typically 110 volts for measuring, metering and protection purposes. Whereas efficiency is of prime importance for power transformers, the accurate representation of the primary voltage is of concern in the case of VT's.

At transmission voltages the active components are often mounted in a tank, onto which a bushing is mounted. At medium voltage levels the voltage transformers are often encapsulated in epoxy resin and the device is mounted inside the metal-clad switchgear cubicles.

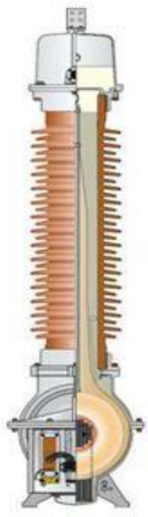


Figure 22: Voltage transformer

Function

- The function voltage transformer is to produce electric voltage in the secondary side as per applied to the primary side and that can be treated by a measuring device.

Symbolic representation of voltage transformer

Functional characteristics

- Current transformer connected between the observing system conductor and the earth (parallel connection);

- It is necessary to apply a TT for each phase of the system to observe.

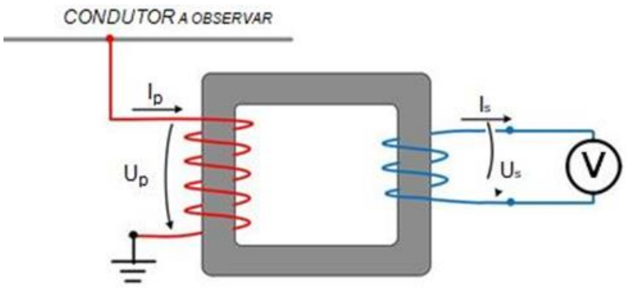


Figure 23: Diagram of voltage transformer

Main electrical characteristics

- Transformation ratio (primary and secondary current);
- Accuracy rate;
- Precision power.

2.2.10 Auto transformers

Auto transformer is kind of electrical transformer where primary and secondary shares same common single winding. So basically, it's a one winding transformer.

In Auto transformer, one single winding is used as primary winding as well as secondary winding. But in two windings transformer two different windings are used for primary and secondary purpose.

A diagram of auto transformer is shown below:

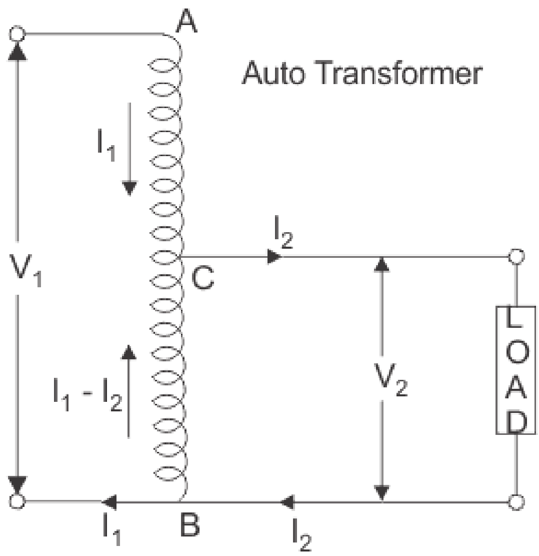


Figure 24: Schematic diagram of auto transformer

The winding AB of total turns N1 is considered as primary winding. This winding is tapped from point ′C′ and the portion BC is considered as secondary. Let's assume the number of turns in between points ′B′ and ′C′ is N2.

If V1 voltage is applied across the winding i.e. in between ′A′ and ′C′.

So voltage per turn in this winding is $\frac{V1}{N1}$

Hence, the $V_1/N_1 \times N_2$ voltage across the portion BC of the winding, will be:

Hence, $V_1/N_1 \times N_2 = V_2$

$= V_2/V_1 = N_2/N_1$ = Constant=K

As BC portion of the winding is considered as secondary, it can easily be understood that value of constant [K] is nothing but turns ratio or voltage ratio of that auto transformer.

When load is connected between secondary terminals; that means, between [B] and [C] load current I2 starts flowing. The current in the secondary winding or common winding is the difference of I2 & I1.

In railways, owing to the installation of autotransformers at regular intervals along the line, distance protection relays cannot be used with the aim of locating ground faults in 2 × 25 kV railway power supply systems. The reason is that the ratio between impedance and distance to the fault point is not linear in these electrification systems, unlike in 1 × 25 kV power systems. Therefore, the location of ground faults represents a complicated task in 2 × 25 kV railway power supply systems. Various methods have been used to localize the ground fault position in 2 × 25 kV systems. Using the modules of the circulating currents in different autotransformers when the ground fault occurs, which allows to spot the location of a ground fault to be economically found in an accurate way in real time.

Function

- It has the function of transferring energy from the feeder to the catenary.

Symbolic representation of Autotransformer

Functional characteristics

- They are constructively identical to power or power transformers;
- Have only one winding with an outlet at the midpoint.

It has three connection terminals:

- Catenary Line (+25KV AC);
- Feeder Line (-25KV AC);
- Ground / Return current system.

Main electrical characteristics

- Transformation ratio (primary and secondary voltage);
- Rated power;
- Short-circuit impedance.

Advantages of using Auto Transformers

- For transformation ratio = 2, the size of the auto transformer would be approximately 50% of the corresponding size of two winding transformer. For transformation ratio say 20 however the size would be 95 %. The saving in cost of the material is of course not in the same proportion. The saving of cost is appreciable when the ratio of transformer is low, that is lower than 2. Thus, auto transformer is smaller in size and cheaper.
- An auto transformer has higher efficiency than two winding transformers. This is because of less ohmic loss and core loss due to reduction of transformer material;
- Auto transformer has better voltage regulation as voltage drop in resistance and reactance of the single winding is less.

Disadvantages of using Auto Transformer

- Because of electrical conductivity of the primary and secondary windings the lower voltage circuit is liable to be impressed upon by higher voltage. To avoid breakdown in the lower voltage circuit, it becomes necessary to design the low voltage circuit to withstand higher voltage.
- The leakage flux between the primary and secondary windings is small and hence the impedance is low. This results into severer short circuit currents under fault conditions.
- The connections on primary and secondary sides have necessarily needs to be same, except when using interconnected starring connections. This introduces complications due to changing primary and secondary phase angle particularly in the case of delta/delta connection.

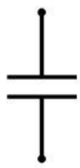
- It is more difficult to maintain the electromagnetic balance of the winding when voltage adjustment tapping is provided. It should be known that the provision of tapping on an auto transformer increases considerably the frame size of the transformer. If the range of tapping is very large, the advantages gained in initial cost is lost to a great event.

2.2.11 Capacitors

Function

- Passive electrical component that stores energy in the form of electric field when voltage is applied to its terminals;
- They are used for several functions, such as:
  Reactive Power Compensation, Correction of the power factor, Current harmonics, Stabilization of voltage, Transmission and Reception of signals.

Symbolic representation of Capacitors



Functional characteristics

- A bank of capacitors is connected in series and parallel to achieve the voltage and reactive power required.

Main electrical characteristics

- Reactive Power or Capacity (F - Farad)

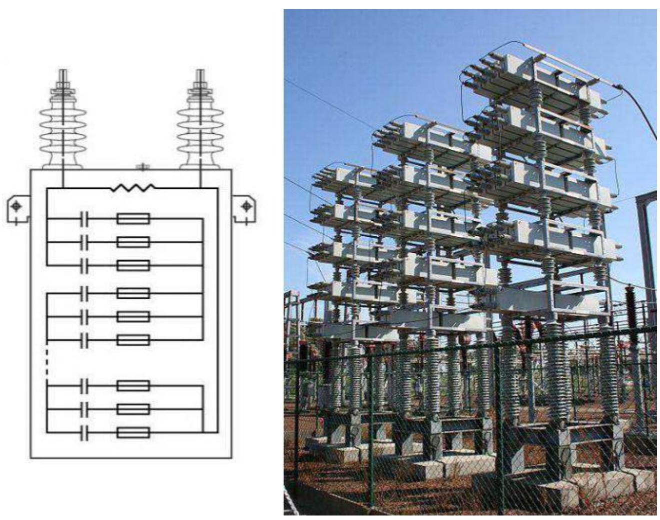


Figure 25: Representation of the interior of a condenser (left) real time condensers (right)

2.2.12 Reactors (Coil)

Function

- Passive electrical component that stores energy in the form of a magnetic field;
- They are used for several functions, such as:
    - Reactive Power Compensation, Correction of the Power Factor, Current Harmonics, Limitation of Current, Transmission and Reception of Signals.

Symbolic representation of Reactors

Functional characteristics

- Banks of reactors are connected in series and parallel to achieve the voltage and reactive power required.

Figure 26: Filter consisting of a reactor and a capacitor

Main electrical characteristics

- Reactive Power or Inductance (H - Henry)

2.2.13 Gas-Insulated Switchgear for Substations

Since 1968, the concept of gas-insulated metal-enclosed high-voltage switchgear has proved itself in more than 29,000 bay installations in all regions of the world. Gas-insulated metal-enclosed high-voltage switchgear (GIS) Figure: 27, is constantly gaining on other types of switchgear because it offers the following outstanding advantages:

- **Minimum space requirements:**
  Where the availability of land is low and/or prices are high, for instance, in urban centers, industrial conurbations, mountainous regions with narrow valleys, or in underground power plants, gas-insulated switchgear is replacing conventional switchgear because of its very small space requirements.

- **Full protection against contact with live parts:**
  The surrounding metal enclosure affords maximum safety for personnel under all operating and fault conditions.

- **Protection against pollution:**
  Its metal enclosure fully protects the switchgear interior against environmental effects such as salt deposits in coastal regions, industrial vapors and precipitates, and sandstorms. The compact switchgear can be installed as an indoor as well as an outdoor solution.

- **Free choice of installation site:**
  The small site area required for gas-insulated switchgear saves expensive grading and foundation work, e.g., in permafrost zones. Another advantage is the rapid on-side installation and commissioning because off the short erection time and the use of prefabricated and factory tested bay units.

- **Protection of the environment:**
  The necessity to protect the environment often makes it difficult to install outdoor switchgear of conventional design. Gas-insulated switchgear, however, can almost always be designed to blend well with the surroundings. Gas-insulated metal-enclosed switchgear is, because of the modular design, very flexible, and meets all requirements for configuration that exist in the network design and operating conditions.

Figure 27:8DN8 GIS for a rated voltage of 110 kV

Each circuit-breaker bay includes the full complement of disconnecting and earthing switches (regular or make-proof), instrument transformers, control and protection equipment, and interlocking and monitoring facilities commonly used for this type of installation. Thanks to “single-function” assemblies (assignment of just one task to each module) and the versatile modular structure, even unconventional arrangements can be set up from a pool of only 20 different modules. The modules are connected to each other with a standard interface that allows implementing an extensive range of bay structures. Switchgear design with standardized modules and the scope of services ensure that all types of bay structures can be set up in a small area. The compact design allows supplying of complete bays that are fully assembled and tested at the factory, providing smooth and efficient installation and commissioning.

Figure 28: Comparison between traditional and new GIS substation

2.3 Power supply to Power use

The supply of electricity to power trains is divided into 4 stages, Figure: 29:

- Power generation
- Power transmission
- Power feeding
- Power collection

Power is generated at an electricity generating source; the production of electric energy is done in several ways, by the dams, thermal, solar panels, wind systems, tidal strength. This first phase it is called the Production or Generation phase. The next phase is transmission of the power. For that the energy produced the first phase the will transmitted to elevating substations [3] that transform the voltage into Very High Voltage (VHV) so that active losses will be lower with higher voltage. REN is the company in Portugal responsible for transportation. In the transport network the tensions used are 150, 220 and 400 kV. The change in voltage as per the requirement is called power rating. The supply is alternating current (AC). Because, AC is more economical and practical to transmit over long distances than direct current (DC), it suffers from smaller losses. High voltage means smaller wires: to transmit the same power at low voltage needs high currents and therefore large conductors (wires). Power is taken from the National Grid at feeder substations located next to the transmission lines, as shown in Figure: 29, which reduce the voltage to 25,000V and transmit the power to the catenary line. Although it is more economical to transmit electricity at higher voltages as the voltage grows the required clearances increase as does the cost of the equipment. Therefore, it has been found that 25,000V is the optimum voltage for main line trains. Post and catenary support the overhead wire carrying the power - the contact wire. The power is transmitted from the contact wire to the train by a sprung ‘Pantograph’, which is attached to the roof of the moving train. In the train, the current is used to drive the motors with the aid of on-board controllers. There has to be a closed electrical circuit in order for the current to flow and the train to move. The circuit can be completed through the train wheels to the rails and then by connecting the rails back to the feeder substation. However, significant complications arise from power loss over long distances and safety-critical interference with signalling and telecommunication through grounding.

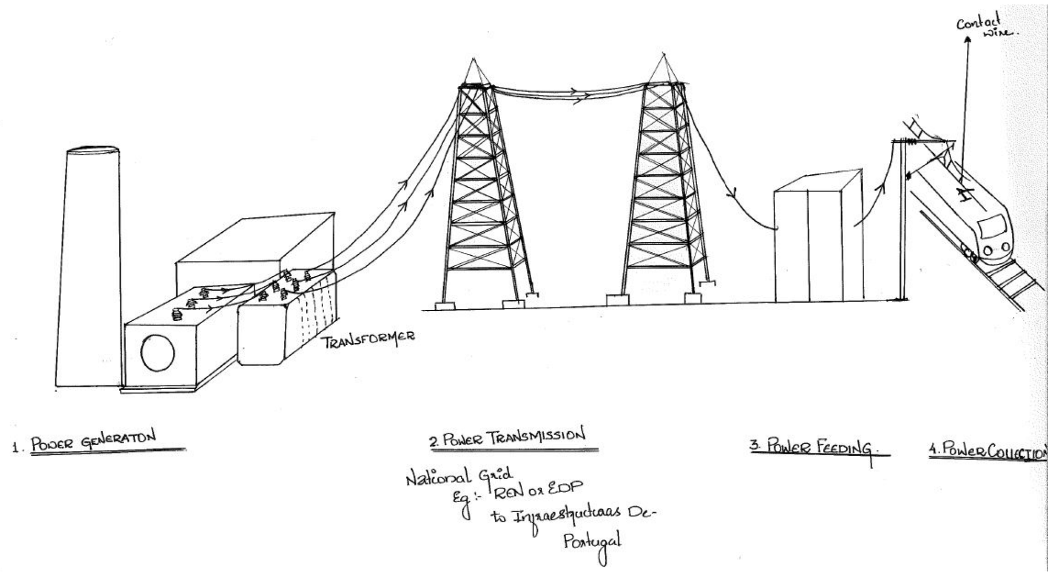


Figure 29: The process of Energy Transmission

2.4 Catenary

A catenary is an aerial and fixed installation, whose main function is the transport of electric energy to the receivers (motor units and transformers). The installation is formed by one or more contact wires and one or more longitudinal conductors which mechanically support them. Air lines consisting solely of contact wire are considered to be included in this designation.

2.4.1 Parts of Catenary

- **Main catenary:**

  They are generally the catenaries of main circulation lines and exceptionally, the catenaries of secondary lines, when these are permanently connected to the catenary of said main line. Any intervention in them implies the performance of the Central Command Station (PCT).

- **Earth electrode:**

  A set of buried conductive materials intended to ensure good electrical connection to the earth and connected at a single point (electrode connector) to the earthing conductor.

- **Feeder:**

  Feeder is an electrically insulated overhead or underground contact line that is connecting to contact wire through suitable electrical isolation equipment.

- **Contact wire:**

  An aerial line consisting of an electrolytic copper conductor in which the pantograph is supported to pick up the current.

- **Posts of catenary:**

  They are placed that whose equipment (switches or breakers) is always remote controlled from the Central Post of Remote Control and can be classified according to their functions.

- **Traction substation:**

  Installation intended for the electrical power supply of catenaries, carefully located along the track. These substations are connected directly to substations of the Primary Network of the Country, at high voltage and very high voltage levels, turning it into 25 kV.

- **Neutral zone:**

  As per rule, all traction substations are associated with a neutral zone. Between two traction substations, contiguous, there is always a neutral zone [15]. When the substations are of the "single-phase" type can dispense with the construction of a neutral zone. In certain situations, like, different substations, with different phase difference in voltage, and same substations with different transformer. A neutral zone is constructed in such a way that it allows the aerodynamic passage of all the pantographs of the motor units without any mechanical imposition and determines an electrical order, which is the obligation to disconnect the breaker of the motor unit.

Figure 30: Neutral Zone

2.4.2 Equipment of the main routes

Console

The console [14] consists of a 40 ×49 or 30 × 38 galvanized steel tubes, depending on the efforts to which it is subjected. This tube is made integral with the head of an insulator and tightened by means of two clamps. The console consists of a 40 ×49 or 30 ×38 galvanized steel tube, depending on the efforts to which it is subjected. This tube is made integral with the head of an insulator and is tightened by means of two clamps. This isolator is attached to the post by means of a console foot link.

An aluminium plug seals the end of the tube to prevent infiltration of water into the interior. The contact wire is held in a position relative to the axis of the pantograph on each support by means of a counterbalance hinged on the console near the pantograph insulator and the called arm. The opening of the catenary, that is the distance between the support cable and the contact wire, on the vertical of each suspension, is usually 1.60 m and its value in the tracks to be electrified.

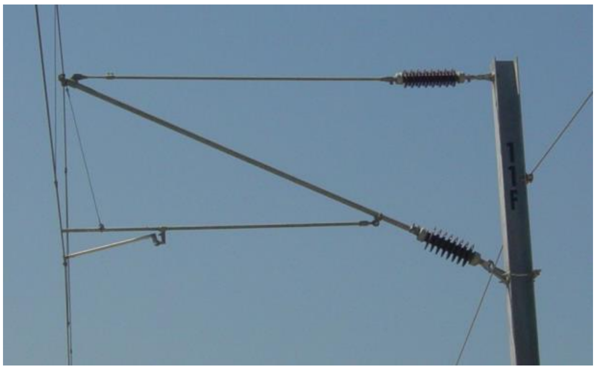


Figure 31: Console

The height of the contact wire above the rolling plane is usually between 5.60 and 5.75 m in existing lines and its height in the tracks to be electrified will be 5.50 m. The limits of maximum and minimum height are of 6.5 m and 4.76m respectively.

Flexible portics

In stations, the distance between roads does not normally allow the deployment of independent posts for each track. The alternative solution for this situation is, frames consisting of two posts deployed on either side of the tracks and between which is fixed a network of cables (Figure 31; flexible frames):

- When flexible frames reach one or several main rail tracks, they consist of two single or twin posts.
- The distance between the two posts are called the span.

- The top cable or funicular (F), supports the vertical loads due to overhead contact lines. The upper intermediate or transverse cable (T.S.) holds in position the insulators from which the catenary supports are suspended. The lower or transverse lower cable (T.I.) allows the contact wires to be maintained in the correct position relative to the pantograph axis.
- Cables are insulated at both ends using 5 or 9 ton insulation.
- The electrical separation of two neighbouring elementary sections is ensured by insulators inserted in the gantry.

Figure 32: Flexible Portics

2.5 Maintenance of traction facilities and electrical power equipment

To provide a safe and reliable service, all elements of the traction system must be effectively maintained. The principal elements include:

- Catenary System
- Substations
- Track
- Structures

The maintenance schedules for railway system is based on the recommendations of the original equipment manufacturers and evolved over a period based on the O&M (Operation & Maintenance) experience. The schedules need to be continuously monitored and reviewed for their adequacy and their periodicity is based on the Operation & Maintenance field experience. There may be need to eliminate/reduce the frequency of schedules of some items. On the other hand, if the field performance mandates based on experience, some items may require more attention. Here in

Portugal, maintenance is classified into three categories based on the schedule, complexity of the problem and the urgency.

Three categories are given below:

- MPS - Manutenção Preventiva Sistemática e Periódica
  (Systematic Periodic Preventive Maintenance);
- MPC - Manutenção Preventiva Condicionada, quando necessário
  (Preventive Maintenance Conditioned, when it is necessary);
- MC - Manutenção Corretiva, quando está em avaria ou quase avaria
  (Corrective Maintenance, when equipment is in malfunction or near failure).

It is intended to provide preventive maintenance, corrective maintenance and assistance in case of failure in installed equipment. Systematic preventive maintenance consists of a number of periodic actions of a different nature, depending on the type and function of such equipment. These periodic actions are intended to keep the devices operational and to avoid defects or wear and tear.

Corrective maintenance consists of servicing and repairing the installed equipment in case of failure. The assistance consists in acquiring and repairing all faults, whatever their cause, that appear on the equipment, in order to put them into operation in the shortest possible time, and the personnel of the Service Provider must be present at the place of the damage, with the necessary means, in a maximum time of 2 (two) hours, including night time, Saturday, Sunday or public holiday.

For the implementation of the aforementioned paragraphs, IP will make available to the Service Provider the facilities that are the subject of the provision of services and will allow the access and intervention of its personnel to the technical places where it is obliged to act and cannot, under any circumstances, interfere with the normal operating environment. IP will provide the available information on the electrical installations in question whenever requested by the Service Provider.

Along with that, for carrying out the maintenance work, there are some international standards [11] and company rules to follow, such as:

- IT-C-041 - Regulation of Safety of Rail Traction Lines.
- Internal Regulations REFER / Rail Operator applicable to the works
- CEI Standards - International Electro Technical Commission
- 60056 - High voltage alternating voltage circuit breakers.
- 60076 - Power transformers.

- 60099 - Surge Arresters.
- 60129 - Alternating voltage disconnectors and Interrupters.
- 60185 - Current transformers.
- 60186 - Transformers of tension.

All works will be executed in accordance with the applicable legislation in force, and the Service Provider will also provide all the information sent to operator by IP's Inspection authority. Ignorance of the subject premises of the service cannot be an excuse for any poor performance of the work, so it makes easier for competitors site inspection requested in advance.

2.5.1 Maintenance actions

The maintenance actions [2] cover all the electrical equipment of MAT, AT, MT and BT, including protection of relays, disconnectors and interrupters and measuring and recording equipment existing in the premises subject to the provision of services. The Service Provider will perform minor repairs and replacement of electrical equipment, excluding the provision of services for the remodeling of facilities, alterations to schemes, new wiring, replacement of main power transformers and civil construction.

The maintenance actions generally comprise:

- Control, measurement, adjustment and cleaning of electrical and mechanical equipment;
- Replacement of equipment, with the prior agreement of IP, which correspond to small work, namely, replacement of measurement transformers;
- Transportation of equipment, such as power and metering transformers, disconnectors and current transformers;
- Painting, where warranted, of electrical equipment, in particular all kinds of transformers and chassis of accumulator batteries;
- Cleaning of the command buildings of the substations, headquarters buildings of the brigades and cabins of catenary stations.

The detection of problems will give rise to a corrective maintenance action, through a careful analysis of its degree of urgency. Preventive maintenance includes two types of interventions:

Inspection and Rectification

This work consists of inspecting and rectifying the general condition of the equipment:

- The electrolyte level of the accumulator batteries;
- The oil level and silica status of the transformers;
- Power transformer's thermometers;
- Pressure of SF6 and nitrogen in circuit breakers;
- The state of cable and bus bar connections in general, tightening checks;
- The condition of the insulators;
- Control boxes of circuit breakers, switches, disconnectors and voltage regulators in charge;
- Lubrications;
- LV and MV fuses.

Verification

This work consists of verification of the reported problems:

- Verification of the manual and electrical operation of the circuit breakers and voltage regulators;
- Checking the state of charge of the accumulator batteries;
- Insulation resistance test of main power transformers;
- Measurement of dielectric strength and oil acidity of transformers;
- Checking the operation of the surge devices;
- Checking the tightness of cables and connections in general, including earthing connections;
- Verification of the earth resistance, its measurement and annual registration.

3. METHODOLOGY

Here, methodology involved a detailed study and gathering relevant information for developing each solution based on the situation. The combination of all the aspects makes an energy traction system more effective and functional, for instance; Electrical, Mechanical, Telecommunication and fault free (Maintenances).

Here, the case studies are different based on the situations and the equipment involved:

- Situation 3.1: Changing Aerial Feeder Line at Alfarelos
- Situation 3.2: Project of Changing the Flexible cable at Rua do Jau
- Situation 3.3: Develop the Maintenance actions in Excel
- Situation 3.4: Selection of Posts
- Situation 3.5: Upgrading Energy Equipment at Ovar

3.1 Changing Aerial Feeder Line at Alfarelos

Situation:

An aerial feeder supply method is used in between North line and Alfarelos, which was crossing a warehouse/freight terminal (See Figure: 33). Now the company has decided to upgrade facilities and operation, but the floor height of the overhead power line creates safety problems. Thus, there will be movement of containers with impellers under the feeder, creating serious safety problems for people and for the infrastructure itself. By considering all the above factors the Infraestruturas de Portugal (IP) demanded a detailed alternative solution.

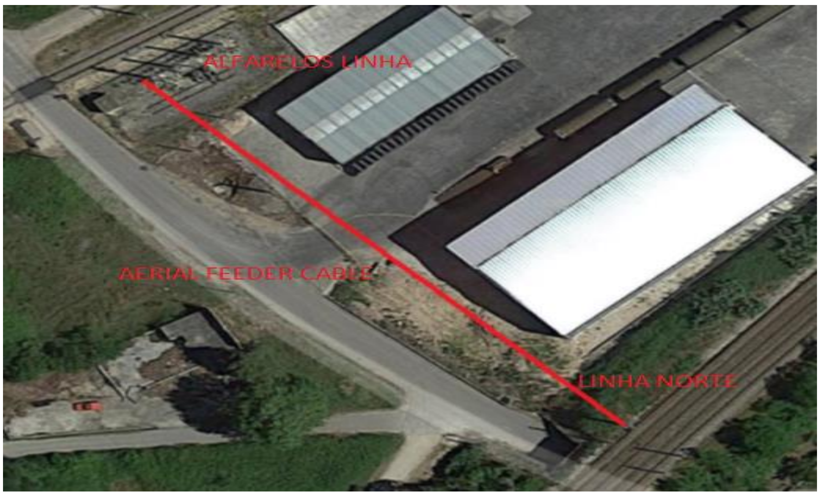


Figure 33: Image from the Location Aerial cable in between North line and Alfarelos

Proposed Solution:

The main function of the Feeder cable is to transport the energy from the Northern Line to Alfarelos Line, the activity of energizing and de-energizing takes place with the help of a Switch (Seccionador), Figure: 34. When the normal energy supply would not active. Especially, during the time of maintenance in the line or any fault occurrence in the transformers, this feeder cable will keep that energy line active and the works will not interfere the passage of trains.

By considering the safety factor, matter of getting contact with the feeder cable, and the future developments of the place. The best solution to tackle this situation is usage of underground cable even though; there are other possibilities such as increasing the height of the posts. But in future the further development might create the same problem. Moreover, this works demands the detailed study and diagrammatic presentation of all equipment and the end result.

Figure 34: Switch (Seccionador) in Alfarelos Line

Figure 35: Aerial Feeder Lines

Figure 36: Post of North Line

In this situation, as shown in Figure 37, it would be better to use highly insulated underground feeder cable (LXHIV 1×95 mm²), connects between Norte and Alfarelos Line, with supporting isolators (XH10), which isolates the post from the feeder cable and ensures the safety. Along with that, it would be very important to choose proper grounding system, for avoiding the fault current. In this case selected grounding cable is (LXV 1×95 mm²), which would be suitable to transfer the fault current, occurs due to lightening or short circuit, to the ground from the Surge arresters (SA).

Required Energy material:

- Isolators
- Surge Arrestors
- Insulated Feeder Cable
- Grounding Cable
- Visiting Box

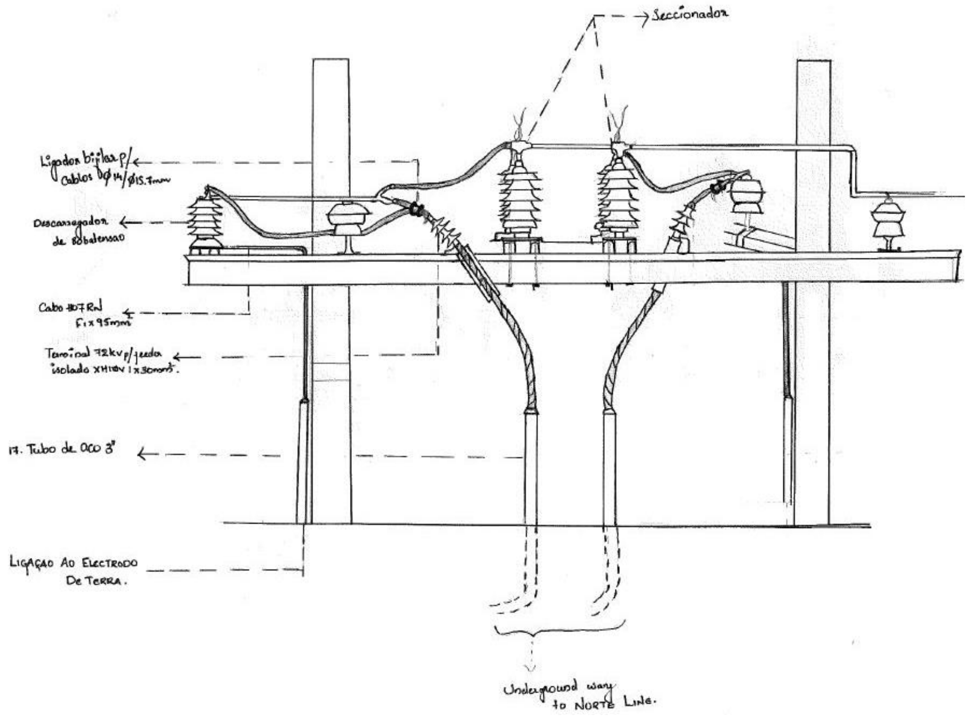


Figure 37: Proposed solution of underground Feeder in Alfarelos Line

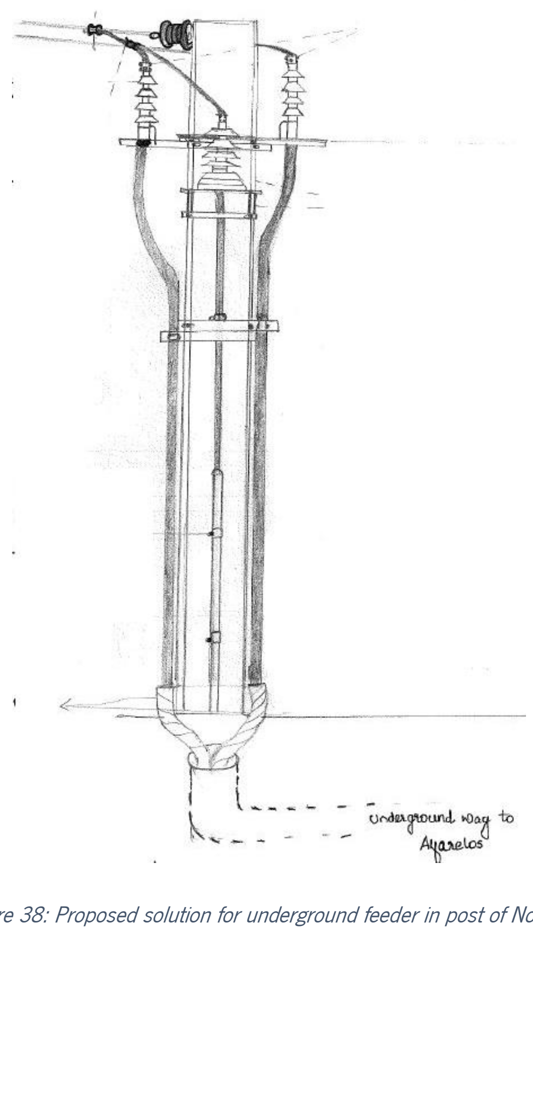


Figure 38: Proposed solution for underground feeder in post of North Line

Here, from Figure 37 represents the switch (Seccionador) in Alfarelos Line, a detailed comparison between Figure 34 and 37 shows that, the aerial feeder cables are replaced with underground cables with new equipment associated; such as, surge arresters (SA) and earth cable.

Detailed drawing developed, which gives the entire operation and all the equipment associated. Along with that, comparison between Figure 36 and 38, Pole of Northern Line, the catenary is connected with underground feeder cable by replacing aerial feeder.

Conclusion

After a detailed study about the all the circumstances related to the location and the safety aspects this work has proposed a detailed solution, changing feeder cable with insulated underground cable, after a brief review IP has accepted this developed solution. Now, the work is on progress at this location.

3.2 Project of Changing the Flexible cable at Rua do Jau

At General Torres station in Vila Nova de Gaia, access from the Rua do Jau (see Figure 38) to the railway platforms was very far from the street, so the Infraestruturas de Portugal (IP) has decided to make stairs and elevator option, which will be an easy path for physically challenged people also for commuters, that connects the platforms and also the underground parking lot.

Figure 39: Rua do Jao station

But the Catenary's support through flexible gantry (see Figure: 40 and 41) and the distance between power cables and the stairs were so close, which should not be authorized as per the IP standards.

Figure 40: Flexible Portics

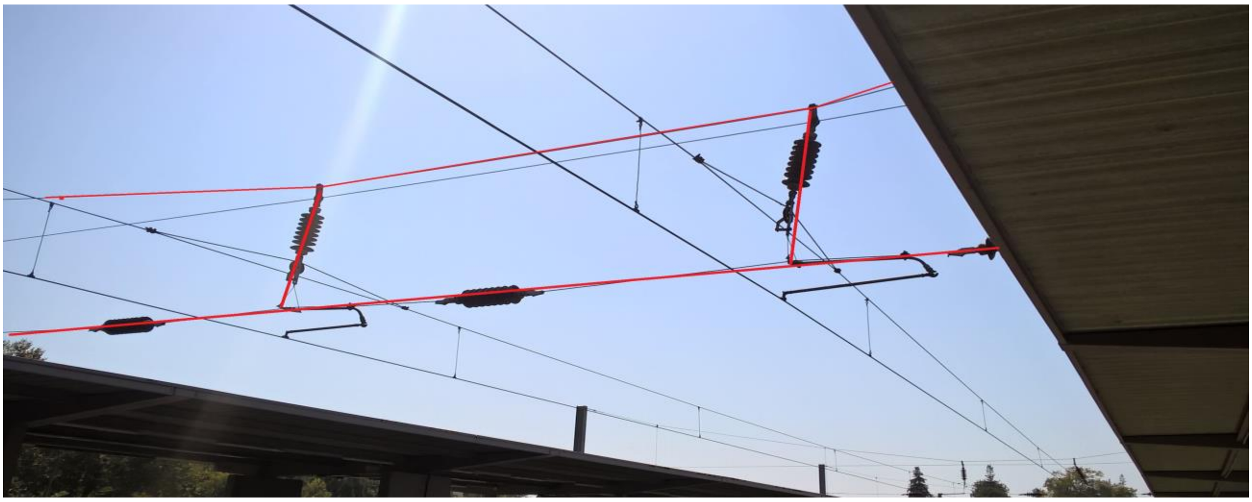


Figure 41: Flexible Portics at Rua do Jau:

Hence, the company proposed to develop a detailed cost-effective solution which satisfies all the aspects; for instance, safest, economical and fastest.

Solution:

Rua do Jau is the station with four active tracks (See Figure: 42) named as follows:

- VA Linha 1
- VD Linha 2
- VA Linha 3
- VD Linha 4

Here, the reason behind the application of flexible system instead of poles is mainly because the minimum distance between railway tracks are not normally enough for the deployment of independent poles for each track. As per standards of IP, minimum distance to install a post in between tracks is 1.50m from both sides of the tracks.

Here, distances between both tracks are 2.75m, (See Figure: 43)

Hence 2.75/2= 1.375m

That means, application of independent poles is not possible at this location. Along with that, this station is an entrance point of a tunnel; limited space is another issue that should be taken into address.

For the developing a solution for this situation required an intense study of the document and frequent visit to the location. The proposed and accepted solution is shown in Figure: 43.

Here, as said before lack of space for independent post in between tracks, a special kind of system has used named as Alonga Para Consolas, Appendix A. There are two reasons behind the selection of this specific console, for VA Linha 1 and VD Linha 2, mainly because it can attach on the wall and the velocity of the train will be less than 120 km/h, Rua do Jau is a station, hence the tension and force on the console will be comparatively lower than the normal situations. Along with that, for Linha 3 and 4, the flexible cable has replaced with normal consoles. That completely fits with the situation.

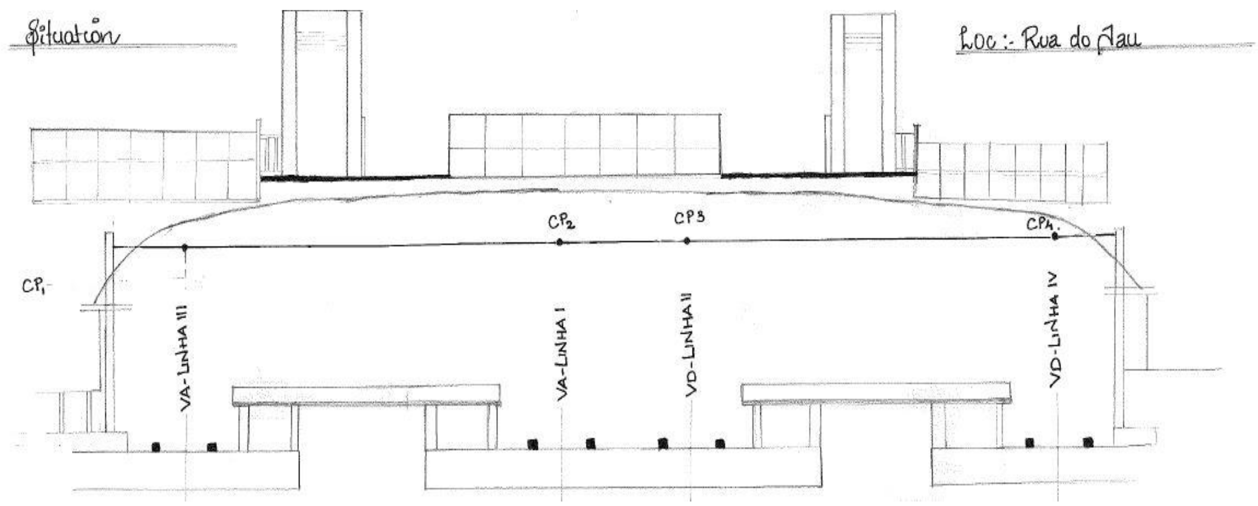


Figure 42: Diagrammatic representation of the situation at Rua do Jau

CP – Represents Contact Point, which means the contact between Pantograph and Power cables are taking place. Here four active lines, hence CP1, CP2, CP3 and CP4.

Now diagrammatic proposed solution, Figure:42, the developed solution shows that, all the cables and equipment are replaced at the same time the steps and elevators connect the platforms with street without interfering the power cable and ensure the maximum safety. Detailed solution presented at APPENDIX A.

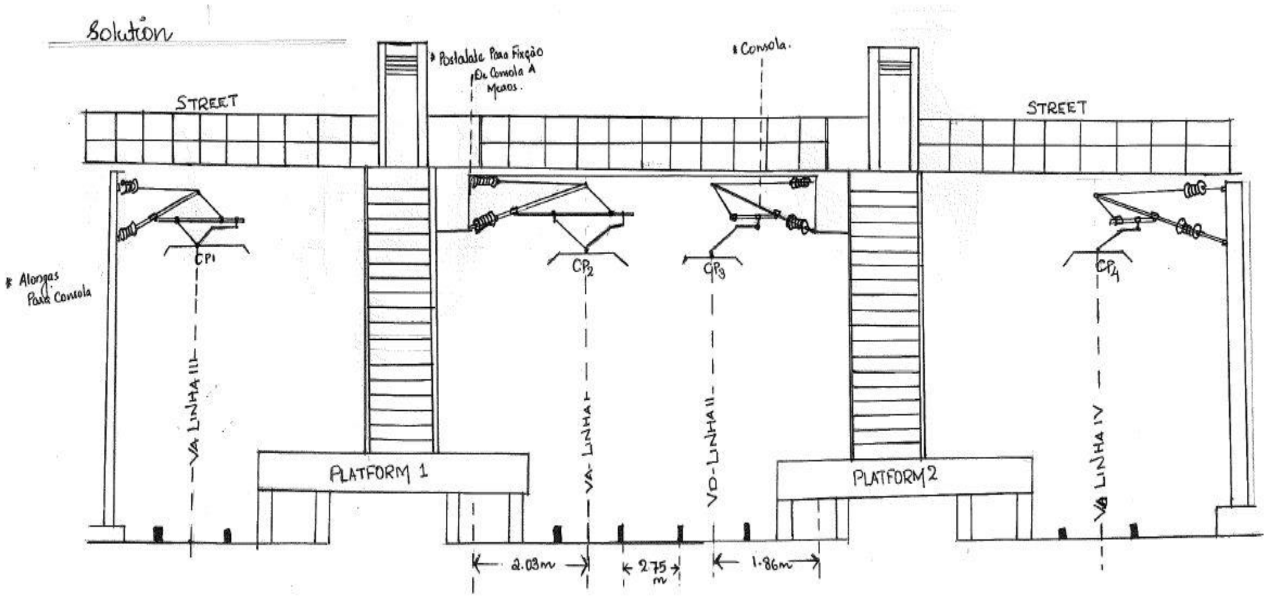


Figure 43: Diagrammatic representation of the solution at Rua do Jau

Conclusion

In Rua do Jau, the major obstacle for the upgrading the station was flexible cables and the equipment involved. Now, this proposed solution has accounted the main aspects; such as, safety, cost effective and fastest, remarked by IP. After a detailed analysis of the solution the company has accepted, and the work will start in near come future.

3.3 Develop the Maintenance actions in Excel

The main objective of this work is to define what kind of maintenance action [2] should be taken depending on the following factors:

- Seriousness of the problem
- Period to solve the problem
- Cost to solve the problem

Based on the above circumstances, it is important to suggest an effective solution out from the three maintenance types, such as MPS, MPC and MC (Chapter 2), for the north zone of Portugal.
The north zone of the Portugal divided into six zones, they are:

- Linha do Minho
- Concordância de São Gemil
- Linha de Leixões
- Linha do Douro
- Ramal de Braga
- Linha de Guimarães

Along with that, for an effective operation of traction system Infraestructuras de Portugal (IP) mainly concentrates the preventive maintenance actions in:

- Substations (SST)
- Post of Catenary (PC),
- Post of Catenary in Stations (PCE)
- Power Transformers (TA, TT)

This works required a detailed inspection of the location and rectify the issue associated with that case, and mention in the inspection check-list. Then it should be classified into the maintenance category in excel. The following excel tables will show the maintenance actions have proposed for different lines and system:

Maintenance in Linha do Douro

Item	Ref.ª (Col/Linha)	Tipo Instalação	Local	PK	Anomalia (Descrição sucinta e causa provável)	Estado/Nota Técnica
1	A-30	PCE	VALONGO	16.00	NÃO EXISTENCIA DE CABOS NOS EQUIPAMENTOS (CX. SECCIONADORES)	MPC, Clear the problem by connecting new Cable
2	A-46	PCE	VALONGO	16.00	FALTA LISTA DE CONTACTOS DE EMERGENCIA	MPC, Make a new print and Paste on the wall
3	A-48	PCE	VALONGO	16.00	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Buy more New Locks
4	A-49	PCE	VALONGO	16.00	FALTA ESQUEMA LONGITUDINAL DE CATENÁRIA	MPC, Change the catenary
5	A-51	PCE	VALONGO	16.00	FALTA EXTINTOR	MPC, Buy Extinguisher from the Authority
6	B-22	PCE	VALONGO	16.00	FALTA CABOS DE COMANDO E SINALIZAÇÃO	MPC, Change the cable of signalling
7	P-39	PCE	VALONGO	16.00	FALTA ESQUEMAS ELECTRICOS DESENVOLVIDOS	MPC, print it and fix on the wall.
8	X-38	PCE	VALONGO	16.00	TELEFONE SELECTIVO DE ENERGIA AVARIADO	MPC, Inform to the authority.
9	A-16	PC	S. MARTINHO DO CAMPO	19.02	VEDANTES DAS CX. CMD. DOS INTERRUPTORES FBM97 EM MAU ESTADO	MPC, Apply silica gel, to prevent water going inside the box of interrupter.

10	A-29	PC	S. MARTINHO DO CAMPO	19.02	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS	MPC, Do the repair work
11	A-48	PC	S. MARTINHO DO CAMPO	19.02	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Buy more New Locks
12	H-22	PC	S. MARTINHO DO CAMPO	19.02	ABRAÇADEIRAS DE FIXAÇÃO DOS TUBOS NOS POSTESPARTIDAS	MPC, Fix the clamps to the right position
13	J-6	PC	S. MARTINHO DO CAMPO	19.02	PLACA DE CARACTERISTICAS DO TA 19-02A EM FALTA (CAÍDA NO CHÃO)	MPC, Replace with new one and fix it.
14	S-1	PC	S. MARTINHO DO CAMPO	19.02	DESERVAGEM NO RECINTO PERIFERIA DO EDIFICIO	MPS, Remove the vegetation
15	S-2	PC	S. MARTINHO DO CAMPO	19.02	DESERVAGEM NA PERIFERIA DOS POSTES	MPS, Remove the vegetation
16	V-41	PC	S. MARTINHO DO CAMPO	19.02	PINTURA DE PAREDES E TETO EM MAU ESTADO DE CONSERVAÇÃO	MPC, Do painting on the structures
17	V-51	PC	S. MARTINHO DO CAMPO	19.02	LIMPEZA DO INTERIOR DA CABINE DO POSTO	MPS, Clean the Cabin of the PC
18	W-25	PC	S. MARTINHO DO CAMPO	19.02	EXTINTOR FORA DE PRAZO	MPC, Buy Extinguisher from the Authority
19	A-29	PCE	RECAREI-SOBREIRA	25.30	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS	MPC, Do the repair work.
20	A-39	PCE	RECAREI-SOBREIRA	25.30	FALTA ESQUEMAS ELECTRICOS DESENVOLVIDOS	MPC, print it and fix on the wall.

Table 1: Maintenance in Linha do Douro

Maintenance in Linha do Minho

Item	Ref.ª (Col/Linha)	Tipo Instalação	Local	PK	Anomalia (Descrição sucinta e causa provável)	Estado/Nota Técnica
1	A-16	PC BARRAMENTO	CAMPANHÃ 2	0.70	VEDANTE DAS CAIXAS DE CMD DOS INTERRUPTORES EM MAU ESTADO	MPC, Change the rubbers
2	A-29	PC BARRAMENTO	CAMPANHÃ 2	0.70	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS	MPC, Repair the connection problem
3	A-48	PC BARRAMENTO	CAMPANHÃ 2	0.70	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Keep the Keys in the PC
4	A-51	PC BARRAMENTO	CAMPANHÃ 2	0.70	FALTA EXTINTOR	MPC, Keep the extinguisher in the PC
5	I-6	PC BARRAMENTO	CAMPANHÃ 2	0.70	FALTA CHAPA DE IDENTIFICAÇÃ DO SECC. DO TT 0/27	MPC, Mark the proper identification tag
6	K-22	PC BARRAMENTO	CAMPANHÃ 2	0.70	FALTA DE ABRAÇADEIRAS DE FIVELA NOS CABOS DOS TTs	MPC, Use cable tie to make the lines more perfect
7	L-10	PC BARRAMENTO	CAMPANHÃ 2	0.70	RETOQUES DE PINTURA, PONTOS DE CORROSÃO NO GERAL	MPS, Do the spray paint on the corroded parts
8	O-1	PC BARRAMENTO	CAMPANHÃ 2	0.70	DESERVAGEM NO RECINTO JUNTO AO PC	MPS, Remove the vegetation
9	O-2	PC BARRAMENTO	CAMPANHÃ 2	0.70	DESERVAGEM NA PERIFERIA DOS POSTES COM EQUIPAMENTO	MPS, Remove the vegetation
10	O-15	PC BARRAMENTO	CAMPANHÃ 2	0.70	AFINAÇÃO DE SECCIONADORES VARAS EM ESFORÇO	MPS, Tightening the bars of the disconnectors

11	R-5	PC BARRAMENTO	CAMPANHÃ 2	0.70	FALTA LIGAÇÃO DE TERRAS NOS CABOS NAS CX. CMD. SECC	MPC Repair the connection problem
12	R-21	PC BARRAMENTO	CAMPANHÃ 2	0.70	LIMPEZA DE PLATAFORMAS DE MANOBRA DE SECCIONADORES	MPS, cleaning the platforms
13	S-3	PC BARRAMENTO	CAMPANHÃ 2	0.70	TAMPONAMENTO DE TUBOS NAS CX. DE CMD COM ESPUMA POLIURETANO	MPC, Close the holes with spray
14	W-20	PC BARRAMENTO	CAMPANHÃ 2	0.70	TA Y7 EM CURTO-CIRCUITO (FUSIVEL FUNDIDO, SECC. ABERTO,)	MPC, Changing the Current transformer with a new one.
15	A-3	PC SS	CAMPANHÃ TUNEL	1.03	TAMPAS DOS CANELETES EXTERIORES DANIFICADOS	MPC, Make new slabs
16	A-29	PC SS	CAMPANHÃ TUNEL	1.03	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS	MPC, Do the repair work.
17	A-48	PC SS	CAMPANHÃ TUNEL	1.03	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Keep the Keys in the PC
18	A-51	PC SS	CAMPANHÃ TUNEL	1.03	FALTA EXTINTOR	MPC, Get Extinguisher from the Authority
19	F-5	PC SS	CAMPANHÃ TUNEL	1.03	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS EXTERIORES	MPC, Do the repair work.
20		PC SS	CAMPANHÃ TUNEL	1.03	FALTA LIGAÇÃO DE TERRA NAS BAINHAS DOS CABOS DO SECC.	MPC, Do the repair work.

Table 2: Maintenance actions in Linha do Minho

Maintenance in Linha de Leixões

Item	Ref.ª	Tipo	Local	PK	Anomalia	Estado/Nota Técnica
	(Col/Linha	Instalação			(Descrição sucinta e causa provável)	
1	A-29	PC	CONTUMIL 2	3.47	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS(PORTA/JANELAS)	MPC, Do the repair work.
2	A-30	PC	CONTUMIL 2	3.47	FALTA DE IDENTICAÇÃO DOS DISJUNTORES NO QUADRO BT	MPC, Spot the circuit breaker and put the identity tag
3	A-39	PC	CONTUMIL 2	3.47	FALTA DE ESQUEMAS ELECTRICOS DESENVOLVIDOS	MPC, print it and fix on the wall.
4	A-46	PC	CONTUMIL 2	3.47	FALTA LISTA DE CONTACTOS DE EMERGENCIA	MPC, find it and make a print and Paste on the wall
5	A-48	PC	CONTUMIL 2	3.47	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Keep the Keys in the PC
6	A-49	PC	CONTUMIL 2	3.47	FALTA ESQUEMA LONGITUDINAL DE CATENÁRIA	MPC, Change the catenary
7	B-51	PC	CONTUMIL 2	3.47	FALTA EXTINTOR	MPC, Get Extinguisher from the Authority
9	R-15	PC	CONTUMIL 2	3.47	AFINAÇÃO DE VARA DE CMD NO SECC. DO TA 3-24A	MPS, Tightening the bars of the disconnectors
10	S-38	PC	CONTUMIL 2	3.47	CAMARA DE VIDEOVIGILANCIA NÃO FUNCIONA	MPC, Inform to the concerned authority
11	T-10	PC	CONTUMIL 2	3.47	PONTOS DE CORROSÃO NOS EQUIPAMENTOS DE ALTA TENSÃO	MPS, Paint the corroded parts of the High Tension Equipment
12	T-42	PC	CONTUMIL 2	3.47	HUMIDADE NO TETO DO EDIFICIO DO POSTO	MPC, Apply silica gel, to prevent water going inside the box of interrupter.
13	V-1	PC	CONTUMIL 2	3.47	DESERVAGEM NO RECINTO	MPS, Remove the vegetation
14	V-2	PC	CONTUMIL 2	3.47	DESERVAGEM NA PERIFERIA DOS POSTES	MPS, Remove the vegetation

15	W-25	PC	CONTUMIL 2	3.47	LIMPEZA DO INTERIOR DA CABINE DO POSTO	MPS, Clean the Cabin of the PC
17	A-11	PCE	S. GEMIL	5.72	SUBSTITUIR ISOLADOR DE APOIO DO SECC. 5-19A (COM SAIAS PARTIDAS)	MPC, Replace with a new isolator
18	A-29	PCE	S. GEMIL	5.72	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS(PORTA)	MPC, Do the repair work.
19	A-41	PCE	S. GEMIL	5.72	PINTURA DA SALA TECNICA EM MAU ESTADO	MPC, Do repainting
20	A-48	PCE	S. GEMIL	5.72	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Keep the Keys in the PC

Table 3: Maintenance actions in Linha de Leixoes

Maintenance Linha de Guimarães

Item	**Ref.ª** (Col/Linha	**Tipo** Instalação	**Local**	**PK**	**Anomalia** (Descrição sucinta e causa provável)	**Estado/Nota Técnica**
1	A-29	PCE	STº. TIRSO	30.40	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS	MPC, Do the repair work.
2	A-46	PCE	STº. TIRSO	30.40	FALTA LISTA DE CONTACTOS DE EMERGENCIA	MPC, find it and make a print and Paste on the wall
3	A-48	PCE	STº. TIRSO	30.40	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Keep the Keys in the PC
4	A-49	PCE	STº. TIRSO	30.40	FALTA ESQUEMA LONGITUDINAL DE CATENÁRIA	MPC, Change the catenary
5	H-22	PCE	STº. TIRSO	30.40	CABOS SEGUROS COM ARAMES A SUBSTITUIR ABRAÇADEIRAS DE SERRILHA	MPC, Apply silica gel, to prevent water going inside the box of interrupter.
6	I-42	PCE	STº. TIRSO	30.40	HUMIDADE NAS PAREDES E TECTO DA SALA TECNICA	MPC, Make the proper insulation to avoid moisture
8	V-2	PCE	STº. TIRSO	30.40	DESERVAGEM NA PERIFERA DOS POSTES	MPS, Remove the vegetation

9	V-10	PCE	STº. TIRSO	30.40	PONTOS DE CORROSÃO NOS EQUIPAMENTOS	MPC, Paint the corroded parts
10	V-51	PCE	STº. TIRSO	30.40	EXTINTOR COM DATA DE MANUTENÇÃO FORA DE PRAZO	MPC, Replace with a new Extinguisher
12	A-29	PCE	CANIÇOS	34.90	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS	MPC, Do the repair work.
13	A-46	PCE	CANIÇOS	34.90	FALTA LISTA DE CONTACTOS DE EMERGENCIA	MPC, find it and make a print and Paste on the wall
14	A-48	PCE	CANIÇOS	34.90	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Keep the Keys in the PC
15	A-49	PCE	CANIÇOS	34.90	FALTA ESQUEMA LONGITUDINAL DE CATENÁRIA	MPC, Change the catenary
16	A-51	PCE	CANIÇOS	34.90	FALTA EXTINTOR	MPC, Replace with a new Extinguisher
18	X-2	PCE	CANIÇOS	34.90	DESERVAGEM NA PERIFERIA DOS POSTES	MPS, Remove the vegetation
19	A-29	PCE	VILA DAS AVES	38.00	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS	MPC, Do the repair work.
20	A-46	PCE	VILA DAS AVES	38.00	FALTA LISTA DE CONTACTOS DE EMERGENCIA	MPC, find it and make a print and Paste on the wall

Table 4 Maintenance actions in Linha de Guimaraes

Maintenance in Ramal de Braga

Item	Ref.ª	Tipo	Local	PK	Anomalia	Estado/Nota Técnica
	(Col/Linha	Instalação			(Descrição sucinta e causa provável)	

1	A-29	PCE	ARENTIM	44.00	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS	MPC, Do the repair work.
2	A-46	PCE	ARENTIM	44.00	FALTA LISTA DE CONTACTOS DE EMERGENCIA	MPC, find it and make a print and Paste on the wall
3	A-48	PCE	ARENTIM	44.00	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Keep the Keys in the PC
4	A-49	PCE	ARENTIM	44.00	FALTA ESQUEMA LONGITUDINAL DE CATENÁRIA	MPC, Change the catenary
6	V-51	PCE	ARENTIM	44.00	EXTINTOR FORA DE VALIDADE	MPC, Replace with a new Extinguisher
7	W-2	PCE	ARENTIM	44.00	DESERVAGEM NA PERIFERIA DOS POSTES	MPS, Remove the vegetation
8	X-42	PCE	ARENTIM	44.00	HUMIDADE NAS PAREDES JUNTO À PORTA DA SALA TÉCNICA	MPC, Make the proper insulation to avoid moisture
9	A-29	PCE	TADIM	47.50	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS	MPC, Do the repair work.

					METALICAS	
10	A-46	PCE	TADIM	47.50	FALTA LISTA DE CONTACTOS DE EMERGENCIA	MPC, Find it and make a print and Paste on the wall
11	A-48	PCE	TADIM	47.50	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Keep the Keys in the PC

Table 5 Maintenance actions in Braga

Maintenance in Concordância de São Gemil

Item	Ref.ª (Col/Linha)	Tipo Instalação	Local	PK	Anomalia (Descrição sucinta e causa provável)	Estado/Nota Técnica
1	A-29	PX	S. GEMIL 2	2.430	FALTA LIGAÇÃO DE TERRA NAS ESTRUTURAS METALICAS(PORTA/JANELAS)	MPC, Do the repair work.
2	A-39	PX	S. GEMIL 2	2.430	FALTA ESQUEMAS ELECTRICOS DESENVOLVIDOS	MPC, Print it and fix on the wall.
3	A-46	PX	S. GEMIL 2	2.430	FALTA LISTA DE CONTACTOS DE EMERGENCIA	MPC, Find it and make a print and Paste on the wall
4	A-48	PX	S. GEMIL 2	2.430	FALTA CHAVEIRO, CHAVES E MANIVELA	MPC, Buy more New Locks
5	A-49	PX	S. GEMIL 2	2.430	FALTA ESQUEMA LONGITUDINAL DE CATENÁRIA	MPC, Change the catenary
6	B-51	PX	S. GEMIL 2	2.430	FALTA EXTINTOR	MPC, Buy Extinguisher from the Authority
7	F-32	PX	S. GEMIL 2	2.430	FALTA SUPORTES DO DIFUSOR DA ARMADURA FLURECENTE	MPC, Change the florescent

						lamp.
8	M-38	PX	S. GEMIL 2	2.430	FALTA TELEFONE	MPC, inform to the authority.
9	S-1	PX	S. GEMIL 2	2.430	DESERVAGEM NO RECINTO (PERIFERIA DO EDIFICIO)	MPS, Remove the vegetation
10	T-10	PX	S. GEMIL 2	2.430	PONTOS DE CORROSÃO NOS EQUIPAMENTOS AT	MPS, Paint the corroded parts of the ATs
11	T-21	PX	S. GEMIL 2	2.430	CABOS DE TTs COM ARAMES (RETIRAR)	MPS, Remove the unused wires
12	W-2	PX	S. GEMIL 2	2.430	DESERVAGEM NA PERIFERIA DOS POSTES	MPS, Remove the vegetation

Table 6 Maintenance actions in S.Gemil

Conclusion:

To make train traction system more continuous, to ensure maximum equipment redundancy, reduce the cost and save energy, for all these adequate maintenance of the traction system plays a crucial role. This Excel work mainly dealt with the problems associated with Substations (SST), Post of Catenary (PC), Post of Catenary at Station (PCE) and Power Transformers (TA, TT).

Along with that, explained the maintenance action should be taken to solve that trouble, before it will affect the train service. For the future, Infraestruturas de Portugal (IP) intends to continue tackling development of technologies that require less maintenance, provide more energy efficiency, and are environmentally friendly.

3.4 Selection of Posts

In traction system, posts are the backbone; hence the selection of posts for a location really plays an important role. The objective of this work is the selection of poles for the traction system based on different scenarios, such as; Cost associated, Tension on the post during the winter time and summer time, Force on the posts with or without wind, Radius of curvature, Weight of the equipment and cables (Catenary and Feeder) and the Safest tension that a post can withstand with all the above factors

Situation:

Considering a single console posts, as shown in Figure 44, located on the outside of 700 m radius bend with adjacent spans of 45 m, equipped with earth cable, feeder post 2.60 m long mounted to the side of the field, section of the feeder 150mm ^{2} and average distance of 49.5 m. The catenary is compensated and is type LP1, with the height of the contact wire 5.75 m, an opening of 1.60 m, and the tensile strength of the support cable and the contact wire is 1000 kgf. The pole will have a level of 0.4 m, the deployment of 2.15 m and a height above the beam of 7.9 m, the isolation is sea area.

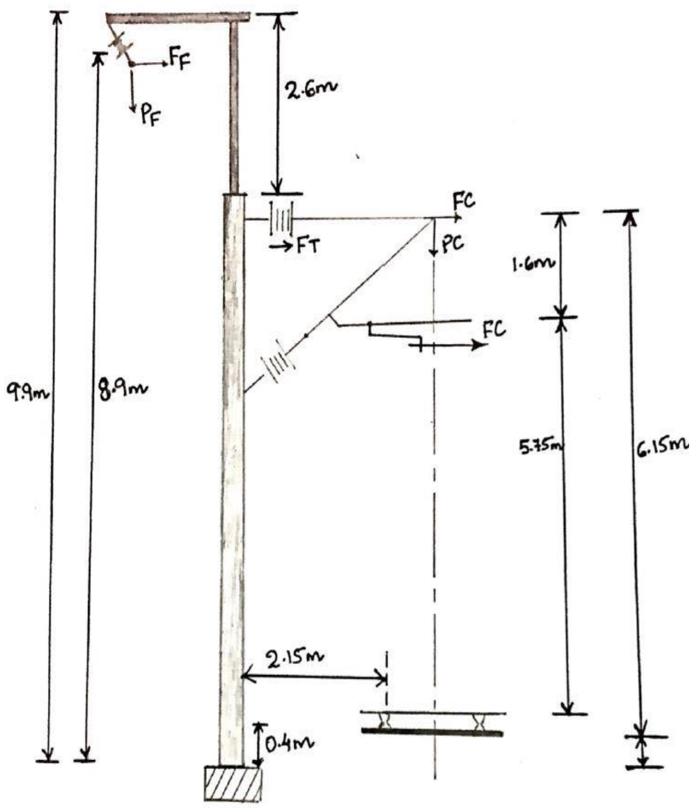


Figure 44: Schematic representation of post

In this case,

Distance between the post =45 m

Radius of curvature=700 m

Distance to the feeder from top of the post=2,60 m

Medium distance between posts=49,5m

Catenary-LP1-Velocity-120 km/h

Height to the contact cable from the track=5,75 m

Distance between support cable and contact cable=1,60 m

Radial Forces:

tC - Tension in the contact wire

tS – Tension in the support cable

tC = tS = 1000 kg

a= Distance between posts=45 m

R=Radius of curvature=700 m

$$F_c = F_s = \frac{a}{R} \times t = \frac{45}{700} \times 1000 = 64{,}29 \text{ kgf}$$

Here, kilogram-force (kgf) = one kilogram-force is equal to 9.80665 N

tF – Tension on the feeder (APPENDIX A)

tF(summer) = 983 kgf

tF'(15°C without wind)= 913 kgf (APPENDIX A)

$$F_F = \frac{45}{700} \times 983 = 63{,}19 \text{ kgf}$$

$$F_F' = \frac{45}{700} \times 913 = 58{,}69 \text{ kgf}$$

tT – Tension on the earth cable

tT(summer)= 383 kgf

tT'(15°C without wind)= 324 kgf

$$F_T = \frac{45}{700} \times 383 = 24{,}62 \text{ kgf}$$

$$F_T' = \frac{45}{700} \times 324 = 20{,}83 \text{ kgf}$$

Vertical Forces

PC – Weight of the catenary (A)= 1,60 kgf

$$PC = 1,6 \times a = 1,6 \times 45 = 72 \text{ kgf}$$

PF – Weight of the feeder (APPENDIX A)

Pi – Weight of the isolator=16 kgf

$$P_F = 1.33 \times a + P_i = 1.33 \times 45 + 16 = 75,85 \text{ kgf}$$

PT – Weight of the earth cable

$$P_T = 0,44 \times 45 = 19,8 \text{ kgf}$$

PP – Weight of the feeder= 60 kg (APPENDIX A)

PA – Weight of the console = 62 kgf

MA –Force on the console and the connectors = 78 kgf (APPENDIX A)

Compression divided on equipment;

P1 = PC + PF + PT + PP + PA = 72 + 75,85 + 19,8 + 60 + 62 = 289,65 kgf

Bending of Curve

H – Total height of the beam = 7,9+(2,6-0,6) =9,9 m

h1 – Height of the post = 7,75 m

h1' – Total height of the beam = 7,90 m

h2 –height from Contact wire+ Track + Catenary = 7,75 m

h3 – height from contact cable +ground level =5,75+0,4= 6,15 m

h4 – Height of the earth cable = 7,70 m

h5 – Height till console = 5,51 m

hF – Height till feeder = 7,75 m

b – Horizontal distance of support cable to beam= 3 ,05 m

d – Horizontal distance of feeder to beam= 1,80 m

$$M_{x\perp} = M_A + P_C \times d + P_F \times b + F_F \times H + F_S \times h_2 + F_C \times h_3 + F_T \times h_4$$

$$M_{x\perp} = 78+72\times3,05+75,94\times(-1,8)^*+63,19\times9,90+64,29\times7,75+64,29\times6,15+24,62\times7,70$$

$$M_{x\perp} = 1.869,69 \text{ kgf}\times\text{m}$$

*Reason why (-1,8), Because the arm of the feeder is opposite to the console,

(See Figure: 44)

$$M_{x//} = M_A + P_C \times d + P_F \times b + F_F' \times H + F_S \times h_2 + F_C \times h_3 + F_T' \times h_4$$

$M_{X//}$ = 78+72×3,05+75,94×(-1,8)+58,69×9,90+64,29×7,75+64,29×6,15+20,83×7,70

$M_{X//}$ = 1.795,95 kg×m

Transient effects:

- Force of wind ⊥;(APPENDIX A)

VF – Force of the wind to the feeder

$V_F = 0,91 \times a = 0,91 \times 45 = 40,95$ kgf

VT – Force of the wind to the earth cable

$V_T = 0,57 \times a = 0,57 \times 45 = 25,65$ kgf

VS – Force of wind to the support cable and droppers

$V_S = 0,69 \times a = 0,69 \times 45 = 31,05$ kgf

VC – Force of wind to the contact wire and droppers

$V_C = 0,80 \times a = 0,80 \times 45 = 36,00$ kgf

$V_P = 22,50$ kgf (APPENDIX A)

- Force of wind //; (APPENDIX A)

RF – Force of wind on the console of the feeder = 15 kgf

Ri – Force of wind on isolator of the feeder = 6,25 kgf

RC – Force of the wind on console = 18,75 kgf

$h_6 = 0,65 + h_3 = 0,65 + 6,15 = 6,8$ m

Total basement = 1.3m

So; the Centre =1,3/2=0,65m

$R_P = 18,80$ kg (APPENDIX A)

H_F = Height of the feeder

$M_{//Y} = (R_F + R_i) \times H + R_C \times h_6 + R_P \times H_F$

$M_{//Y} = (15+6,25) \times 9,9 + 18,75 \times 6,8 + 18,80 \times 8,9 = 505,20$ kgf×m

Case Study 1: Beam Type, HE 200A

Values in (APPENDIX A), for the chosen beam

P = 42,3 kg/m

X = b = 0,20 m

Y = h = 0,19 m

S = 53,8 cm^2

$(I/V)_x$ = 389 cm^3

$(I/V)_Y = 134\ cm^3$

Force applied on the beam

$P_V = P_2 = P \times H = 42,3 \times 7,9 = 334,17$ kg

$M_{\perp V} = 69,4 \times H^2 \times X = 69,4 \times 7,9^2 \times 0,20 = 866,25$ kgf×m

$M_{//V} = 58,2 \times H^2 \times Y = 58,2 \times 7,9^2 \times 0,19 = 690,13$ kgf×m

Verification of Beam

- Compression tension

  A – 11.75 (APPENDIX A)

$$\frac{P_1}{S} \times A = \frac{289,74}{53,8} \times 11,75 = 63,28 \text{ kgf/cm}$$

- Flexion tension $\overline{OX}$ (wind ⊥)

$$\frac{M_{X\perp} + M_X}{(I/V)_X} = \frac{1869,69 + 1265,21}{389} \times 100 = 805,89 \text{Kgf}$$

- Flexion tension $\overline{OX}$ (wind //)

$$\frac{M_{X//}}{(I/V)_X} = \frac{1795,95}{389} \times 100 = 461,68 \text{kgf}$$

- Flexion tension $\overline{OY}$ (wind //)

$$\frac{M_{//Y}}{(I/V)_Y} = \frac{505,20}{134} \times 100 = 377,01 \text{ kgf}$$

Deformation of beam

- Wind ⊥

$$\frac{P_2}{S} + \frac{M_{\perp V}}{(I/V)_X} = \frac{334,17}{53,8} + \frac{866,25}{389} \times 100 = 228,90 \text{ kgf/cm}^2$$

- Wind //

$$\frac{P_2}{S} + \frac{M_{//V}}{(I/V)_Y} = \frac{334,17}{53,8} + \frac{690,13}{134} \times 100 = 521,23 \text{ kgf/cm}^2$$

Total Tension

Here, Safest tension that a beam can survive σ_S = 1700 kgf/cm^2 (APPENDIX A)

- Wind ⊥- Force of wind perpendicularly apply on the post and associated equipment.

σS > $\frac{p_1}{S} \times A + \frac{|M_{\perp X}|}{(I/V)_X} + \frac{|M_{\perp Y}|}{(I/V)_Y} + \frac{P_2}{S} + \frac{|M_{\perp V}|}{(I/V)_X}$ =

σS > 63,28 + 805,89 + 228,90 = **1.038,07 kg/cm^2**

σS >**1.038,07 kg/cm^2**

- Wind //- Force of wind parallelly apply on the post and associated equipment.

σS > $\frac{p_1}{S} \times A + \frac{|M_{//X}|}{(I/V)_X} + \frac{|M_{//Y}|}{(I/V)_Y} + \frac{P_2}{S} + \frac{|M_{//V}|}{(I/V)_X}$ =

σS > 63,28 + 461,68 + 377,01 + 521,23 = **1.423,20 kg/cm^2**

σS > **1.423,20 kg/cm^2**

Conclusion

Here, HE 200 A type post is applicable for this situation. Because the total tension in the case of wind, flexion tension, compression tension in case of perpendicular and parallel are satisfying the condition, along with that, total weight of the equipment on that specific post, HE 200A, is lower than the safest withstanding point, that is 1700.

3.5 Upgrading Energy Equipment at Ovar

At Ovar, the energy equipment is getting outdated and continuous mechanical failure of the systems are reporting, see Figure 45. So, the company has decided to upgrade the system with new energy system and devices.

Figure 45: Outdated equipment at Ovar

Solution

At this place, main problem associated with interrupters, named as IP, IL1 and IL2, the main function of this is interrupt the flow of energy during the time of fault or short circuit and at the time maintenance interrupters are required to disconnect the voltage.

In the past, interrupters were larger in size and in weight, 520 kg and required a wide space on ground for installing, than the new device, 25 kg can attach on the post. Moreover, considering the safety aspects the company had to make barricade around these devices to avoid the interference of human or animals. In addition to that, at the present situation it is become a serious problem to find the spare parts of this outdated devices.

Nowadays, the Interrupters are more compact as well as easy to attach with the post, hence there would not be any wasting of lands. Along with that, this equipment is more efficient in operation. But, it was an important task to select the posts which new device could attach with. After the process of calculation of the posts, by considering the existing equipment tension and varying climatic condition as well as the lifespan of the existing posts, this work has proposed a solution of changing the posts with new. The diagrammatic proposed solution is shown in Figure 46

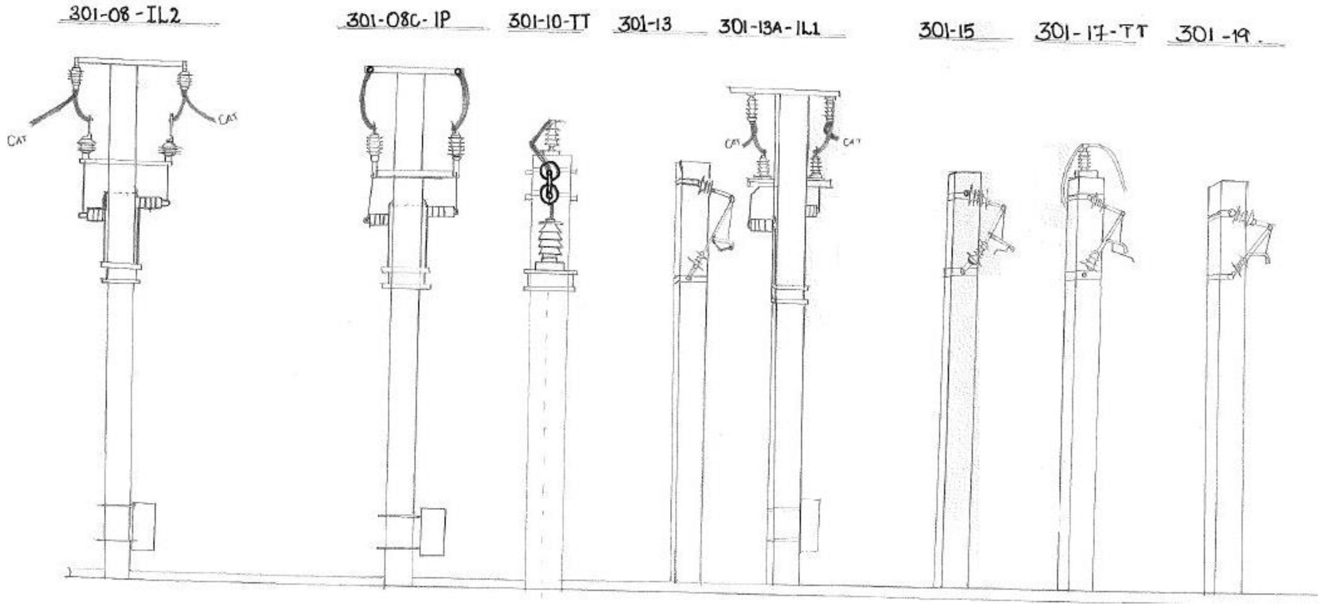


Figure 46: Proposed solution for Ovar

Here as in Figure 46, the new interrupters, IL1, IL2 and IP, are attached with new posts and the new devices are arranged in regular intervals based on the length of the overhead cables. A detailed solution is given in Appendix A.

Conclusion

In Ovar, the mechanical failure of the devices and the safety of the people were the main issues, after thorough study about the system and devices associated this works has proposed a solution of replacing the outdated devices with new equipment. After a detailed review the company has accepted the proposed solution.

4. RESULTS

This chapter mainly explains about solutions was developed based on the case studies; such as, works associated with power systems, maintenance actions for the traction system and the entity and the process of selection of posts.

4.1 Case study 1: Changing Aerial Feeder Line at Alfarelos

An aerial feeder line, which transfers energy from Alfarelos line to Norte line, was the objective of this case study. The company has decided to improve the entity, but the floor height of the overhead power cable creates safety threat, because the height of the impellers increases, and the possibilities of contacts are very high.

Developing a solution for this scenario mainly considered two factors; that is, safest and cost effective. Increasing the height of the posts was another solution and that was a good choice in terms of budget and time to finish the work. But, in terms of safety, this solution was not convenient. After a detailed study about the circumstance, concluded changing aerial feeder cables with underground insulated cables.

An insulated feeder cables were the best alternatives, mainly because of the safety terms and assures a fault free operation as comparing with aerial feeder lines at the same time the future development of that area will not be affected by these feeder cables.

This work designed a complete solution, which points the equipment associated and the detailed specification.

4.2 Case study 2: Project of Changing the Flexible cable

General Torres, is a station with four active tracks, IP has decided to upgrade the station facilities by introducing stairs and elevators. The main obstacle for the development was the presence of energy cables and associated equipment.

As associated in this work, that was an obligation to develop a suitable solution by giving prime priority for the safety of people followed by the fastest and under budgeted solution.

Implementation of new posts was an alternative. But, by considering the cost of new posts as well as insufficient place available in between tracks, came to conclusion of searching for a new better solution. After a thorough study, this work developed a solution with special kind of console named as "Alongas Consola", which can attach on the walls of the stair structure, Appendix A. Another reason to proceed with the solution was, the velocity of the trains would be comparatively low, mainly because the force on the equipment will be less.

4.3 Case study 3: Develop the Maintenance actions in Excel

The aim of this project is to define the methodology to adopt for Preventive Maintenance Systematic (MPS) for traction power facilities depending on the type of installation and the surrounding conditions. To accomplish, this required a detailed inspection in the location and remark the problems in the inspection checklist, after this work the process of verification would start, once the problem have verified then the maintenance action should be proposed.

This work mainly associated with the projects of six locations in the north zone, mainly focused on the problems involved with Substations, Post of Catenaries, Post of Catenary at stations and Power transformers. This developed solution in excel which gives the information about the trouble associated with the equipment, the distance of the location, the reference number of that issue at the end which maintenance action should be taken for that problem. This proposed solution has considered and the maintenance actions also performed.

4.4 Case study 4: Selection of Posts

The posts play an important role in energy traction system. So, the task of selecting the posts should be well calculated and observed, because a wrong selection of post will lead to losses of money and may leads to damage of the entire system. The main factors associated with selection of the post the weight of the cables and equipment attached with, the force of the wind applied on the post and the tension of the cable.

As part of works at Ovar, related with upgrading the energy equipment, to propose a solution it was important to define the types of posts for each case. By considering all the company standards and weight of the equipment, this work has proposed a detailed solution. For accomplishing this work demands a detailed comparison of each post with the maximum withstanding capacity. After a thorough observation the IP has accepted the developed solution.

4.5 Case study 5: Up gradation Energy Equipment at Ovar

In Ovar, mechanical failure of the systems was reporting adequately, and the main reason behind the issue was life span of the devices, mainly interrupters for Line1, Line 2 and one parallel connected between two lines; such as, IL1, IL2 and IP. So, as per the information from the company, this work has to find a solution to tackle that problem. For developing a solution for this work came to a conclusion of replacing the entire systems mainly, because the old equipment was fixed on the ground which consumes a lot of space, along with that, it was quite difficult to find the spare parts of those devices. The solution proposed by this work defined new Interrupters, which can attach on the posts and more efficient than the old devices. The posts are selected after the calculation process by including the weight of the new equipment. The diagrammatic solution Figure:47 gives the information about the posts which new devices should attach and the alignment of the posts.

5. CONCLUSION

The aim of the dissertation is to give a detailed information about the current railway system and the operation of the power devices. Along with that, the equipment has involved for keeping the energy traction active. Once the energy from the national grid (REN) has reached to the substations of the Infrastruturas de Portugal (IP), each energy device has own responsibility to perform, starts from the switch to catenary cable. An error less systems and equipment keep the catenary more functional.

To achieve an error less system, there should be proper maintenance of the traction entity and the devices in a certain period of time. The maintenance actions would be based on the seriousness of the issue, cost involved to solve that issue and finally time require to solve. In Infrastruturas de Portugal, after the rectification of problems the concerned person, energy traction manager, must suggest the maintenance action, which should follow the standards both European and Company, out from the three. For the future, (IP) intends to continue tackling development of technologies that require less maintenance, provide more energy efficiency, and are environmentally friendly.

The core of this thesis is chapter 3, which describes the developed solutions for all the case studies. A traction system is the combination of mechanical electrical and civil sector. But, this dissertation has been dealt with the case studies based on the real-time problems related with the power systems. The solution was developed by giving more weight for the safety aspects, the budget for carrying out the work and future oriented.

The development of this work allowed consolidating the knowledge acquired during the course, with emphasis in electrical engineering, power system, high voltage devices and operation. It also improved some soft-skills like the ability of project management, self-discipline, ability of designing and learning foreign language.

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7. APPENDIX A

Vão	Forças tensoras em condutores não compensados (kg)															
	Cabo de suporte (C.S.)				Cabo de terra (C.D.T.)				Feeder 95				Feeder 150			
	Verão	+15ºC s/v	Inverno	-5ºC s/v	Verão	+15ºC s/v	Inverno	-5ºC s/v	Verão	+15ºC s/v	Inverno	-5ºC s/v	Verão	+15ºC s/v	Inverno	-5ºC s/v
31.5	1 098	1 043	1 220	1 215	365	328	455	453	589	551	782	781	970	934	1 304	1 303
36.0	1 111	1 041	1 216	1 210	371	327	450	447	593	547	768	765	973	928	1 285	1 283
40.5	1 124	1 040	1 211	1 203	377	326	444	441	597	544	752	750	977	923	1 264	1 262
45.0	1 137	1 038	1 206	1 198	383	325	438	434	602	540	736	733	980	918	1 242	1 239
49.5	1 150	1 036	1 200	1 192	388	324	432	428	605	537	721	717	983	913	1 219	1 217
54.0	1 163	1 035	1 194	1 185	394	320	425	420	609	534	705	700	986	909	1 197	1 193
58.5	1 175	1 031	1 188	1 175	402	319	419	413	612	531	690	685	989	905	1 175	1 170
63.0	1 188	1 030	1 183	1 165	404	317	413	406	615	529	675	670	991	900	1 153	1 140

Table 7: Tension Force on Conductor

Forças do vento em condutores e cabos		
Condutores ou cabos	Força do vento (kg/m)	
	q = 75 (kg/m²)	q = 18,75(kg/m²)
Cabo de suporte (BZ65)	0.66	0.16
Fio de contacto (Cu 107)	0.77	0.19
C.S. + pêndulos (metro)	0.69	0.17
F.C. + pêndulos (metro)	0.80	0.20
Cabo de terra	0.57	0.14
Feeder 95	0.72	0.18
Feeder 150	0.91	0.23
Cabo:		
BZ 25	0.36	0.09
BZ 35	0.45	0.11
BZ 50	0.57	0.14
BZ 95	0.72	0.18
BZ 120	0.81	0.20

Table 8: Wind Force on Conductors

Distâncias entre postes (m)	
Alinhamento	63
Curva 00 > R ≥ 1845 m	63
Curva 1125 > R ≥ 875 m	49.5
Curva 1445 > R ≥ 1125 m	54
Curva 1845 > R ≥ 1445 m	58.5
Curva 375 > R ≥ 275 m	31.5
Curva 525 > R ≥ 375 m	36
Curva 675 > R ≥ 525 m	40.5
Curva 875 > R ≥ 675 m	45

Table 9: Distance between Posts

0	–	–	–
2.10	48.50	16.90	14.10
2.60	60.00	22.50	18.80
3.10	71.50	28.20	23.50
3.60	83.00	33.80	28.20
4.10	94.50	39.40	32.90

Table 10: PP,VP and RP

Viga	PV (peso)	x (b)	y (h)	E (secção)	Nx	Ny	K	A	C
HE 160 A	30.4	0.16	0.15	38.3	220	77	47.44	–	–
HE 180 A	35.5	0.18	0.17	45.3	294	103	31.62	1.127	1118
HE 200 A	42.3	0.20	0.19	53.8	389	134	21.50	1.316	1462
HE 220 A	50.5	0.22	0.21	64.3	515	178	14.67	1.459	2127
HE 240 A	60.3	0.24	0.23	76.8	675	231	10.23	1.603	2996
HE 260 A	68.2	0.26	0.25	86.8	836	282	7.60	1.822	3626
HE 280 A	76.4	0.28	0.27	97.3	1010	340	5.80	2.030	4426
HE 300 A	88.3	0.30	0.29	112.5	1260	421	4.35	2.173	5900
HE 320 A	97.6	0.30	0.31	124.4	1480	466	3.46	2.105	7957
HE 340 A	105	0.30	0.33	133.5	1680	496	2.87	–	–
HE 360 A	112	0.30	0.35	142.8	1890	526	2.40	–	–
HE 160 B	42.6	0.16	0.16	54.3	311	111	31.85		
HE 180 B	51.2	0.18	0.18	65.3	426	151	20.72	0.808	3552
HE 200 B	61.3	0.20	0.20	78.1	570	200	13.94	0.933	4837
HE 220 B	71.5	0.22	0.22	91	736	258	9.81	1.059	6438
HE 240 B	83.2	0.24	0.24	106	938	327	7.05	1.188	8403
HE 260 B	93	0.26	0.26	118.4	1150	395	5.32	1.360	9853
HE 280 B	103	0.28	0.28	131.4	1380	471	4.12	1.529	11610
HE 300 B	117	0.30	0.30	149.1	1680	571	3.16	1.663	1460
HE 320 B	127	0.30	0.32	161.3	1930	616	2.58	1.648	1829
HE 340 B	134	0.30	0.34	170.9	2160	646	2.17	–	–
HE 360 B	142	0.30	0.36	180.6	2400	676	1.38	–	–

Table 11: Specification of Posts

		Peso	Vento
Cabos	Catenária (kg/m)	1.60	1.30
	Fio de contacto (kg/m)	0.95	0.70
	Cabo de suporte (kg/m)	0.65	0.60
	Cabo de suporte auxiliar (kg/m)	7	6
	Cabo de terra (Cu) (kg/m)	0.44	0.49
	Cabo de terra (Al-Aço) (kg/m)	0.44	0.68
	Feeder 95	0.85	0.68
	Feeder 150	1.33	0.78
	Cabo Bz 50 [Força Máxima = 750 kg	0.435	0.49
	Cabo Bz 65 [Força Máxima = 1050 kg	0.615	0.57
	Cabo Bz 95 [Força Máxima = 1440 kg	0.832	0.68
	Cabo Bz 120 [Força Máxima = 1725 kg	1.044	0.76

Table12: Weight of the Isolator

Detailed Solution of Case Study 1

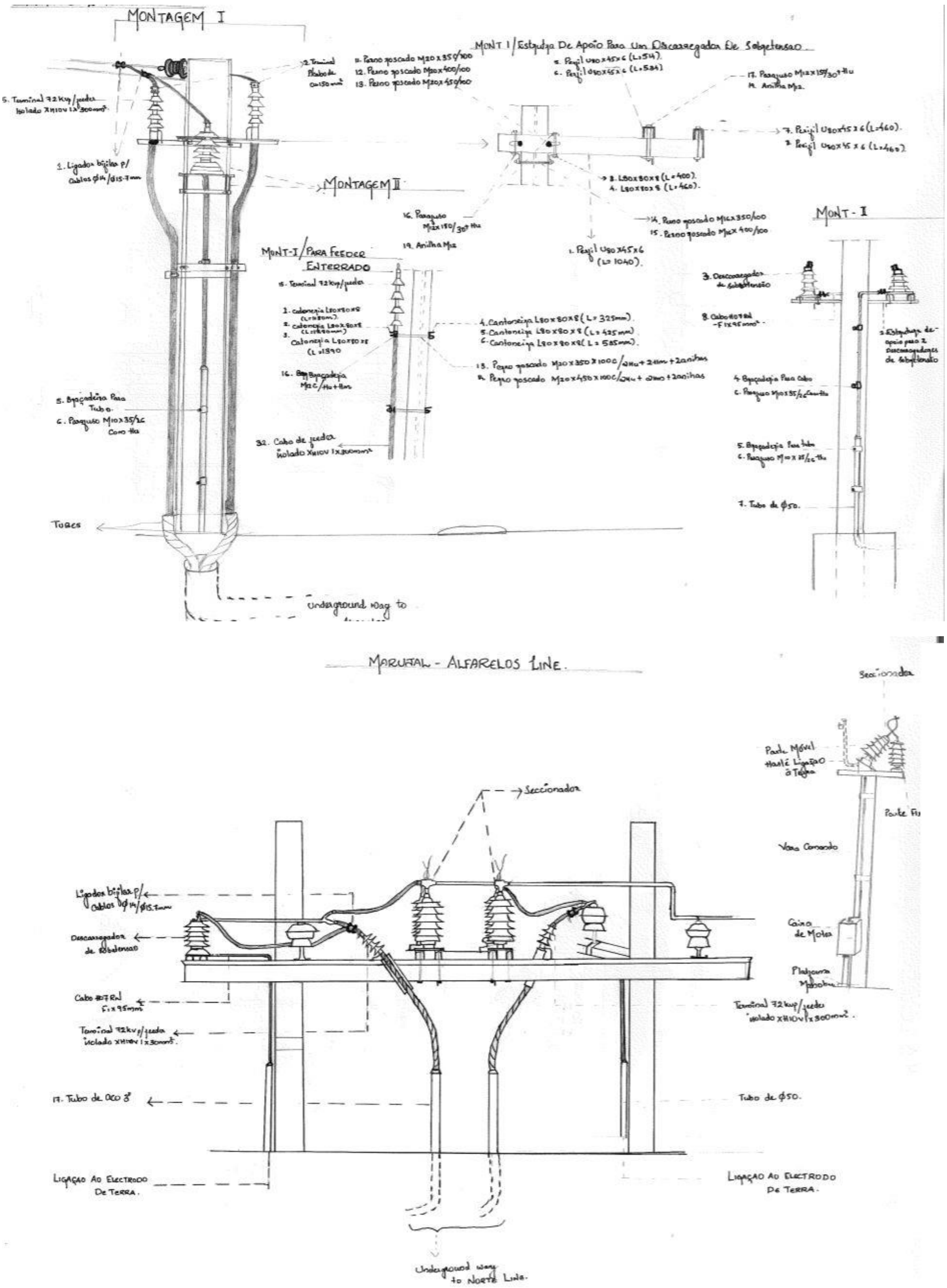
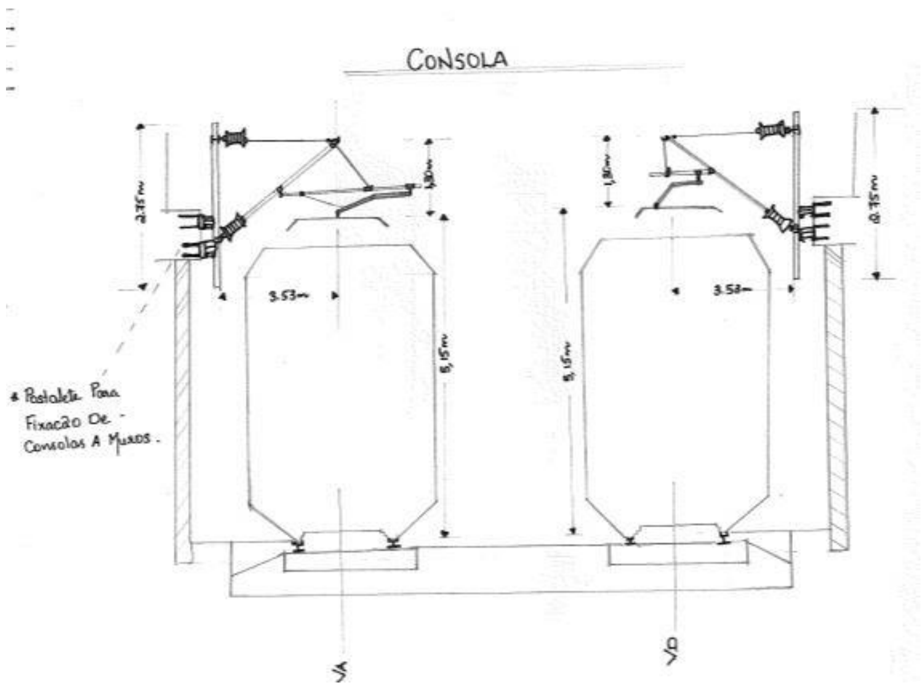
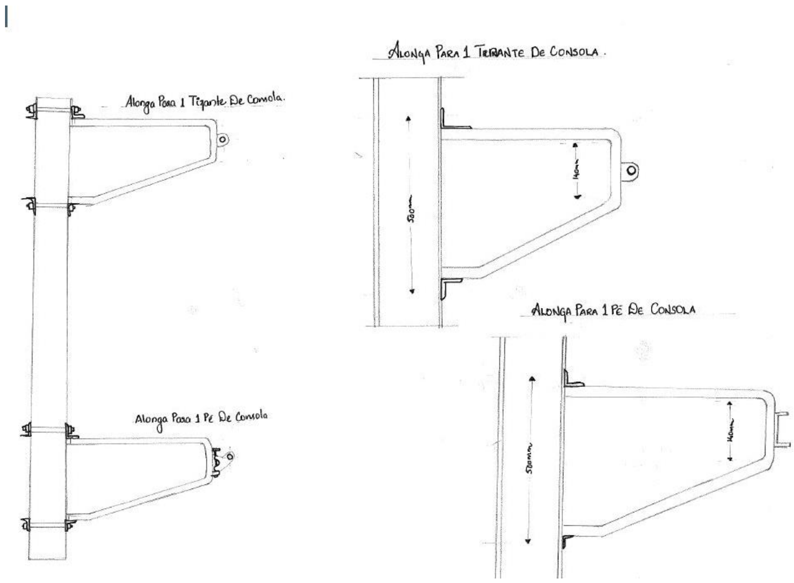


Figure 47: Detailed solution for case study 1

Detailed Solution of Case Study 2





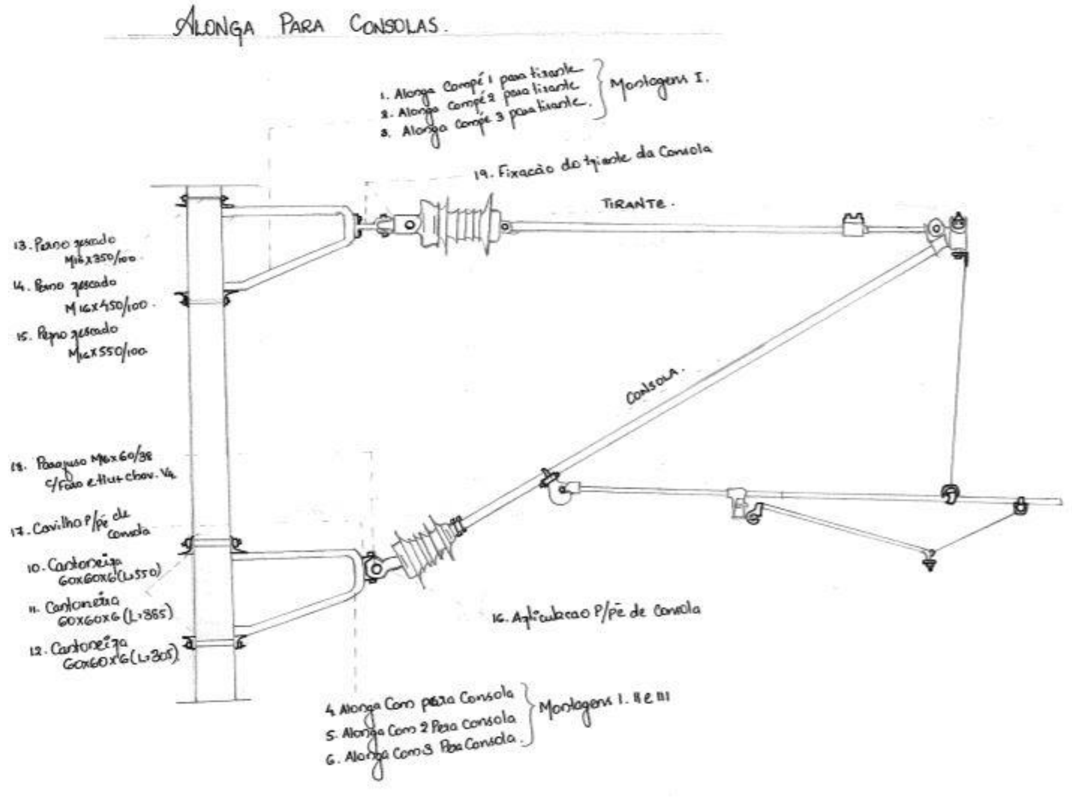
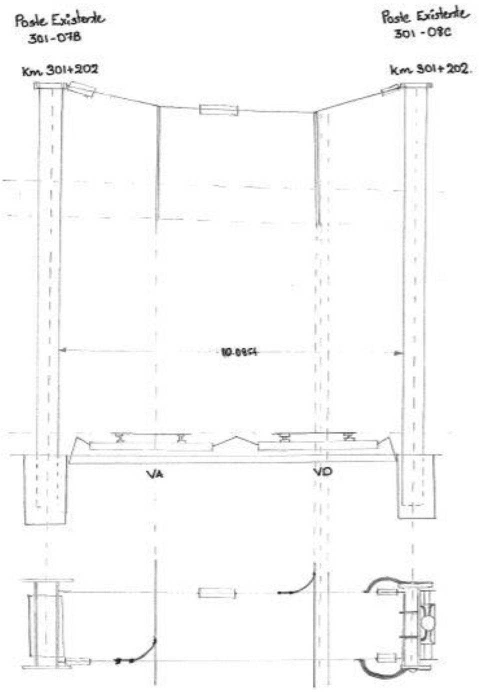
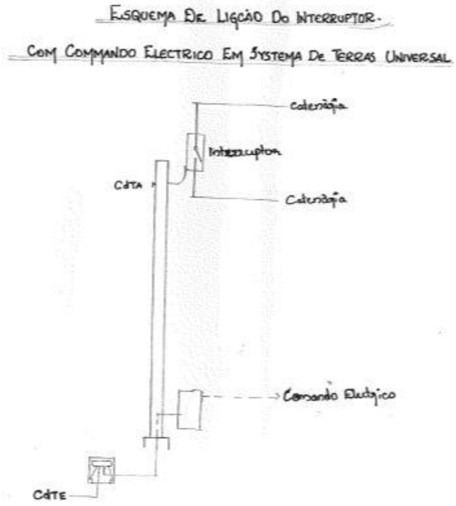
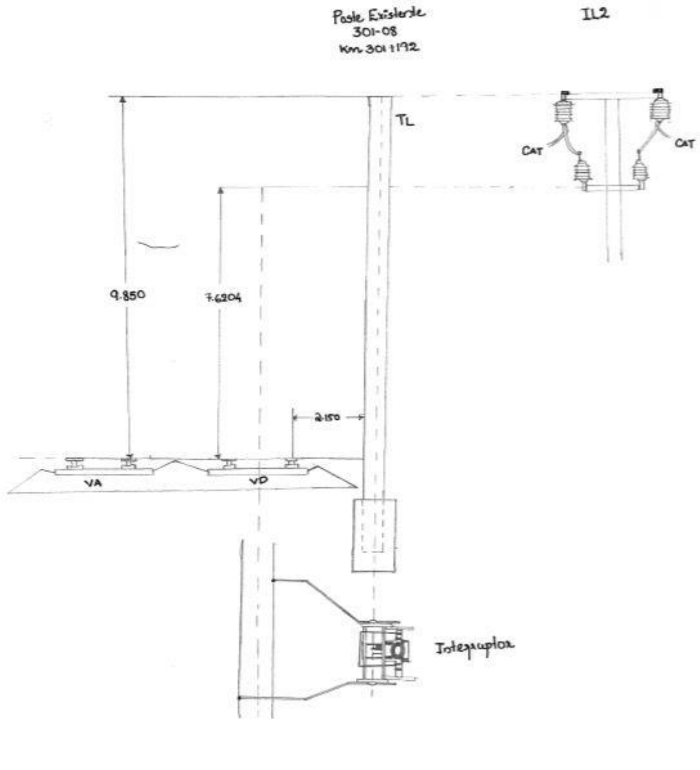


Figure 48: Detailed solution of case study2

Detailed Solution of Case Study 5







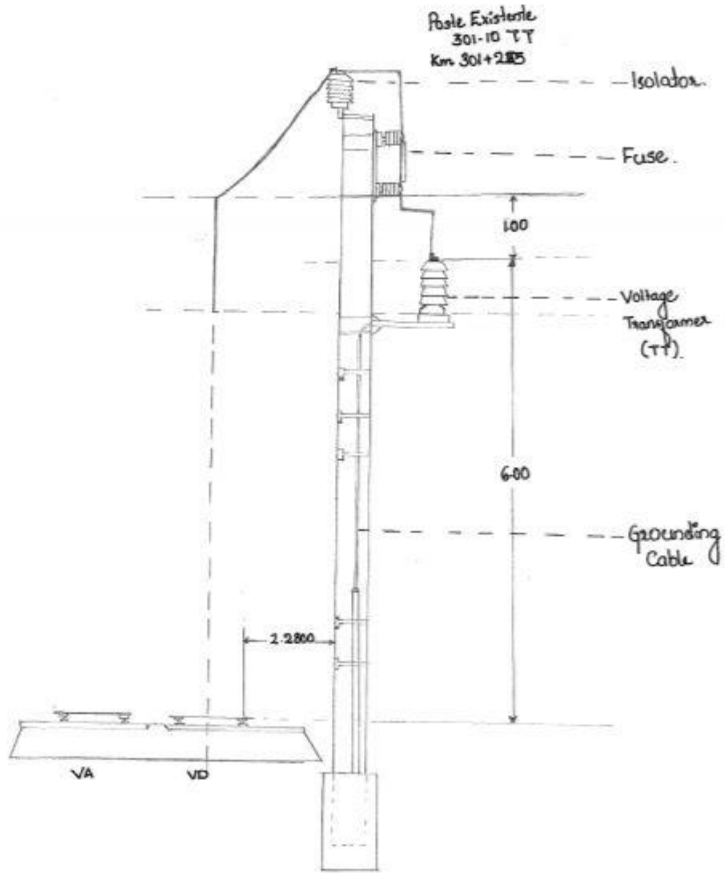


Figure 49: Detailed solution of case study 5