



**Addis Ababa University
Addis Ababa Institute of Technology
School of Electrical and Computer Engineering**

**Analysis of Third Rail Technology for 750 V DC Power Feeder
Light Railway Transportation: Case Study of AALRT**

**A Thesis Submitted to Addis Ababa University
Addis Ababa Institute of Technology**

**In Partial Fulfillment of the Requirement for the Degree of Master's
of
Science in Electrical Engineering
(Railway Engineering)**

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**ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING**

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**CHAIRMAN DEPARTMENT OF
GRADUATE COMMITTEE**

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Declaration

I declare that this thesis represents my own work, except where due acknowledgement is made, and that it has not been previously submitted to this university or to any other institution for a degree or other qualification.

Signed _____

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Abstract

This thesis analyzes two different transportation electrification DC traction power feeder structures, i.e., an embedded wireless power transfer system and an overhead catenary wire system. The efficiency, feasibility, and benefits of the two systems are considered.

Addis Ababa LRT was started OCS, but they have problems like: bad environmental visualization, wind effect on catenary, wind effect on the catenary cable and alignment problem of Track with respect to Catenary cable. Those problems are solved based on third rail DC traction power feeder relatively run at safely, durable, harmonic effect reduce and environmental attractiveness. The method of solved the problems based on data analyzed and design of third rail power sequence. This situation needs an effective alternative traction power feeder for train control and protection system power sequence apply and working safely.

A rail track switching system has been designed to control railway track controlling devices including railway switches and signals within a given area from a single point. Such control is exercised through the use of various track circuits which detect the presence of trains on a particular segment track and monitor the train's safety.

Normal modeling approaches for power electronics and train usage were developed in MATLAB/Simulink to compare the two systems, each at two power levels 0 VDC and 750 VDC were chosen to demonstrate the differences between power levels depend on the relay energized or not in the power box controller. Component efficiencies, energy transfer levels, from power cable to contact rails for the various models were determined.

The process has not been completed but key results from the analysis and lessons learned from this process will be discussed in this Thesis.

Keywords: Third rail, DC power supply, harmonics, traction power system, shoe, OCS.

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List of Abbreviation and Symbol

AC	Alternate current
DC	Direct current
OCS	Overhead Contact System
ERC	Ethiopia Railway Corporation
APS	Aesthetics Per sol
EMU	Electrical multiple unit
ETR	Embedded third rail
AALRT	Addis Ababa Light Rail Transit
LRT	Light Rail Transit
LRV	Light Rail Vehicle
S-N	South-North
UPS	uninterrupted power supply
PG	power Good
EN	Enable
I/O	Input/output
SVS	Supply voltage supervisors
LDO	Low-dropout
PGT	Power Good Timer
CPGT	Capacitor Power Good Timer
CTMR	Capacity Timer
UK	United Kingdom
EDLCs	Electrochemical Double Layer Capacitors
DLC	Double Layer Capacitor
BXD	Bordeaux
O & M	Operation and Maintenance
M	Mega
μ	Micro
Ω	Ohms
m	mili
V	Voltage
I	current
P	power
R	Resistance
r	weight ratio b/n freight net weight and gross weight
N	Number of Train per day

V sense	Voltage sensor
E	Energy
$I_{av f}$	Average feeding current
S	Station
P_{loss}	Power loss
V	volt
A	Ampere
F	Frequency
V_{drop}	Voltage drop
K1	Fluctuation coefficient
K2	Over designed coefficient.
R_{eq}	equivalent series resistance of supercapacitor bank in ohm
G	Traction weight
PD	discharge power in kW
pf	Power factor

Chapter One

1. Introduction

The problem of urban transportation in Addis Ababa, specially Kality to Stadium, Hayat to Megenagna, Torhayloch to Mexico, Merkato to Stadium and Piyasa to Stadium just reduce some problems of transportation because of the train provided service was started.

i. Current Collectors

Electric locomotives, metros and tramways need electric power to move. Power transfer has to be safe and reliable, both in stationary mode for auxiliary power and for motive power when moving. Transmission of power is done by either an overhead wire or by rails at ground level. AC systems always use overhead wires; DC systems can use either an overhead wire or a third rail.

There are 2 types of current collectors:

a. Pantograph Systems

- ▶ Railways (electric locomotives, Electrical Multiple Units)
- ▶ Transit systems (light rail, tramways, and some metros)

b. Third or Fourth Rail Systems

- ▶ Transit systems (metros, light rail, automated light vehicles)
- ▶ Monorail (UK)
- ▶ Bordeaux (France)

The projects Engineers tried to solve the issue by designing an optimal system in terms of environmental pollution, cost, quality, durability and energy. When the all parameters took into account, railway systems have accepted a considerable way for transportation by all over the world. These systems can be operated with 750 V, 1500 V and 3000 V DC voltage from third rail or catenary line [1]. Third rail systems are a means of providing electric traction power to railway trains, and they use an additional rail for the purpose. On most systems, the conductor rail is placed on the sleeper ends outside the running rails, but in some cases a central conductor rail is used.

Basically third rail technology specifically apply up to 750VDC at this voltage not hazard happened, but electrical power feeder will be above 1500VDC may occurred.

1.1. Background

Before 100 years ago the beginning of the 20th C during Emperor Minilik II regime was constructed charcoal railway from Ethiopia to the Port of Djibouti. The road is now highly overfilled and it takes days to reach the capital, Addis Ababa, from the port [4]. Now a time applied overhead contact system traction power supply. At 750 VDC Power feeders for LRT implemented.

The Third rail technology of railway transportation system construction is initiated due to the following imperatives:-

- Reliable and safe.
- Harmonic and ripple are reduce
- Operation and maintenance better than OCS.
- Attractive for urbanization.
- Green economy development strategy (environmentally friendly).

1.2. Statement of the problem

The main problem of electrical power supply feeder in urban LRT OCS respect of Third rail as follow:

- Effects of wind, suspension of contact cable, and temperature of the Catenary and contact line
- Can't be built any construction overhead the rails
- Its dangers because of wind shorting cables each other
- Environmental attractiveness
- On level crossing the cars carry very high length of materials cannot pass through the OCS
- Its very danger when car accident on the rail etc.

In addition to the above constraints any railway system needs an efficient, reliable and cost effective protection system. Thus, in railway transport systems there are a lot of solution of methods issued so far.

1.3. Technical Aspects of Third Rail

The third rail is usually located outside the two running rails, but occasionally between them. The electricity is transmitted to the train by means of a sliding shoe, which is held in contact with the rail. On many systems an insulating cover is provided above the third rail to protect employees working near the track; sometimes the shoe is designed to contact the side (called side running) or bottom (called bottom running) of the third rail, allowing the protective cover to be mounted directly to its top surface. When the shoe slides on top, it is referred to as top running. When the shoe slides on the bottom it is not affected by the build-up of snow or leaves. As with overhead wires, the return current usually flows through one or both running rails and leakage to ground is not considered serious.

1.4. Description of Third Rail

Third rail systems are a means of providing electric traction power to railway trains, and they use an additional rail (called a "conductor rail") for the purpose. On most systems, the conductor rail is placed on the sleeper ends outside the running rails, but in some cases a central conductor rail is used. The conductor rail is supported on ceramic insulators or insulated brackets, typically at intervals of 3 meters or so. The trains have metal contact blocks called "shoes" which make contact with the conductor rail. The traction current is returned to the generating station through the running rails. The conductor rail is usually made of high conductivity steel, and the running rails have to be electrically connected using wire bonds or other devices, to minimize resistance in the electric circuit. The conductor rails have to be interrupted at level crossings and at crossovers, and ramps are provided at the ends of the sections to give a smooth transition to the train shoes. There is considerable diversity about the contact position between the train and the rail; some of the earliest systems used top contact, but developments used side or bottom contact, which enabled the conductor rail to be covered, protecting track workers from accidental contact and protecting the conductor rail from snow and leaf fall. However as third rail systems present the hazard of electric shock, higher system voltages (above 1500 v) is not considered safe. Very high currents are therefore used, resulting in considerable power loss in the system, and requiring relatively closely spaced feed points (sub-stations). The

presence of an electrified rail also makes it extremely dangerous for a person to fall into the tracks.

1.5. Alstom's APS System

The Alstom's APS system 750 VDC ETR is made up of 8 m long conducting segments separated by 3 m insulating joints. Power is supplied to the conducting segments by underground boxes every 22 m. The electricity transmitted through the ETR picked up by two collector shoes located in the mid-section of the tram, while a block of roof-mounted batteries allows the vehicle to maintain power at stations or if a power control unit fails. Bordeaux (France) is the first city in the world to have picked for this completely new technology on 14 km of its 44 km long tram network. It has been operating since the end of 2003. This solution had some initial troubles, due to drainage problems in buried power boxes. These troubles were solved and APS is now operating successfully in Bordeaux at 99.8% reliability since the end of 2005. Three other French cities, Angers, Reims and Orléans, decided in 2006 to install APS on their new light rail networks, and Alstom won its first contract for a system outside Europe.

In relation to maintenance costs, Alstom assures that maintenance over cost due to APS is marginal. Finally, concern exists in relation to the potential for stray currents where the roadway is wet or wet with a salt solution for snow clearing. On the other hand, it is probable that extra care must be taken in the case of extreme-weather cities, for avoiding the contact strip to suffer from ice and salt buildup across the conductors [12].

1.6. Literature Review

In 1906, the Lionel electric trains became the first model trains to use a third rail to power the locomotive. Lionel track uses a third rail in the center, while the two outer rails are electrically connected together. This solved the problem two-rail model trains have when the track is arranged to loop back on itself, as ordinarily this causes a short-circuit. (Even if the loop was gapped, the locomotive would create a short and stop as it crossed the gaps.) Lionel electric trains also operate on alternating current. The use of alternating current means that a Lionel locomotive cannot be reversed by changing polarity; instead, the locomotive sequences among several states (forward, neutral, backward, for example) each time it is started.

Märklin three-rail trains use a short spike of DC voltage to reverse a relay within the locomotive while it is stopped. Märklin's track does not have an actual third rail; instead, a series of short pins provide the current, taken up by a long "shoe" under the engine. This shoe is long enough to always be in contact with several pins. This is known as the stud contact system and has certain advantages when used on outdoor model railway systems. The ski collector rubs over the studs and thus inherently self-cleans. When both track rails are used for the return in parallel there is much less chance of current interruption due to dirt on the line.

Modern model train sets today use only two rails. Many supply locomotives with direct current (DC) where the voltage and polarity of the current controls the speed and direction of the DC motor in the train. A growing exception is Digital Command Control (DCC), where bi-polar DC is delivered to the rails at a constant voltage, along with digital signals that are decoded within the locomotive. The bi-polar DC carries digital information to indicate the command and the locomotive that is being commanded, even when multiple locomotives are present on the same track. Some model railroads realistically mimic the third rail configurations of their full-sized counterparts although most do not draw power from the third rail [21].

In 1956 the world's first rubber-tyred railway line, Line 11 of Paris Metro, opened. The conductor rail evolved into a pair of guiding rails required to keep the bogie in proper position on the new type of track. This solution was modified on the 1971 Namboku Line of

Sapporo Subway, where a centrally placed guiding/return rail was used plus one power rail placed laterally as on conventional railways. This advantage is especially marked in urban and rapid transit systems with a high traffic density. So far as first cost is concerned, third-rail systems are relatively cheap to install, compared to overhead wire contact systems, as no structures for carrying the overhead contact wires are required, and there is no need to reconstruct over bridges to provide clearances. There is much less visual intrusion on the environment [6].



Figure 1.1 Third rails is located between the two running rails [6].



Figure 1.2. Current collector shoe [6].

This third rail technology used to take as an experience for Ethiopia Railway Corporation. Depends on the new technology applies third rails in Ethiopia compare with OCS better solution.

1.7. Embedded Third Rail (ETR) Technology

ETR is the only one that means a real alternative to OCS if elimination of wires along the whole network is desired. Nevertheless, existing implementations do usually not affect the whole networks, but are combined with OCS, using the ETR solution only in sensitive areas.

General advantages of ETR are:

- Protection of the urban visual environment.
- Total safety for pedestrians and road users.
- Avoidance of access problems for emergency vehicles (as firefighters) to building facades.

On the other hand, there are still some inconveniences in this solution, which are supposed to be counteracted with time and experience, as the concerns about its operation with rain, ice and salt; the construction and maintenance costs; and the reliability of the system.



(a)



(b)

Figure 1.3. AALRT access problems (a) and (b) [17].



Figure 1.4. OCS is not attractiveness on the urban area [17].

1.8. Scope of Thesis

The scope of this thesis provides sufficient information to allow the analysis of third rail traction power supply using for LRT in Ethiopia. Determine of the third rail effects of operations and construction about cost, durability and reliable. In most cases, third rail systems supply direct current electricity. These components define the scope and limits of the study area of the research.

1.9. Objectives

1.9.1. General Objective

The general objective of this thesis is analysis of third rail system for public transport electrical power feeder 750 VDC.

1.9.2. Specific Objectives

- Theoretical background of the third rail technology data collects.
- Compare of third rail and OCS supply system.
- Analysis the third rail technology.
- Design of third rail DC traction power sequence supply system.
- Simulate third rail DC traction power sequence supply system.



Figure 1.5. Third rail APS system is on the urban area [6].

1.10. Motivation for the Studies

Several strategies for the next advances third rail technology are interesting for urban railway transportation system. The key focus therefore is to understand how technology and collaboration strategies in electrical power feeder will impact transit ridership and costs. The initiate of this thesis analysis of third rail accordingly to the AALRT.

1.11. Methodology

1.11.1. Data Collection

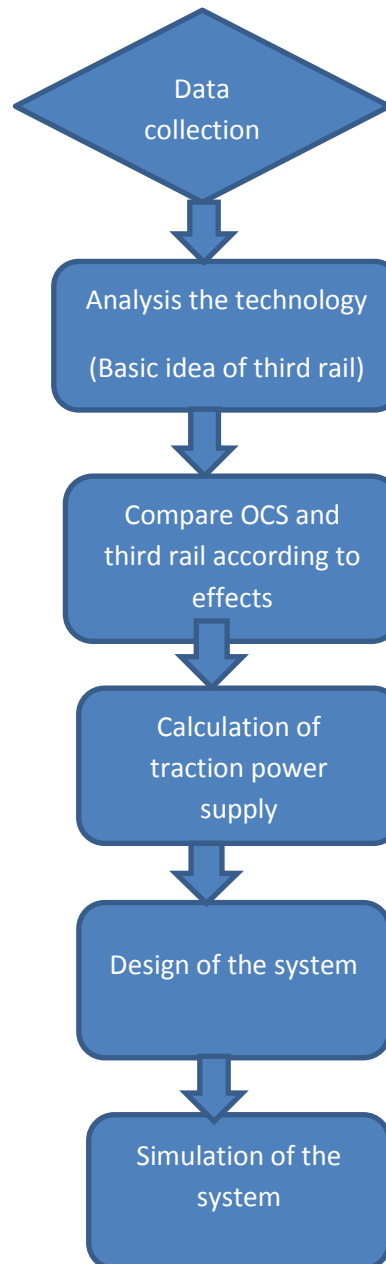
In this thesis, the third rail DC traction power performance has been evaluated using comprehensive empirical data on the ERC Company and Internet access. The empirical data related to the performance of the DC traction power supply used in this study were gathered using three different sources, i.e. archival records, interviews, and documents.

The archival records consisted of the operational and maintenance history of the DC traction power supply system and its DC traction power supply, from January 2011 until June 2014, as stored in the Feasibility and conceptual design of the ERC of Light Rail Transit.

The interviews were performed with experienced practitioners at the ERC staff which concerned on the Electrical power supply department, including both project and field technicians in the operation and maintenance departments on the Kality Revenue Station staffs. The interviews and discussions supported the DC traction power supply in solving the challenges faced concerning the data collection, filtering and validity of the alternator feeder solution.

The documentation used as a source of data consisted of different descriptions, policies, and procedures pertaining to the operation, maintenance and reliability analysis of the DC traction power supply system, as well as documents and standards supporting reliability analysis of DC traction power supply, such as IEEE and IEC documents, etc.

1.11.2. Data Analysis



If there are any available electrical power feeder options in the selected technologies; toward attaining safe, reliable and comfortable. In any case the applied technical measure is economical, safety and durability. The study follows theoretical analysis and some analytical calculations concerning the proposal. These components define the scope and limits of the study area of the research. In addition detail calculation concerning each will not be discussed.

Chapter Two

2. Theoretical Background of Third Rail DC Traction Power Feeder

There are two types of alternatives power feeder accessible on LRT such as OCS and third rails, but some technology extreme technological challenges.



(a)



(b)

Figure 2.1. Urban landscape (a) with OCS wires; and (b) without OCS wires [20].

2.1. DC Feeder System

The DC feeder system includes the positive DC feeders from the traction power substation to the overhead contact system, the negative DC feeders from the substation to the rails or impedance bonds, and any underground along-track parallel feeders required to locally reinforce the overhead contact system's electrical capacity.

2.1.1. Cables Used to DC traction power supply system

DC traction power feeder cables shall be insulated, non-shielded, single conductors suitable for use in wet or dry locations and rated at not less than 2,000 VDC, 90°C conductor temperature for normal operation, 130 °C for emergency operation, and 250 °C for short-circuit conditions. The cables shall have sufficient conductivity to maintain traction power voltage levels at the required level. Traction power feeder cables shall be sized to operate at rated insulation temperature during normal operating conditions. Traction power cables connecting dc feeder breakers to the overhead contact system and from running rails or

impedance bonds to the negative bus shall be sized to accept maximum overload and short-circuit currents with a temperature rise not to exceed safe insulation design limits of the cables. The appropriate number and size of cables shall be determined in conjunction with the traction power system analysis.

The positive and negative traction power cables shall be installed in separate conduits and manholes. Where installed in exposed locations, the positive and negative cables shall be isolated with barriers, and suitably routed and supported on insulated racks or trays to minimize the possibility of incurring physical damage. Flame-resistant jacketed cables shall be used in such installations. Insulated feeder conductors shall be protected against switching surges and lightning. No cable splices shall be permitted unless specifically approved by METRO System Engineers. If approved, cable splices shall only be permitted inside suitably sized splice boxes, pull boxes, and manholes.

2.2. Third Rail Ground Level Switch Contact System

Based on proven third rail power transfer systems, a promising approach might be to place the power supply rails directly between the running rails and pick up the power using third rail type shoe gear. The basic concept will remind many of Lionel and Marklin model trains. The problem with this approach is, of course, the danger inherent in having ground level power rails energized at 750 VDC when the rails are accessible to the public. This problem can be solved by making the power rails a series of separate sections—the system can switch each section on or off individually so that a power rail section is energized only when the vehicle is directly over it. There have been a number of recent attempts at making this approach work.

2.2.1. Bordeaux's Light Rail Transit System as a Driver for New Technology

When the new Bordeaux light rail transit (LRT) system vehicle specification was released for tender to potential suppliers in 1999, it included a requirement to provide a power supply system that did not use overhead contact wires through an architecturally important and aesthetically sensitive section of the city adjacent to the Cathedral, some 1.8 mi (3 km) of the system route. Historically, it is important to note that even in their earlier streetcar days, Bordeaux never had overhead contact wire in the town center, as a conduit power system provided vehicle power until the system was dismantled.

Potential suppliers experimented with various options to meet these requirements, including flywheel energy storage. Upon close evaluation, all existing technological solutions had significant drawbacks, including weight, cost, space requirements, and performance between stations when stopping was required.

Eventually, it was determined that a completely new development, the ground level switched contact system, known in France as the APS system, short for Alimentation par Sol, was required to provide the reliable system needed.

2.2.2. INNORAIL Basics

As is common with all the earlier ground level contact system approaches, the INNORAIL system uses a series of switched contact rails installed between the running rails, separated by insulated rail sections to ensure complete electrical isolation of each section. Each individual section is only energized when its local power rail contactor receives and verifies a low power, specially coded signal coming from the vehicle transponder that can only be detected when the vehicle is directly over the section. At all other times, the power rail segment is automatically grounded. Two sets of pickup shoes are provided on the vehicle to provide continuity of power as the vehicle crosses insulated sections. The basic elements of the system are illustrated in the following two diagrams.

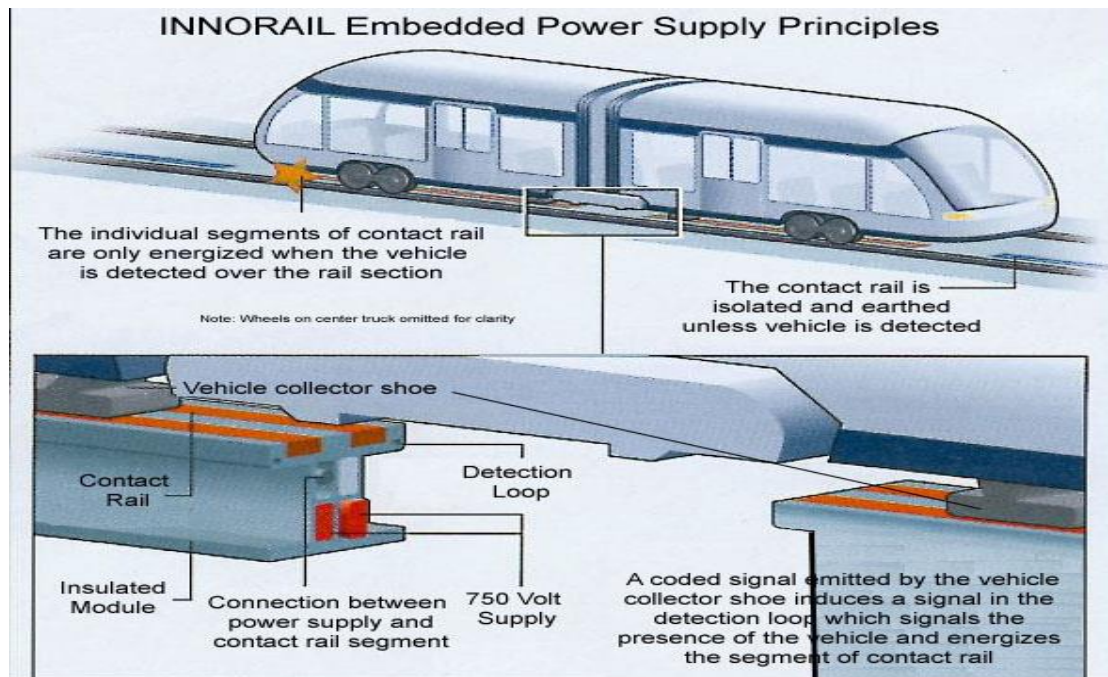


Figure 2.2. Innorail embedded power supply principle [6].

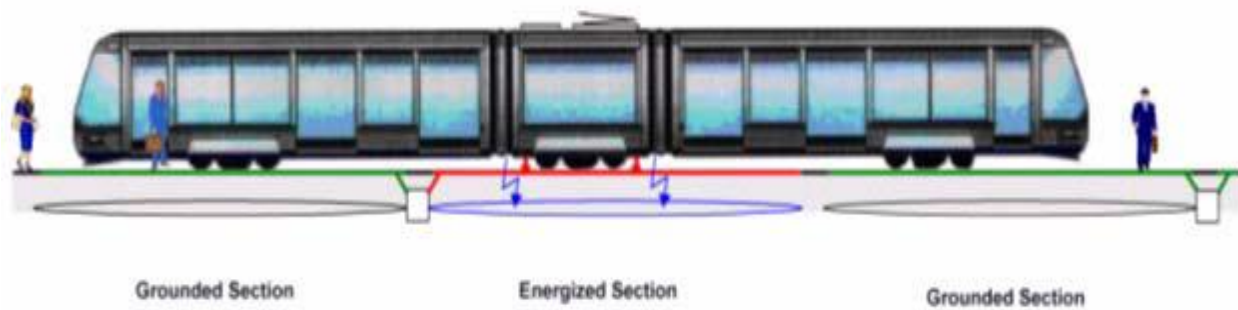


Figure 2.3. INNORAIL ground level switched contact system [6].

In Bordeaux, transitions from INNORAIL to conventional OCS (and vice versa) are manually initiated by the vehicle operator with the vehicle stopped at a passenger platform. This transition is completed within normal station dwell times. According to the manufacturer, it is also possible for this process to be automated, allowing the transition to be accomplished with the vehicle moving. The crossing of special track work such as turnouts and crossovers is made using special insulated sections, which allow the pick-up shoes to cross the running rails.

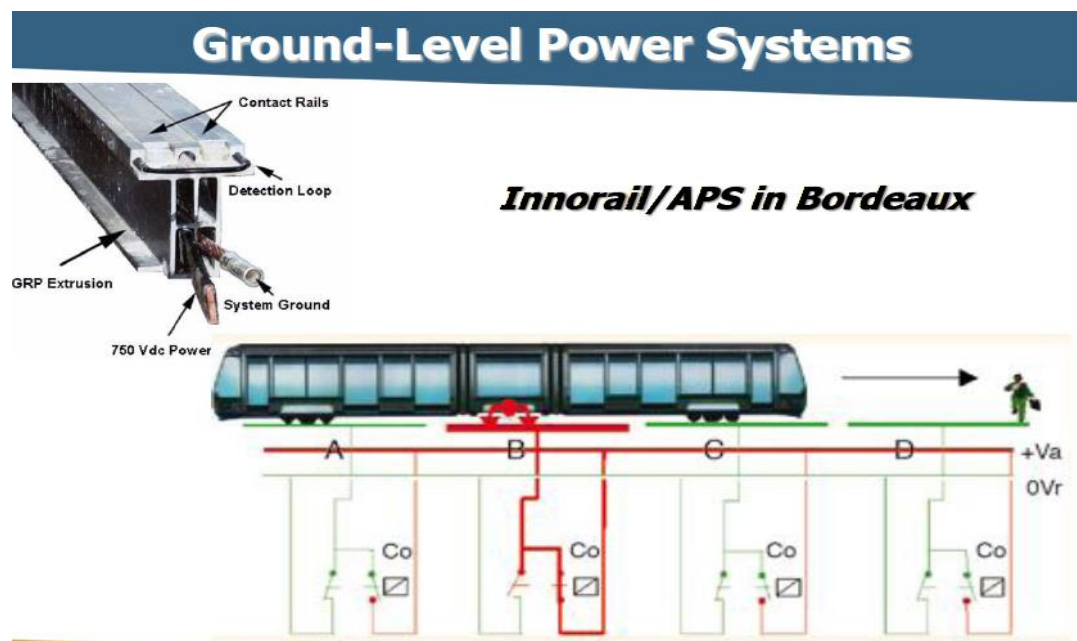


Figure 2.4. Ground level power systems [10].

**Embedded Track****Grass Track****Paved Track****Ballasted Track**

Figure 2.5. Types of Third rail track [10]

2.3. Systems based on a Continuous Power Supply

2.3.1. APS by Alstom

i. Operating Principles

Alstom's APS system is based on traction power supplied to the vehicle by a power rail located between the running rails. The rolling stock uses a current collector shoe to obtain power via physical contact between the collector shoe and the track-embedded power supply rail. The power supply rail is divided into 8 m long segments separated by 3 m long insulation segments. The rail is fed with 750 V DC from "power boxes" embedded in the track. Segments of power supply rail are only activated when they are completely covered by a tram vehicle. This principle ensures a live rail is never accessible to pedestrians. Loops embedded in the track bed detect the presence of a vehicle via a coded radio signal emitted by the trams. This energy-distribution principle through segmentation is illustrated in the figure below:

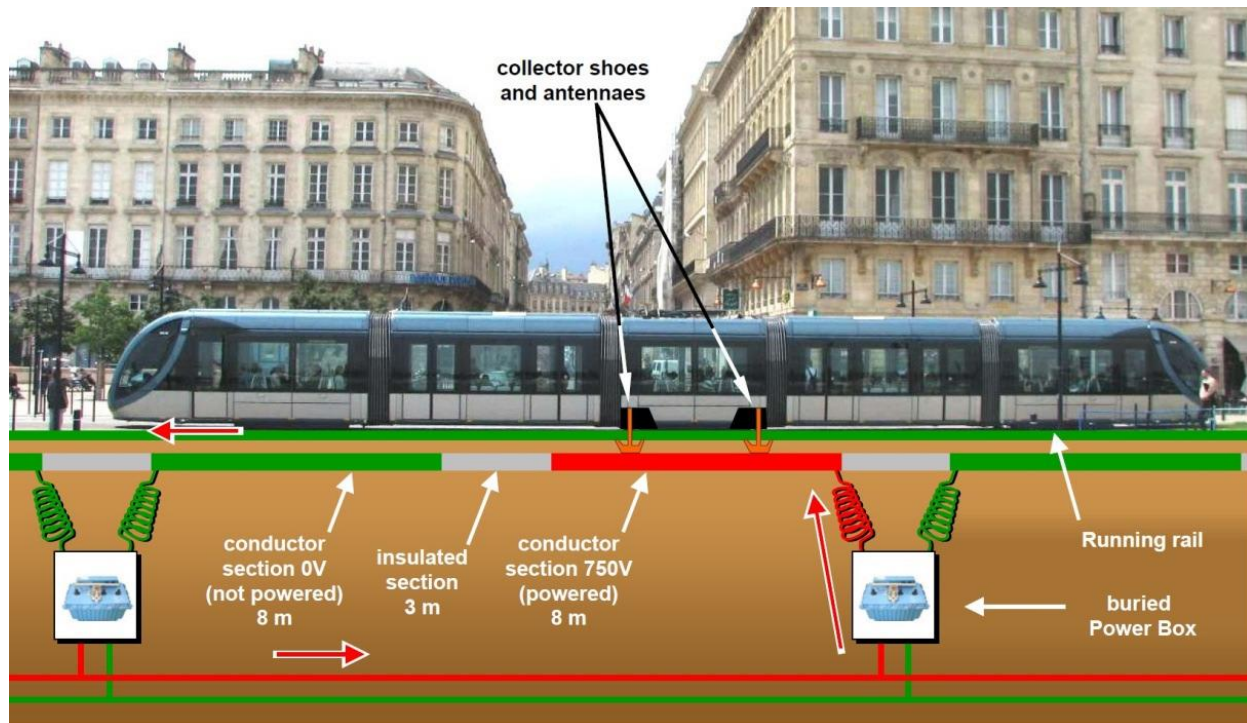


Figure 2.6. APS by Alstom Operating principles [10].

ii. Specific Features

The maximum operating speed on APS sections is 50 km/h, while an Alstom Citadis vehicle can operate at 70 km/h with overhead catenary. In order to mitigate local failure of the system, the vehicles are equipped with batteries. These batteries enable trams to cross failed sections of up to 50 meters.

2.3.2. Alstom APS Underground Power for LRVs

The Alstom Transport Alimentation Par Sol, or Aesthetic Power Supply (APS) in-ground wireless power system for inner city LRV transit system,⁹³ has replaced catenary and pantographs with a set of powered loops embedded in the pavement. On board the LRVs is an antenna and contact shoes so that the in-ground loop segment is activated only when the LRV is above it. The energy is captured by two collector slippers located under the tram center. For pedestrian safety, charging of the LRV in-ground buried conductor segments is triggered only when they are covered by the tram.



Figure 2.7. Alstom APS Underground Power for LRVs [10].

The APS advantage in historic inner city tracks is that overhead electric lines are replaced by a ground level third rail that provides power via contact shoes from in-ground power to trams equipped with an antenna and switch to activate the power supply while above a track segment. Currently, five cities in France have operational Citadis light rail transit systems powered wirelessly by the APS in-ground supplies.

2.3.3. Tram Wave by Ansaldo

i. Operating Principle of the Tram Wave System

The tram wave system provides trams with a continuous 750 V DC power supply thanks to modules embedded in the track between the running rails. The power is collected through a collector shoe. For safety reasons, only the modules located beneath the tramway collector shoe are powered up, so the hot part is never accessible to the pedestrians. The powering up of the sections under the collector shoe is ensured by a relatively simple electromechanical solution: the collector shoe contains a powerful permanent magnet which lifts a metallic belt contained in the track-embedded module. When this belt is positioned in the upward position, contact is ensured between the 750 V DC feeder running along the Tram wave module (“internal positive feeder” on the upper left of the drawing below) and the “internal elements variable polarity” (on the upper right of the drawing) and the metallic surface segment on the top of the module. The part labeled as “internal

elements variable polarity” is permanently connected to the “surface segment” (top of the drawing), so the “surface segment” is brought to 750 V DC potential.

2.4. Operation of the Collector Shoe

The collector shoe contains the permanent magnets which lift the belt in the plat form embedded module. For safety reasons, these magnets are made up of several magnets and are arranged in a way such that they repulse each other (S-N N-S S-N), but they are kept together by the structure of the collector shoe. In the event of a breakage of the collector shoe, the magnets will repulse each other. Each magnet taken individually is not strong enough to lift the belt, so a broken collector shoe cannot lead to a powered module by leaving loose magnets. The collector shoe is maintained in the upward position by a spring. In order to lower it, a hydraulic system has to compensate the force of the spring.

The force of the spring is greater than the force of the magnet, so any failure of the hydraulic system would release the collector shoe to the upward position, thus setting the rail to 0 V.

2.4.1. INNORIAL Innovation

A distinguishing feature of the Bordeaux network is the absence of overhead wires in the central area. When the original tram network was built, the city authorities adopted a conduit power supply for the tram network, to protect the visual image of the city centre as laid out by Baron Haussmann at the end of the 19th century, and this lasted until closure in the 1950s. Options considered included battery, flywheel or diesel powerpacks, but all of these would have posed operating restrictions due to the limited power availability. Eventually the choice fell on the Innorail APS (Alimentation par Sol) ground-level power supply system. Innorail was originally formed as a wholly-owned subsidiary of electrification specialist Spie Enertrans, but when that firm was acquired by Amec it sold its shares in Innorail to Alstom. Getting approval of the APS equipment under new French safety-case regulations proved one of the time-critical factors in commissioning the network, according to Alstom Project Director Hubert Peugeot and Innorail Managing Director Antoine Picard. Test running was undertaken on an isolated 500m section in Lormont, which could be physically sealed off from other road users. After formal tests and an independent audit, the safety case was finally signed off on October 21, allowing

commissioning trials on the remainder of the network to start barely two months before 'T-Day'. Even before APS received its safety approval, it had already become clear that all three routes would not be ready in time.

2.4.2. INNORAIL System Development

Development of INNORAIL began in the Spie Rail works in Vitrolles in the south of France in early 1999. Full size system component mockups were installed on streetcar Line 68 in nearby Marseille by December 1999, with fully functional prototype components installed by May 2001. This allowed the operation of a limited proof of concept installation using a modified 600 VDC high-floor vehicle and 1,968.5 ft (600 m) of sectional power rails, of which 492 ft (150 m) were installed in city streets. By 2002, INNORAIL early production components had been installed on 2,296.6 ft (700 m) of LRV test track at the Alstom La Rochelle factory where the new Citadis LRVs for Bordeaux are being constructed. Extensive testing followed, using a state-of-the-art 100% low floor Citadis vehicle operating at 750 VDC. To date, over 2,100 mi (3,500 km) of endurance running tests have been performed, including crossing special track work and automatic transition to emergency battery power.



Figure 2.8. Citadis LRV [6].

2.5. INNORAIL System Components

The fixed installation part of the INNORAIL system is made up of the following elements:

2.5.1. Sectional Power Rails

These low profile sections are typically in 36 ft (11 m) lengths fitted with 26.25 ft (8 m) of conductor rail and 9.84 ft (3 m) of insulating rail. These FRP pultrusions contain integral duct banks that carry all power, ground and control cabling, as well as the vehicle detection loop for that section. These assemblies also have a spare cable duct that could potentially be leased to local fiber optic or coax cable service providers. The ratio of conducting rail to insulating rail is based on the vehicle operating speed, which in the case of Bordeaux, is 44.7 mph (20m/sec or 72 km/h).

2.5.2. Power Rail Control Contactor Units

Power box located on every 72.2 feet (22 m), and controls two segments of power rail. These units are modular and can be replaced in less than 5 min.

Although a solid state switching unit would logically be utilized, traditional contactor units were chosen for this application because the short duty cycles caused difficulties in semiconductor heat rejection at these current levels. It is still very likely that a solid state solution will eventually be applied.

Insulating Junction Boxes An insulating joint box is located every 72.2 feet (22 m) to mechanically and electrically join the ends of the power rails at all locations. These boxes are silicone sealed after all connections are made to keep out moisture.

2.5.3. Grounding Contactor and System Monitoring Equipment

For safety purposes, a cabinet containing a grounding contactor and system monitoring equipment is installed in each substation. The condition monitoring system is designed to detect faults in any power rail segment within 200 milliseconds, disconnect and ground the main 750 VDC power feeder to all segments fed by that substation, automatically isolate the faulty segment and restore the system power to the remainder of the system in less than 2 seconds. These faults include, most importantly, a segment remaining live after the vehicle signal is lost and of course, short circuit or similar faults.

The INNORAIL system is capable of being installed on almost any type of light rail vehicle, including 100% low-floor vehicles.

2.5.4. Emergency Battery Set

One roof mounted unit is required on each vehicle to allow it to transition through any dead power segments. To save space, this unit is mounted under the pantograph frame on the vehicle center section. This battery set contains 63 x 12 volt sealed, aircraft certified, lead acid batteries and can provide approximately 1 min of vehicle movement at reduced speed [1.8 mph (3 km/h)]. This will move the vehicle a minimum of two failed power rail segments, although 500 ft (152 m) is routinely achieved.

2.5.5. Retractable Power Pickup Shoes

Two sets of center truck mounted pickup shoes are necessary for current collection, mounted at the ends of the truck. The shoe gear uses graphite shoes to keep the fixed installation wear to a minimum, although in the initial stages, soft iron shoes have been used to clean and polish all the contact surfaces.

i. Operating Principles of Power Box Control Unit

Conducting segments are placed at regular intervals, separated by insulated joints. The segments are supplied by power boxes, only activated when the tram passes directly over them to ensure perfect safety for pedestrians and traffic. The power supply is triggered by coded radio dialogue between tram and ground. Power is collected through two collector shoes located in the tram's mid-section as shown the below figure.

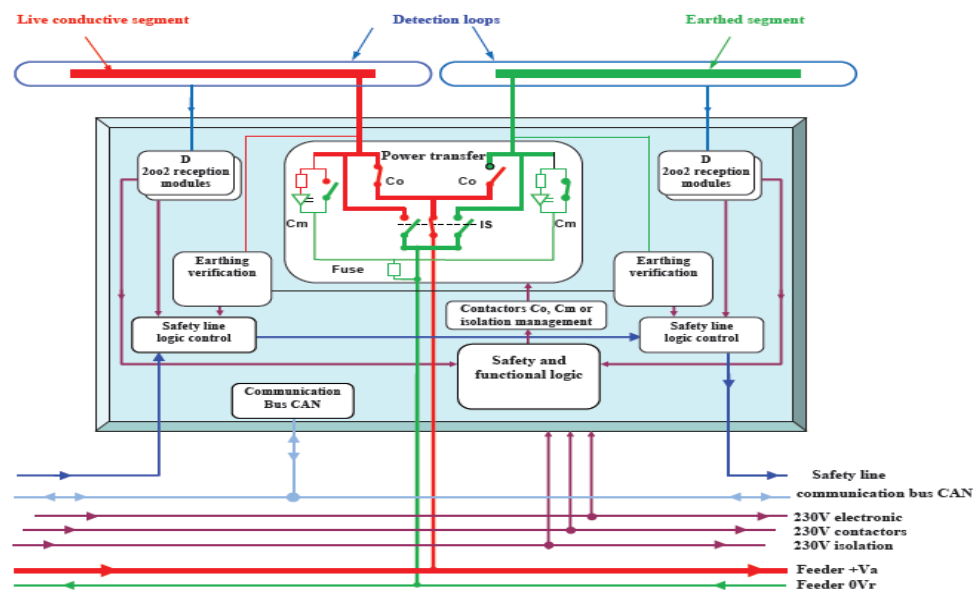


Figure 2.9. Power box control unit [18].

- i. **Pickup Shoe Control Box** Extra control components required to activate the pickup shoes and interlock with the pantograph controls.
- ii. **Power Control Box** This roof mounted box contains the additional contactors and controls needed for switching 750VDC
- iii. Power coming from the pickup shoes or the emergency battery set.
- iv. **Cab Controls and Monitoring Equipment** Additional controls required to operate and monitor the vehicle's INNORAIL related equipment.
- v. **Safety Grounds** Extra ground points installed under the low-floor section of the vehicle to suppress any possible fault conditions.
- vi. **Safety and Certification**

With a readily accessible ground level power system, safety is clearly a key concern. A variety of safeguards are designed into the system to prevent any single point failure from causing a hazardous condition. Independent safety certification insures that the designs perform as expected.

2.6. DC Track Circuits

In all track circuits an electrical signal of some kind is impressed between the running rails, and the presence of a train is detected by the electrical connection that the wheels and axles of the train make between the two running rails. In D.C. track circuits, the electrical signal is direct current, usually supplied by batteries. The detector for the electrical signal is a relay.

The track circuit consists of a block or length of track which is defined at each end by insulated joints in the running rails. The insulated joints provide electrical insulation between a given track circuit and the adjoining tracks which comprise other track circuits. The signal source, in this case a battery, is connected to the rails at one end of the track circuit while the receiver (a relay) is connected to the other end, When no train is present, the track circuit is said to be unoccupied, and the direct current supplied by the battery is transmitted by the running rails to the relay and energizes it or –picks it up|. When the relay is energized, the upper set of relay contacts is connected causing the green signal light to be turned on. When a train enters the track circuit its wheels and axles connect the two running rails together, shorting the battery and thereby reducing the current through the relay. This action connects the bottom set of relay contacts, turning off the green signal

light and turning on the red light to indicate that the block is occupied by a train. The resistor in series with the battery protects the battery by limiting the current the battery must provide when a train is present.

The relay would have several sets of contacts connected in combination with the contacts from other relays in nearby track circuits to form logic circuits for the control of the signaling devices (the red and green lights).

The breaking of any conductor or the loss of power in the circuit will cause either a red signal or no signal at all to be displayed. A red or dark signal is always to be interpreted as a command to stop. To put it another way, all signaling systems are designed so that a green signal (meaning proceed) is presented only when the track circuits provide positive information that it is safe to do so.

The double-rail D.C. track circuit is susceptible to interference when the running rails are also used as the return for D.C. electric propulsion current. For this reason, D.C. circuits are not used in rail rapid transit. Single-rail D.C. track circuits could be used, but in fact all modern rail rapid transit systems use some form of A.C. track circuit.

2.7. APS – Underground Power Supply

The power supply is an innovative aspect of the Bordeaux tram system. The APS system, 'Alimentation Par le Sol' (power supply from the ground) was developed for Bordeaux.

2.7.1. Motivation

The decision was taken primarily to preserve the cultural heritage and aesthetic quality of Bordeaux.

- ✓ The French Ministry of Culture had requested that the 18th Century buildings should be preserved
- ✓ The buildings are made of friable materials, so drilling the support for the catenaries into the walls would have damaged the materials and might not have been structurally sound
- ✓ The aesthetic value of the prospect along the banks of the Garonne and the bridge, as well as the central area was not consistent with prominent overhead wires and their support

Third rail technology has long been in use in metro systems, but passengers are excluded from the running way. The challenge was to find a safe way to have the power available to the trams, while ensuring there was zero risk to citizens who could walk freely over the rails. After some technical difficulties, a reliable, safe solution is now in place [10].

2.7.2. APS Principles

The APS system works on the following principles:

- An underground cable runs along the tramway, and acts as a power feeder
- A 'third rail' is aligned between the two running rail.
- The rail consists of many short sections, each of which is connected to the main cable.
- Power is only drawn down to the section when the tram is over it, otherwise it is grounded and passive. Therefore there is no dangerous area which needs to be protected, including in wet weather or flood conditions.
- Ceramic insulators means that power cannot pass from one section to another, so only the part under the tram can ever be live.
- The underside of the tram is fitted with two current collectors which pick-up the power.

Switching between APS and catenary power supply is activated by the driver who presses a switch in the cab. This is done at tram stops. It takes about 15 seconds, or less than the normal stop dwell-time, so the switchover is not evident to the customers [10].

2.8. Safety

The system is designed as a fail-safe system and it is not considered possible for pedestrians, road users, passengers or others to come into contact with live rails. The record in Bordeaux is that there has not been a single such incident or accident involving the APS system.



Figure 2.10. Third rail safely underground power supply [9].

The system now has a high degree of reliability, meeting the contract level of 99.8%. When the system was first implemented, there were teething problems. The CUB readily admits that they had the mandate and instruction to proceed before they had the mature technical solution, so there was quite a bit of 'learning by doing'. While the initial system worked reasonably well, there were reliability problems. In particular:

- ❖ The main cable had to be upgraded to improve connectivity. This was due to a combination of design problems and how the work had been executed. The cable had to be replaced.
- ❖ There were problems of seepage and moisture, so some aspects of the electrical units and housing, as well as insulators, etc. had to be redesigned.

The tram was launched in 2003. It took about two years to identify and resolve the entire problem. They feel that performance data from early-2006 would reflect the stable system and the current level of performance. CUB is satisfied that they now have a robust, reliable system.

2.9. Drainage

The goal in the design of the system drainage is to protect the rail system line and facilities from all weather conditions (i.e. storm-runoff damage, etc.), and to protect METRO from liability for damage to property from resulting storm-runoff either passing through or caused by Light Rail construction, while maintaining consistency with the requirements of the Clean Water Act.

Design of drainage facilities located within the jurisdiction of other agencies requiring relocation or modifications because of LRT construction shall conform to the latest design criteria standards (i.e. design criteria manual) of METRO and the various municipalities as referenced below1:

- City of Glendale – 2002 Engineering and Construction Standards

<http://www.glendaleaz.com/engineering/documents/2002-Engineering-Standards.pdf>

- City of Mesa – Engineering Procedure Manual, Vol. 2, 2005,

http://www.cityofmesa.org/building_safety/pdf/Forms/EngineeringDesignStandards2005Edition.pdf

- City of Phoenix – Storm Water Policies and Standards, March 2004,

<http://phoenix.gov/STREETS/index.html>

- City of Tempe – Engineering Design Criteria, January 2006,

http://www.tempe.gov/engineering/design_criteria.htm

The Design Engineer will be responsible to adhere to the latest revisions set forth by the local jurisdiction and understands that it is his responsibility to make himself aware of the local jurisdiction guidelines. Coordinate the drainage study and outfalls with the local jurisdiction and their drainage master plans.

Drainage design shall be in accordance with the standards, practices, and methodology of METRO and the local jurisdiction each project or section of a project falls within. In a case where the local jurisdiction has no codes or standards, the Flood Control District of Maricopa County standards and drainage methodology shall be followed. The drainage design criteria provided in this section shall be considered a minimum standard.

2.9.1. Flooding

As already explained for the APS power rail, the Tramwave power rail cannot operate when it is covered by water, because such a situation would lead to current leaks when the rail is powered up, and thus tripping of the circuit breaker protecting the traction power circuit. Flooding of the trackbed is an exceptional situation which should be prevented by an appropriate drainage arrangement embedded in the track. The Tramwave equipment embedded in the track bed is designed and tested to be Watertight [14].

2.9.2. Snow and Ice

Snow and ice stuck on the power rail prevent proper contact with the collector shoe and thus may disrupt operation. The Tramwave system has not yet faced this type of problem because of the mild climate of the location where it has been implemented, but it is likely it would suffer the same kind of operational issue as APS has when exposed to snow and ice. The solutions adopted for the APS (brush mounted on the tram and specific maintenance vehicle) could likely be adopted for the Tramwave solution [14].

2.10. Overview Of Current Collection Grade Manufacture

2.10.1. The Advantages of Carbon for Current Collection

Steel, cast-iron, copper or bronze shoes on third rail collection systems mechanically damage the rail due to their relatively high mass. Carbon has many advantages over metallic materials, and the benefits to user systems are numerous. As a consequence, more and more railway, third rail and tramway/trolleybus systems have changed to carbon throughout the world [16].

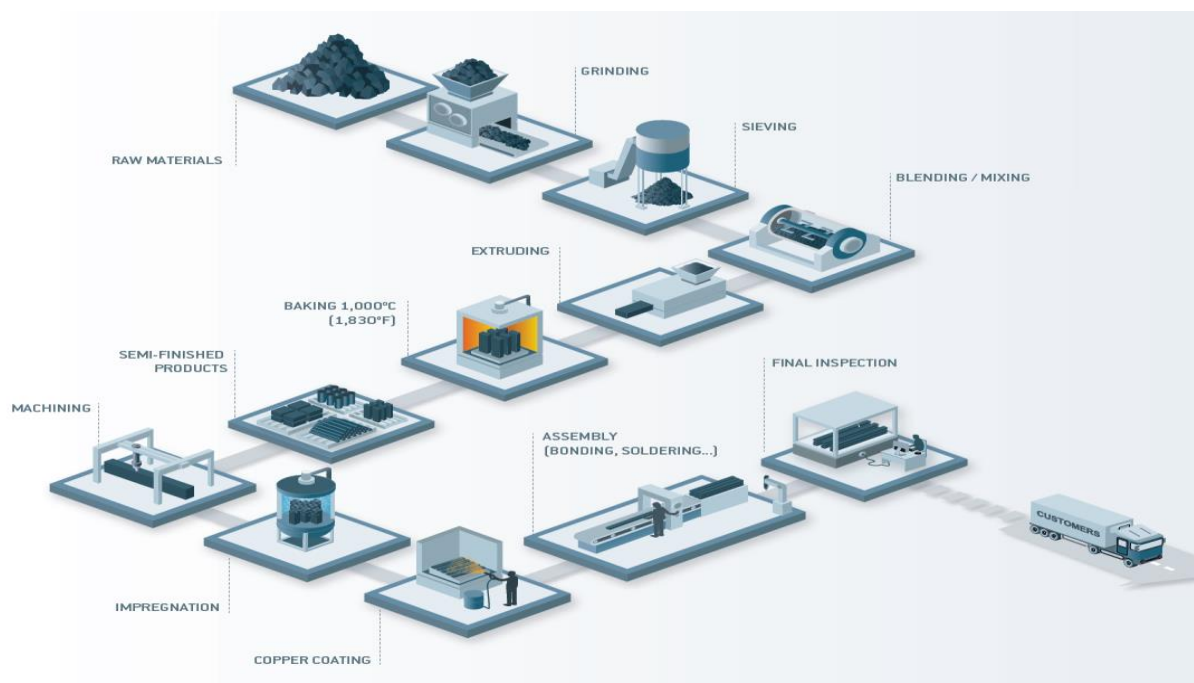


Figure 2.11. Overview of current collection grade manufactures [16].

Friction behavior and self-lubrication

- ✓ Elimination or reduction of greasing
- ✓ Longer wire and rail life time thanks to proper film creation
- ✓ Carbon skin provides the 3rd rail with a de-icing capability

- ✓ Maintenance cost reduction

Very low sparking

- ✓ Arcing reduction
- ✓ Reduced burn or spark damage
- ✓ Prevention of radio interference

Weight reduction

- ✓ Stable contact
- ✓ Better current collection

Resistance

- ✓ To high temperatures: no tendency to weld, even after long periods of static current loading
- ✓ To thermal shocks
- ✓ To chemical attack [15].

2.11. MOSFET

When utilizing N Channel MOSFETs to switch a DC voltage across a load, the drain terminals of the high side MOSFETs are often connected to the highest voltage in the system. This creates a difficulty, as the gate terminal must be approximately 10V higher than the drain terminal for the MOSFET to conduct. Often, integrated circuit devices known as MOSFET drivers are utilized to achieve this difference through charge pumps or bootstrapping techniques. These chips are capable of quickly charging the input capacitance of the MOSFET (C_{giss}) quickly before the potential difference is reached, causing the gate to source voltage to be the highest system voltage plus the capacitor voltage, allowing it to conduct.

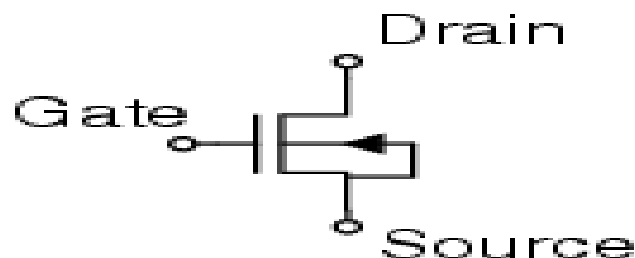


Figure 2.12. N Channel MOSFET [15].

There are many MOSFET drivers available to power N Channel MOSFETs through level translation of low voltage control signals into voltages capable of supplying sufficient gate voltage. Advanced drivers contain circuitry for powering high and low side devices as well as N and P Channel MOSFETs.

In this design, all MOSFETs are N Channel due to their increased current handling capabilities. To overcome the difficulties of driving high side N Channel MOSFETs, the driver devices use an external source to charge a bootstrapping capacitor connected between Vcc and source terminals. The bootstrap capacitor provides gate charge to the high side MOSFET. As the switch begins to conduct, the capacitor maintains a potential difference, rapidly causing the MOSFET to further conduct, until it is fully on. The name bootstrap component refers to this process and how the MOSFET acts as if it is “pulling itself up by its own boot strap.

2.11.1 The Characteristics of a MOSFET

a. High input impedance - voltage controlled device - easy to drive.

To maintain the on-state, a base drive current which is 1/5th or 1/10th of collector current is required for the current controlled device (BJT). And also a larger reverse base drive current is needed for the high speed turn-off of the current controlled device (BJT).

b. Unipolar device - majority carrier device - fast switching speed. As there are no delays due to storage and recombination of the minority carrier, as in the BJT, the switching speed is faster than the BJT by orders of magnitude. Hence, it has an advantage in a high frequency operation circuit where switching power loss is prevalent.

c. Wide SOA (Safe Operating Area) - It has a wider SOA than the BJT because high voltage and current can be applied simultaneously for a short duration. This eliminates destructive device failure due to second breakdown.

d. Forward voltage drop with positive temperature coefficient - easy to use in parallel. When the temperature increases, the forward voltage drop also increases. This causes the current to flow equally through each device when they are in parallel. Hence, the MOSFET is easier to use in parallel than the BJT, which has a forward voltage drop with negative temperature coefficient.

Chapter Three

3. Comparative of Third Rail and OCS DC Supply System

3.1. Conceptual of Third rail Supply System

A third rail is a method of providing electric power to a railway train, through a semi-continuous rigid conductor placed alongside or between the rails of a railway track. It is used typically in a mass transit or rapid transit system, which has alignments in its own corridors, fully or almost fully segregated from the outside environment. Third rail systems are always supplied from direct current electricity.

Third-rail systems are a means of providing electric traction power to trains, and they use an additional rail (called a "conductor rail") for the purpose. On most systems, the conductor rail is placed on the sleeper ends outside the running rails, but in some systems a central conductor rail is used. The conductor rail is supported on ceramic insulators (known as "pots") or insulated brackets, typically at intervals of around 10 feet (3 meters).

The trains have metal contact blocks called shoes (or contact shoes or pickup shoes) which make contact with the conductor rail. The traction current is returned to the generating station through the running rails. The conductor rail is usually made of high conductivity steel, and the running rails are electrically connected using wire bonds or other devices, to minimize resistance in the electric circuit. Contact shoes can be positioned below, above, or beside the third rail, depending on the type of third rail used; these third rails are referred to as bottom-contact, top-contact, or side-contact, respectively.

The conductor rails have to be interrupted at level crossings, crossovers, and substation gaps. Tapered rails are provided at the ends of each section, to allow a smooth engagement of the train's contact shoes. The position of contact between the train and the rail varies: some of the earliest systems used top contact, but later developments use side or bottom contact, which enabled the conductor rail to be covered, protecting track workers from accidental contact and protecting the conductor rail from snow and leaf fall [21].

3.1.1. Safety of Third Rail

Because third rail systems present electric shock hazards close to the ground, high voltages (above 1500 V) are not considered safe. A very high current must therefore be used to transfer adequate power, resulting in high resistive losses, and requiring relatively closely spaced feed points (electrical substations). The electrified rail threatens electrocution of anyone wandering or falling onto the tracks. This can be avoided by using platform screen doors, or the risk can be reduced by placing the conductor rail on the side of the track away from the platform, when allowed by the station layout [21].

3.1.2. Weather Effects of Third Rails

Third rail systems using top contact are prone to accumulations of snow, or ice formed from refrozen snow, and this can interrupt operations. Some systems operate dedicated de-icing trains to deposit an oily fluid or antifreeze (such as propylene glycol) on the conductor rail to prevent the frozen build-up. The third rail can also be heated to alleviate the problem of ice.

Unlike third rail systems, overhead line equipment can be affected by strong winds or freezing rain bringing the wires down and stopping all trains. Thunderstorms can also disable the power with lightning strikes on systems with overhead wires, disabling trains if there is a power surge or a break in the wires [21].

3.1.3. Running rails for power supply

The first idea for feeding electricity to a train from an external source was by using both rails on which a train runs, whereby each rail is a conductor for each polarity, and is insulated by the sleepers. This method is used by most scale model trains, however it does not work so well for large trains as the sleepers are not good insulators, and furthermore the use of insulated wheels or insulated axles is required. As most insulation materials have poor mechanical properties compared with metals used for this purpose, this results in a less stable train vehicle [21].

3.1.4. Shoe contact of Third Rails

The third rail is usually located outside the two running rails, but on some systems it is mounted between them. The electricity is transmitted to the train by means of a sliding shoe, which is held in contact with the rail. On many systems, an insulating cover is provided above the third rail to protect employees working near the track; sometimes the shoe is designed to contact the side (called "side running") or bottom (called "bottom running") of the third rail, allowing the protective cover to be mounted directly to its top surface. When the shoe slides on top surface, it is referred to as "top running". When the shoe slides along the bottom surface, it is less affected by the build-up of snow, ice, or leaves [21].

3.2. Conceptual of OCS Supply System

OCS is designed on the principle of one or more overhead wires or rails (particularly in tunnels) situated over rail tracks, raised to a high electrical potential by connection to feeder stations at regular intervals. The feeder stations are usually fed from a high-voltage electrical grid.

Electric trains that collect their current from an overhead line system use a device such as a pantograph, bow collector, or trolley pole. The device presses against the underside of the lowest wire of an overhead line system, the contact wire. The current collectors are electrically conductive and allow current to flow through to the train or tram and back to the feeder station through the steel wheels on one or both running rails [20].

3.3. Meteorological Factor to be Consider for OCS Design

Meteorological factors are one of the major factors that affect design, construction and operation of OCS.

Major meteorological factors: The major meteorological factors that affect OCS during operation are: temperature and its changes, wind, ice, dust, suns radiation and corrosive agents. OCS should withstand such factors throughout its lifetime. The major parameters used when designing OCS are wind speed and air temperature near the area where OCS is

designed to operate. However, such parameters have a varying nature through the day, month and years [20].

3.3.1. Design Value or Wind Speed

OCS must withstand the maximum pressure or load acting on it. This happens when the wind speed reaches a maximum value at any unknown specific future time.

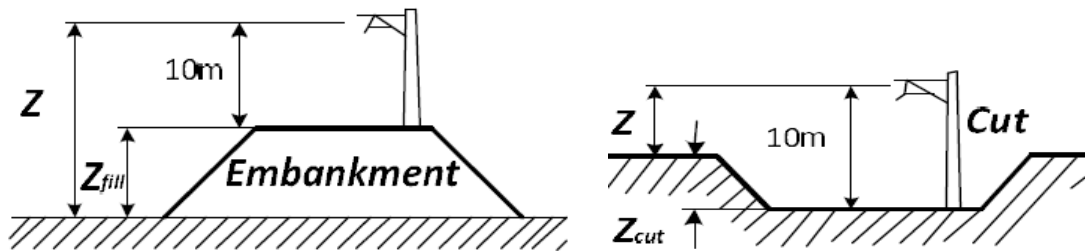


Figure 3.1 OCS in fill and cut section [20].

Maximum design value of wind speed at height Z is calculated as:

$$V_z = V_{ref} (Z/10)^{z_0} \dots\dots\dots 3.1$$

Where:

V_{ref} - The reference maximum value of wind speed, 10m above earth surface measure for 10 mints that happed in the area in the past.

z - Height above the earth where the air speed is measured

z_0 - Surface roughness parameter in which, $z_0=0.2$ for hilly, forest and park area

z- is determined by,

$$z = z_{pole} + z_{fill} \text{ for embankment (fill) section}$$

$$z = z_{pole} - z_{cutt} \text{ for cut section}$$

Where:

z_{pole} - Standard height of the pole of OCS- 10 meter

z_{Fill} and z_{cut} - Embankment (fill) or cut height for the section [20].

3.3.2. Design Value of Minimum and Maximum Air Temperature

The same as wind speed, OCS should withstand the two extreme value of temperature, t_{Max} and t_{Min} , for that particular area. Hence, the design maximum and minimum air temperature values are the extreme minimum and maximum temperature for that area. This is because, maximum t determines the maximum allowed sag and minimum T determines the maximum allowed tension on the conductor.

Extreme minimum air temperature is determined by:

$$t_{min} = t_{average} - \Delta t - 6 \dots \dots \dots 3.2$$

Where:

$t_{average}$ - the average temperature of the coldest month on that area over a long time

Δt - Change of temperature during the coldest day in the past years for that particular area

The extreme maximum air temperature is determined by considering the absolute extreme temperature that exists in the area in the past plus the temperature increment on the conductor because of sun's radiation [20].

$$t_{max} = t_{absolute} + t_{radiation} \dots \dots \dots 3.3$$

Where:

$t_{absolute}$ - The absolute maximum air temperature for that area

$t_{radiation}$ -The conductor's temperature because of sun's radiation

$$t_{radiation} = 0.0162 \phi_{max} \text{ tradition} \dots \dots \dots 3.4$$

Where ϕ_{max} - maximum sun's radiation energy in that area in Watt/m²

3.4. Loads Acting on the OCS

Loads acting on OCS can be divided in to three different type based on the origin of the load as shown below.

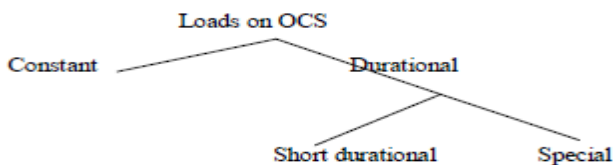


Figure 3.2 Types of loads on OCS [20]

Constant Loads acting on OCS are loads due to:

- Weights of wires and structures
- The normal tension on the wires and structures (along the wire or structure)
- Horizontal tension due to change of direction of wires or structure

Short durational Loads on OCS are loads due to:

- Wind
- Ice (at extreme low temperature-not a case in Ethiopia)

Special Loads on OCS are loads due to:

- ♦ Wire breaking
- ♦ Pole breakage
- ♦ Etc...

During designing OCS; the maximum value or a combination of maximum value of each types of load acting on OCS should be lower than the load carrying capacity or limit stress value of OCS structure or element, to ensure OCS operates normally [20].

In addition to their origin, loads acting on OCS can be classified based on their direction, as horizontal and vertical loads, as shown below:

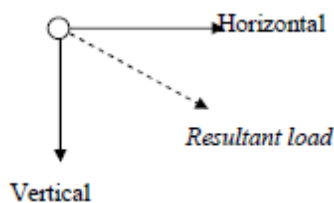


Figure 3.3 Resultant loads on appoint on OCS [20].

3.4.1. Vertical Loads

Vertical loads are loads which act vertically downward on the OCS pole. This load is due to weight of wires (contact wire, messenger wires and additive wire), weight of OCS structures (insulators and cantilever) and weight of ice deposited on the wires or structures. Because of the geographical location of the AALRT stations; vertical load due to moisture deposition on the wires and structures is not included in the study [20].

3.4.1.1. Vertical Loads Due to Wires

Weight of a wire is usually treated as uniformly distributed along the wire and it is calculated as:

$$W = 9.81.A.\rho.\alpha.10^{-6} \dots\dots\dots 3.5$$

Where:

w -weight of the wire per unit length, N/m

A - Cross sectional area of the wire, in mm²

ρ - Density of the wire, kg/m³

α - Coefficient considering the wire manufacturing (for mono-stranded wire =1; for multi stranded wire $\alpha =1.025$)

Hence, the total weights of all wires (contact wires, messenger wire, and additive wires) of an OCS:

$$W_{\text{wire}}=W_m+n_c(W_c+0.1) \dots\dots\dots 3.6$$

Where:

W_m and W_c -Weight of the contact wire and messenger wire per a unit length, N/m

n_c - The number of contact wires

0.1 - Weight of approximate value of additive wires per a unit length [20]

3.3.1.2. Vertical Loads Due to Structures

This is the total load, due to weight of insulators and cantilever

$$W_{\text{structure}}=W_{\text{insulator}}+W_{\text{cantilever}} \dots\dots\dots 3.7$$

Where:

$W_{\text{insulator}}$ -The total weight of the insulators on the OCS in N

$W_{\text{cantilever}}$ - Weight of the cantilever in N

$W_{\text{structure}}$ - The total weight structures on the suspension mast (Pole) in N [20].

3.4.2. Horizontal Loads

Horizontal loads are loads which act horizontal on the OCS structure. This load is due force of wind blow and horizontal tension due to change of direction of wires [20].

3.4.2.1 Horizontal Loads Due to Wind Blow on the Wire

When wind blows in the horizontal direction with respect to OCS wires, it exerts horizontal force on the wire .To calculate this force or load, the design value of wind speed is used as discussed previously. Wind force exerted per a unit length of wire is given as (N/m).

$$F'_w=q_zG_cC_{cd} \dots\dots\dots 3.8$$

Where

$$q_z = 0.5qG_qG_tV_z^2 \text{ and } Q = 1.225(288/t) \frac{e^{-1.2 \cdot 10^{-4} \cdot \text{altitude}}}{e^{-1.2 \cdot 10^{-4} \cdot \text{altitude}}} \dots\dots\dots 3.9$$

Where:

- q_z – The dynamic wind pressure (N/m)
- G_c - Structural response factor for the conductor related to wind
- C_c - Aerodynamic drag factor of the conductor
- G_q - Gust response factor
- d - Diameter of the conductor (m)
- G_t - Terrain factor taking in to account the protection of the line
- Q - Air density (kg/m³)
- v_z - design value of wind speed (m/s) [20].

3.4.2.2. Horizontal Loads Due to Wire Bend or Horizontal Curves

For a bend (change of direction), if the total bend distance (h) is known, the horizontal force on OCS pole is determined by

$$F_s = Th/l_2 \dots\dots\dots 3.10$$

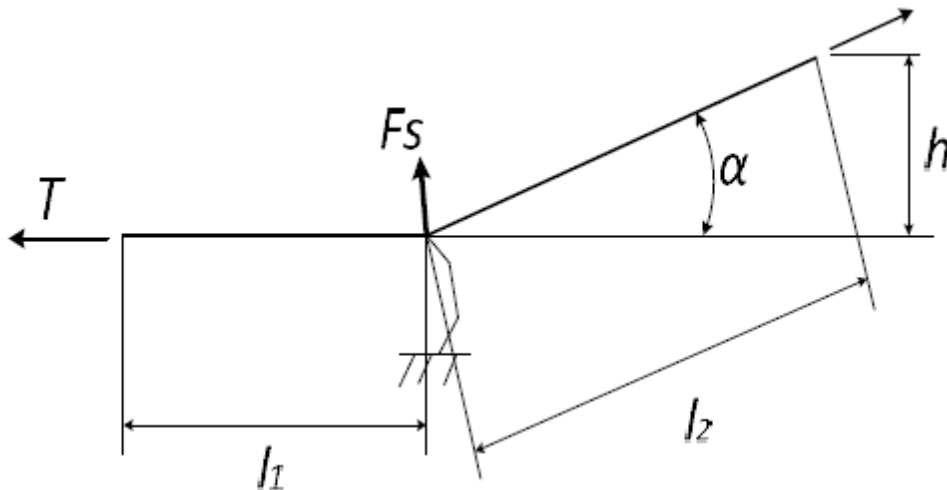


Figure 3.4 Horizontal forces on mast due to bend [20].

Where:

F_s - Force on the OCS structure (pole) due to bend

h -the total bending width

l_2 -the bend span length

For a curve, if the curve radius(R) is known, the horizontal force on OCS pole, located in between two poles inside the curve, is determined by:

$$F_s = \frac{T(l_1 + l_2)}{2R} \dots\dots\dots 3.11$$

Where:

F_s - Force on the OCS structure (pole) due to bend

R -The radius of curvature

l_1 and l_2 - span lengths

3.4.3. Resultant Loads on OCS Mast

The total loads acting on a single OCS suspension mast is calculated by considering vertical and horizontal load shared by adjacent masts.

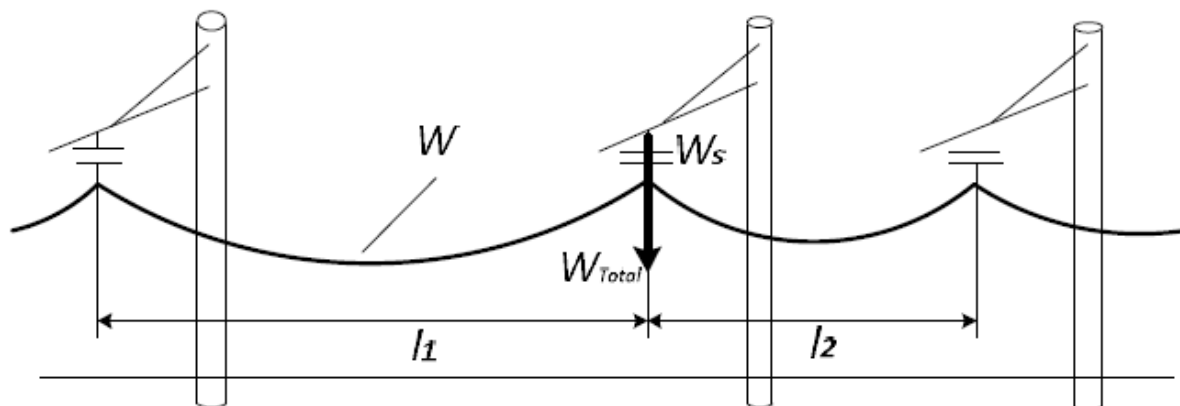


Figure 3.5 Vertical loads on OCS mast [20].

Total vertical weight on the mast is determined by:

$$W_{total} = W_{wire} \frac{l_1 + l_2}{2} + W_{structure} \dots\dots\dots 3.12$$

Where:

W_{wires} -The total vertical loads/weight on a single OCS suspension mast in N

$W_{structures}$ -Weight of the structures on the OCS suspension mast in N

W_{wires} -Weight per a unit length of all wires on the OCS suspension mast in N/m

l_1 and l_2 - the span length between adjacent masts in m

Total Horizontal loads on the mast are determined by:

$$F_{total} = F_w \frac{l_1 + l_2}{2} + F_s \dots\dots\dots 3.13$$

Where:

Total F - The total horizontal loads on a single OCS suspension mast in N

F_s - Force on the OCS suspension mast due to curve or bend in N

f_w - Force per a unit length, due to wind force on OCS wires in N/m

l_1 and l_2 - the span length between adjacent masts in m

The resultant load on a single OCS suspension mast is the vector sum of horizontal and vertical loads.

$$G = F_{total} + W_{total} \dots\dots\dots 3.14$$

3.5. Methods of Analyzing Loads Acting on OCS

Generally there are two approaches that are used to analysis load acting on OCS. The two approaches are used on for different scenarios during designing OCS.

These are:

- ◆ Maximum allowable stress calculation
- ◆ Limiting state calculation [20].

3.5.1 Maximum Allowable Stress Value Method

For this calculation, all the external loads that are directly acting on the single element of OCS are accounted, by considering their maximum value in the past 10 years. When all external loads (Constant, short durational or specials) during their maximum value are directly acting on OCS wires, cantilever and structures; the stress on that particular OCS element should not excide it’s maximum allowed value considering safety factors. Chinas and Europeans use different formula for this computation. Here both of them are presented

but this thesis use Europeans approach since it observes different factors separately and assign appropriate constants for each factor according to the situation.

According to Chinas standard, Stress σ on any element on OCS is determined by

$$\sigma = T/A \dots\dots\dots 3.15$$

Where

T - Force acting on the element

A - Cross sectional area of the element

The maximum allowed values of stress on a particular OCS element are calculated by multiplying and dividing coefficients on the limit stress value i.e.

$$\sigma_{max} = \frac{\sigma_{limit}}{K_3} K$$

Where

σ_{limit} - The limit stress value for that particular object elasticity limit

k - Correction coefficient to account the possible change of σ_{limit} during operation

k_3 - Strength safety coefficient

Hence, to ensure the safe operation of OCS, the actual stress σ_{actual} on any of OCS element of, should not excide the above maximum allowed stress. i.e.

$$\sigma_{actual} \leq \sigma_{max} \dots\dots\dots 3.15$$

This calculation is convenient when checking stress on OCS wire, cantilever and selecting span length of OCS.

For contact wires and messenger wires, instead of maximum stress value check, maximum allowed tension on the wire could be used i.e.

$$T_{max} = \sigma_{max} \cdot A = \frac{\sigma_{limit}}{K_3} K \cdot A \dots\dots\dots 3.16$$

Note: for contact and messenger wire the Chinese standard use $k = 1$; for safety strength coefficient 3 k not less than 2 for and additive wires (hangers, and other wires on OCS) 3 k not less than 2.5.

The above formula does not account the possible cross sectional area decrement of contact wire during operation due to wearing of contact wire by the pantograph. In the Chinese standard, this is accounted by considering the maximum allowed wear on the contact wire to be 25% of the total cross section area of contact wire.

$$T_{\max\text{contactwire}} = \frac{\sigma_{\text{limit}}}{2} \cdot A \cdot 0.75 \dots\dots\dots 3.17$$

Since there is no wear on messenger wire, the formula for maximum tension of messenger wire is

$$T_{\max\text{catenarywire}} = \frac{\sigma_{\text{limit}}}{2} \cdot A \dots\dots\dots 3.18$$

According to Europeans standard,

The calculated grooved contact wire working tensile stress shall not exceed 65 % of the minimum tensile stress of the grooved contact wire. The minimum tensile stress of the grooved contact wire shall be multiplied by the product of these factors to get the maximum permissible working tensile load.

$$\sigma_{\text{per}} = \sigma_{\text{min}} \cdot 0.65 \cdot K_{\text{temp}} \cdot K_{\text{wear}} \cdot K_{\text{load}} \cdot K_{\text{eff}} \cdot K_{\text{clamp}} \cdot K_{\text{joint}} \dots\dots\dots 3.19$$

Whereas the maximum allowed stress value on the catenary wire in which wear is not concerned is given by

$$\sigma_{\text{per}} = \sigma_{\text{min}} \cdot 0.65 \cdot K_{\text{temp}} \cdot K_{\text{wind}} \cdot K_{\text{eff}} \cdot K_{\text{clamp}} \cdot K_{\text{load}} \dots\dots\dots 3.20$$

Where

σ_{min} -is the minimum breaking stress of the contact line

K_{temp} -factor which relate maximum working temperature and permissible working stress

K_{wear} -permitted maximum wear

K_{load} -factor which express the effect of wind

K_{eff} -tensioning equipment efficiency

K_{clamp} -Tensioning clamp characteristics

K_{joint} - factor which describe reduction of tension due to joint [20].

The maximum working (permissible) tensile force for both contact and catenary wire becomes

$$T_{per} = \sigma_{per} * A \dots\dots\dots 3.21$$

3.6. Sequence Schemes

There are three distinct schemes to power-up and power-down multi-rail power supplies: sequential, ratio-metric, and simultaneous.

The appropriate sequencing scheme is dependent on device requirements. The manufacturer’s data sheet does not explicitly name which power sequencing scheme to implement, but rather outlines voltage and timing conditions that cannot be exceeded on power supply pins. Note that some devices allow out-of-bounds conditions for a short period of time. Using the pin conditions and the waveforms in the following section, a sequencing methodology can be chosen to meet the processor requirements.

3.6.1. Sequential Sequencing

The sequential scheme of power supply sequencing is best described as one power supply ramping and settling to its final regulation voltage and then the second power supply ramping after a time delay. This method is used to initialize certain circuitry to a known state before activating another supply rail. The following is a selection from a footnote in a device specification with recommendations best suited to using sequential power supply sequencing: “System-level concerns such as bus contention may require supply sequencing to be implemented. In this case, the core supply should be powered up at the same time as or prior to the I/O buffers and then powered down after the I/O buffers.” As presented later in this topic, a typical hardware implementation employs an output voltage monitor to develop a power good (PG) signal for the first power supply, which then connects to the enable (EN) function of the second power supply.

3.6.2. Ratio-Metric Sequencing

For a dual power supply implementing ratio metric sequencing, both power supply outputs ramp at the same time and in proportion until regulation is reached. During power-up the core supply is a percentage of the I/O supply until regulation is reached. Similarly, during power-down the core is a specific percentage of the I/O supply voltage.

Another example of ratio-metric sequencing may find the core supply voltage slightly greater than the I/O supply during the power-up and down. In this particular case, to

ensure the I/O buffers have valid inputs, the core rail is powered slightly before the I/O rail to eliminate problems with bus contention.

3.6.3. Simultaneous Sequencing

The simultaneous power sequencing method is similar to ratio-metric sequencing in that both power supply outputs ramp at the same time.

However, in simultaneous sequencing, the objective is to minimize the voltage difference between the two supply rails during power up and down, until regulation is reached for the core supply. This sequencing method is useful for devices that have “sneak paths” between supply pins or draw excessive current during startup if internal logic has not transitioned to a stable state.

The following sections show many examples of power sequencing implemented with:

- Diodes
- Low-dropout (LDO) linear regulators
- Supply voltage supervisors (SVS)
- Power distribution switches
- Hot-swap controllers
- Microcontrollers
- Switch-mode controllers (external)
- Switch-mode converters (internal)
- Plug-in power modules.

3.7. APS (Aesthetic Power Supply)

A modern, clean, quiet technology for transport in city centers, APS (for Alimentation par le sol, or ground-level power supply) is a proven power system developed by Alstom for light rail. By supplying electricity at ground level, APS makes it possible to do without overhead wires. With APS, cities can introduce tram service to their historic quarters while respecting their unique characters. Bordeaux, one of France’s most visited cities, was the first city to recognize the APS advantage. The open-sky system, integrated over 13 km of its 44 km tramway network, has a 99.8% rate of availability. The French cities of Reims, Angers and Orleans ordered APS systems in 2006. More than 15 km of APS will soon be installed and operated in Dubai, on the Al Safouh line. APS functions via a third rail

embedded in the ground. Conducting segments are placed at regular intervals, separated by insulated joints. The segments are supplied by power boxes, only activated when the tram passes directly over them to ensure perfect safety for pedestrians and traffic. The power supply is triggered by coded radio dialogue between tram and ground. Power is collected through two collector shoes located in the tram's mid-section. APS is a system designed to power trams without overhead catenaries, allowing the tram to operate "wire-free" over journeys of any distance and hence to blend into the urban environment.

Ground-level power supply, also known as surface current collection and APS is a modern method of third-rail electrical pick-up for street trams. It was firstly developed for the Bordeaux tramway, which was constructed starting with 2000 and opened in 2003.

Ground-level power supply is used, primarily for aesthetic reasons, as an alternative to overhead lines. It is different from the conduit current collection system which was one of the first ways of supplying power to a tram system by burying a third and fourth rail in an underground conduit between the running rails.

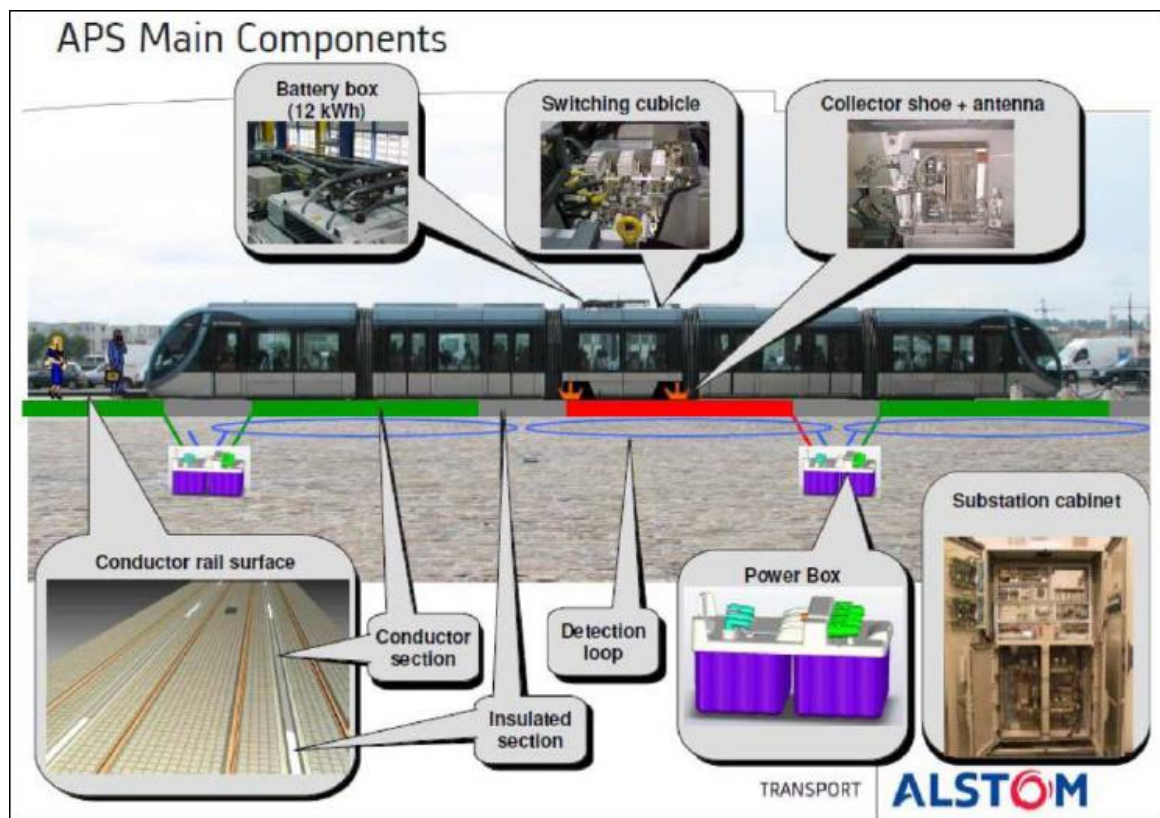


Figure 3.6. ALSTOM APS system components [10].

Power is supplied to the tram through a third rail embedded in the tracks. This third rail is made up of 8 meter-long conducting segments, which can be powered, and which are separated by 3 meter insulating joints. Power is supplied to the conducting segments by underground boxes every 22 meters. The electricity transmitted through this third rail is picked up by two friction contacts located in the mid-section of the tram. The delivery of power to the conducting segments is triggered by coded radio dialogue between the tram and the ground, and only occurs once the conducting segment has been covered by the tram, which represents the novelty of the system, ensuring total safety for pedestrians.

3.8. Power Rectifiers

The rectifiers are naturally ventilated silicon traction power rectifiers with silicon disc-type diodes. There are two three-phase bridges connected in parallel with two diodes per arm of one of the three-phase bridge. This configuration results in a total of 24 diodes per power rectifier.

The two three phase bridges are connected in accordance with ANSI circuit 31 configuration. The nominal rated DC output is 825 VDC. The rectifiers are rated at 1000 kW continuous load with the overload capabilities as specified in NEMA RI-9 for extra heavy-duty traction service [17].

3.9. DC Switchgear

The DC switchgear consists of a positive cubicle, which houses the motor operated disconnect switch connected to the positive bus, two DC feeder breakers and a negative cubicle. The negative cubicle includes a 2000A manual disconnect switch, keyed interlock with the positive switch, DC shunt current measurement, an inter-phase transformer, and a low resistance frame fault protection device with current and voltage tripping. Each feeder cubicle includes a 2000A high speed circuit breaker, solenoid operated with direct acting over-current trip device, 2000A Shunt and a Digital Protection Unit for incomplete sequence, over-current trip and rate-of-rise relays, reclosing, load measuring devices, and transfer trip protection [17].

3.10. Types of Shoe

A shoe consists of a carbon part mounted on a supporting carrier.

The carrier's role is to protect the carbon collector from impacts, to resist deflection and to conduct the current.

The carrier can be made of Aluminium, stainless steel or copper.

i. Metal end piece

- ✓ Assembly: metal end pieces
- ✓ Application: fitted to a new system to create a film or to a rail in bad condition to clean its surface with the bronze contact [15].



ii. Soldered version

- ✓ Assembly: clamped, soldered
- ✓ Application: all networks [15].



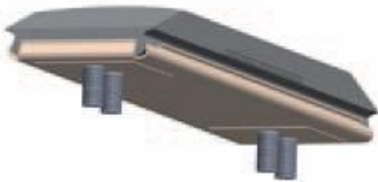
iii. Cast version

- ✓ Assembly: carbon inserts cast in place
- ✓ Application: new rail in order to create a patina or rail in bad condition to clean its surface by bronze contact [15].



iv. Eco type

- ✓ Assembly: clipped
- ✓ Application: all networks
- ✓ Replacement of the carbon wear strip only
- ✓ No more corrosion of the carrier and bolts
- ✓ Excellent resistance to shock, vibrations and mechanical stress [15]

**Characteristics of Eco type better than other shoe types:**

- Plain or impregnated carbon Third rail shoe welded to steel sheaths
- Third rail shoe with metal nose pieces
- Third rail shoe with carbon inserts cast into bronze carriers
- Eco Design Third rail shoe, a dismountable and recyclable system
- Lead-free carbon material (pure or impregnated with metal - copper or bronze)
- Extrusion or stamped and machined
- Welded, bonded or crimped
- Mechanically robust
- Lubricating power
- Sheaths in aluminum, copper, tinned steel or tinned copper
- End horn designs

3.11. Super Capacitors

Capacitors store the electrical charge. Because the charge is stored physically, with no chemical or phase changes taking place, the process is highly reversible and the discharge-charge cycle can be repeated over and over again, virtually without limit.

Electric double-layer capacitors, also known as super capacitors, pseudo-capacitors, electrochemical double layer capacitors (EDLCs), or ultra-capacitors, are electrochemical capacitors that have an unusually high energy density when compared to common

capacitors, typically on the order of thousands of times greater than a high capacity electrolytic capacitor. For instance, a typical D-cell sized electrolytic capacitor will have a capacitance in the range of tens of mF. The same size electric double-layer capacitor would have a capacitance of several farads, an improvement of about two or three orders of magnitude in capacitance, but usually at a lower working voltage.

	Capacitors	EDLC	Batteries
Energy density [Wh/kg]	0.1	3	100
Power density [W/kg]	10^7	3000	100
Time of charge [s]	$10^{-3} - 10^{-6}$	0.3 - 30	> 1000
Time of discharge [s]	$10^{-3} - 10^{-6}$	0.3 - 30	1000 – 10000
Cyclability [1]	10^{10}	10^6	1000
Typical lifetime [years]	30	30	5
Efficiency [%]	>95	85 - 98	70 - 85

Table 3.1: Storage component property comparisons [14].

3.12. Investment Costs

The investment costs provided below are based on recent contracts or bids. These costs have to be considered cautiously, keeping in mind the high variability of the prices proposed by the tramway providers from one project to another. It has been observed that, depending on the level of competition and the desire of a provider to get a first reference for a new solution, the price may vary by +/- 25% [14].

3.12.1. Alstom APS

The APS system is made of on-board equipment and track side equipment. To this date, On-board equipment has always been delivered on new trams.

The cost of this on-board equipment *delivered on a new tram* is estimated to be around 300,000 €, in addition to the basic cost of the tram. A retrofit of in-service trams to install on-board APS equipment has never been performed, so we lack references. Nonetheless,

given the specificity of the operation, we can estimate the retrofit of a Citadis 402 will add an extra 100,000 € approximately to the price of the on-board APS equipment [14].

In the case of a Citadis 401, more extensive modifications may be needed; we cannot estimate the cost of such an operation. The cost of the APS track side equipment is estimated to be 1,850,000 €/km. The overall additional cost for APS implementation is estimated to be about 19,000,000 [14].

3.13. Discussion of Advantage and Disadvantage of Third Rail and OCS Supply Systems

The most common DC feeding topologies have been presented in this thesis; each has their advantages and disadvantages, although these must be viewed in the context of the light weight rail vehicles and service pattern that is being considered in this thesis.

No.	Types of DC Traction power feeder	Advantages	Disadvantages
1	OCS	-Separation of “up” and “down” lines provides higher reliability and flexibility	Requires additional circuit breakers to implement independent feeding of each line
		-Independent feeding of each line can be justified on a conductor rail system which has a potentially high fault frequency	-Overhead line systems have a lower fault rate than conductor rail systems, making independent feeding more difficult to justify
		-Independent feeding has to be implemented where trains draw heavy currents for sustained periods due to circuit breaker rating	-Bulky for environmental attractiveness
		-Using for AC power supply	-Temperature effects
		- Using above 1500 VDC	-Wind effects
2	Third Rail	-Environmental attractive	-Not used AC power supply
		-No Wind effects	-Not used above DC 1500V power supply
		-A reliable source of current	
		-High current intensity guaranteed	
		-Safety on all fronts	
		-The third rail for durable	

		-No Temperature effects	
		– Compatible with existing third-rail systems, to ensure economic operation and cost-efficient maintenance, individual components can be replaced easily.	
		– optional choice of materials and forms, suitable for individual demands and technical requirements	
		– great advantage for aluminum and power rails due to greater distances between the feed points	
		– high-tech components provide maximum flexibility and effectiveness for the whole system	
		– innovative, cutting-edge product based on state-of-the-art technology	
		– excellent running characteristics of the continuous rail	
		– excellent running characteristics of the continuous rail	
		– low maintenance due to optimized system components	
		– eco-friendly, recyclable technology; all parts are fully recyclable	

Table 3.2. Comparison of Third Rail and OCS

Chapter Four

4. Design of Third rail DC Traction Power Feeder

4.1. System Design

4.1.1. Sensing Unit

When the Train arrived Conducting segments are placed at regular intervals, separated by insulated joints. The segments are supplied by power boxes, only activated when the tram passes directly over them to ensure perfect safety for pedestrians and traffic. The power supply is triggered by coded radio dialogue between tram and ground. Power is collected through two collector shoes located in the tram’s mid-section. APS is a system designed to power trams without overhead catenaries, allowing the tram to operate “wire-free” over journeys of any distance and hence to blend into the urban environment.

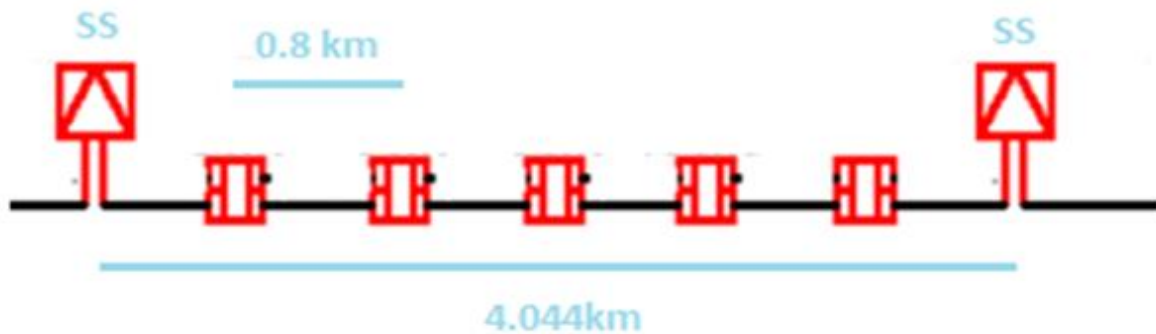


Figure 4.1. Samples station and feeding sections [17].

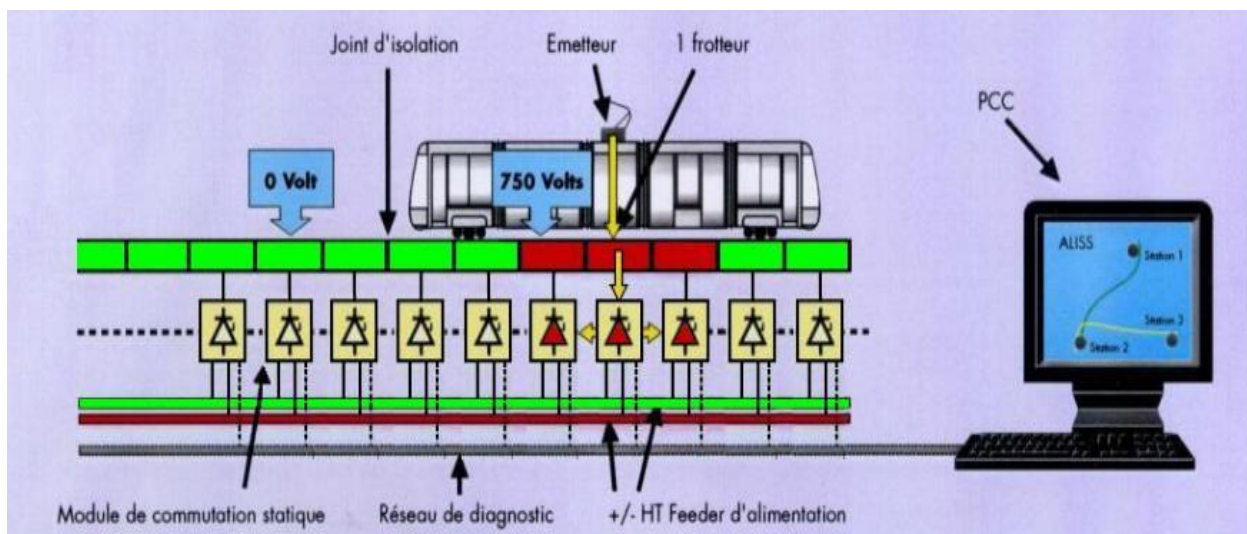


Figure 4.2. Third rail current collector principle [22].

$$S = \frac{E_{cons}}{pf} = \frac{5.24MWh}{0.85} = 6165 \text{ KVA.h} \dots\dots\dots 4.1$$

Average current of the line I_{av} is:

$$I_{av} = \frac{60 * S}{t * V} + 7amp \dots\dots\dots 4.2$$

$$= \frac{60 *}{18.6 * 25} 6165 \text{ KVA. h} + 7amp = 802.484A$$

Average feeding current is:

$$I_{avf1} = nPI_a, \quad P = (2 * N * t) / (n * T) \dots\dots\dots 4.3$$

$$I_{avf1} = \frac{2 * N * t}{T} * I_{av} \dots\dots\dots 4.4$$

$$I_{avf1} = \frac{2 * 40 * 18.6}{1440} * 802.484 A$$

$$= 829.233A$$

Effective feeding current is: $I_{ef} = I_{avf1} \sqrt{1 + \frac{K_{ef}^2 - P}{n * P}}$, n=number of trains in a section=2, K_{ef} is Effective feeding current constant equal to 1.035(technical assumption).

$$P = \frac{2 * N * t}{n * T} \dots\dots\dots 4.5$$

$$P = \frac{2 * 40 * 18.6}{2 * 1440} = 0.517$$

$$\text{Then, } I_{ef} = 829.233A \sqrt{1 + \frac{1.035^2 - 0.517}{2 * 0.517}}$$

$$= 1.028KA$$

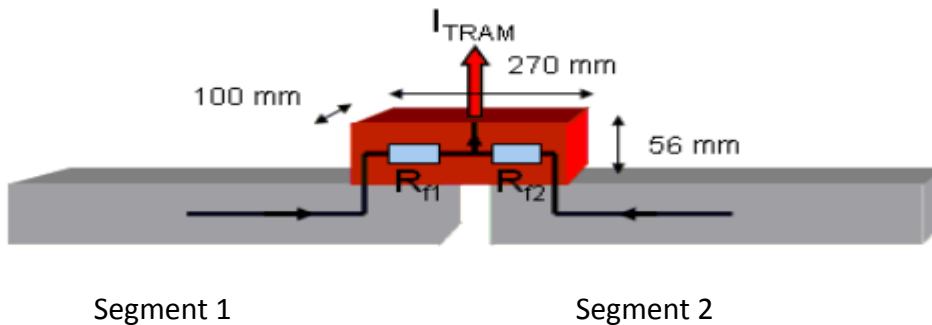
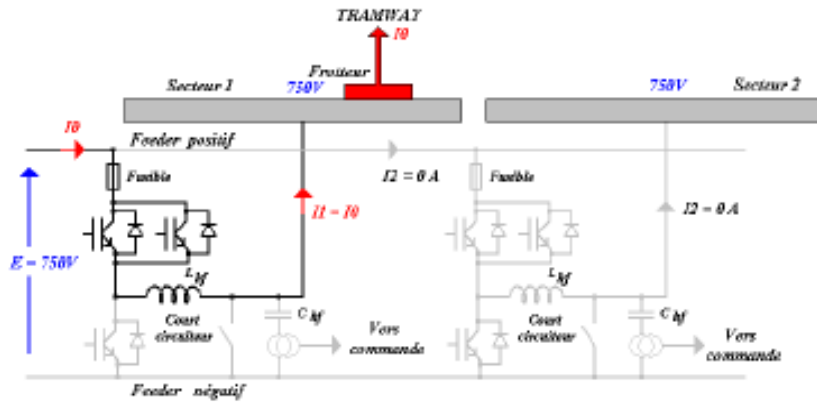
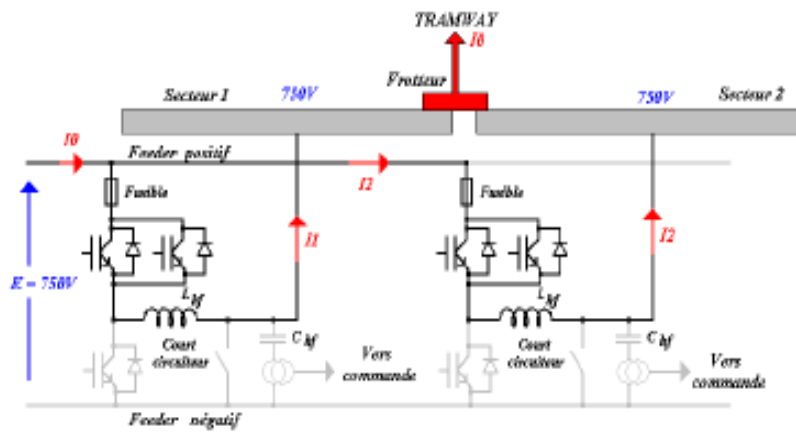


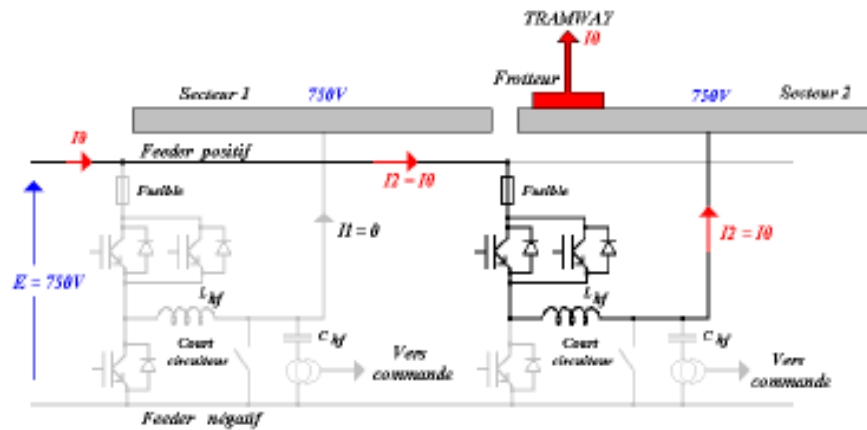
Figure 4.3. Between adjacent segments power transfer principle in one block [22].



System a



System b



System c

Figure 4.4. System working principle: system a, system b and system c [22].

$$R_{f1}=R_{f2}=\rho \times \frac{L_{1/2}}{S} \dots\dots\dots 4.6$$

$$P=10^{-5} \text{m}\Omega$$

$$L_{1/2}=135 \text{mm}$$

$$S=5.6 \times 10^{-3} \text{m}^2$$

$$R_{f1}=R_{f2}=10^{-5} \text{m}\Omega \times 135 \text{mm} / 5.6 \times 10^{-3} \text{m}^2 = 0.24 \text{m}\Omega$$

$$(2.L+2L_{hf}+2.L_{44}-2.L_{34}) \frac{di_1(t)}{dt} + (2.R+2.R_{33}+2.R_{44}+R_1(t)+R_2(t)+2.R_f).i_1(t) = (R+R_{33}+2.R_{44}+R_2(t)+R_f)I_0 \dots\dots 4.7$$

$$i_1(t)+i_2(t)=I_0 \dots\dots\dots 4.8$$

$$U_1(t)=R_1(t).i_1(t) \dots\dots\dots 4.9$$

Parametrs of circuit	Value	Unit
R ₄₄	0.2	mΩ
L ₄₄	6.53	μH
R	2	mΩ
L	1.1	μH
L _{hf}	5	μH
L ₃₄	3.62	μH
R ₃₃	56	mΩ
L ₃₃	6.33	μH
R ₁ (t)	0.24	mΩ
R ₂ (t)	0.24	mΩ

Table 4.1. Parameter of DC power feeder [22].

Chapter Five

5. Result and Discussion

5.1. Simulation

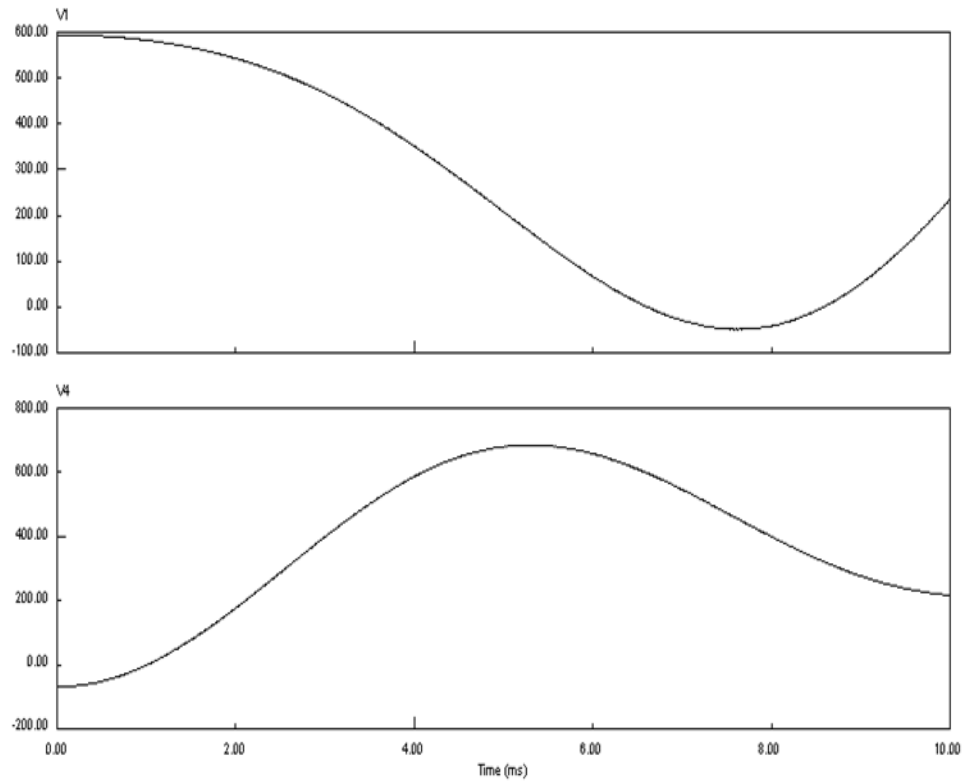


Figure 5.1. Voltage Vs Time V1 and V2 in different adjacent segment

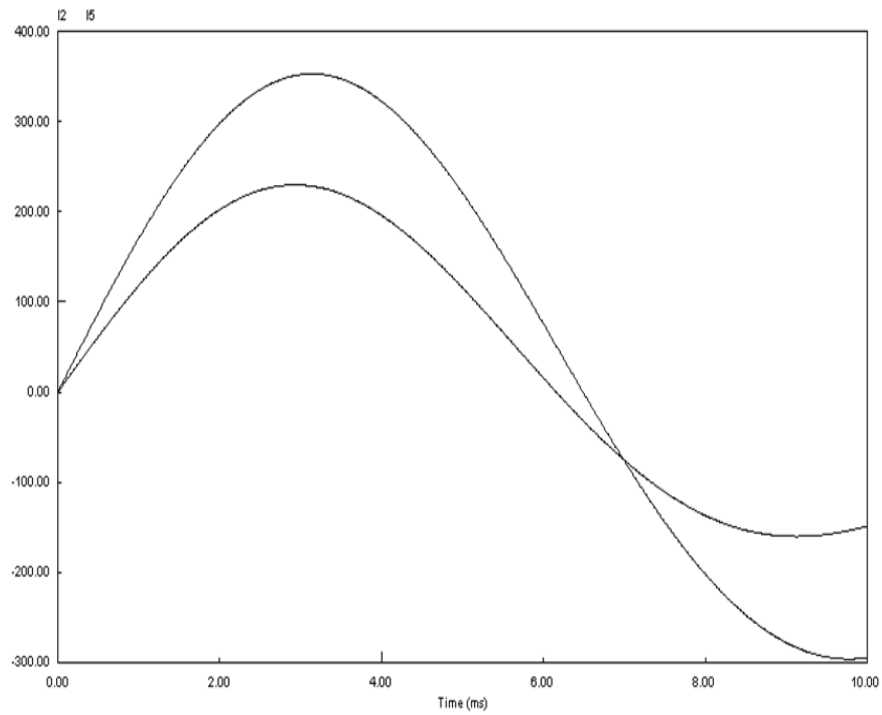


Figure 5.2. Current vs Time

5.2. Discussion

This simulation deals with designing proper, power sequence third rail DC traction power feeder coverage network for automatic control. Train detection loop mechanism is within a segment system. This thesis includes power sequence feeder discussed in detail.

An APS technology requires a pick-up to transfer energy from the insulated power cable to contact rails.

It is likely that the transfer input power from the power cable to the contact segment third rail, when train reached the occupied segment energized.

The Train detection function and the rail segment switching function in the APS track have also been tested with positive results, with the train at various speeds.

The contacts rails (third rail) are current collector shoe reach detect the blocks the result as:

- ◆ Occupied blocks (Segments) 750 V DC
- ◆ Unoccupied blocks (Segments) about 0 V DC

Chapter Six

6. Conclusion and Recommendation

6.1. Conclusion

This thesis can be used for simulations of a basic railway DC traction power sequence. Third rail power sequence simulation was performed to visualize the usability of the simulation PSIM software and used models. A two-step optimization was also introduced power up and down on the contact rail 750 V DC and 0 V DC.

This thesis concerned about the DC traction power supply rail is divided into 8 m long segments separated by 3 m long insulation segments. The rail is fed with 750 V DC from “power boxes” embedded in the track. Segments of power supply rail are only activated when they are completely covered by a tram vehicle.

The sequential system of power supply sequencing is best described as one power supply ramping and settling to its final regulation voltage and then the second power supply ramping after a time delay. Also to avoid the wind harmonic effect and other disturbance of harmonics on third rail compare with OCS.

In this design using switch, all MOSFETs are N Channel due to their increased current handling capabilities. Select the shoe according to characteristics of Eco type better than other shoe types:

- Plain or impregnated carbon third rail shoe welded to steel sheaths
- Third rail shoe with carbon inserts cast into bronze carriers
- Lead-free carbon material

For safety reasons, only the modules located under the tramway collector shoe are powered up, so the hot part is never accessible to the foot-travelers. When this belt is positioned in the upward position, contact is ensured between the 750 V DC feeders.

6.2. Recommendation

In general, this thesis recommends that, it is critical to design power sequence for reliable and safe operation of railway transport.

This thesis more concerned the analysis of third rail the alternative DC traction power feeder for ERC Train, so that worker should be done the design implementation of power equipment compare with OCS based on this thesis. Can be add anyone based on this thesis APS in Bordeaux power sequential sequence and practically implemented.

Civil Engineer must be design and implement available drainage system to protect any electrical equipment and available service provide for people.

The APS rail consists of segments with a specific length for safety and efficiency. The basic safety principle of the APS system is based on a fundamental moving zone in front of and behind the train. The costs and efficiency measurements are based on the data from the basic consequence description combined with the APS technology delivered for the test track.

Therefore third rail designed for this thesis is energetic to other worker by taking in to consider feeder. Some suggestions for further works that can be used as input or idea to formulate new research in the DC traction power feeder, it is better to implement third rail for future railway transportation.

In this thesis, the analysis is assumed for contact rail on the track, direct power supply with return line mode. The technology selected and recommended for development of conceptual design and cost estimate of the third rail system electrification of DC traction power feeder.

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