NeTIRail

Needs Tailored Interoperable Railway Infrastructure

Deliverable D3.1

Power supply technologies and practices of low and high-density railways, identifying learning points and future opportunities

Submission date: 30/11/2015

NeTIRail-INFRA is funded by the European Commission under the Horizon 2020 programme - Grant agreement n° 636237

Lead contractor

ADS-ELECTRONIC RESEARCH

Contributors

USFD, UIC, TCDD, SZ

Project Coordinator

University of Sheffield, USFD

1 Executive Summary

In this report the existing power supply systems around the world were identified and characterised, but this report focuses mainly on the power supply infrastructures in European countries.

Information is detailed on components and subsystems that are included in the infrastructure of power supply systems.

The technical and quality characteristics for various existing power supply system solutions have been analysed and those that have outstanding performance in terms of reliability, security in operation and safety have been highlighted.

Where applicable, technological solutions are presented as new alternatives to existing systems. These technologies have led to superior results although these are not yet sufficiently known and promoted. We also present the technical differences between the systems used for high transport density compared to those with low transport density.

T3.1 assumed analysis result of T1.1, related to the list with case study lines selected. This task considered a list with seven lines that could be included in the three categories (busy passenger line, low density rural/secondary line, freight dominated route) defined as purpose for analysis and improvement in the NeTIRail Project. All these lines have in common characteristics that made them candidates for selection: they are routes with distinctive features (context or purpose) and for this reason there are specific characteristics to be studied; they have good availability of technical, financial and operational data, related to the infrastructure and operations.

From the list of seven, five lines are electrified and will be included in a comparative table with components and technologies used, with respect to their power supply system; these power supply systems will be a focal point for improvements in the next tasks. These case study lines are the following:

Divača – Koper: Freight dominated route (SZ – Slovenia);

Pivka – Ilirska Bistrica: Low density rural / secondary line (SZ – Slovenia);

Kayaş – Sincan: Busy passenger line (INTADER - Turkey).

Divriği – Malatya: Low density rural / secondary line (INTADER - Turkey).

Malatya – İskenderun: Freight dominated route (INTADER - Turkey).

In the final part of the document, were described the structure of the database, which will contain the types of main components of power supply systems for the case lines taken in consideration, for the future analysis.

2 Table of contents

3 Abbreviations and acronyms

Abbreviation / Acronym	Description
ABC	Activity Based Costing
AT	Aluminothermic Weld
BV	Banverket – former Swedish IM
CM	Corrective Maintenance
DB	Deutsche Bahn – German IM
EC	Eddy Current
EU	European Union
FB	Flash Butt Weld
FME(C)A	Failure Mode, Effects (and Criticality) Analysis
FMEA	Failure Modes and Effects Analysis
HA	Hazard Analysis
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IM	Infrastructure Manager
IM's	Infrastructure Managers
JBV	Jernbaneverket – Norwegian IM
LCA	Life-Cycle Assessment
LCC	Life-Cycle Costing / Life-Cycle Cost
M&R	Maintenance and Renewal
MAD	Mean Administrative Delay
MGT	Traffic in million gross tonnes
MGT/MGTPA	A measure of traffic in units of million gross tonnes per annum

Abbreviation / Acronym	Description
MLD	Mean Logistic Delay
MRT	Mean Repair Time
MTTF	Mean Time To Failure
NR	Network Rail – British IM
ÖBB	Österreichische Bundesbahnen – Austrian IM
OCL	Overhead Contact Line
OCS	Overhead Contact line System
OLE	Overhead Line Equipment
PM	Preventive Maintenance
RAM	Reliability, Availability and Maintainability
RAMS	Reliability, Availability, Maintainability and Safety
RCF	Rolling Contact Fatigue (in this case usually related to head checks)
S&C	Switches & crossings
SA	Safety Analysis
TCDD	Türkiye Cumhuriyeti Devlet Demiryolları – Turkish IM
TGV	Train à Grande Vitesse (High Speed Train)
TSL	Temporary Speed Limitation
UIC	Union Internationale des Chemins (International Union of Railways)
US/UT	Ultra-Sonic / Ultra Sonic Testing
Vac	Voltage with alternating current
Vdc	Voltage with direct current

1 Railway power supply systems – general aspects

Electric power supply systems in railway networks have as their main function to perform electric traction. Railway power supplies should ensure uninterrupted functioning, reliable and safe electric vehicle traction. The power supply system includes all installations necessary for electrical traction function. From systemic point of view the traction power supply is assured by:

- The function of generating power supply;
- The function of transmitting power supply;
- The function of feeding power supply;
- The function of collecting power supply by mobile electric vehicles.

A power supply system for the railways must provide electricity to locomotives and multiple units for traction so these units can operate without having an on-board storage of energy, like diesel or steam engines.

In the most frequently used system, the railway electricity power is supplied from the public high voltage networks, through the individual traction substations with special role to convert high voltage levels and sometimes nominal frequency of primary power supply parameters according to the railway needs.

For example, German Railway (DB) and other European railway networks have traction power provided by alternative current (AC) high voltage networks: AC 55 kV, AC 110 kV or AC 132 kV with 16.7 Hz frequency as input characteristics for traction power supply grid. The power distribution function has a major role in power supply system for railways and is performed by the components named power substations which realise the compatibility between high voltage grid network and overhead contact lines.

Considering the evolution and diversity of railway electricity supply networks, a classification of these can be achieved based on the component that makes contact and transfers energy between the infrastructure and moving units. Taking as criteria for classification the contact type, the power supply infrastructure can be divided into:

- Overhead conductor wire infrastructure;
- Third rail infrastructure;
- Four rail;
- Overhead conductor rail infrastructure;

Due to the great importance that the electricity supply system has, the following criteria must be respected for the quality and safety of overhead lines:

- Supply electricity without interruption to the pantograph of traction vehicles.
- The railway network has to implement function of continuously absorbing regenerated braking energy.

- Comply with specified and standardized quality parameters for the voltages and frequency at the pantographs of electric traction vehicles.

It should be noted that the electricity supply to the railway network differs from the supply network power for public consumers due to the large variations absorbed in relatively short sections; this variation is recorded actually at point level of overhead line that means high electrical stress for the conductor section.

There are several different railway traction power supply systems in use throughout the world and each system has different advantages in utilisation, robustness and cost effectiveness, and newest electrification schemes require significant capital expenditure for installation.

2 Existing power supply systems - Classification

2.1 Characteristics of railway power supply systems

A railway power supply system provides electric power to rail vehicles without an on-board or local fuel supply. This type of system to provide electric power has many advantages but at the same time, requires significant capital expenditure. The selection of the type of solution is based on the costs of energy supply, maintenance, and capital cost compared to the revenue obtained for freight and passenger traffic. For freight and passengers transport, different electrification systems are used for urban and intercity areas; some electric locomotives can switch to different supply voltages to allow flexibility in operation.

Railway electrical system are characterised by:

- Using electric locomotives to transport freight and passengers from one point to other, in separated transport units (wagon) or electric multiple units - passenger cars with their own motors;
- Electricity is provided with efficiency and at high voltage, and power is provided from dedicated generating stations; the energy is transmitted to the railway network and distributed to the trains from power generating stations. The railway usually provides its own distribution lines, switches and transformers;
- Some electric railways have their own dedicated generating stations and transmission lines but most railways purchase power from an electric utility;
- The electric power is provided, for running trains, through a conductor placed in parallel to the track that usually takes one of two technical solutions. First solution is an overhead wire or catenary wire, suspended from poles or towers along the track or from existing structure or tunnel ceilings. Locomotives or multiple units with electric traction get the power from the contact wire with specific devices: pantographs, placed on their roofs, which press a conductive strip against it with a spring or air pressure. The second solution is to use a third rail, mounted at track level and making contact with traction unit by a sliding "pickup shoe" or “contact shoe”. In most cases, overhead line and third-rail systems use the running rails as the return path for current; however, some systems use a separate fourth rail for this purpose;
- Must operate at variable speeds. The speed is controlled through connecting the traction motors used in combination by series or parallel. These are done by varying the traction motors' fields, and limiting motor current;
- Motors, generally have low voltage ratings. Early railway train technologies were supplied with a relatively low DC voltage that the motors can use directly. Since utilities supply high voltage AC as a standard for civilian and industrial consumers, in railways power traction supply systems converter stations are used to provide low voltage DC (3kVdc or less). For

using direct current, for example on a 750 Vdc third-rail system, between power supply stations is a distance about 2,5 km; between stations for 3 kVdc is about 7,5 km;

- Modern high-speed railway projects have generally use high-voltage AC, when the technology made up possible. Trend in current days is the DC routes have to be converted to AC standard systems, excepting special situations.

2.2 Classification of electrification systems

Electrification systems are classified by three main parameters:

- Voltage level of electricity power supply;
- Current types used for electricity power supply: Direct current (DC), Alternating or alternative current (AC), Frequency – for alternative current;
- Contact system type with electricity power supply system: Overhead line (catenary), Third rail, Fourth rail;

The electrification systems which exist in Europe are represented in the next figure:

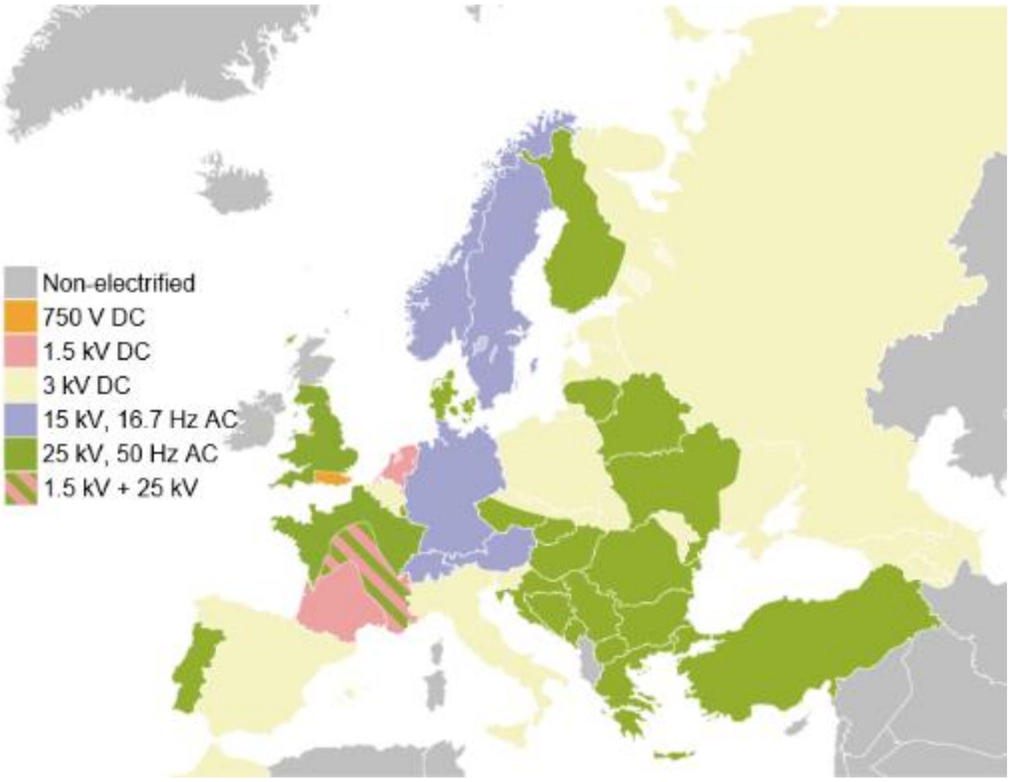


Figure 2.1 - Electrification systems in Europe

High speed lines, as the most technologically advanced lines, for France, Spain, Italy, United Kingdom, the Netherlands, Belgium and Turkey operate under 25kVac; also when any new power lines are constructed in the former Soviet Union, they have to comply with 25kVac / 50 Hz standard.

2.3 Classification based on voltage level of electricity power supply

2.3.1 General considerations

Generally, the type of current used distinguishes between the various types of electrical energy supply for moving railway vehicles.

The power supply systems are extremely diverse and heterogeneous and a classification of them can be performed taking into account the most used voltages and frequencies. The classification is independent of the type of contact used and refers only to voltage and frequency values, for AC alternating signal.

There are many voltage systems used for railway electrification systems around the world, some of them are presented in the tables below which covers both standard voltage and non-standard voltage systems.

The voltages are nominal and vary depending on load and distance from the substations. Many modern trams and trains use on-board solid-state electronics to convert these supplies to run three-phase AC induction motors.

In order to establish and characterize permitted tensions for power supply systems, standards SR EN 50163 and IEC 60850 are used. These standards indicate the conditions for power supply systems and take into account both the number of trains that consume energy at a time and the distance that is to fixed power substations.

Electrification System	Lowest Non-permanent Voltage	Lowest Permanent Voltage	Nominal Voltage	Highest Permanent Voltage	Highest Non-permanent Voltage
600 Vdc	400 V	400V	600 V	720 V	800 V
750 Vdc	500 V	500V	750 V	900 V	1 kV
1, 5kVdc	1000 V	1000V	1, 5 kV	1800 V	1950 V
3 kVdc	2 kV	2 kV	3 kV	3 kV	3 kV
15 kVac/ 16.7 Hz	11 kV	12 kV	15 kV	17, 5 kV	18 kV
25 kVac/ 50 Hz	17, 5 kV	19 kV	25 kV	27, 5 kV	29 kV

Table 2.1 - Mainly used voltage levels of railways electricity power supply (7)

Key factors used in classification of electrification systems are:

- Volts: voltages at contact line;
- Current:
  - DC (dc) - direct current;
  - xx Hz - frequency in hertz (only for alternating current (AC));

- AC (ac) – alternating or alternative current; single-phase, except where marked three-phase;
- Conductors:
  - overhead line;
  - conductor rail, usually a third rail to one side of the running rails
    - top contact: oldest, least safe, affected by ice, snow and leaves;
    - side contact: newer, safer, less affected by ice, snow and leaves;
    - bottom contact: newer, safer, least affected by ice, snow and leaves;

Tables of the types of electrification systems can be found in “ANNEX 1: Power supply systems related to power supply voltage and type of current”; here, tables with railway lines, representative of electrification systems, with different supply voltages are presented.

2.4 Classification based on current types used for power supply system

2.4.1 Direct current (DC)

The most common DC voltages are 600 Vdc and 750 Vdc - for trams and metros; in the UK some electrification systems still use electricity power supplies with 1.5 kVdc, 650 / 750 Vdc with third rail and 3 kVdc with overhead line solution.

The lower voltages are often used with third or fourth rail systems, whereas voltages levels above 1kV are normally raised to overhead wiring for safety reasons.

Some exceptions are suburban trains (SBahn) lines in Hamburg, Germany. These operate using a third rail with 1200 Vdc. The French SNCF Culoz-Modane line in the Alps used 1500 Vdc and a third rail until 1976, when a catenary wire was installed and the third rail was removed.

Early electric systems used low-voltage DC. An advantage for direct current is electric motors which can be fed directly from the traction supply and are controlled using a combination of resistors and relays that connect the motors in parallel or series.

In the south of London, the supply uses continuous current at 750 Vdc, together with the third rail contact feeding system while, for inner London, 650 Vdc is used to allow inter-running with London Underground which uses a 650 Vdc with fourth rail system but with the fourth rail as centre rail.

The systems with DC current is relative simple but it requires thick cables and short distances between railway electricity supply stations because of the high currents required.

The direct current solution involves major power losses through resistive consuming. In the United Kingdom, 6800 A at 750 Vdc is the maximum current that can be drawn by a traction vehicle; for this reason, on many cases, only a single locomotive can run inside a feeding section.

The distance between two electric feeder stations at 750 Vdc on third-rail systems is about 2.5 km. The distance between two electric feeder stations at 3 kVdc is about 7.5km; this could be increased even up to 25 km but with restriction for number of trains, in the same feeder section. Sometimes auxiliary machinery, such as fans and compressors are powered by motors supplied directly from the traction supply, for these extra insulation is needed for the relatively high operating voltage.

Other examples of DC electric power supply used are: systems supplied with 1500 Vdc which are used in the Netherlands, Japan, Hong Kong, Ireland, Australia, France, New Zealand (Wellington) and the United States. In Portugal, this system is used in the Cascais Line; in Denmark the 1500 Vdc system is used on the suburban S-train system.

Figure 2.2 – United Kingdom railway power supply system that uses 1500 Vdc

1.5 kVdc system was also used for suburban electrification in East London and Manchester, now converted to 25 kVac.

Figure 2.3 – Nottingham Express Transit in United Kingdom uses a 750 Vdc overhead, in common with tram systems[1]

[1] http://www.bwbconsulting.com/project/NTH2130_nottingham-net-light-transit-nottingham

3 kVdc is used in Belgium, Italy, Spain, Poland, the northern Czech Republic, Slovakia, Slovenia, western Croatia, South Africa and former Soviet Union countries (also using 25 kVac/ 50 Hz). It was also formerly used by the Milwaukee Road's extensive electrification across the Continental Divide and by the Delaware, Lackawanna & Western Railroad, in United States; now is converted to 25 kVac.

2.4.2 Alternative current (AC)

This category represents the overhead power supply system. Alternating current can be transformed to lower voltages inside the locomotive. This allows much higher voltages and therefore smaller currents along the line, which means smaller energy losses for long railways.

A variable of alternative current is frequency. This can have variation from region to region and is depends on the installed infrastructure.

Figure 2.4 – 15 kV 16.7 Hz AC traction current used in Switzerland[2]

Use of power signal with low frequency, requires that electricity should be converted from primary utility power, with highest voltage, using generators or inverters; for this process, special substations are needed.

A version of railway power supply is multiphase electricity feeding. One example of this is the Italian State railway when three-phase system was 3,300 V at 15 Hz – 16.7 Hz. It is also possible to use the multi-phase regenerative system, as on Italian State railway's mountain lines; a loaded train descending could supply part of the power for a train ascending. At experimental level, some multi-phase installations in Italy used higher voltage (10 kVac) at industrial frequencies (45 Hz or 50 Hz).

[2] https://bahnbilder.ch/picture/1419; Author: David Gubler

Figure 2.5 – Train using a multiphase electrification system, with multiple pantographs, on the Petit trains de la Rhune, France

The complexity for the three-phase systems is the need for three power supply conductors (including the rails) and two overhead conductors. The dual conductor pantograph system is used on four mountain railways that continue to use three phase power (e.g. Corcovado Rack Railway in Rio de Janeiro, Jungfraubahn and Gornergratbahn in Switzerland and the Petit train de la Rhune in France).

In time, based on experience and results obtained for the different frequencies used in the power supply of alternating current systems, also, counting the need for interoperability of railway networks it became necessary to standardize the electricity supply network for the railways; where alternative voltage and working frequency for traction lines have been set.

The first experiments to use alternative current standard-frequency and single-phase were developed in Hungary from 1923, on line between Budapest (Nyugati) and Alag; where 16 kVac/ 50 Hz was used. The experiments were successful, from 1932 until 1960s and trains on the line Budapest - Hegyeshalom (towards Vienna) regularly used the same system. After the Second World War, the 16 kVac was changed to the Russian and later to the French system: 25kVac.

Nowadays many types of locomotives use this system with a transformer and rectifier to provide low voltage, direct current to motors and the speed of train controlled by winding taps that are switched on the transformer. Other, advanced technological locomotives use thyristor or IGBT circuitry to generate chopped or variable-frequency alternating current that supply the AC induction traction motor. This system is economical but the phases of the external power system are not equally loaded and there are major electromagnetic generated interferences; also, acoustic noise.

In the United States 12.5 kVac and 25 kVac/ 25 Hz or 60 Hz are used; but the variant of 25kVac/ 60 Hz is the preferred for new high-speed and long-distance railways, even though they are not compatible with the other railway systems. That represents the trend to provide for the future the highest technologically and low consuming systems for railway transportation.

Apart from a few cases, almost all AC traction units draw alternating current from an overhead line. At present at least 30% length of the world rail networks was electrified and at least 60% of all rail transport is carried by electric traction.

2.4.3 Mixing electricity power supply systems

Because of the variety of railway electrification systems, which can vary even within a country, trains often have to pass from one system to another. One way to accomplish this is by changing locomotives at the switching stations. These stations have overhead wires that can be switched from one voltage to another and so the train arrives with one locomotive and then departs with another. The switching stations have very sophisticated components and they are very expensive. The other disadvantage is the extra time waiting for the changing locomotives; this time is added to the trip and is not acceptable for high speed railways and busy passenger lines.

Other solution is to use locomotives with multi-system voltages tractions; can operate under few types of voltages, current and frequency types. For Europe, four system locomotives are considered: 1.5 kVdc, 3 kVdc, 15 kVac/ 16.7Hz, 25 kVac/ 50 Hz).

These locomotives advantages are they do not stop when passing from one electrification system to other, the changeover is done when the train coasts for a short time. Eurostar trains through the Channel Tunnel are a multi system; a significant part of the route near London used to be on southern England's 750 Vdc third rail system, the route into Brussels is 3 kVdc but overhead line system, while the rest of the route is 25 kVac/ 50 Hz overhead line system.

Another combination is to use electro-diesel locomotives type, which can operate as an electric locomotive on electrified lines but have a diesel engine for non-electrified sections; that solution has been used in several countries.

United Kingdom - The first line systems were as third rail, low voltage, mainly 600 Vdc and 750 Vdc; these were combined with DC or AC overhead line.

Southern England has overhead and third rail dual-system locomotives and multiple units to allow running between 750 Vdc as third rail for south of London and the 25 kVac/ 50Hz overhead line system for north and east of London.

Starting with the West Coast Mainline electrification in the 1960s, the 25 kVac/ 50Hz overhead line system was adopted for all further mainline electrified lines in the UK; exceptions are extensions to other existing systems having third rail lines, for compatibility reasons.

The "Automatic Power Control" system was developed to allow trains to automatically switch between voltages, whilst moving. The driver has to close the power and coast clear of the neutral section. Then, the system automatically opens the circuit breaker, detects a change in voltage and switches over the transformer to the correct input voltage setting, then closes the circuit breaker.

Italy - Italian railways have systems with overhead power supply lines from a catenary, for 3 kVdc voltage and for 25kVac/ 50Hz. The last version of the system is used on the new high speed lines.

Spain - Spanish railways have two systems with overhead supply, from a catenary: 3 kVdc and 25 kVac/ 50Hz; this last system is installed on the high speed lines.

Czech Republic and Slovakia - In the Czech Republic also in Slovakia, the railways power supply systems have 3 kVdc and 25 kVac/ 50Hz systems but there are no switching stations - the two systems meet at simple breaks on overhead wires. From these breaks, there are two stations (Kutná Hora and Nedakonice).

United States - In the United States, multi system ALP- 44 and ALP- 46 locomotives (New Jersey Transit) are used; Amtrak company uses multi-system AEM-7, HHP-8 and Acela locomotives for service into New York and Northeast Corridor, between Washington and Boston.

In these cases, trains run on both the newer system of 25 kV at 60 Hz and the older system of 12 kV at 25 Hz.

Figure 2.6 – New Jersey Transit ALP-46 AC locomotive based on the DBAG Class 101[3]

India – 1.5 kVdc and 25 kVac/ 50 Hz are used. The alternative current is provided for main line trains. As particularity, the 1.5 kVdc overhead system with negative earth and positive current for catenary is used around Mumbai, but there are plans to change this to 25 kVac as its more efficient and with no excessive cost for translation. The 25 kVac system with overhead lines is used almost throughout the rest of the country. Now the dual-voltage WCAM series locomotives are running as intercity trains for Mumbai and suburban regions. These EMU variants are designed to be powered by DC and AC currents.

South Africa - South Africa has sections of dual system track, both 3 kVdc and 25 kVac/ 50Hz.

[3] http://www.wikiwand.com/es/Locomotora_electrica

3 Technical, functional and quality characteristics for power supply systems

This Chapter will present technical and functional characteristics of power supply systems for railways. Also analysed are quality issues – reliability, efficiency, security, safety, and performances – that these systems introduce when used in the railway infrastructure.

3.1 General requirements

Reliability in operation electrified railway networks depends largely on the availability and reliability of the electricity traction supply system. Contact line requirements – even overhead line or third rail - must take into account the contact line is the only component of the power supply system cannot be installed redundant, from economic and technical reasons. Requirements on contact line system should fulfil the following functions:

- Electric power supply distribution should be done reliably over a certain distance;
- Providing a sliding contact current collector, reliable in all conditions;

The need for high availability contact line systems requires a planning cycle as detailed as possible for electrification of railway sections or networks. This planning should include only verified technical solutions to be accepted in the system, tested equipment with long life with easy installation and low maintenance costs during exploitation. The following basic requirements must be met in the design of an installation of the contact line:

- People but also sensitive equipment must not be endangered by operation of the contact line.
- Project solution must ensure that power transmission interruptions do not occur in normal operation, up to the maximum permitted speed for the type of contact line considered in the project. This applies whatever type of dynamic interaction of the current collector: overhead contact line or third rail.
- System components must have a production quality that would ensure a long life.
  The following requirements are important:
    - Suitable electrical and mechanical strength;
    - Durability to weights and torsion due to wind and ice or other aggressive substances in the air;
    - Increased corrosion resistance components;
    - Assures a uniform wear and as low as possible wear for the contact line.
- During the design of the overhead power line, particular conditions and restrictions must be observed and respected. These are external, generated by residential areas, special construction zones, areas with existing overhead supply networks, historical and aesthetic aspects of cities must be respected, etc.

- Environmental protection has to be respected.
- The costs for initial investment and installation, for operation and maintenance during the cycle life of the equipment, should be as low as possible.

The individual characteristics derived from these basic requirements of a contact line system, can be classified into mechanical, electrical, environmental, operational and maintenance-related aspects; but a strict distinction between the individual requirements is not always possible.

3.2 Characteristics of railway power supply systems

3.2.1 Advantages

In comparison to the principal alternative of diesel locomotion, the electric railways offer substantially better energy efficiency, lower emissions and lower operating costs. Electric locomotives are usually quieter, more powerful, and more responsive and reliable than diesels and have no local emissions, an important advantage in tunnels and urban areas. There are electric traction systems which provide regenerative braking that turns the trains braking energy back into electricity and returns it to the supply system to be used by other trains or the general utility grid.

Compared to other railway traction systems, electric traction has the main advantage of a higher power to weight ratio than other forms of traction: diesel or steam engines that generate power on board. Power supply allows rapid acceleration and less towing effort on steep slopes. In addition, locomotives equipped with regenerative braking when the speed drops, power generated are sent back into the supply system or is used local in place of main energy supply; ex. heating or lighting systems for passenger cars.

Relative to the list of advantages that electricity supply systems for railways bring, those related to the environment and quality of service should be mentioned. These include lack of exhaust gases of diesel locomotives, much less noise and much lower volume of activity for maintaining traction units. Given the large and growing density of traffic, especially at passengers travelling, electric trains produce less carbon emissions than diesel trains. This has economic importance in countries where fossil energy resources are low and not sufficient.

To summarize, the benefits can be grouped as follows:

- Lower operating costs for traction locomotives and multiple units;
- Lower maintenance costs for traction locomotives and multiple units;
- Greater power to weight ratio, resulting in fewer locomotives used for the same amount transported;
- Faster acceleration resulting in shorter travel times;
- Upper limit of the effective power supplied is higher;
- Maximum speed limit is also higher;
- Less noise pollution;
- No power loss at high altitudes;
- Less dependence on fossil fuels;

- Environmental pollution is greatly reduced, even when the electricity is produced by fossil fuel plants.
- Provide some level of independence of running costs from fuel prices and decreasing fuel reserves.
- It is the only solution for the underground stations, where trains with diesel traction cannot operate because of safety reasons
- More comfortable ride on multiple units because electric engines are smoother than diesel engines

3.2.2 Disadvantages

The disadvantages of electric traction are the high initial investment that may be uneconomic on lightly trafficked routes, a relative lack of flexibility since electric trains need electrified tracks or on-board and charging infrastructure at stations, and a vulnerability to power interruptions.

In different regions, relating mainly to historical reasons, different supply systems voltages and frequencies are used, involving expensive costs for services and operational activities.

Highest voltages at contact line level and third rails are a hazard for railway workers, passengers, and other people and animals. Overhead contact lines are considered safer than third rails, because of distance and hard accessibility, but it is often considered not aesthetic.

The main disadvantage of old existing railways to be upgraded by electrification and also for new railway network that will be built is the significant costs needed. These costs are especially significant, to existing poorly used secondary lines.

Due to the low income, the investor return after future exploitation is unlikely to recover; thus, their investment is in danger. In these situations, secondary lines are unlikely to achieve modernization and electrification of railways unless the costs are covered by public authorities.

Special situations can occur when forecasting the industrial development of a region without developed urban infrastructures; in this case, the phenomenon of transport by rail of commuters can encourage investment in electrification of the railway networks.

Another situation is the development of investment in other areas that require a massive increase in freight transport, like: new mining exploitations, harbours modernization, etc.

Some cost targets for modernization of existing railway involve clearance. That means alterations on obstructions like tunnels and bridges; also, modifications or upgrades will be needed on the railway signalling for new traffic characteristics.

To summarize, the disadvantages can be grouped as follows: electrification initial and continuous maintenance cost; electrical load for existing and limited power grid; un esthetical appearance of the overhead line structures and cabling; fragility and also vulnerability because the overhead electrification systems suffer severe interruptions due to minor mechanical faults; theft events are significate because of high value of material used in power supply system’s infrastructure.

3.2.3 Acceptable compromises

Maintenance costs of the lines will be increased when upgraded to electrification, there are additional maintenance costs associated with the electrical equipment. Relative to the maintenance cost, all infrastructure managers and rolling stock operators claim lower maintenance costs as principal condition for new investments.

Modernization of the railway network by introducing electrical power supply capacity, has an effect opposite to the one desired relative to maintenance costs, they will grow. The only argument for accepting investment is the demonstration that will get high enough income to cover increased maintenance costs and retain net worth higher than earlier gains.

A main reason for electrification is networks compatibility. When electrifying a line, the compatible connections with other railway lines must be considered.

Depending on the situations to be examined the option for changing locomotive, to transition from one section to another railway section: electrified – none electrified should be considered. That will produce time delay and additional operational cost for manoeuvres but may be accepted if there is a benefit.

If travel times are very important, for example in the case of passenger transportation more expensive locomotives with dual mode engines should be used.

Different traction modes for sections in a railway network is an issue for long distance trips, but many lines come to be dominated by traffic from long freight trains (usually running coal, or containers to or from ports). These trains could get advantages and savings through electric power supply, but it can be too costly to extend electrification to isolated areas, and unless an entire network is electrified, companies often find that they need to continue using diesel trains even if some sections are electrified.

Figure 3.1 – Most overhead electrification do not allow sufficient clearance for a double-stack car[4]

[4] http://www.wig-wag-trains.com/KatoPages/Freight/Gunderson-Maxi-IV_Page.html

An important part of railways operations is freight transportation that have increasing demand for container traffic. This is more efficient when double-stack goods containers are used; this may not be possible because the characteristics of insufficient clearance of overhead lines, the system may have to be modified to have sufficient height, at supplementary cost.

Negative implications are given by the connection problems between different power supply standards for intercity lines, and local area electrified sections, providing local services, for example commuter traffic; there may be differences even between the electrification of commuter lines that operate at different standards. This can cause increased costs because of difficulty with section connecting.

Some lines have come to be overlaid with multiple electrification standards for complying with different feeding systems of trains. This is a solution to avoid replacing the existing rolling stock on those lines. There are situations where diesel trains are running along completely electrified routes and this can be due to incompatibility of electrification standards along the route.

Related to goals of NeTIRail project, especially for low density rural or secondary lines, electrification may not be feasible (especially using newest technologies, e.g. regenerative braking), because lower running cost of trains may be overcome by the higher costs of maintenance. Therefore, most long-distance lines in North America and many countries are not profitable to be electrified due to relatively low frequency of running trains.

Electric locomotives may provide greater power output than most diesel locomotives, in some cases for passenger operation it is possible to provide enough power with diesel engines but if it performance and higher speeds are needed, diesel traction is not feasible; therefore, almost all high speed trains in the world have electric power traction.

Also, for freight transportation, the same arguments exist; power of electric locomotives gives them the possibility to transport higher freight weights at higher speed; in present and for the future, increasing speed will increase the capacity of railway transport, mostly when the time between trains it is a restricted factor.

3.2.4 Energy efficiency

It is obvious that electric trains are more energy efficient than diesel trains; also produce less pollution having a smaller carbon dioxide footprint. The main reasons are:

- The electric trains are lighter than diesel variant because they do not have to carry the weight of a motor that turns the fossil fuel into traction energy; Electric trains receive direct energy by overhead lines and do not need to carry fuel. However, the weight of electrical control equipment should be considered, mainly the weight of the transformer.
- The electric power can be generated from various energy sources that are more efficient than the one generated by a diesel engine. Thus, electric trains also have the advantage of decreasing the dependence by the oil products and reduce carbon dioxide emissions. The list of these alternative sources can include: nuclear, renewable energy sources (hydro, wind, hydrothermal, etc.).

- An important advantage of electric traction systems is that significant power can be obtained from regenerative braking in certain circumstances, with the appropriate equipment. These energy sources can be fed back into the power supply railway network and used by other vehicles in the same section. The solution is effective if there is a high density of electric rolling stock in a section. In case of electrified railway lines in mountain areas, trains can be programmed so that the climb of a train is helped by a train that descends and brakes. In other cases, renewable energy is collected and used later in the same section of railway network, for example for accelerating trains stopped in stations. Some systems, for example in the UK there are systems based on the voltage of 25 kVac, are able to load renewable energy into the public network.

Worldwide reserves of fossil fuel energy are decreasing very rapidly. Thus it is estimated that oil reserves can be still used approximately 42 years; gas reserves are estimated at 167 years; coal reserves are estimated at 416 years. Most industrialized countries, with important railway networks do not have reserves of fossil fuels or have exhausted most of their reserves in the process of industrial development – for example, USA and UK. These countries, to keep their level of development, will generate a trend of replacing traditional energy with clean energy.

Railway electrification process is often considered a successful experience in reforming energy sources. It can reduce pollution and the greenhouse effect, in accordance with the Kyoto Protocol. In addition, lower energy costs are advantages to introducing the electrification on railway networks.

Other benefits of electrification are increased productivity of railway infrastructure as well as rolling stock (i.e. locomotives and wagons) through continuous R&D activities. Research and development in the electrified railway sector involve technical areas such as: electrical engineering, electronics and automation. Good results were achieved by adopting technologies like GTO (gate turn-off thyristor) or IGBT (insulated gate bipolar transistor) that resulted in increasing the power traction and operational reliability of locomotives.

3.3 Overhead line

Overhead lines represent a system used to transmit electrical energy to trains from the energy supply point.

The mechanics of power supply wiring it is not simple. Hanging a wire over the track which provides current and allow trains to run under it is not so easy if it provides the reliability to justify the expense of its installation.

The wire must be able to carry the current (several thousand amperes), to remain in line with the route, and to withstand wind even if this reaches 200 km/h, extreme cold and heat, and other hostile weather conditions.

Overhead catenary systems, named "catenary" due to the form of the curve of the supporting cable, have a complex geometry. The contact wire has to be held horizontally in tension and pulled laterally to negotiate curves in the track and the contact wire tension is in the region of 2 tones. The length of wire is between 1000 and 1500 meters, depending on the temperature ranges. The wire is zigzagged relative to the centre line of the track to equally wear the train's pantograph.

A tram depot may have just a single wire hung directly from insulated supports. In a slow speed depot environment, it is necessary that the wire can be seen to rise and fall when a pantograph passes along it.

The contact wire (see Figure 3.2) is grooved to allow a clamp to attach the dropper wire to be fixed on the top side. The tension of the wire is maintained by weights suspended at each end of its length. Each length is overlapped by its neighbour to ensure a smooth passage for the pantograph.

The pantograph head starts to bounce if the tension is incorrect and trains have a wrong speed. An electric arc occurs with each bounce so that the pantograph and the wire will wear under such conditions.

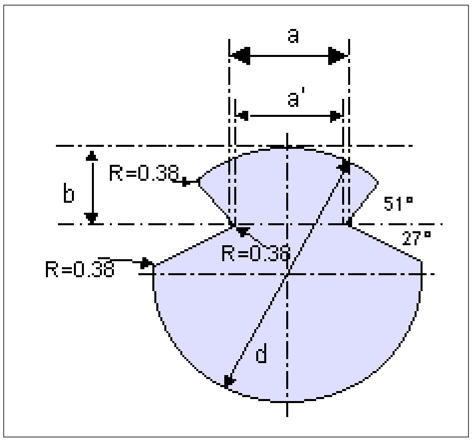


Figure 3.2 – Contact wire cross section

A similar problem can appear when a train has more than one pantograph when the leading pantograph head sets up a wave in the wire and the rear head cannot stay in contact. High speeds increase the wave.

Figure 3.3 – Catenary and Railway Power Supply[5]

The overhead lines have different technical names:

- For Europe, except UK and Spain: Overhead Contact System (OCS);
- For UK: Overhead Line Equipment (OLE or OHLE);
- For UK, India, Pakistan and Malaysia: Overhead Equipment (OHE) ;
- Australia: Overhead Wiring (OHW);
- India, United States, Canada, UK, Singapore, and Spain: Catenary.

In this category two versions of aerial electricity supply are included: overhead line as wire power transmission and overhead rail. The generic name will be used for overhead wires and technical features will differentiate the two versions.

3.3.1 Requirements

Interoperability requirements – Interoperability is necessary and became a political goal of the European Community (EC) to improve the trans-European rail traffic in Europe. To accomplishing this target, the EC ratified the directive on the interoperability of the trans-European high-speed rail system in 1996, of the trans-European conventional rail system in 2001 and a directive with the modification of the mentioned directives, in 2004.

The directives classify the trans-European rail system into subsystems based on structural and operational areas. Technical Specifications for Interoperability (TSI) were specially introduced as links between the directives and the European standards.

Interoperability will remove technical and operational obstacles for railways traffic. Also, it will reduce difficulties of railway equipment procurement.

[5] http://www.ivv-gmbh.de/en/business-areas/catenary-and-railway-power-supply.html

The main advantage of interoperability achievement refers to high-speed technology trains. These have to be designed to guarantee safe, uninterrupted travel through different sections: to reach at least 250 km/h speed on lines specially built for high speed and enabling speeds of over 300 km/h to be reached in future development and appropriate circumstances; to get a speed in the order of 200 km/h for existing lines but which have been specially upgraded.

According to the definition, high-speed trains are those designed for 250 km/h and greater speeds. The high-speed lines cover three categories:

- Category line I (high speed lines) - special built category for high-speed lines; there are equipped for speeds equal or greater than 250 km/h;
- Category line II (upgraded lines) - upgraded high-speed lines for speeds around of 200 km/h;
- Category line III (connecting lines) - specially upgraded high-speed lines with special features for topographic characteristics, town-planning constraints; on these situations the speed is adapted to each case.

As a consequence, the existing standards **EN 50 163** and **EN 50 119** evolved. New standards were established:

- **EN 50 388** on technical criteria for the coordination between power supply and rolling stock to achieve interoperability;
- **EN 50 367** on technical criteria for the interaction between pantograph and overhead contact line;
- **EN 50 317** on the requirements for validation of measurements of the dynamic interaction between pantograph and contact line;
- **EN 50 318** on the validation of simulation of the dynamic interaction between pantograph and overhead contact line.

The TSI establishes provisions for subsystems and their component have to be complied when designing the overhead contact lines for high-speed installations; it contains essential requirements concerning safety, reliability, availability and maintainability, health, environmental protection and technical compatibility. Strict application of the specification guarantees the compliance of the installation with the essential requirements of the TSI.

Requirements from costs point of view – The costs for investments in construction, operation and maintenance of overhead contact line systems should be as low as possible for the entire service life. The components and devices should be reliable and require low cost maintenance. The entire system should be designed for a long service life, for these should be adopted, for example corrosion protection measures. Electrical components and mechanical elements have to be easy to install and easy to change when is needed.

For reducing the contact wire wear and the pantograph wear quality and suitable materials combinations should be used; the design stage is very important in this aspect. If it is possible, separate poles for each track should be used. The contact line should be designed so that the periods of line closure for planned maintenance or to repair contact lines and tracks are kept low.

Mechanical requirements – Technical and functional characteristics for power supply lines from mechanical point of view, take into account the strength and quality of the wires, stranded conductors and other elements. To gain reliable interaction from the contact line or third rail and the current collector (pantograph collector, shoe collector, etc.) defined clearances between the contact line or third rail and the rails have to be specified. The height of the contact wire is specified according to the type of railway and field of application. The minimum contact wire height, the maximum contact wire height and the permissible contact wire gradient are all important.

During normal operational activities, the forces in stranded conductors, wires and other components have to be kept within permissible limits. The sag of conductors has not to exceed permissible values for safety of people and operations, also maintenance activities. When the required safety clearance or the minimum clearance is breached, danger situations may arise. Minimum free air space, to energized parts, has to be maintained under all operating conditions, such as different positions due to pantograph moving and different sags, this involves variable heights of overhead lines. The wind and ice loads when this situation appears against the conductors and other elements should not have a negative effect on railway operations.

For uniform and low wear of the pantograph collector strips and the contact wire, these contact wires need to be places at lateral offset to the track centre line, called stagger. All mechanical loads acting on the overhead contact line must be carried by the poles and foundations and transmitted reliably to the subsoil. Deformation of parts such as bending of poles or any incurred resonant vibrations should not affect the transmission of power.

The overhead contact line has to comply with electrical quality criteria for successful power transmission. Quality criteria such as elasticity and its uniformity along the span and contact wire uplift have to be considered. The dynamic quality criteria include the wave propagation velocity, the Doppler factor and the reflection factor. The contact force as a function of the running speed and its standard deviation are also significant quality features. Overhead contact lines, shall also be capable of allowing operation of trains that contact two or more pantographs at the same time.

Electrical requirements – From this point of view significant characteristics are the type of current and the nominal voltage. A principal characteristic for the performance of an electrified line is the capacity of current carried by the contact line system. In comparison with industrial or public distribution systems of power supply, short-circuits occur more frequently in contact line networks. Therefore, the short circuit current capacity of a contact line system is also a determining feature.

In addition, as an obligatory condition, the voltage of the overhead line network has to be maintained within designed limits under all normal operating conditions. The losses during power transmission also have to be maintained within acceptable limits.

Minimizing the effects of frequent faults on railway operations, overhead contact line installations need to be divided into distinct sections. Additionally, it is important that every designed installation allow faults to be quickly and precisely localized. If conductors or other components of overhead contact line installations fail, defined fault conditions should occur which allow a correct determination of the fault condition.

The insulation should be accommodated by associating insulating materials and their design to requirements and by respecting defined minimum air gaps. Protective measures should be effective to avoid exposing any person to the possibility of electric shock.

Important considerations should be taken into account related to impacts against the public energy network, e.g. harmonic frequencies and electromagnetic fields should be as low as possible. The transmission of power through the contact line network can cause interference to adjacent lines of all kinds through inductive, capacitive and galvanic coupling. In direct current railways, extensive measures are necessary to limit current corrosion. Rail-to-earth voltages occurring in operation or under fault conditions may not exceed permissible limits.

Environmental requirements – Power supply systems have to be reliable and to function according with the technical characteristics. One of the most important characteristics is temperature range; this is defined as ambient temperature: -30 °C to 40 °C for Central Europe, -30 °C to 45 °C for Spain, etc. According with standard EN 50125-2 are specified environmental conditions to be accommodated by the design of overhead contact lines. Lateral deflections of contact lines are caused by wind loading, which in turn could lead to the pantograph de-wiring under extreme conditions. For this reason, contact lines have to be designed for particular wind velocities, under which operation are considered. Beyond this, extreme wind loads should not lead to mechanical damage of the contact line installation itself. The magnitude of the wind velocities, upon which the design is based, is agreed with the railway company or authorities or taken from EN 50 125-2.

The ice accretion on contact line has to be taken into account in the design, especially when this phenomenon is frequent. Atmospheric precipitation, aggressive vapours, gases and dust are to be taken into account when determining the electrical values and the life expectancy of components and elements.

Relating to the insulating materials and other elements in the contact line installation, the properties should not be altered by climatic impacts and sunlight other else the operational life cycle could be affected.

3.3.2 Components of overheads contact line system

Overheads contact line system have the principal function to make contact through electrical wires or conductor rails with a sliding current collector, to supply electrical energy to railway vehicles. For this reason, it is frequently named Overhead Contact Line System. The contact line is considered to include insulators and these are classed as being part of the electrical system in contact with high voltages.

Overhead contact line systems include:

- All overhead contact line conductors and wiring, including the catenary wire, contact wire, return current conductors, earthed conductors, lightning protection conductors, feeder and parallel feeder lines if these are installed on the same supporting structures;
- Foundations, supporting structures and any other components which serve to hold and support, align and insulate the contact wire and conductors;
- Switchgear equipment, monitoring and protective equipment installed on the same supporting structure as the lines;

The pantograph is a device used by trains to collect necessary current from power supply systems, through the contact line. This collector device presses against the underside of the lowest wire of an overhead line system, the contact wire. The current collector of the pantograph is conductive and the current will flow to the train or tram and back to the feeder station through the steel wheels on running rails. Diesel trains or other kind of non-electric trains could run on these tracks without affecting the overhead line infrastructure. Other types of transmission for electrical power include third rail, batteries, electromagnetic induction, etc.

To get high current, especially for high-speed lines, it is important to keep the contact wire geometry within standardised and defined limits. This is usually done by supporting the contact line as wire, from above, by a second wire known as the messenger wire (US & Canada) or catenary (Europe). This wire approximates the natural path of a wire strung between two points, a catenary curve, thus the catenary is generic name to describe all wires system. This wire is linked to the contact wire at designed intervals, by vertical wires known as droppers or drop wires. The whole system is subjected to a mechanical tension and the messenger wire is supported at railway structures elements, by a pulley, simple link, or clamp.

The contact wire is zigzagged slightly related to the straight track, between successive supports; so, the pantograph will wear evenly. Running when a curve, the wire between supports will made the contact wire to cross over the whole surface of the pantograph, causing an even wear and avoiding the apparition of notches.

For areas of depots only a single wire is used as simple equipment.

At the beginning of overhead line systems, when they were first conceived, current collection was possible and sufficient using a single wire. To enable higher speeds, additional two types of solutions were developed:

- Stitched wire solution that uses an additional wire at each support structure, symmetric on either side of the messenger wire;
- Compound overhead line solution that uses a second support wire – auxiliary line (wire) - between the messenger wire and the contact wire. Droppers are devices which will support the auxiliary wire from the messenger line, and additional droppers support the contact wire from the auxiliary. One advantage for this solution, beside the almost perfect horizontal contact lines, is that auxiliary wire can be constructed of a more conductive but less wear-resistant metal, increasing the efficiency of power transmission.

Dropper wires as main function provide physical support of the contact wire. Nowadays modern systems use current carrying droppers, which eliminate the need for separate wires.

In some cases, there is limited clearance space to provide wire suspensions systems solution – for example in tunnels; in these situations, the overhead contact line as wire may be replaced by rigid overhead rail.

3.3.3 Pantograph

A pantograph is a device that collects electric current from overhead lines for electric trains or trams. The term resides from the pantograph devices for copying writing and drawings.

The purpose of the pantograph is to transfer power from the contact line to the electric traction unit. This transfer of power has to be safe and reliable both in a stationary condition for auxiliary and convenience power and for motive power for the operating traction vehicle. The pantograph consists of a main frame, arm, pantograph head and drive.

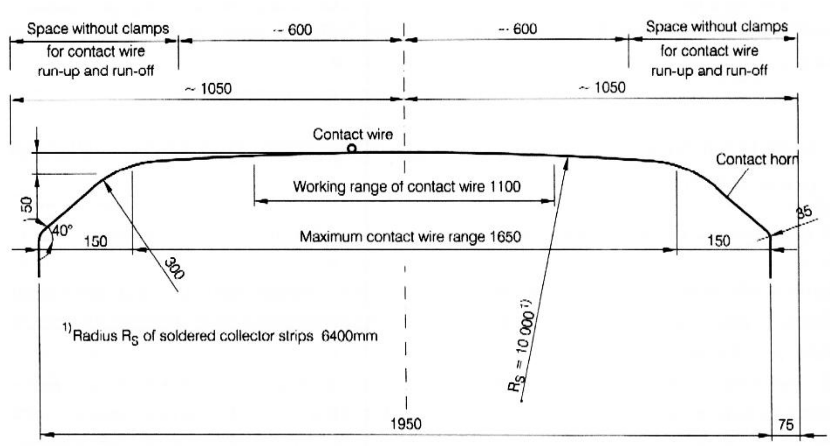


Figure 3.4 - Characteristic values of geometrical interaction of the contact wire and the 1950 mm wide pantograph (8)

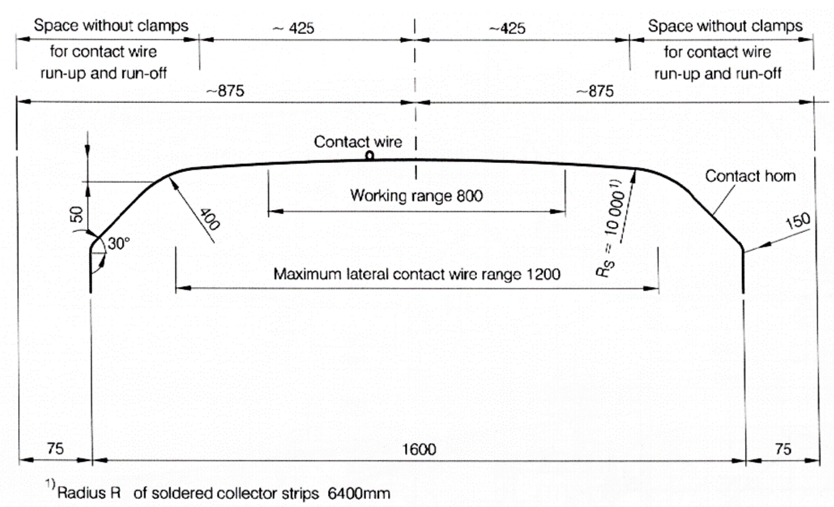


Figure 3.5 – Characteristic values of geometrical interaction of the contact wire and the 1600 mm wide European pantograph (9)

To meet the functional requirements, the lateral ends of the pantograph shall always emerge beyond the most unfavourable position of the contact wire because the overhead contact line will have a zigzag pattern to the direction of pantograph travel. The proper functioning of the system is possible only if the contact wire does not leave the pantograph width of the collector head, during the movement - as an example see the working range of two pantographs on Figure 3.4 and Figure 3.5.

The range between lower and upper working position of the pantograph is considered the working range. The highest and lowest working positions are between approximately 2800 mm and 3000 mm in relation to the upper edge of the pantograph frame.

The common type of pantograph is the so called half-pantograph (shape 'Z', Figure 3.6), which has evolved to provide a more reliable, compact and responsive single-arm design at high speeds. The half-pantograph can be seen in use from very fast trains (ex. TGV) but also for low-speed urban tram systems. The design operates with equal efficiency in either direction of moving, as experimented by the Swiss and Austrian railways with their high performance locomotives the Re 460; this can operate with pantograph set in opposite directions.

Figure 3.6 – The (asymmetrical) 'Z'-shaped pantograph using a single-arm design

The power supply transportation system for railway, synthetic consists of catenary line, from which is suspended the contact wire through vertical droppers. From its construction, the pantograph collector is spring loaded and pushes a contact shoe against the contact wire, to load transmitted electricity for train moving. Steel rails have role to return path of electric signal. During operation, train movement can cause mechanical vibrations at the contact between the pantograph and line and produce large variations of the electrical flow power and, in some situations, interruption for short time of electric contact; these cases lead to strong electromagnetic fields disturbing.

The pantograph is a successor technology for trolley poles which have been used extensively in early versions of the tram; for trolleybuses are still used. The main reasons are greater freedom of movement for the two separate arms but also necessity for the current return paths, that trolleybus cannot provide through the wheels. In some cases, ex. Toronto trolley pole systems are still used for tram cars, because freedom of movement into a network with sharp turns.

Pantographs in contact with overhead wires are the most used solution for current collection on modern electric trains because they allow the use of higher voltages, even if it is more expensive and fragile than a third rail system.

Pantographs are driven by compressed air supplied from the locomotive brake system. This system is used to raise the current collector and pressing on the contact line or when it is lowered for interrupting electrical contact. As a precaution for the pressure loss, when is not active, the arm is held in the lowered position through a mechanical fastening system.

Pantographs are designed as a single or a double arm. Double arm pantographs (see Figure 3.7) are heavier and require more power to be raised and lowered; the advantage is that to be more fault tolerant. For example, for increasing reliability of the contact with overhead line, in the North-east Corridor Branch (New York City – Trenton, NJ), the single arm pantographs was replaced with a more reliable dual arm model Also, on railways of the former URSS, the most widely used pantographs are a double arm. With time, single arm variant is replacing the systems with two arms due to technological improvements.

Figure 3.7 – Symmetrical, diamond shaped pantographs of the Swiss cogwheel locomotive of the Schynige Platte railway

As comparative situations, in Table 3.1 are presented characteristics of traction power supply systems in Europe.

	Characteristics		
Country	Type of power supply	Stagger mm	Pantograph width mm
France			
High-speed lines	AC 25kV/ 50Hz	200	1450 or 1600
Conventional lines	DC 1.5kV	200	1600 or 1950
Germany			
High-speed lines	AC 15kV/ 16.7Hz	300	1600 or 1950
Conventional lines	AC 15kV/ 16.7Hz	400	1950
Austria			
Conventional lines	AC 15kV/ 16.7Hz	400	1950
Denmark			
Conventional lines (2)	AC 25kV/ 50Hz	275	1950
Spain			
High-speed lines	AC 25kV/ 50Hz	300 or 200	1 950 and 1 600
Conventional lines	DC 3kV	200	1950
Netherlands			
High-speed lines	AC 25 kV/ 50Hz	200	1600
Conventional lines	DC 1.5 kV	350	1600 or 1950
Portugal			
Conventional lines	AC 25 kV/ 50Hz	200	1450 or 1600
Italy			
High-speed lines	DC 3 kV or AC 25 kV/ 50 Hz	300	1600
Conventional lines	DC 3 kV	300	1600
Belgium			
High-speed lines	AC 25 kV/ 50Hz	200	1450 or 1600
Conventional lines	DC 3 kV	350	1950

	Characteristics		
Country	Type of power supply	Stagger mm	Pantograph width mm
Great Britain			
High-speed lines	AC 25 kV/ 50Hz	200	1600
Conventional lines	DC 750V or AC 25 kV/ 50Hz	230	1600

Table 3.1 – Characteristics of traction power supply systems in Europe

High-performance pantograph models – In this section is presented the DSA-350 S pantograph with a total mass of 109 kg as an example of high-performance pantograph with a single-arm unit designed for 350 km/h. The main frame has a mass of 52.7 kg including the lifting drive and dampers.

Technical performance:

- Design speed: 350 km/h;
- Voltage/current: 25 kV/ 1000A;
- Static contact force: 50 N to 140 N, adjustable;
- Drive: Compressed air lifting drive;
- Collector strips: Carbon on strip holder made of aluminium alloy;
- Service life at v = 250 km/h: 100.000 km;
- Travel of individual springs: 40 to 60 mm;
- Total mass: 109 kg;
- Materials for main frame: Stainless steel;
- Material for other elements: Aluminium alloy.

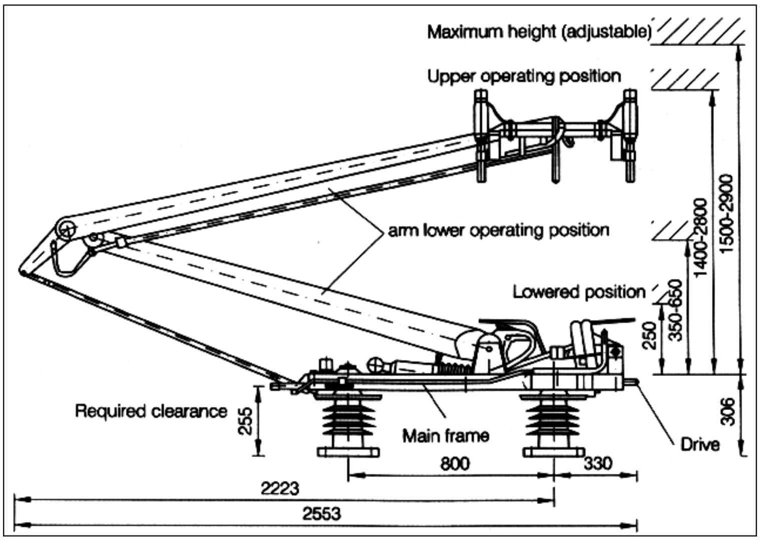


Figure 3.8 – Model Pantograph DSA-350 S – side view

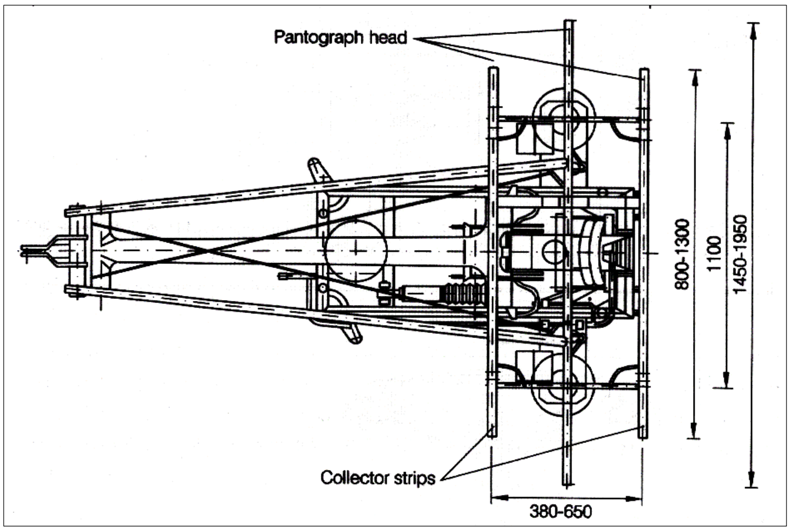


Figure 3.9 – Model Pantograph DSA-350 S – upper view (8)

Lower arm and the control bar have a mass of 34.6 kg, the upper arm and head have 9.1 kg. The two collector strips with holders have a mass of 2.9 kg each. The pantograph head, consisting of collector strip holder, pantograph head guide with horns and collector strips are available for AC 25 kVac/ 1000 A and for DC 3 kVdc/ 2400A. Figure 3.8 and Figure 3.9 present the main characteristic data of this pantograph.

Other performance pantograph model is the one used for the high-speed line Madrid-Barcelona; here, the Siemens Velaro train uses the pantograph DSS 400+ (see Figure 3.10 and Figure 3.11). The pantograph DSS 400+ fulfils the requirements of TSI Energy, EN50206-1 and EN50219.

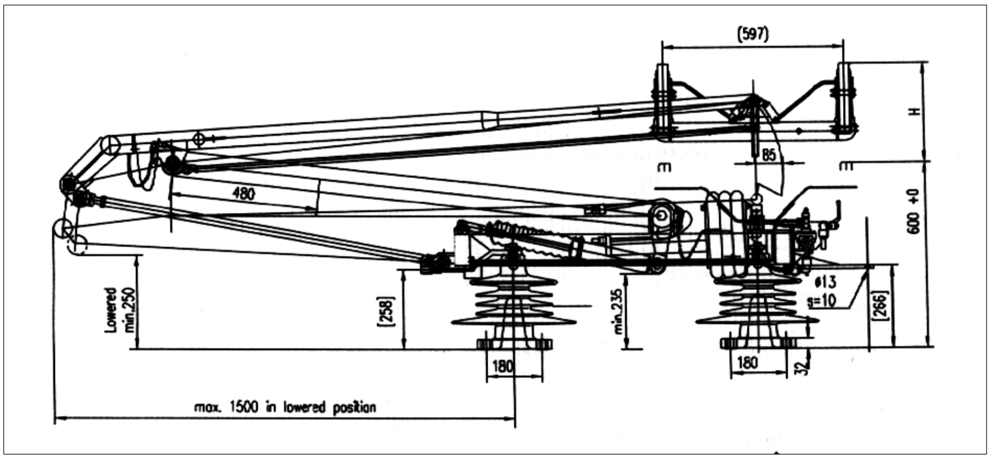


Figure 3.10 – Model Pantograph SSS 400+ – side view

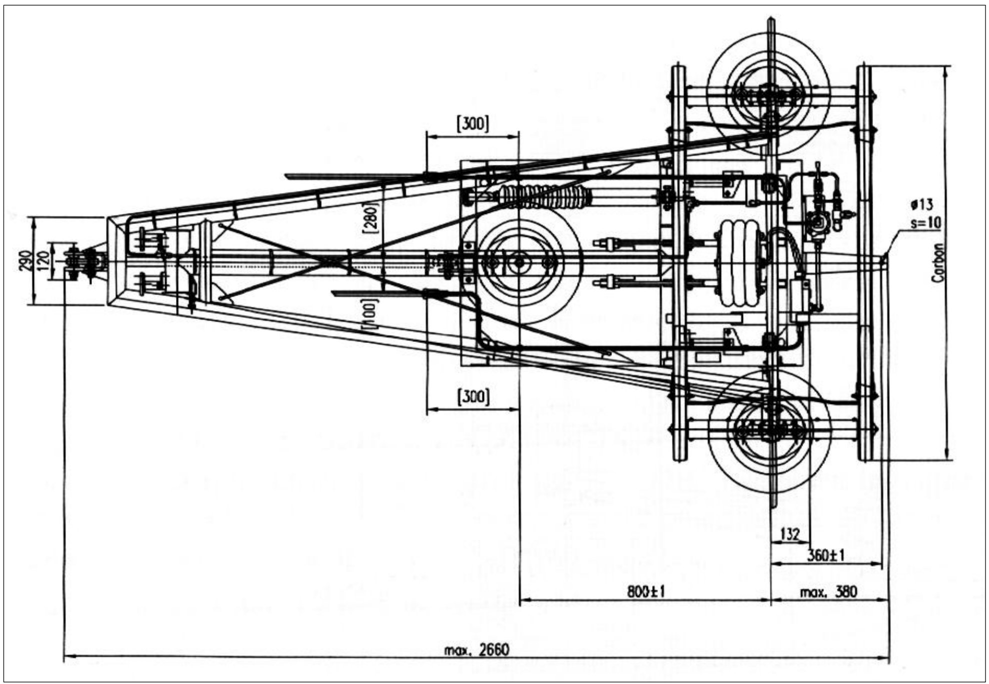


Figure 3.11 – Model Pantograph SSS 400+ – upper view (9)

Technical performance:

- Design speed: 350 km/h;
- Voltage/current: 25 kVac/ 1000 A;
- Static contact force: 50 N to 140 N, adjustable;
- Drive: Compressed air lifting drive;
- Collector strips: Carbon on strip holder made of aluminium alloy;
- Service life at v = 350 km/h: 100.000 km;
- Materials of main frame: Stainless steel;
- Materials of other elements: Aluminium alloy.

Overhead pantographs can be used as alternatives to third rails, even where third rail is dedicated, because third rails present at least two disadvantages: many crossings make impractically the third rail solution and third rails can collect ice in certain winter weather conditions. As other example, the Metro system of Barcelona in Spain, uses overhead wiring and pantographs. The Oslo metro Line 1 changed from third rail to overhead line power due to the many level crossings, where it is very difficult to install a third rail.

3.3.4 Overhead tensioning lines

In electrification railways networks, the contact lines should be at relative constant mechanical tension to prevent pantograph oscillations in the electrical lines. Furthermore, the wave generated by trains at high speed must go faster than the train to prevent the generation of standing waves because this phenomenon can cause the wires to break. Tensioning the line makes waves to travel faster.

When the speed is medium to high, the contact lines and the catenary wires are generally strained by weights or hydraulics tension. This method is known as auto-tensioning (AT), or the constant tension; the tension in the catenary line and the contact line is independent of temperature. Tensions are usually between 9 kN - 20 kN on line. If weights are used, they slide up and down on a rod or tube attached to sustaining poles, to stop movement of the mid-section of the line (see Figure 3.12).

With low speeds and in tunnels, where temperatures are constant, fixed termination (FT) equipment can be used. In this way, the wires terminate directly on structures at each end side of the overhead line. In this applications, the tension is generally about 10 kN.

Figure 3.12 – Example of tensioning line[6]

There is a limitation to the continuous length of overhead line which may be installed, when the auto tensioning is used. This is related to changing in the position of the weights with temperature because the overhead wires expand and contract. This movement is proportional to the tension length, with the distance between fixing points. For most 25 kVac power supply system's overhead line equipment in the UK which uses tensioning process has 1970 m as the maximum length. If balance weights are attached to both ends, the whole tension length will be free to move along the

[6] http://www.wikiwand.com/en/Overhead_line

track. To avoid this issue, a midpoint anchor (MPA), close to the centre of the line tensioning length, restricts the movement of the wire by fixing it. Thus, the contact wire can move only within the constraints of the MPA.

MPAs are anchored in many cases to the typical vertical catenary poles or portal catenary supports. So, a tension length can be seen as a fixed centre point, with two half wires tension lengths, expanding and contracting with temperature.

Most systems from overhead tensioning line category, include a brake suspended to stop threads to gather at every tensioning side or fall on the track when the mechanical tension is lost or the wire is broken for any other reason. German systems typically use a single high tension pulley with a serrated edge mounted on an articulated arm to the mast. In this case the downward pull of the weights, and the reactive upward pull of the tensioned wires, lifts the pulley so its teeth are well clear of a stop on the mast. The pulley can move and turn freely while the weights move up or down as the wires contract or expand. If a contact wire or catenary wire break or tension is lost from other causes, the pulley back falls, toward the mast, and one of its teeth will block the system and will provide the stop of the falling wires. This stops the wheel rotation, limits the damage and keeps intact the not damaged section of the contact and catenary wire, until it can be repaired.

In this case, the weight of the tensioning system is balanced with tension wires and do not touch the gear of lock wheel. If the contact wire is broken or nominal tension is lost from different reasons, tensioner wheel falls back to supporting mast and one of his teeth will block unwanted rotation. This lock limits damage and keep intact a portion of the wire until it can be repaired.

3.3.5 Electric multiple unit

An electric multiple unit or EMU is a multiple unit train consisting of self-propelled carriages, using electricity as the motive power. An EMU requires no separate locomotive because the electric traction motors are incorporated within one or more of the carriages.

Most EMUs are used for passenger trains, but some have been built or converted for specialised non-passenger roles, such as carrying mail or luggage, or in departmental and maintenance use, for example as de-icing trains.

EMUs are used frequently on commuter and suburban rail networks, due to their fast acceleration and low level of pollution. Being quieter than DMUs, EMUs can operate later at night and more frequently without disturbing residents living close to the railway section. Also, very importantly, the tunnel design will be economically acceptable when EMU trains are considered, because there is no need to make supplementary facilities for diesel fumes ventilation.

The railway cars that form a complete EMU set can usually be separated by function into four types: power car, motor car, driving car, and trailer car. But in generally, each of them can have more than one function, ex.: motor-driving car has also equipment for power-driving car.

Power car - carries the necessary equipment to draw power from the electrified infrastructure, such as pickup shoes for third rail systems and pantographs for overhead systems, and transformers.

Motor cars - carry the traction motors to move the train, and are often combined with the power car to avoid high-voltage inter-car connections.

Driving cars - are similar to a cab car, containing a driver's cab for controlling the train. An EMU will usually have two driving cars at both its both.

Trailer cars - are any cars that carry little or no traction or power related equipment, and are similar to passenger cars in a locomotive-hauled train. On third rail systems the outer vehicles usually carry the pickup shoes, with the motor vehicles receiving the current via intra-unit connections. (5)

Some of the more famous electric multiple units in the world are high speed trains: ICE 3 EMU in Germany (see Figure 3.13), the Shinkansen in Japan (see Figure 3.14), CRH3 EMU in China, and ED4MKM EMU in Russia.

Figure 3.13 – German ICE 3 EMU (Deutsche Bahn)[7]

[7] Author: Sebastian Terfloth

Figure 3.14 – Japanese JR West Shinkansen Type 500 EMU

3.3.6 Neutral sections

Neutral sections usually represent an earthed section of wire which is separated from the current feeding wires, on either side, by insulating material, e.g. ceramic beads. This is designed so that the pantograph will run smoothly between the two electrified sections.

Electric isolations are necessary to subdivide the contact line installation into different electrical sections or circuits. Dependent upon the operating speed, sectioning devices or section insulators are used for this purpose in stations and at speeds up to 160 km/h. On main line tracks and at speeds above 160 km/h, special insulated overlaps are provided in the overhead contact line.

Neutral sections are designed to fulfil the following:

- Help maintenance process, allowing inspection and repairing when is needed, for sections of the overhead line without to turn off the entire system – this is case of section break;
- Isolates power supply sections from different power supply stations, avoiding mixing power supply characteristics; prevent the risk out of phase supplies mixing – this is case of phase break.

Section insulator - For transition through break section, the locomotive's pantograph should be in continuous contact with the wire. This is accomplished by two contact wires running in parallel to each other over a specified length: a new one dropping down and the old one rising up until the pantograph smoothly transfers from one to the next section. The two wires are not in electrical contact even if the pantograph is briefly in contact with both wires. In normal service, the two sections are electrically connected to different substations with different electrical parameters.

The pantograph may have problems to run through a section break when one side is de-energized. The locomotive would then become trapped, but most dangerously, if it passes the section break, the pantograph will make short circuit with the two catenary lines together. If the opposite line is de-energized, this voltage transient may supply this line. If the line is under maintenance, personnel injury may occur as the contact line and catenary are suddenly energized. Other negative effect is the arc generated across the pantograph which will cause damage to the pantograph and/or the catenary insulator.

In the Figure 3.15 is showed an example of short neutral section with insulation.

Figure 3.15 – Neutral section insulator

Phase separation – On a larger electrified railway it is necessary to power different section of track from different power grids, the synchronisation of the phases cannot be guaranteed, even if they are designed for the same phase.

Another situation is when the sections are powered with different voltages or frequencies. Even if equipment to synchronize these sections electrically is used, on a normal basis but events may cause de-synchronisation. It is recommended not to connect two grids even designed to be synchronised but supplied from different sources. A normal section break is insufficient to guard against this, since the pantograph briefly connects both sections. For this situation a phase separation break technique is used. This means two section breaks back-to-back; so, existing a short section of overhead line that are not connected to any power supplied section. The locomotive will pass from one grid to other not disturbing any one section; this separation will ensure that the two grids cannot be connected to each other.

Neutral sections as phase separation are necessary in the following situations:

- Areas with different energy supply systems, e.g. between DC 3 kV and AC 25 kVac/ 50 Hz or AC 15 kVac/ 16.7 Hz;
- Feeder sections with different phases, e.g. feeder sections in AC 25 kV networks, which are supplied from different phases of the national public power grid. From this situation this neutral section design known as phase separation;

- Feeder sections that can have different phases, e.g. to isolate overhead contact line sections that are fed from de centralised converter stations;
- Continuously earthed overhead contact line sections e.g. under structures against energised overhead contact line sections.

The neutral earthed section have to prevent any arc being drawn from one live section to the other, as the voltage difference may be higher if the live sections are on different phases and the protective circuit breakers may not be able to safely interrupt the considerable current that would flow. As preventive measures against the risk of an arc being drawn when passing the phase separation neutral section, the train must be coasting and the circuit breakers must be open. In many cases, this is done manually by the driver and warning boards have to be installed before the neutral section (see an example in Figure 3.16); a next attention board have to be provided, after the neutral section, to indicate the driver to close the circuit breaker.

In the UK, Automatic Power Control (APC) system, opens and closes the circuit breaker in an automatically way, for these are using sets of permanent magnets alongside the track and communicating with a detector on the train; the driver has to shut off power and coast neutral section.

Figure 3.16 – Neutral Section Indication Board used in UK

Neutral sections are negotiated automatically on French high-speed rail lines and in the Channel Tunnel.

3.4 Third Rail

3.4.1 Overview

Systems from "third rail" category are implementing an older technology that is supplying electricity, required to running a train, through a rigid conductor placed continuously near or between the railroad tracks (see an example in Figure 3.17). It is mostly used in systems for transport passengers, where the system has its own alignment, are separate from the external environment and not interrupted by other networks and transport systems. The conductor rail is sustained with ceramic insulators brackets, at a fixed interval, typically 3 meters

Trains have electrical contact with the contact rail through devices called "contact shoes". The current return path is through the running rails. The rail supply lines are made of steel with high conductivity, and rails must be electrically connected using wire bonds or other devices to minimize resistance in the electrical circuit.

When at level crossings and crossovers, the conductor rails have to be interrupted; ramps are provided at the ends of the sections to give a smooth transition for the train shoes.

Figure 3.17 – British Class 442 third rail electric multiple unit in Dorset; this is the fastest class of third rail EMU in the world, reaching 172 km/h

The contact point between train shoe and the third rail are provided in multiple variants; some of these use top contact but experience has determined that the variants side or bottom contacts are betters. In these situations, conductor rail could be covered and protecting track workers and pedestrians from accidental contact, also protecting the contact conductor from snow and leaf fall.

3.4.2 Technical aspects

Third rail systems provide electric power to a railway train, through a semi-continuous rigid conductor placed alongside or between the rails of a railway track, are used in a mass transit or rapid transit system and are always supplied from direct current electricity

Most railway power supply systems use overhead contact lines, but the third rail can be an efficient solution for voltages lower than 1200 V. The third rail is more compact and a better solution in small diameter tunnels; this is an important condition in the subway systems.

Third rail systems are designed to use one of the next variants related to contact position: top contact, side contact or bottom contact. The top contact is considered less safe while side-contact and bottom-contact can be provided with safety shields. Also, top-contact for third rails are vulnerable to interruptions caused by fallen leaves, ice and snow.

Figure 3.18 – Arc which appear in third rail systems

The electrical arcs occur when the collection shoes of a train drawing power reach the end of a section of power rail (see Figure 3.18).

Mainly the third rail are placed outside the two running rails, but sometimes between the rails. The electric current is transmitted to the train through a sliding shoe, which are in direct contact with the rail. An insulating covering is provided above the electric third rail to protect pedestrians from accidental contact or employees working near the track.

When the running shoe is in contact with the side of third rail is called side running; when is in bottom contact it is named bottom running of the third rail, allowing the protective cover to be mounted to its top surface; when the train contact device slides on top, it is referred to as top running. From experience the shoe slides on the bottom is the best choice it is not affected by the snow or leaves. In Figure 3.19 are presented types of current collector contacts in 3-Rail Traction System and in Figure 3.20 is presented an example for mechanism detail about top contact collector shoe.

As with overhead wires, the return current usually flows through one or both running rails and leakage to ground is not considered serious. Where trains run on rubber tyres, as on parts of the Paris Métro, Mexico City metro, Santiago Metro, and the Montreal Metro, live guide bars must be provided to feed the current. The return path is through the rails of the conventional track between the guide bars.

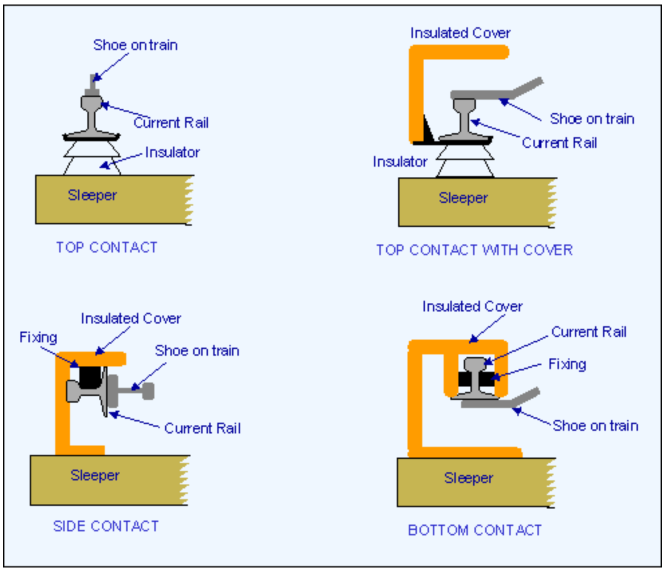


Figure 3.19 – Types of current collector contacts in 3-Rail Traction System[8]

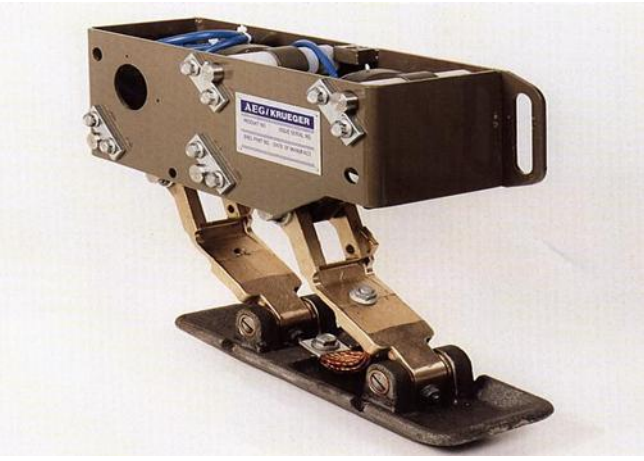


Figure 3.20 – Top contact collector shoe – London Underground – Central Line[9]

Another version of the design shows a third rail outside the running rails, with role of current feed and a fourth rail used for current return and it is placed half way between the running rails; this type is used by a few steel-wheel systems. The London Underground is the largest of these. The third rail could be considered an alternative to overhead lines, but in particular situations.

The third rail system uses a “contact collector shoe" to collect the current on the train based on a top contact third rail system.

[8] http://www.railway-technical.com/etracp.shtml

[9] http://www.railway-technical.com/etracp.shtml

Recently, mechanical or pneumatic systems have been devised to make it possible to lift shoes from inside the train remotely from the driving cab. Side and bottom contact shoes are spring loaded to provide the necessary contact force. The bottom contact shoe, as example, is used on a German metro line.

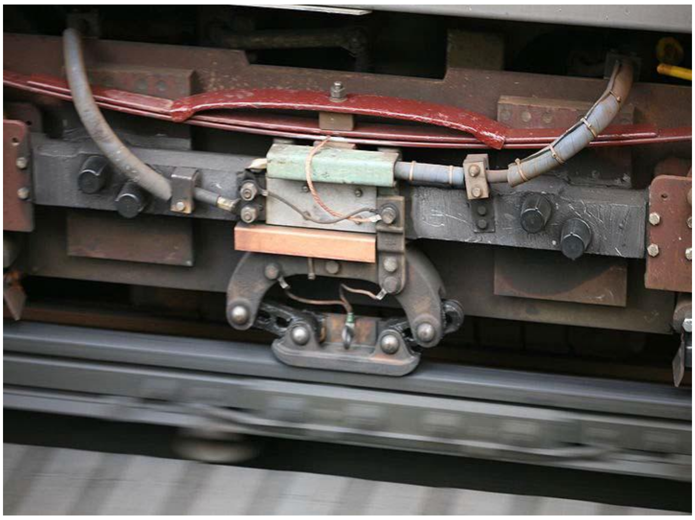


Figure 3.21 – Third rail contact shoe[10]

The third rail must be broken at junctions to allow the continuity of running rails. These third rail breaks, or "gaps", as they are called, can lead to loss of power on the train. Current rail gaps are also provided where the substations feed the line. Each track is fed in each direction towards the next substation and this allows over supply and provides continuity if one substation fails. These substation gaps are usually marked by a sign or a light which indicates the current is on/off in the section ahead. A train must stop before entering the dead section. Today there are more sophisticated systems in use which link the traction current status to the signalling so that a train will not be allowed to proceed onto a dead section.

The choice of AC or DC power transmission system along the line is important. AC is for long distance and DC is for short distance. AC is easier to transmit over long distances being an ideal medium for electric railways. The problems of converting it on the train to run DC motors restricted its widespread adoption until the 1960s. DC was the preferred option for shorter lines, urban systems and tramways and was used on a number of main line railway systems, and still is in some parts of continental Europe The smaller size of urban operations needed trains usually lighter and less power, a heavier transmission medium, a third rail or a thick wire, to carry the power and it lost a fair amount of voltage as the distance between supplies connections increased.

The corrosion is always a factor to be considered in electric supply systems, particularly DC systems. The tendency of return currents to wander away from the running rails into the ground can set up

[10] Author: Daniel Schwen

electrolysis with water pipes and similar metallic. Underground railways adopted a fully insulated DC system with a separate negative return rail as well as a positive rail – the four rail system.

3.4.3 Advantages and disadvantages

Third rail in railway systems is limited in use due to the small tensions can run. Limitation due to relatively small voltages will limit the size and speed of trains and comfort levels; for example, the amount of air-conditioning that the trains can offer. This could be a reason favouring overhead wires and high voltage alternative current, even for urban systems. From testing and experiments, the top speed of trains on third rail systems is up to 100 mph; above that speed, the contact between the shoe and the rail cannot be maintained enough to be stable.

Obviously, traction system based on electricity supply of locomotives, as a principle, is more advantageous in terms of operational costs but also more effective in terms of service quality provided than diesel or steam locomotives. Diesel and steam car units produce energy locally while traction power supply variant produce the same traction energy in remote fixed substations, and send it through the overhead lines to traction units.

For electric power supply systems, taking in account the costs, mainly initial investment cost, third-rail systems are advantageous to install and operate, 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. Third rail system type has much less visual intrusion for environment.

The main disadvantage of third rail systems is that they present the hazard of electric shock because higher system voltages; for this reason, all voltages used, above 1500 V are not considered safe. When voltage is reduced, to compensate, the current into circuit has to be increased; that results in considerable power loss in the system and relatively closely substations for electricity supply are needed.

An electric power supply system for railway could become extremely dangerous for a person that fall into the tracks. This, however, can be avoided using platform screen doors. Also the risk could be easy minimized by placing the conductor rail on one side of the track, away from the platform.

In addition, third rail systems must be fully separated from the route of pedestrians. If it is operated at the same grade, mechanisms that stop people from walking onto the tracks at grade crossings must be implemented. Due to the mechanical technology used at contact point between third rail and current collector the speed for this type of traction is generally lower than overhead line systems. A speed of 160 km/h is considered the highest limit of practical third rail operation. The world speed record for a third rail train is 174 km/h reached on 11 April 1988 by a British Class 442 EMU.

Third rail systems using top contact are susceptible to accumulations of snow, and ice formed from refrozen snow, and this can interrupt operations. Some systems operate with dedicated de-icing trains to deposit an oily or glycol based anti-icing fluid on the conductor rail to prevent the accumulation of ice.

A special situation happens at level crossings and railroad crossings. In this section it is possible for a train to stop in a position in which the running shoe is not in contact with the rail and no traction power is available. The train is said to be "gapped". In these circumstances another train is brought back to push the blocked train over power rail interrupted section until one of his shoes gets back in contact with the third line. One solution to prevent such situations is that way of hauling trains to be equipped with several contact shoes at distance one from other, larger than maximum gap.

Electrical systems for traction using third rail are not obsolete; there are countries - Japan, South Korea, India, Spain, etc. accepting and adopting in particular cases new third rail systems building, especially where small capacity people movements exist. The type of railways where third rail is very rarely used in new systems, is regional and long distance rail, which require higher speeds and higher voltages.

3.5 Fourth rail

There are few networks that use a four rail system, one of them being London Underground in England. The additional rail transports the electric return current; on the third rail and overhead networks this function is provided by the running rails. As an example, the London Underground uses a top-contact third rail, energized at +420Vdc and a top-contact fourth rail is located between the running rails at a negative voltage of −210Vdc so that voltages provide a traction voltage of 630 Vdc. In the figure below the unprotected third rail is at the right of the track and the fourth rail at the centre.

Figure 3.22 – Fourth rail and third rail[11]

The main advantage of the four-rail system is that the running rail carries no current and does not involve problems caused by return currents. Returning current can cause electrolytic damage and

[11] http://www.wikiwand.com/en/Railway_electrification_system

even arcing if the tunnel segments are not electrically bonded together. This problem became major because the return current had to flow through closer iron pipes, nails, etc.

Figure 3.23 shows the London Underground track at Ealing Common on the District line the third and fourth rails are beside and between the running rails

Figure 3.23 – Rail station in London with third rail and fourth rail

Paris Métro in France operate, on few lines, a four rail power supply as they run on rubber tyres which run on a pair of narrow roadways made of steel. The trains are designed to operate at both supply polarities because lines use reversing loops at one end, causing the train to be reversed after every complete journey.

3.6 Combined railway systems

There are systems that use a combination of power supply systems as third rail for part of the system, and overhead catenary system or diesel power engine for the rest of the track section. These compromises are taken because of the connection of separately-owned railways using the different systems, local ordinances and rules, or other historical reasons.

3.6.1 British Railways combining railway systems

On the southern region of UK, freight yards had wire with overhead wiring to avoid the hazards of third rail. The locomotives were fitted with a pantograph as well as pick up shoes.

Several types of British trains have been able to operate on both overhead and third rail systems, including class British Rail Class 313, 319, 325, 365, 375/6, 377/2, 377/5, 378, 373 and 395 EMUs, plus Class 92 locomotives.

In London, the North London Line changes its power supply several times between Richmond and Stratford stations. The route was originally third rail throughout but a number of technical electrical grounding problems, plus part of the route also being covered already by overhead electric contact wires, provided for electrical-hauled freight and Regional Eurostar services.

The cross-city Thameslink service runs on the Southern Region third rail network from Farringdon station southwards and on overhead line northwards from Farringdon to Bedford. The changeover is made whilst stationary at Farringdon.

On the Moorgate to Hertford and Welwyn suburban service routes, the East Coast Main Line sections are 25 kVac, with a changeover to third rail made at Drayton Park railway station. Third rail is still used in the tunnel-section of the route, because the size of the tunnels, leading to Moorgate station, was too small to allow overhead electrification. (5)

The British Rail Class 373 or TGV TMST train is an electric multiple unit that operates Eurostar's inter-city high-speed rail service between England, France and Belgium via the Channel Tunnel and uses overhead collector at 25 kVas for most of its journey, with sections of 3 kVdc or 1.5 kVdc on the Continent. The first models (the Class 373 units) were additionally fitted with 750 Vdc collection shoes so that they were designed for drive in London via the suburban lines for commuter. A switch between third rail and overhead collection was performed whilst running at speed, initially at Continental Junction near Folkstone, and later on at Fawkham Junction after the opening of the first section of the Channel Tunnel rail link. The dual system caused some problems when drivers forgot to switch between modes. Failure to retract the shoes when entering France caused severe damage to track side equipment; for this reason, SNCF installed a concrete block at the Calais at end of the Channel Tunnel to break off the 3rd rail shoe if it had not been retracted. Other case was an accident occurred in the UK when a Eurostar driver failed to retract the pantograph before entering the third rail system, damaging a signal gantry and the pantograph.

On 14 November 2007, Eurostar passenger operations were transferred to St. Pancras railway station and maintenance operations to Temple Mills depot deprecating the requirement for the 750 Vdc, third rail power collecting equipment and leading to its removal from the fleet.

UK South-eastern railway starts to operate internal services from 2009, on High Speed 1 from St. Pancras using Class 395 EMU. These services operate on the high speed line after that transferring to the classic lines to serve north and mid Kent. As a consequence, these trains are dual voltage enabled, as the majority of the routes over which they operate are third rail electrified.

3.6.2 USA combining railway systems

In New York City, electric trains when leaving Grand Central Terminal on the Metro-North Railroad must use the third rail and later switch to overhead lines at Pelham when they need to operate out onto the former New York, New Haven and Hartford Railroad (now Metro North's New Haven Line) line to Connecticut. The switch is made "on the go" controlled from the engineer's position.

In New York City, where diesel engines can be a health hazard in underground stations like Metro-North, the Long Island Rail Road and Amtrak use diesel locomotives but also can be electrically powered by a third rail. This type of locomotive (e.g. P32AC-DM or DM30AC) may transition between the two modes, during operation. Auxiliary third rail traction type is not as strong as diesel engine, so when locomotives arrive at the surface, on open air, switch to running with diesel engines traction, even if third rail system is also available.

In Manhattan, New York City, and in Washington DC, the local ordinances and rules required electrified railways to draw current from a third rail and return the current to a fourth rail, both installed in a continuous vault underneath the street and accessed by means of a collector that passed through a slot between the running rails. When streetcars on such systems entered territory where overhead lines were allowed, they stopped over a pit where a man detached the plough collector and the motorman placed a trolley pole on the overhead.

The Blue Line of Boston's MBTA uses third rail electrification from the start of the line downtown to Airport, where it switches to overhead catenary for the remainder of the line to Wonderland.

3.6.3 Conversion Strategy

Despite various technical possibilities of operating stock with dual power collecting modes, the best technical solution is to achieve full compatibility of entire networks. This is the cause of conversions from third rail to overhead supply (or vice versa).

Three lines from five, of Barcelona Metro network, changed from third rail system to overhead power supply system. This operation was also done by stages and completed in 2003.

The South London Line of the LBSCR network between Victoria and London Bridge was electrified with catenary in 1909. The system was later extended to Crystal Palace, Coulsdon North and Sutton. In the course of mainline third rail electrification in south-east England, the lines were converted by 1929.

The first overhead electric trains appeared on the Hamburg - Altonaer Stadt-und Vorortbahn in 1907. Thirty years later, the main-line railway operator, Deutsche Reichsbahn, influenced by the success of the third rail Berlin S-Bahn, decided to switch what was now called Hamburg S-Bahn to third rail.

Highest voltages used:

- Hamburg S-Bahn: 1200 V; since 1940.
- Manchester - Bury, England: 1200V (side contact).
- Culoz–Modane railway, France: 1500 V; 1925–1976.
- Guangzhou Metro, Line 4 and Line 5: 1500 V.

Simultaneous using of power supply systems - a railway can be electrified with overhead wire system and a third rail system on same time; for example, on the Hamburg S-Bahn between 1940 and 1955. A modern example is Birkenwerder Railway Station near Berlin; this section uses third rail on both sides and simultaneous overhead wire; whole Penn Station complex in New York City is also electrified with both systems. But, such systems have problems with the electromagnetic perturbations of the different current supplies types. For this reason, double electrification is usually avoided.

The border station of Modane on the French-Italian Fréjus railway was electrified at both 1.5 kVdc using third rail system for French trains and with overhead wires that provide 3 kVdc for Italian trains. When the French line was converted to overhead contact line, the voltage of the Italian wires was dropped to 1,5kVdc and now run in Modane with 1.5 kVdc having half of their nominal power.

3.6.4 New technologies

The introduction of super capacitors has the potential to lower the cost for trains operating on third rail and overhead wires. Kinetic energy generated while braking is stored in super capacitors on board the vehicle. This energy is later used when accelerating. This allows the super capacitors to reduce current draw through the electrical pickup during acceleration, putting less stress on the electrical grid. From theory and experiments, claimed peak energy reduction is around 30%.

This technology can also be used for diesel electric locomotives, where 25% to 40% reduction in energy consumption is possible.

Since 2003, Mannheim Stadtbahn in Mannheim, Germany has operated a light-rail vehicle using electric double-layer super capacitors to store braking energy.

A number of companies are developing electric double-layer super capacitor technology. Siemens AG is developing mobile energy storage based on double-layer super capacitors; also the Cegelec Company is developing an electric double-layer capacitor-based as energy storage system.

4 New trends and technologies in building, develop and operate installations of railway power supply systems

4.1 High performance Overhead Power Supply Systems

Described here are the most representatives and high performance existing overhead contact lines systems

4.1.1 Overhead contact lines for 3 kVdc

4.1.1.1 DC 3 kV overhead contact line for the Moscow-St. Petersburg line

This line is named "The October Railway" (OEB) and have operating the distance between Moscow and St. Petersburg on DC 3 kVdc; maximum speed is stated to 200 km/h. This line is one of the most used tracks in Russia. Two steady-arms guide the contact wires with a spacing of 40 mm and a suspension insulator attaches the catenary wire to the cantilever, which consists of angle sections. The cantilevers are mounted predominantly on concrete poles on inter station tracks, which also support telephone and signalling lines. Pulley-wheel tensioners compensate for temperature induced wire length changes of both catenary and contact wires. The insulators used also suitable for 25 kVac operation. OEB also uses portal structures in addition to flexible head-span equipment in station areas. Concrete poles support the lattice portal and the lower cross-span wire fixes the contact wire supports at the portals. (9)

4.1.1.2 Direttissima Rome-Florence

The 238 km long high-speed line operated by the Italian State Railway (FS) completed in 1991, the Direttissima Rome-Florence, is operated at 3 kVdc and a maximum speed of 250 km/h (see Figure 4.1). On the southern section of the line, the contact line system consists of one catenary wire and two contact wires. Stitch wires are not used in this design. The catenary wire is tensioned at 27.5 kN and each of the contact wires at 15 kN. Pulley-wheel tensioners with two pulleys compensate for temperature induced wire length changes to both catenary and contact wires in this section. The contact line system on the northern part of the high-speed line consists of two copper contact wires Cu AC-150 each tensioned at 15 kN and two 160mm^2 cadmium – copper catenary wires each tensioned at 15 kN.

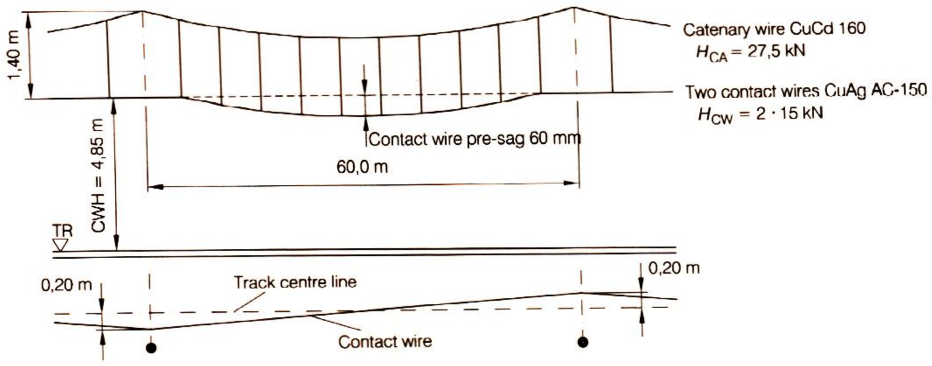


Figure 4.1 - Layout of DC 3kV overhead contact line for the Direttissima Rome-Florence, Italy

Portal structures support tensioning devices above the contact line. Pulleys guide the wires out of the portal.

Tensioning equipment is used to tension the catenary and contact wires separately. Three span overlaps provide contact line transitions.

Hinged tubular cantilevers support the contact line. Steel wire ropes are usually adopted as top ties. Drop posts made of galvanised lattice steel mounted on the portals support the cantilevers. Portals are predominantly employed. A hinged joint is used to attach the portal to the foundation transmitting only vertical and horizontal forces to the foundation but no moments. (10)

4.1.2 Overhead contact lines for 1.5 kVdc

4.1.2.1 1.5 kVdc network at SNCF in France

The French State Railway (SNCF) operates almost a 6 000 km track network at 1.5 kVdc (see Figure 4.2). Compound contact line equipment consists of a catenary wire, auxiliary catenary wire and two contact wires, predominates on main lines and are presented in Figure 4.2 (a); stitch wires are not employed.

Secondary lines are equipped with a simple or light catenary system as shown in Figure 4.2(b).

The maximum span lengths are 63m on straight track. Pulley-wheel tensioners with a gear ratio of 1:5 are mainly used. Single H-beam steel poles carry the contact and catenary wire supports.

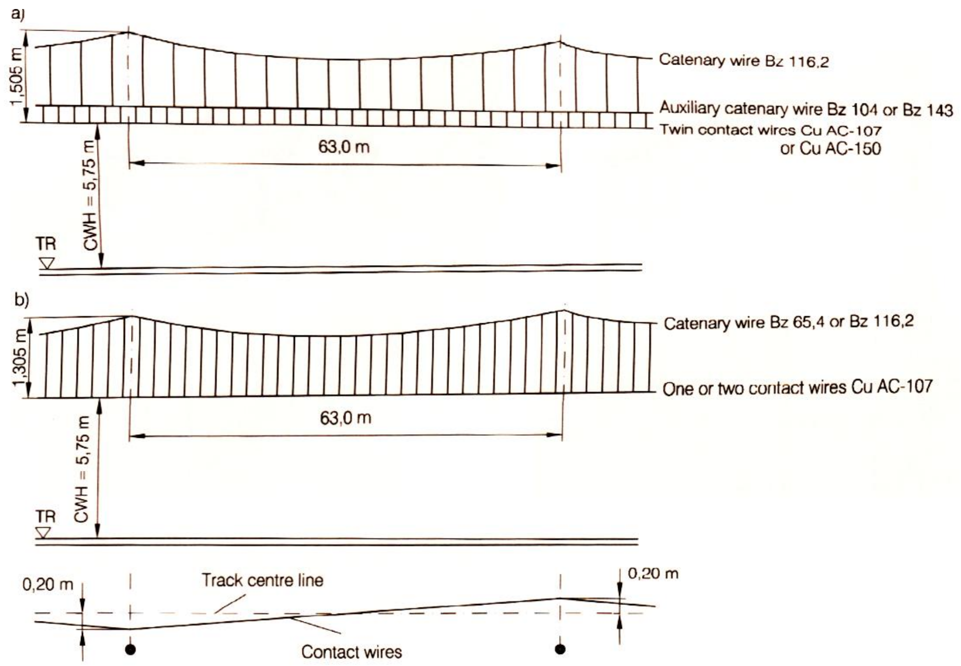


Figure 4.2 - Layout of the SNCF DC 1,5kV overhead contact line system. a) Normal or reinforced overhead lines for main lines; b) light and normal overhead contact line for secondary lines

4.1.3 Overhead contact lines for 15 kVac/ 16.7Hz

4.1.3.1 German Railway (DB) Power Supply System

Electrical power generating for railway power supply - Power supply system for Deutsche Bahn (DB) has characteristic by single-phase current AC 15kV and 16.7 Hz frequency. The necessary energy is generated in 12 hydroelectric and 12 thermal power plants and used 10 converter stations. At the end of 2006, 2676 MW of power was installed to supply the central network, of which 1325 MW was generated in thermal power plants, 344 MW in hydroelectric power plants, 1007 MW in central converter stations and 368 MW in the decentralized network.

The largest 16.7Hz single-phase generator is installed in the joint nuclear power plant at Neckarwestheirn and produces 187.5 MVA. The pump storage plant in Langenprozelten with two 16.7 Hz single-phase generators of 75 MW each, used to cover peaks load in the power supply network.

Electric current at 16.7 Hz is generated and then transmitted into the central network of the DB via the 110 kV overhead power lines. Furthermore, the power of 110 kV voltages is sent to at least 150 substations; now, the 110 kV overhead line network of the DB means a line length of at least 7000 km. At Haltingen and Singen, three coupling transformers are used to connect the 110 kV systems to the 132 kV traction power networks of the SBB (Swiss National Railways). In Steindorf and Zirl the 110 kV from DB network is connected directly to 110 kV network of the OBB (Austrian National

Railways). Because it is operated as a resonant earthed system, 12 arc suppression coils of 100 A each, compensate for the line capacitances.

A part of the 110 kV overhead line runs beside the main lines of the DB to supply the individual substations, which are designed as node-type substations or as simple block-type substations. (6)

4.1.3.2 Standard substations

Function and types of standard substations - As standard definition, substations are electrical installations with transformers, switchgear, control equipment, metering; also, substations include protection and signalling facilities with the necessary instrument transformers. With these, it is possible to switch circuits on and off as required; to switch off faulty equipment and selectively or to isolate it for maintenance purposes.

With the DB, substations, switching posts and coupling posts for single phase AC 15 kV; 16.7Hz are designed in accordance with DB directive 995.

DB's standard substations are in operation with no permanent staff and consist of standardized components with standard interfaces, which can be put together and rated in a modular manner according to functional requirements.

The standard substation types:

- **Substations (SS) with equipment for 110 kV and 15 kV.** This type of station converts the 110 kV nominal voltage from the transmission line network with frequency 16.7 Hz, to the 15 kV nominal voltage of the overhead contact lines. They distribute the traction power to the individual feeding branches.
- **Switching stations with only equipment for 110 kV.** They are used to connect and branch the 110 kV electrical traction lines.
- **Switching Posts (SP) with a several 15 kV supply branches.** Switching posts connect the overhead contact lines and feeders of several railway lines and supply overhead contact line sections supplied from one end with 15 kV power.
- **Coupling Posts (CP) with one 15 kV circuit breaker only.** These railway installations connect two feeding sections and are used especially in cases of long distances between substations or long sections fed from one end to guarantee safety and protection in functioning.

The standardized interfaces and components enable using, achievement and development of functionally equivalent equipment of various manufactures. Old generation substations still contain pneumatically operated circuit breakers, control, signalling, and protection technology with mostly mechanical relays.

A substation could have several branches: traction power supply lines, transformer and longitudinal isolation branches or block branches which are chosen according to the local requirements from standard branch types. A typical block-type substation plan view is shown in Figure 4.3.

Standard specifications for the electrical, mechanical and geometrical design are intended to help achievement and interchange ability of equivalent types of equipment from different manufacturers.

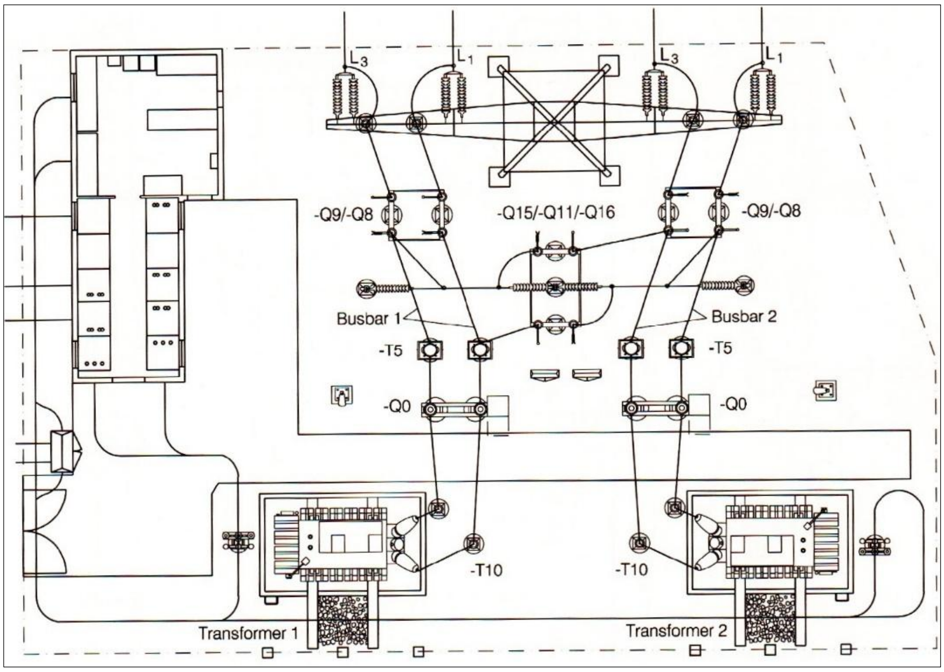


Figure 4.3 – Substation - Plan view

For outdoor installation the 15 MVA single-phase oil transformers is used; the transformers are insulated against earth and earthed by tank leakage protection transformers.

In DB substations and switching posts the equipment are arranged in two rows of steel racks with a centre passage, protected by doors from steel and an anti-arcing ceiling. To detect short-circuits the main frame and the steel rack are insulated from the building and earthed through a rack current transformer with a transformation ratio of 1.000 to 1. A typical substation and switching post is shown in Figure 4.3

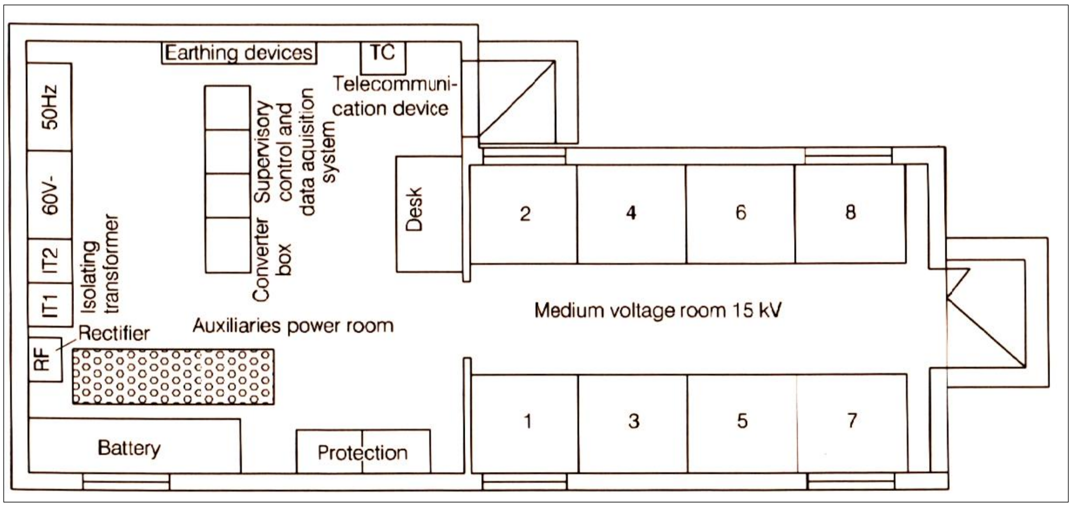


Figure 4.4 - Substation and switching posts – Arrangements for medium voltage and secondary technology

50 VA voltage transformers are used to monitor overhead contact line and bar voltages, in coupling posts and switching posts. High-voltage fuses are installed upstream of the voltage transformers. To limit the current during overhead contact line testing, a high-voltage resistor is installed in the test branch, which is protected by high-voltage fuses started by signals level. (11)

4.1.3.3 Auxiliary supply for substation

Main purpose of the auxiliaries' power supply - Figure 4.5 **-** for substations and switching posts is to separates the supplied equipment into two or three groups according to their importance to maintain the functional capabilities of the equipment and so the electric traction operation. The first group consists of equipment that can be disposable for brief periods: Panel 1 - Figure 4.5. This group includes lighting, the power sockets and heating. The second group includes continuously required equipment such as protection, SCADA and the equipment drives.

Equipment requiring AC 230 V without interruption such as transmission device carrier frequency modulators PLCT, disconnections devices and electric signals of emergency neutral sections are supplied with a nominal voltage of 230 V by an additional AC 230 V /50 Hz distribution Panel 3. The fail-safe voltage for Panel 3 is provided by DC/ AC inverters that are supplied with DC 60 V from the fail-safe voltage of Panel 2.

A special case is the auxiliaries' supply at coupling posts, where the 15 kV voltage of the overhead contact line is transformed to the required voltage by auxiliaries' transformer and the battery is charged by separate rectifiers.

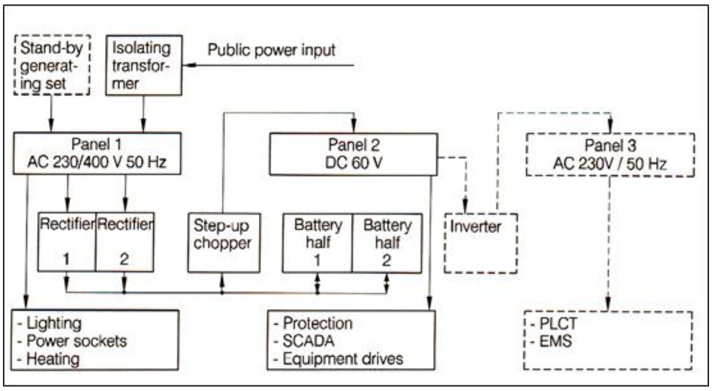


Figure 4.5 – Substation and switching posts – Schematic diagram of the auxiliary's supply (continue line – contained in every installation; interrupted line – installed only required)

The isolating transformers are range from 10 kVA to 40 kVA; these are depending by the substation size and provide supply protection and interference isolation from the local AC 50 Hz network.

Panel 1 can have a connection for an additional stand-by generator unit, which would be provided if the local network failed for more than five hours.

Protection Design – Coupling posts benefit from overhead contact line protection. In switching posts, the general protection is supplemented. Block substations have additional transformer protection. The switching stations, without transformers, only overhead power line protection is used. All other substations are equipped with general protection, overhead contact line protection, transformer and traction power line protection.

4.1.3.4 Supervisory control and data acquisition system

The supervisory control and data acquisition system (SCADA) is a central system for control of switchgear, automation of switching operations, processing signal and measured values, data transfer in substations. SCADA was used in the mid-1970s as a recording system and has been developed becoming a multifunctional substation control system with data display technology.

The SCADA consists of the following functional parts: Local control; Automation components; Signal and measured value processing; Digital meter monitoring and processing (DMM); Remote control system; Interlocking.

Local control was used until 1993 in aspects the form of push buttons on the front panel of the control cubicles. The data are displayed through TFT monitors with full graphics in window technology.

Numerous additional functions such as securing, locking, storing, acknowledging, adoption of responsibility, the fault reporting list, the operational reporting journal, general inquires and parameter adjustment facilities enable dialogue between the operator and the SCADA.

The following are the automatic operation and reduce the work of the operating personnel:

- Automatic overhead contact line testing (ACLT);
- Automatic overhead contact line reverse polarity testing (ACLRT);
- Automatic overhead contact line re-closing (ACLR);
- Automating of emergency neutral sections (AENS);
- 15 kV and 110 kV automatic synchronising device (ASD).

Automatic overhead contact line testing (ACLT) verifies that the overhead contact line branches are free from short-circuits, before the circuit breaker is switched on and off, this is done after every activation of an overhead contact line protection unit.

Automatic overhead contact line residual voltage testing (ACLRT) checks the residual voltage of an overhead contact line branch, when a command is issued to close an earthed disconnector.

Automatic overhead contact line re-closing (ACLR) used in standard substations, without test branches automatically, re-closes the corresponding circuit breaker after a protection unit has responded.

Automating of emergency neutral section (AENS) controls the disconnectors and electric signals of the neutral section located in the network of the DB. They are dependent on the switching state of the feeding circuit breakers and disconnectors.

Automatic synchronising device (ASD) verifies the synchronising conditions before enabling the on command for the circuit breakers. These include the phase synchronization and equal amplitude, considering permissible voltage differences caused by different line loads.

4.1.3.5 Supporting structures involved

The standardised buildings, used to house the 15kV substation equipment and the secondary components are constructed of prefabricated parts with integrated thermal insulation, i.e. sandwich design, on strip foundations and a concrete slab. The reinforcement of all concrete parts including the prefabricated roof is connected via earthed rods to the foundation earth electrode creating a Faraday cage. The short circuit current capability of these earth conductors is 40 kA for a duration time at maximum 1 s.

The foundation earth in switching posts is connected through the main potential compensation bar and earthed cables. In substations the foundation earth is connected to return conductor cable from the main tracks.

The individual rooms are separated by fire walls and fire prevention doors. The 15 kV room is designed for a positive pressure of 0.16 Bar and is equipped with ventilation flaps for air pressure compensation and temperature. Tubular openings are used for the entry of the cables. A sandwich floor is used for laying cables within the building. The room for the secondary equipment, known as the auxiliary room, is equipped with forced ventilation above the battery.

Switching stations for 110 kV do not have a 15 kV section; the minimum permissible room temperature in unmanned units is 5 °C in the auxiliary power room and -5 °C in the medium-voltage room.

Related to 110 kV outdoor switching equipment in substations are used galvanised equipment supports installed in sheaths of standardised round or block foundations made of cast concrete or of prefabricated parts. The type of foundation also depends on the subsoil conditions. Standard arrangements for 110 kV branches and required clearances are specified by DIN VDE 0101 and EN 50110. The transformer foundations in the substations, which must bear a mass of over 50 tonnes, are equipped with an oil drip tray, the level of which is constantly monitored. They are located at a loading rail or at a substation road suitable for heavy transport.

The earth of all structural steel components and the ball earthed components is carried out by the mesh electrode connected in substations to the neutral bar cubicle.

4.1.3.6 Development, functions and design for power system control:

The power system control of the DB includes the total of all technical equipment used for the operation of the traction power and overhead contact line networks, also for equipment used for operation in substations, converter stations and power plants. Its design and principle functions are related to traction power feeding via overhead contact lines, the unmanned substations and the increased requirements for safe and economic operation.

The control system develops a central strategy and today includes the entire network of the DB. The control system functions: Control of the 15 kV disconnectors of the overhead contact lines; Control of the 15 kV circuit breakers and disconnectors in substations; Control of the 110 kV circuit breakers and disconnectors in substations; Telephony services; Transfer and processing of information on the state of equipment; Recording of measured data; Remote diagnosis.

Remote control includes telephony for communication between the maintenance personnel or switching inputs request, etc.; that means, in some cases, hundreds of kilometres distances. The operating facilities are, therefore, equipped with railway-owned telephones and intercom connections. Important installations such as substations and switching posts are connected with the control centres through permanent lines or dialling connections.

The quantity of information and the rapid intervening on running processes require suitable transfer media to ensure data transfer at high speed. The integrated network (IN) and CIR-NET – Computer Integrated Rail Road Network, of the DB are increasingly adopting optical fibre technology to achieve high transfer data rates. The master control centres (MCC) provide control and signalling for 15kV equipment. In transmission control centres (TCC) and network command centre (NCC) only the 110 kV control and signalling transfer is processed.

Remote control technology of the SCADA – The remote control modules of the supervisory control and data acquisition (SCADA) are permanently integrated components.

The transmission of information is carried out with priorities. Protection activation signals have precedence, e.g. before measured values. The extensive additional information provided by digital protection equipment can be transmitted to the processing centre at periods of time. Useless information such as spurious signals caused by relay contact bounce is suppressed and are replaced by a fault signal when this situation occurs. The mechanical loading exerted by the pantograph on the overhead contact, its proximity to railway traffic, heavy electric load fluctuations of starting trains etc. makes perturbation events more frequent in comparison with the transmission lines of public utilities. For these reasons, special requirements must be implemented on the remote control system as part of SCADA to avoid transmissions interruptions.

Master control centres (MCC) – Have the role to control entire 15 kV network, to make protection control and auxiliaries services. The first computer-aided MCC entered regular operations in 1984 in Karlsruhe and complete change to computer technology has been made since 1987 in Berken, Lehrte, Nuremberg, Munich, Cologne and Karlsruhe. In 1993, the first MCC based exclusively on computer technology with full functions was opened in Munich.

In its final configuration, the electrified rail network will be divided into the following new MCC areas apart from Munich: Berlin, Berken, Leipzig, Karlsruhe, Cologne, Lohrto and Nuremberg. A MCC contains remote control nodes, the process computer system, three control desks with 6 screens each and a service desk for data and input simulation.

MCC has additional functions which support economic operation with a very large quantity of switch gear. This includes an appropriate visualisation, automatic image displays, measured value statistics, switching programs, simulation, automatic short circuit localisation, data archiving and recordings for short-circuits, interfering overhead contact line currents and control actions. The MCC also contains the remote control substation for the exchange of 110 kV related information with the general control level.

Transmission control and network command centres – For the operation of the network at the 110 kV voltage level, the electrified network of the DB was divided into the four transmission control centres (TCC): Lehrte, Munich, Cologne and Dresden.

For control optimising, the meter values and circuit breaker position signals of the power plants are transferred every minute to Frankfurt/M; also, the substations transmit every five minutes.

The network command centre (NCC) at Frankfurt occupies the highest place in the hierarchy of the power system control of the DB. It controls the use of power from railway owned and external country producers of 16.7 Hz energy by optimised energy import, the distribution of energy through substations and the exchange of energy with the interconnected grid partners: Austrian and Swiss Federal Railway.

4.1.3.7 Overhead contact line model Siemens Sicat S1.0 AC

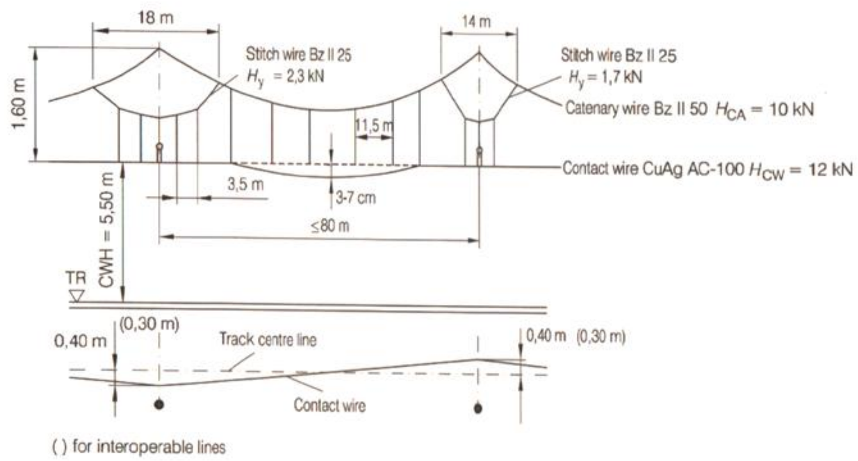


Figure 4.6 - Layout of Siemens overhead contact line design Sicat S1.0.

In Germany Siemens designed the contact line system Sicat S1.0 AC for speeds up to 230 km/h (see Figure 4.6). It consists of a catenary wire Bz 50 and a contact wire CuAgAC-100, tensioned with 10 kN and 12 kN respectively. Stitch wires are used with lengths of 14 m for push-off support and 18 m for pull off support. The system height at single support is 1.6 m. The lines Stendal-Uelzen, Itzehoe-Elmshorn and airport link Cologne-Bonn have been equipped with this design. (12)

4.1.3.8 Overhead contact line model Siemens Sicat H1.0

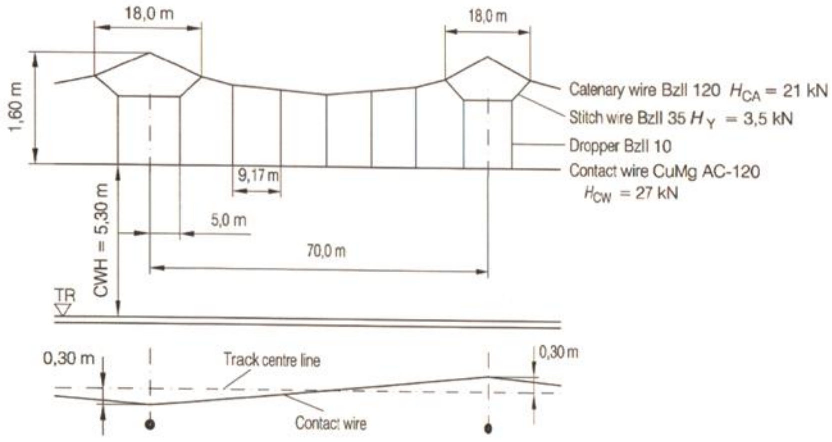


Figure 4.7 - Layout of Siemens overhead contact line design Sicat H1.0.

The Siemens overhead contact line design Sicat H1.0 developed for running speeds up to 350 km/h was first employed for the new high-speed line Cologne to Frankfurt (see Figure 4.7). Compared with the DB AG overhead contact line systems there are some modifications resulting in reduced investment and operating costs, without impairing the running characteristics. (13) (14)

4.1.3.9 Standard overhead contact line at OBB

When the Austrian Federal Railway (OBB) renewed the Otztal - Haiming section on the Innsbruck - Bludenz line, a low maintenance design was achieved using rectangular concrete poles and aluminium cantilevers.

The contact line consists of a 70 mm^2 copper catenary wire and a Cu AC-120 contact wire. OBB implemented the contact line mainly as single-ended tensioning sections with a maximum length of 750 m and equipped with fixed terminations on one end and automatic flexible tensioning devices on the other. The layout of the standard contact line system is illustrated in Figure 4.8.

The parallel feeder line, consisting of ACSR 260/23, is supported on line post insulators at the pole top (see Figure 4.9). OBB uses a flexible head-span design for supporting the contact line in stations. Energised upper cross-span wires and catenary wire supports with droppers are mainly used. The cross-span wires are attached to the rectangular concrete poles using springs.

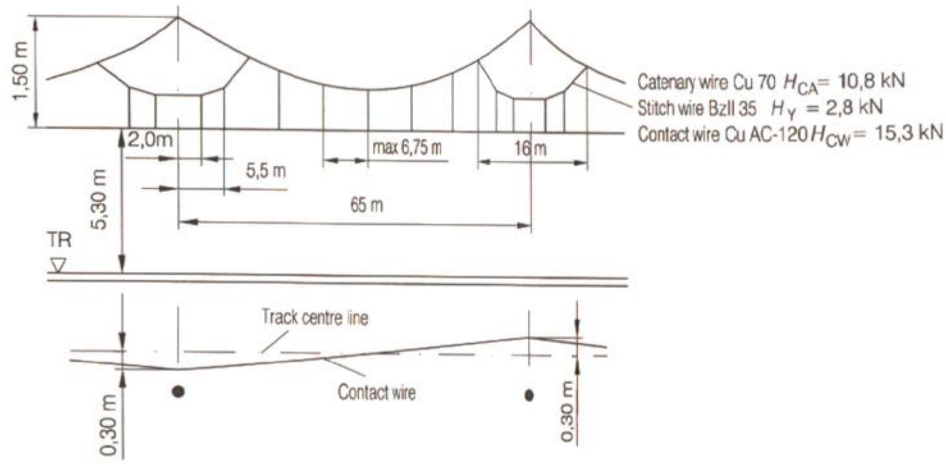


Figure 4.8 - Layout of OBB standard overhead contact line for new lines, Austria.

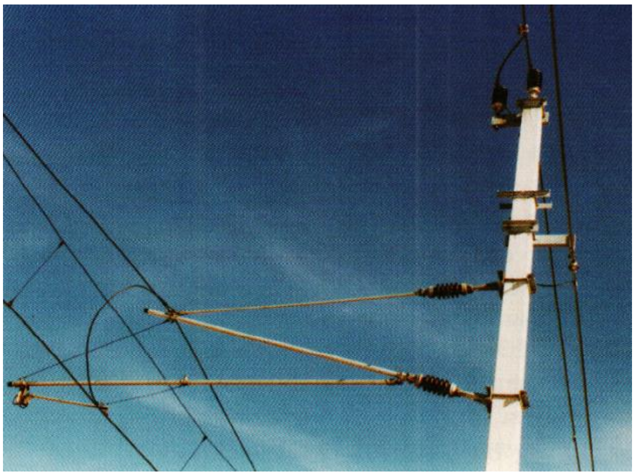


Figure 4.9 - Pole with OBB cantilevers on the Otzal – Haiming section, Austria

4.1.3.10 Overhead contact line designs S20 and S25 at JBV

Norwegian Jernbaneverket (JBV) operates an 15kVac / 16.7Hz network with overhead contact line designs S20 for speeds up to 200 km/h and S25 up to 250 km/h. The S25 system was employed for the high-speed line Oslo-Gardermoen with line speeds up to 250 km/h (see Figure 4.10). This contact line system is equipped with stitch wires.

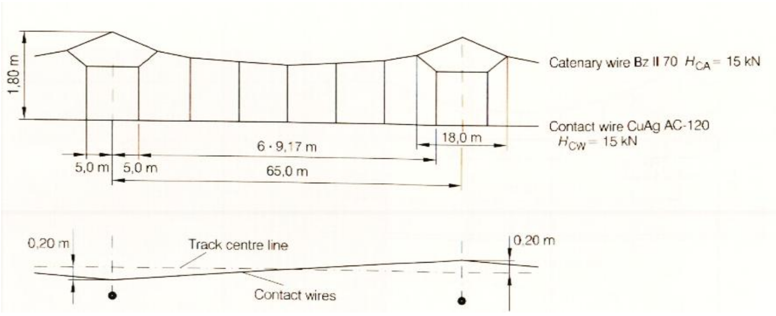


Figure 4.10 - Layout of JBV, S25 overhead contact line design, Norway

Low maintenance cantilevers permit adjustments of the stagger to adapt to track position changes by means of a moveable catenary wire clamp on the top tube. Single poles are most commonly used on the interstation track. Wheel tensioners with a gear ratio of 3:1 separately tension the contact wire and catenary wire. Five-span overlaps are the standard design. Portal structures with solid-wall steel poles in station areas form a modular system that permits adaptation to various cross section widths. (15)

4.1.3.11 Overhead contact line of Lotschberg base tunnel, Switzerland

The 35 km long Lotschberg base tunnel connects the City of Thun in the Bernian Alps north of the tunnel with the City of Brig in the Rhone Valley south of the tunnel. The tunnel forms an essential section of the New Railway Link through the Alps (NRLA) and is part of the European high-speed rail system. It will be traversed by high-speed trains running up to 250 km/h and freight trains hauling trailer loads up to 4 000 t running at 80 to 160 km/h on line gradients between 3,0 % and 1,3 %. This new and attractive connection on rails was conceived to relieve road traffic and provide a more ecologically friendly transport route through Switzerland. The characteristics of the adopted contact line design Re250 LBT- T II (Figure 4.11) correspond to those of the type Re250. The contact line enables the use and operation of Swiss standard pantographs being 1 320 mm and 1450 mm wide as well as that of the 1600 mm wide EURO-pan head. The simulation of the interaction between contact line and pantograph verified that the contact line can be traversed by trains with satisfactory performance operating:

- Two pantographs spaced by 185 m at 275 km/h;
- Two pantographs spaced by 18.5 m at 200 km/h;
- Three pairs of two pantographs spaced by 18.5 m and by 185 m between the clusters;

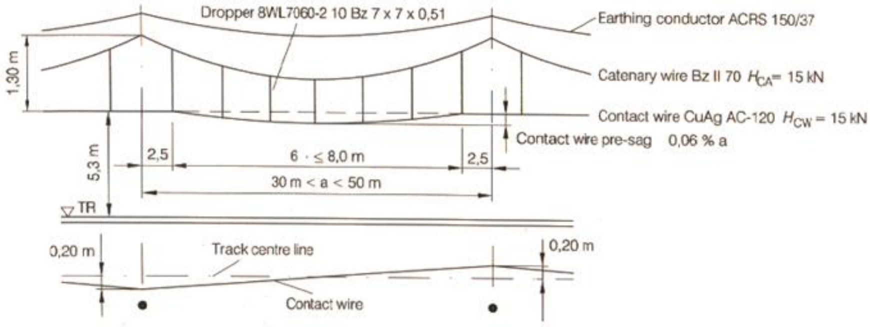


Figure 4.11 - Overhead contact line Re250 LBL-T II at Lotschberg Base Tunnel

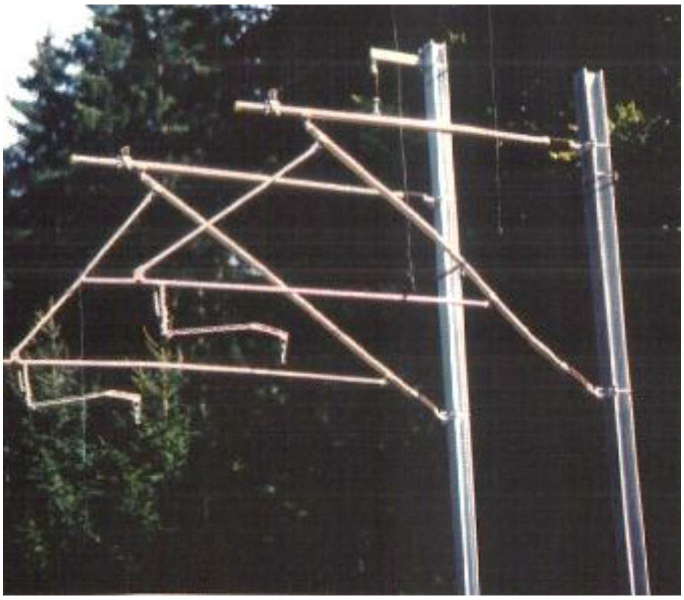


Figure 4.12 - Pole pair in overlaps of Lotschberg-Bahn, Switzerland

The planned traffic, with car and lorry shuttle trains required provisions to adapt the contact wire height to the enlarged vehicle gauge. After conversion, contact wire height and system height will be 5.75 m and 0.75 m, respectively. The span length will be halved such that the length of the droppers will not fall below 0.5 m. The arrangements to parallel and tension contact wires and catenary wires separately are installed 700 m apart and stretch over three spans. The clearance between the contact lines of insulated overlaps is 0.30 m. The current-carrying capacity of the contact line Re250 LBT-T II is 756A with a new unworn contact wire. The cantilevers, having a single arm design, are made from corrosion-resistant material and are equipped with water and pollution repellent composite insulators as security rupture and vandalism (see Figure 4.12). Additional connections bridge the joints in the cantilevers maintaining the mobility of the cantilever also after short circuits. (16) (17) (7)

4.1.3.12 Overhead contact line design BN 160 for the BLS AG in Switzerland

The Lotschberg - Bahn (ELS-Group) improved the infrastructure and power supply on the Bern-Neuenburg line. This included the development of the new overhead contact line design BN 160 shown in Figure 4.13 and its layout in Figure 4.14.

Figure 4.13 - Overhead lines on contact line design BN 160 [12]

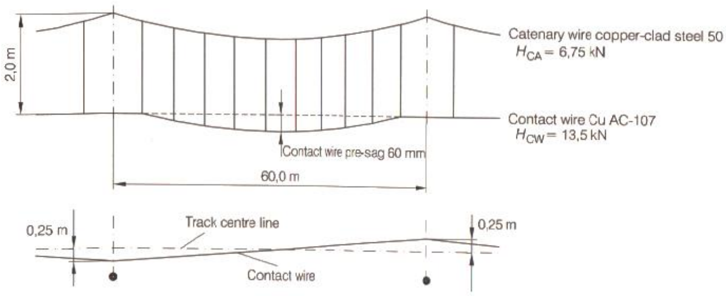


Figure 4.14 - Layout of overhead contact lines BN 160, Switzerland

The overhead contact line consists of a 50 mm^2 copper-clad steel catenary wire tensioned to 6.75 kN and a Cu AC-107 contact wire tensioned to 13.5 kN. The cantilevers can be attached to drop posts on portal structures in multiple-track sections. The cantilever tubes are manufactured from stainless steel, aluminium alloy or galvanised steel, and the fittings from aluminium alloy. The catenary wire support clamp and steady arms are mounted on horizontal tubes to simplify adjustment work. On the interstation track, single poles predominate, allowing electrical and mechanical separation of the contact lines. In stations, the cantilevers are connected to the poles using brackets. This insulation arrangement permits maintenance work to be carried out on poles, parallel lines and the track area lighting without the need to disconnect the overhead contact line. (18)

[12] https://www.flickr.com/photos/chelseagirlphotos/251664372/

4.1.4 Overhead contact lines for 25 kVac/ 50Hz

4.1.4.1 High-speed contact line on the Madrid-Seville line

The Madrid-Seville high-speed line of the Spanish State Railway (RENFE) was completed in 1992 between Madrid and Seville.

At the beginning, starting and ending railway stations where Atocha (Madrid) and St. Justa (Seville), with approximately 470 km long line. Power supply configuration: 8.5 km section, from Atocha, electrified with 3 kVdc, and 12.5 km section electrified from St. Justa. The remaining 450 km of line between the two systems separating sections were electrified with single phase 25 kVac/ 50 Hz and can be travelled at 300 km/h. In 2002, all DC sections were converted to 25 kVac/ 50 Hz power supply.

Two traction power units of 8.8 MW and substations interval less than 50 km are used. This includes the power requirement of the auxiliary loads such as railway stations, point heating and technical buildings of the signal service. The traction power supply of the line is provided by twelve 25 kVac / 50 Hz substations which are powered by 220 kVac and 132 kVac three phase installations from the Spanish public grid. The primary connection of the 25 kVac/ 50 Hz substations to the three-phase network was made to take advantage of the highest possible symmetry of the load for AC circuits.

The overhead contact line design with a catenary wire Bz 70 and a contact wire Cu AC-120 is similar to the DB design Re250. Return current conductors are mounted on the poles to improve the current return. The turnouts and crossovers are wired with intersecting overhead contact lines. Neutral sections separate the sections supplied by individual substations in the case of AC 25 kV/ 50 Hz traction power supplies. Neutral sections were also installed to separate sections supplied by 3 kVdc and 25kVac/ 50Hz from 1992 to 2002 (Figure 4.15).

Figure 4.15 - Madrid-Seville high-speed line, neutral section between DC and AC power supply, Spain

Substations of the Madrid-Seville railway have uniform design. Their general circuit design has similarity with DB's block-type substation.

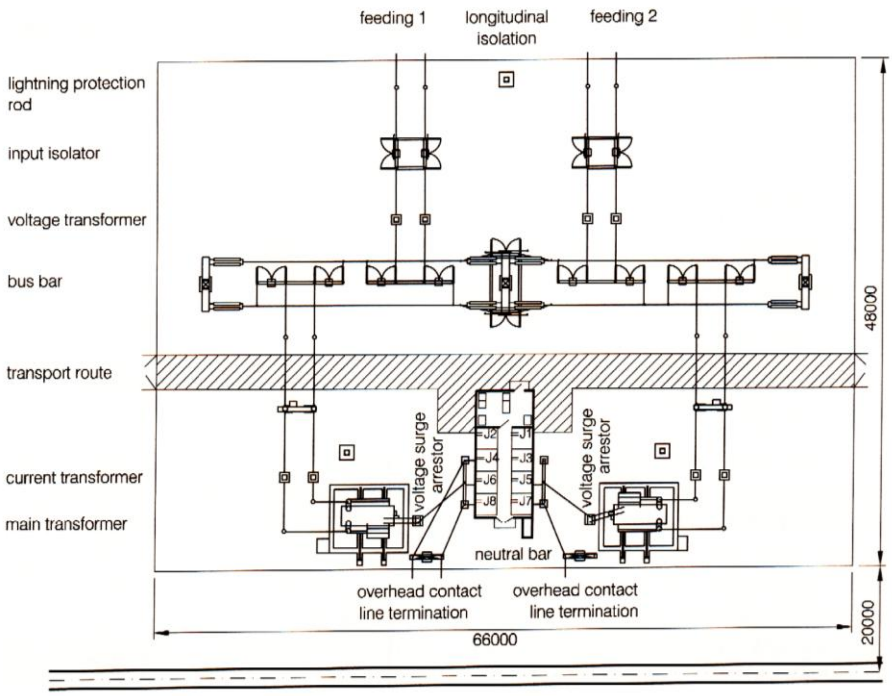


Figure 4.16 - Plan view station for Madrid - Seville railway

The main transformers have a nominal power rating of 20 MVA each and are designed for a load of 150 % for 15 minutes and 200 % for 6 minutes needed operations at nominal power. The circuit breakers are intended for nominal currents of 1600 A and a cut-off capacity of 25 kA. The test resistor allows test currents of 5 A. The auxiliary transformers have a nominal power rating of 100 kVA and simultaneously supply the neighbouring three-phase switch gear with auxiliary power.

Protection design includes the overhead contact line protection, the transformer and general protection in the same way as at DB's block-type substations. Because of the single ended powering it is possible to distribute the power supply with distance protection as part of the overhead contact line protection. The control design is based on substation control and protection system technology as DB (Deutsche Bahn) control but without data displays. Automatic overhead contact line testing and automatic return voltage testing are included as automation components. (19) (3) (4) (7)

4.1.4.2 Overhead contact line on the La Sagra-Toledo branch

The overhead contact line system Sicat H1.0 is used for La Sagra branch of the new Madrid-Toledo high-speed line. The span length is 65 m. On the new line 5300 mm constant contact wire height and 1600 mm system height were used. The overlapping section for the tensioning of individual sections extends over three spans.

The insulators within the cantilevers consist of a composite design with glass fibre reinforced cores and silicone rubber sheds. The fittings of the cantilevers are made of aluminium alloy and connected by stainless steel bolts (Figure 4.17).

Figure 4.17 - Cantilever of the La Sagra-Toledo line

The contact lines are installed on welded lattice steel poles. These are mounted on auger-bored foundations made of reinforced concrete. The connection between the foundations and the poles is carried out by anchor bolts using threaded reinforcing steel bars. (20)

4.1.4.3 High-speed contact line on TGV lines at SNCF, France

The French State Railway SNCF operates about 1840 km of high-speed lines designed for speeds of 300 km/h and above, which are supplied by 1 or 2 at 25 kVac / 50 Hz traction power; Table 4.1 lists these lines. The lines are equipped with four major generations of contact line designs with gradual improvements. The main components like clamps, steady arms, etc. are common to these designs for maintenance efficiency and stock management.

On the Paris-Lyon line a design with stitch wires has been installed. The tensile force of the copper Cu AC-120 contact wire is 15 kN. The line was designed for 260 km/h but has been used in 2009 partially at 270 km/h and 300 km/h.

For the Paris-Le Mans/Tours line the design speed was increased to 300 km/h. Therefore, a contact wire Cu AC-150 with a tensile force of 20 kN was adopted.

Figure 4.19 illustrates a single pole with cantilever and support for the AC 25 kV negative feeder. The design of the contact wire registration permits a contact wire lift of up to 400 mm. H-beam steel poles are widely employed in France. The wheel tensioner with a gear ratio 5:1 provides compensation for the contact wire and catenary wire length variations due to thermal effects and loadings.

Features	Unit	Paris - Lyon	Paris – Le Mans/Tours	Paris – Lille / Calais	Valence – Marseille	Paris – Strasbourg
Length of tracks	km	820	560	660	600	600
Design speed	km/h	260	300	300	300/320	320/350
Contact wire - type - tensile force	- kN	Cu AC-120 15	Cu AC-150 20	CuAC-150 20	CuMg AC-150 25	CuMg AC-150 26
Catenary wire - type - tensile force	- kN	BzII 65 14	BzII 65 14	BzII 65 14	BzII 116 20	BzII 116 20
Stitch wire	-	yes	no	no	no	no
Pre-sag	%	0.1	0.1	0.05	0.05	0.05

Table 4.1 - Major TGV lines and contact line design

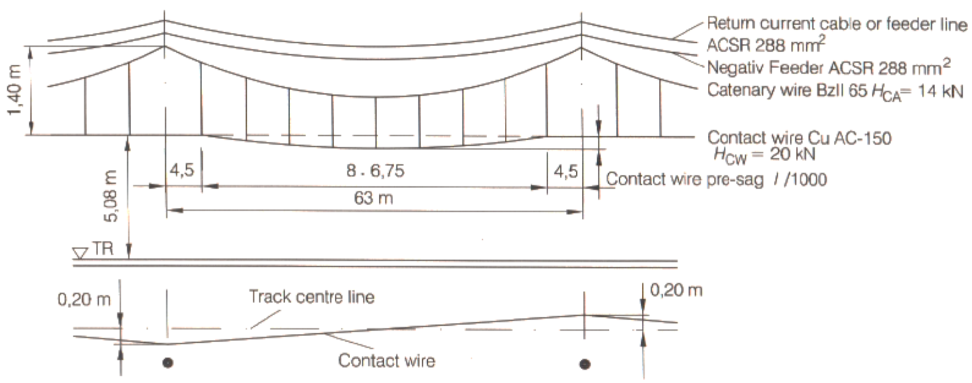


Figure 4.18 - Design of overhead contact line on the SNCF Paris-Tours line, France

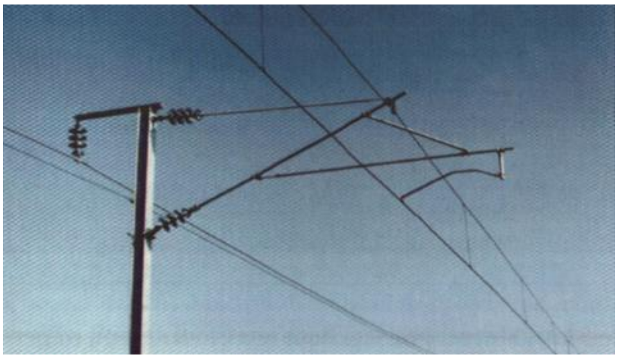


Figure 4.19 - Pole with push-off contact wire support on the Paris-Le Mans/Tours line, France

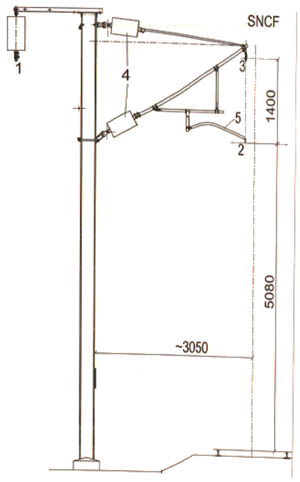


Figure 4.20 - Pole with pull-off contact wire support as adopted on the Paris-Strasbourg line

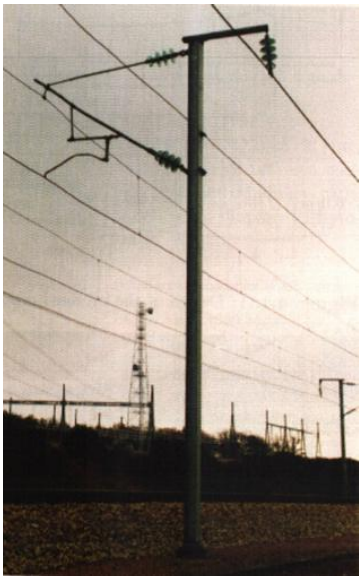


Figure 4.21 - Single pole with pull-off contact wire support on the SNCF Atlantic line, France

On May 5, 1990, a TGV train travelled at a world record speed of 515 km/h on the Paris-Tours line. The overhead contact line design of that line is shown in Figure 4.18 and Figure 4.19.

Figure 4.20 shows a support of the Paris-Strasbourg line, where a contact wire CuMg AC-150 was installed with 26kN tensile force.

On April 3, 2007 SNCF, the Infrastructure Manager Reseau Ferre de France (RFF) and Alstom Transport set a new high-speed world record for railways by achieving 574.8 km/h on the line Paris-Strasbourg. The contact wire was tensioned at 40 kN for the record runs. The modified EMU train V 150, built by Alstom, ran this record under a contact line supplied by 31 kVac/ 50 Hz. (21) (22)

4.1.4.4 High-speed contact line on Tokaido Lines, Japan

The Japanese Railway (JR) moved from the Cape gauge of 1 067 mm used for railways in Japan and adopted the standard gauge for the construction of the Shinkansen. The Tokaido high-speed line, which is operated with a 25 kVac/ 60 Hz traction power supply system, permitted a speed of 210 km/h when it was commissioned in 1964.

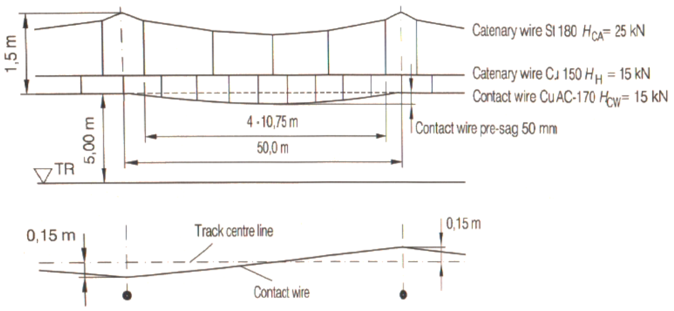


Figure 4.22 - Design of the overhead contact line on the Tokaido high-speed line, Japan.

The compound overhead contact line with an auxiliary catenary wire ensures uniform elasticity (Figure 4.22). The steel catenary wire with a cross section of 180mm^2 is tensioned to 25 kN, the copper cadmium auxiliary catenary wire with a cross section of 150 mm^2 and the hard copper contact wire with a cross section of 70 mm^2 are each tensioned to 15 kN.

One steady arm fixes the contact wire stagger at 150 mm and another fixes the auxiliary catenary wire. Both steady arms are attached to the registration arm. The contact wire height is 5 m. The catenary wire can be moved along the top tube to suit the track geometry. In the case of push-off supports the catenary wire can be moved between the pole and the cantilever end. The pull-off support permits the movement of the catenary wire along a projecting section of support tube. An adjuster plate with drilled holes is located on the top tube to retain the catenary wire clamp and for connection between cantilever tube and top tube.

Damping elements inserted between the contact wire and the auxiliary catenary wire are designed to limit vibrations in the contact line system. The contact wire is attached to the auxiliary catenary wire through the rigid droppers.

While single poles are predominant on the interstation tracks, portals support the con-tact lines in stations. The tensioning section lengths are 1 500 m. Five span overlaps provide transitions between the individual tension lengths. (23) (24)

4.1.4.5 High-speed contact line Sicat HA C on the Beijing-Tianjin line, China

The Beijing-Tianjin high-speed line of the Chinese Ministry of Railways (MOR) with an operational speed of 350 km/h was completed in July 2008. The catenary system in use is Sicat HA C with aluminium cantilever; it is powered by two sub-stations at 25kVac/ 50 Hz; the overhead contact line is equipped with a catenary wire Bz 120. The maximum span length is only 50 m.

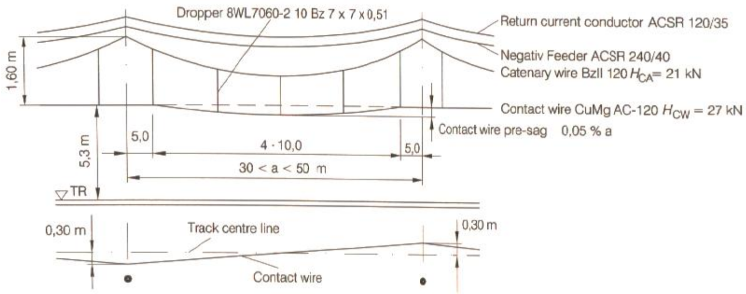


Figure 4.23 - Overhead contact line Sicat HA C for the Beijing-Tianjin line, China.

There are no Y-stitch wires at the supports. The contact wire height is 5300 mm and the contact wire pre-sag is 0.05 % of span length or 30mm (Figure 4.23). The design without stitch wires but with a pre-sag does not provide optimum conditions for high-speed operation. The system height is 1600 mm.

The insulators within the cantilevers consist of ceramic material. The fittings for the cantilevers are made of aluminium alloy and connected by stainless steel bolts. The overlapping section at the ends of individual sections extends over five spans. Wheel tensioning devices with a gear ratio of 3:1 compensates for the contact wire and catenary wire length variations due to thermal effects and loading. The overhead contact line on crossovers uses crossings between traversed contact wires. Portals carry the contact line supports in this case. The cantilevers are installed on H-beam steel poles which are mounted with anchor bolts cast in the reinforced concrete of the 115 km long railway viaduct. The turnouts and crossovers are wired with intersecting overhead contact lines. Neutral sections separate the sections supplied by two individual substations used for traction power supply.

4.1.4.6 Contact line type Re 200C for the Harbin-Dalian line, China (24)

This important railway line connects the cities of Harbin, Changchung, Shengyang and Dalian all having more than one million inhabitants. The line is especially suited for electric operation due to transport of seven million tons of freight and 25 trains per day and direction having headways of 8 to

10 minutes. The design of the adopted overhead contact line type Re 200 C is based on DB's overhead contact line Re200 and is suitable for the local climatic conditions. This is especially true of the temperature range between -40°C and +80°C being more than that of DB's Re200. The main tracks are equipped with a contact wire CuAg AC-100, the secondary tracks with contact wire Cu AC-100 both combined with a catenary wire Bz II50, the tensile force being 10 kN in both cases. The 14m long stitch wire is tensioned to 2.3 kN. Cantilevers and fittings made of aluminium alloy guarantee a long service life. On interstation lines directly embedded steel-reinforced concrete poles are used and in stations steel poles or concrete poles set on concrete foundations, cast in-situ. Reinforcing feeder 243-AL1 and a return conductor 243-AL1 are strung in parallel to the overhead contact line. The return conductor is arranged close to the reinforcing feeder to achieve a close inductive coupling such that a high portion of the return current flows through the return conductor. This reduces the reactance considerably. The magnetic field strength within the contact line area is low due to the return conductor. This reduces the magnetic field strength in the range of neighbouring cable installations and, therefore, the interference. (24)

The permissible current carrying capacity of 1270 A for this type of contact line secures a high power transmission for the transportation of a high number of trains and high loads in the future as well.

4.1.4.7 High-speed contact line type Sicat H1.0 for the HSL Zuid line

The Dutch high-speed line HSL Zuid connects Amsterdam to the high-speed rail system in Belgium. The line has been supplied with 25 kVac/ 50 Hz and will be used at 300 km/h. The line has been equipped with the contact line Sicat H1.0 together with negative feeders and return conductors. The design of the poles had to be adjusted to the design of other structural components - Figure 4.24. (25)

Figure 4.24 - Contact Line arrangement on an interstation section of the HSL Zuid line; 1 - negative feeder; 2 – return conductor; 3 – catenary wire; 4 – contact wire.

4.2 Designing new railway power supply systems – Recommended technical requirements and specifications.

4.2.1 General requirements

The reliability of electric railway operation depends heavily on the availability and reliability of the traction power supply installation. The requirements of the contact line whether an overhead line system or a third rail system need to consider that the contact line is the only component in the traction power supply installation which cannot be installed redundantly for economic and technical reasons.

The required high availability of the contact line system, therefore, necessitates thorough planning as early as practicable in the planning cycle for electrification. It should make use of proven, carefully tested equipment with long service life, correct installation and effective maintenance during operation. The following basic demands must be made on the design of a contact line installation:

- All components of the system should have a long service life. The following specific requirements are therefore important:
    - Adequate mechanical and electrical strength.
    - Resistance to loads imposed by wind and ice and aggressive substances in the air.
    - Corrosion resistance of all components.
    - Uniform, low wear of the contact wire.
- Distribution lines for electric power over a particular distance;
- Provision of a sliding contact for the current collector under all conditions.
- Persons and equipment must not be placed in any danger from the operation of contact lines.
- At all speeds, up to the permissible maximum speed of the contact line type under consideration, the dynamic interaction of the current collector and the contact line or third rail has to ensure that interruptions to power transmission do not occur under normal conditions.
- During the design of overhead contact line installations in built-up areas; aesthetic and city-planning aspects have to be monitored.
- Nature and environmental protection have to be taken into account.
- The investments for the installation and the costs for operation and maintenance should be as low as possible during the life cycle of the equipment.

The individual characteristics derived from these basic requirements of a contact line system, can be classified into mechanical, electrical, environmental, operational and maintenance related aspects, but a strict distinction between the individual requirements is not always possible.

The overhead contact line has to comply with sophisticated quality criteria for successful power transmission. There are static quality criteria such as elasticity and its uniformity along the span and contact wire uplift. The dynamic quality criteria include the wave propagation velocity, the Doppler factor and the reflection factor. The contact force as a function of the running speed and its standard derivation are also significant quality features. Overhead contact lines, shall also be capable of allowing operation of trains with two or more pantographs in contact.

Depending on the purpose of the railway system, the operating conditions and the type of line and track will lead to specific requirements and demands on the contact lines.

The requirements resulting from the operating conditions are a function of the type of transportation required, i.e. system specifications appropriate to low and high density lines, local-area or long-distance traffic, system characteristics according to the traffic frequency and of the mass of the trains using the line. The line and track conditions particularly affecting the contact line design are the track design, the gauge and the geographical location of the line.

Railway traffic density characteristics - As the default, when designing, the long distance line traffic is suitable for freight traffic transportation also, for high speed lines for passengers' transportation. As consequences these lines will be considered as low density traffic. When traffic lines are constructed in local area, especially for high density of population: historical cities, industrial cities, metropolis, etc., distinctions are made between urban railways and metropolitan railway systems according to their main characteristics. These lines designed for short distances but high density of population, will be designed for high density of traffic, especially for passengers' traffic.

4.2.2 Traffic line for low density and long distance

In long distance traffic the railway has to transport trains between stations within a given time and according to a settled schedule. The design for contact line system must be matched to the required traffic volume capacity and density of traffic.

The traffic volume capacity is a measure of the traffic that a railway line can handle and it is defined as the number of trains that actually run on the line within a given period. A train operating activity can be subdivided into the acceleration, steady-speed and braking phases. These phases will be repeated many times but in various sections, depending on the line topography and the train type. The scheduled run, the track condition, the geographical location of the line and operating activities of the train (acceleration, steady-speed and braking) determine the nominal speed for which the respective traction contact line must be designed. In low density traffic, the train speed is one of the essential system characteristics.

The topographic conditions, the required speed and the need of efficiency determine the power to be transmitted via the current collector. During the acceleration phase, the force required to accelerate the train is overlapped on the force required to overcome the motion resistance. Traction vehicles achieve their maximum power at speeds of 80 km/h to 100 km/h due to their typical traction-force/speed characteristics. They can utilize this power either for further acceleration or to maintain a steady speed. The power supply systems and the contact line installations must be able to supply the required power for the planned train traffic.

The maximum train length will affect the length of platforms; will affect also secondary and main lines in stations, the passing tracks as well as protective sections, neutral sections and location of signals. The design of the contact line installation also depends on these factors.

The operating requirements and the power supply systems for long-distance main line traffic are the factors leading to the use of overhead contact lines as traction energy supply installations for railways with low traffic density, capable to provide high energy with high voltage to low density of traction vehicles, in a feeding section. Lines with low density traffic give opportunity to improve the infrastructure for becoming high speed lines.

Electric railway networks have their own track reserves allowing free choice of pole location. To achieve mechanical separation of the overhead contact lines of double-track lines, the poles are placed on the outside edges of the track. In tunnels, the overhead contact line supports can be located above and between the tracks. The track spacing in tunnels affects overhead line design solutions.

As example, the German railway company DB (Deutsche Bahn) use a track spacing of 4.5 m for high speed lines in open air and track spacing in tunnels as different by speed category: 4 m for train speeds up to 200 km/h; 4.5 m for speeds up to 350 km/h. The SNCF uses a track spacing of 4.20 m for high-speed lines.

The super-elevation, which may be as high as 180 mm, the track geometry and the location of switch-points or turnouts are other important factors in the structural design of overhead contact line installations.

The demands on and design of contact line installations of main lines for long-distance traffic and low density traffic is strongly influenced by the desired running speeds. The running speeds, in turn, determine the geometry and topographical location of the railway lines, especially the curve radii and the associated super-elevation.

Trains with tilting bodies permit a further increase of the running speed by 14 % if passive tilting mechanisms are used or by as much as 30 % in the case of active tilting mechanism. If the train speeds in curves are increased, this will have a direct effect on the design of contact line lateral acceptance forces. Traction vehicles with tilting bodies will sense major lateral displacements of the pantographs due to the increased centrifugal forces at higher speeds. This means that the registration of the contact line must be checked and that the lateral contact wire position may need recalibrating; these will influence also steady arms and/ or cantilevers. Alterations to the overhead contact line supporting structures are not needed normally if traction vehicles with tilting bodies and active pantograph controls are used. The maximum gradient is generally limited to maximum 4 % and on future high-speed lines this value will be limited to 3.5 %.

The clearance gauge is of great importance in contact line design since no components of any kind are allowed to exceed clearance into this area.

The independent development of railways in various regions in the past has led to different clearance gauges coded: GA, GB and GC. They have been harmonized by the TSI for Infrastructure subsystem, the TSI for the Rolling Stock subsystem which aim to achieve interoperability of European railways. The smaller GA gauge (Gabarit A) shall be maintained on all lines. For combined road/rail transports, piggyback loads etc., the larger gauges GB and GC have been defined on the basis of specific model loads on special wagons.

The gauge GB is designed to accommodate standard shipping containers. To permit transportation of 2.6 m wide containers instead of the 2.5 m normally used up to now, the gauge variant GB1 has been defined. Another variant, GB2, has been defined for the piggyback transportation of trailer trucks on special low wagons with a floor height of 0.27 m.

Normal trucks and trailer trucks are transported on special wagons on certain corridor lines. The GC gauge has been specifically defined for this purpose. The GC gauge is also required to enable the use of comfortable double-decker passenger wagons on high-speed railway lines. For this reason, all new railway lines for high-speed traffic in Europe will be built with GC gauge clearance.

On the interoperability of the trans-European high-speed rail system on new high-speed lines, on existing high-speed lines, on lines upgraded for high-speed and on their connecting lines, the minimum infrastructure gauge for new structures shall be set on the basis of the gauge GC.

When overhead contact lines have to pass below other structure, an attempt is usually made to maintain the standard contact line height throughout. If the clearance below the structure is to low, first the system height is reduced. If this is insufficient, the contact wire height is reduced to the permitted minimum height. If it is not possible to achieve even this minimum, then construction measures will be necessary, e.g. the bridge must be raised or the track lowered.

4.2.3 Traffic line for high density and short distance

These types of lines are mostly considered suitable for local area traffic where the railway traffic solution can decrease traffic congestions in high populated areas.

The lines of urban railways and metropolitan railway tracks are generally separated from all other traffic. Table 4.2 summarizes the main characteristics of urban railways and metropolitan railway systems.

Characteristics	Urban railway	Metropolitan railway
Vehicle width	2.30 to 2.65 m	2.50 to 3.00 m
Average speed	25 to 40 km/h	> 40 km/h
Reserved track/roadway	mainly	exclusively
Distance between stations	400 to 800 m	500 to 1 000 m

Table 4.2 - Main characteristics of urban railways and metropolitan railway systems

For this reason, urban railways should use overhead contact lines, whereas metros may use conductor rails or overhead contact lines.

The tight, close schedules of traffic, particularly at peak hours, and the low voltage mean that the contact lines must be able to conduct large currents. This is a characteristic of conductor rails.

Overhead contact lines, often installed as simple trolley-type contact wire without a catenary wire, should be designed for new lines as catenary solution, providing the advantages of higher speeds; higher current carrying capacity; better collector running characteristics; less collector strip wear; less dangerous behaviour in the event of contact wire breakage; longer spans.

The use of vertical catenary suspensions is only avoided in areas where aesthetic urban planning and architectural aspects do not permit such systems. Then simple trolley-type contact lines with parallel feeder wires or double contact wires are used instead.

To minimise voltage drops and the associated power loss, the overhead contact lines of both tracks of double-track lines can be electrically interconnected at regular intervals. Remote-controlled coupling disconnectors are installed between the tracks on lines where a single-track, two-way emergency operation is possible if a contact line fault occurs.

On the basis of experience gained with modern over-sized road transports, most urban communities now install overhead contact wires at heights of 5 m to 5.5 m in the open, and approximately 4 m in tunnels due to the restricted space available.

The stagger of the contact wire at the supports is usually ± 0.40 m. To prevent grooves from being formed in the collector strips from localised wear, the stagger variation of the contact wire should be more than 10 mm/m as the collector strip moves along it.

Recommended gradient of the contact wire: should not exceed 5 mm/m, where the track gradient changes from level to an uphill or downhill grade; should not exceed 10 mm/m on uphill or downhill grades;

In an attempt to minimise the overall line width, a central support structure is used wherever possible, for example, the poles are located between the tracks.

In local area lines, the contact lines are mainly fed at both ends via rectifier substations, ensuring adequate distribution of the peak currents when trains are accelerating and braking. The contact line disconnectors and section insulators should be located in the immediate vicinity of the substation to keep the feed cables to the contact line sections as short as possible.

Section isolation installations should be equipped with remote-controlled contact line disconnectors for faster response in the event of a fault.

Occasional overcurrent relay tripping cannot be avoided when trains are run at sight. For this reason, all contact line circuit breakers should be equipped with devices capable of distinguishing between operating overcurrent and short-circuit currents.

With the ever-increasing deployment of traction vehicles able to feed braking energy back into the network, voltages exceeding the nominal traction voltage will occur frequently, meaning that the insulation of the contact line installations must be designed to resist with these increased voltages.

To reduce energy losses and thus to lower operating costs, an increase of the overhead contact line voltage to 750 Vdc is recommended. Transmission losses can be reduced by 5% if the voltage is increased from 600 Vdc to 750 Vdc.

Poles between the tracks are frequently used on lines running on their own reserved right-of-way. Transport systems that use contact rails should always have their own right-of-way.

In high density traffic from agglomerated area, the operating speeds range is from 80 to 100 km/h. The design of the contact line installations will not be determined so much by the train speeds as by the larger currents needed due to the lower traction voltage. Curve radii are also smaller than on long range and high speed lines. Line gradients up to 11 % may also occur for existing lines but on newly-planned lines, try it through requirements to limit gradients to maximum 5 %.

In local-area transportation, systems, a much larger variety of clearance gauges is found than in high speed long range railways. This is a result of the separate development of individual local-area transport companies and the lack of interoperability requirements.

The increasing importance of combined operations, means the use of the same track by long-distance and low density trains, local-area trains and trams, as in the case in Karlsruhe, Germany, for instance, in which illustrates the need to get uniformity gauges.

4.2.4 Climatic requirements for designing new lines

In the design of contact line systems, the climatic conditions applicable for the respective territory have to be observed. The standard EN 50 125-2 gives guidelines for limits to be considered.

Outdoor temperatures above 35^0C occur rarely in Central Europe, the annual averages lie between 8^0C and 10^0C.

The valid temperature limits in Central Europe are:

- Highest temperature of the ambient air $+40^0$C;
- Lowest ambient temperature -30^0C;

In France, the average values are approximately 15^0C. In Russia, the lowest regional outdoor temperature is to be around -60^0C.

Equipment of outdoor systems in the housings (e.g. local control facilities) should not suffer irreversible functional damage between -35^0C and $+70^0$C according to EN 60 529. These statements apply to altitudes up to 1200 m above sea level.

4.2.5 Wind velocities and wind loads

The design of contact lines with respect to wind loads involves to two main aspects: Verification of serviceability, avoidance of pantograph de-wiring caused by wind deflected contact wire; Reliable design of structural elements to withstand the wind loads which probably will occur during the life time of the installation.

According to EN 50 119 the verification of serviceability may be carried out based on a wind velocity having a return period of three years whilst for the structural design of the supports the wind velocity will have a return period of 50 years for using. Basic information on wind velocities or wind loads is provided in EN 1991-1-4 or national standards. Information on wind velocities to be used for railway applications is given in EN 50125-2:2002. Four wind classes are defined, with wind velocities of 24 m/s; 27.5m/s; 32 m/s and 36 m/s. The values represent 10 min average period, applied to open flat terrain with low obstacles and at 10 m height above ground. Since the data given in EN 50 125-2:2002 does not refer to a certain location and, therefore, cannot be used directly, national specifications are applied in most cases. The corresponding data comply with the statistical characteristics.

Germany, according to DIN 1055 - 4:2005, contains wind zones: W1 (22.5 m/s); W2 (25 m/s); W3 (27.5 m/s); W4 (30 m/s).

France, according to NF EN 1991-1-4:2005, contains wind zones: W1 (22 m/s); W2 (24 m/s); W3 (26 m/s); W4 (27.5 m/s).

Spain contains wind zones: W1 (24 m/s); W2 (28 m/s).

In many cases, railway entities specify design data for wind velocities based on their experience but differing from current standards.

In France, three wind regions exist where the wind pressure considered in the design, results from wind velocities of 28.6 m/s, 33.8 m/s and 38.3 m/s. Beyond this, maximum wind velocities are specified by the SNCF that are greater than the normal wind velocities by a factor. A further classification is made according to the terrain formation. Protected land, e.g. basins with surrounding hills, is assessed with a factor of 0.8; normal terrain has a factor of 1.0; exposed terrain includes seashores, cliffs and narrow valleys; exposed terrain has factors between 1.25 and 1.35 depending on the wind region.

The design of DB's overhead contact lines for conventional lines up to running speeds of 200 km/h was based on 26 m/s wind speed, which corresponds approximately to the wind velocity in wind zone 1 – W1 with a return period of three years. For contact lines for high speeds a wind velocity of 33 m/s was applied at heights up 100 m above ground and 37 m/s at heights of more than 100 m. These specifications were used for bridges and viaducts which were considerably higher than their surroundings.

4.2.6 Corrosive substances

Aggressive dust, vapours, gases and extreme levels of humidity can cause rapid contamination of insulators and increased wear of components in contact line installations, particularly when several substances are combined. These active airborne substances may occur in the vicinity of production facilities which emit such substances and near the sea. These factors must be accommodated in the design of contact line systems.

4.2.7 Lightning voltage surges

Lightning striking the contact line and the overhead line installations can cause flashovers at the insulation leading to damage. From measurements, it is approximately that one lightning stroke per 100 km of contact line in a year can be assumed in Central Europe. The probability of lightning is highly variable and also differs according to location.

A direct lightning stroke on an overhead contact line will cause lighting voltage surges.

Indirect lightning voltage surges occur as lightning discharges when an overhead contact line lies in the electric field between a cloud and the earth. When a thunderstorm approaches, charges are induced in the overhead contact line, by an electromagnetic field. The negative charges are drained to earth through the discharge resistance of the numerous parallel contact line insulators and the positive charges are kept by the field emitted by the cloud. If a cloud then discharges in the vicinity of an overhead contact line, the charges are released in this line and are propagated as a travelling wave along the overhead contact line. The indirect lighting overvoltage impulse is lower in magnitude and rise more slowly than a direct lightning stroke.

In overhead contact line installations, impulse voltage limiting can be achieved by over-voltage protection devices. The most important over voltage protection device is the valve-type arrestor. Since only limited protection is possible with over voltage protection devices, they are not used for economic reasons unless an extreme frequency of lightning exists.

4.2.8 Icing, anti-icing and de-icing of railway contact wires

General considerations - As the principal mode of manifestation, the accumulation of ice on the conductors of overhead contact lines will cause an additional weighing load on these systems. The icing of overhead lines from any railway power supply system represents a serious problem for any network infrastructure. The icing causes a series of technical problems for overhead power supply: overloading, non-uniform icing, and wire galloping. In countries with cold climates: Northern Europe countries, U.S.A., Canada, China, etc., glaze and rime deposits on power contact lines and messenger wires create problems for maintenance activities and people working in these areas.

Due to the added burden of ice or reducing contact between the pantograph and contact line because the intermediate layer of ice, power cables were damaged or destroyed in numerous occasions.

In Russia, in regions with extreme ice loads significantly increased sag has occurred on automatically tensioned overhead contact lines, that railway operations have been temporarily impeded. Also, whereas in Germany ice loads must be taken into account, this is unnecessary for SNCF.

Studies of thermo-physics of the environment give a great importance to researching of the mechanisms of icing and anti-icing. These researches are basics for design of the transmission line for power supply systems.

Icing from extreme weather may have a negative influence on the infrastructure railway design but especially for power transmission lines or power railway contact wires. As prior information, there is no ice types and accumulation database that can be used as statistical information.

The icing process of railway contact wires and corresponding anti-icing technologies are described here. Four aspects should be considered: the hazards of the icing of railway contact wires; the characteristics of the icing of railway contact wires and affecting factors, experimental research into the icing and anti-icing of railway contact wires, creating expert system of the icing and ice melting of railway contact wires. Large, heavy ice accretions may form on objects exposed to freezing rain. These can damage or destroy structures and cause great economic and social hardship.

In the United States, Canada, France, Russia, Japan, Korea, etc. are frequently affected by icing on the power supply transmission lines (public or private) and also for overhead railway power supply systems. Large areas of south-eastern United States had affected by heavy ice accretion in February 1994; were result economic losses of 30 billion. Again, in 1998 and 2003, the USA and Canada had a period with major area of wires icing that cause economic losses.

The research of contact wire icing has not developed enough, for the following reasons:

- Railways electrification development is relatively late and networks are not on a large area. The contact wire has not been extended to the areas where ice accretion is frequent;
- Icing events at dangerous and destructing levels for railway infrastructure has not happened in the freezing rain areas for the last tens of years also because of global warming. This situation put the problem of the contact wire icing low in priority.
- Generally, modern electrified railways are designed for busy lines with high traffic: passengers and cargoes. The time between trains is short and in the limited period, icing is difficult to grow the thickness which can affect the operation.

It is anticipated that the icing problems for railways network will be highlighted in the future. Some causes for this tendency are: the continuous extension of the electrification railways, railways network will pass through topographical regions where conditions have difficult features. In addition, the downtime of railways will be extended, so the icing problem will be highlighted.

Methods used for de-icing and/or anti-icing are: manual ice removal, thermal de-icing of contact line, chemical anti-icing, resistive wire de-icing technology.

Manual de-icing - The environmental conditions are difficulty during the period of icing, which brings difficulty for manual de-icing. Removing snow and ice using human force or machines as help is still the simplest but primitive method because it is a time-consuming, inefficient and unsafe operation (see Figure 4.25 and Figure 4.26).

Figure 4.25 – Manual de-icing from a mobile platform (26)

Figure 4.26 – Manual de-icing from ground (26)

Contact wire thermal running – This procedure is the simplest and most used. The icing is observed by staff of the railway, before the operation of overhead contact wire. The staff determine the level grade of icing. If the ice thickness reaches the warning level, operations for de-icing will be started, letting the electric current flow through the overhead contact wire. The electric vehicles get power from the collect strip, letting the collect pantograph strip to keep touching the contact wires in idle mode, and ice is melted until falls.

Chemical anti-icing - uses chemical substances to decrease the freezing point of water in order to prevent icing. The most common and most effective is CaCl. The Railroad Car Company in Bremen, Germany uses the de-icing coating produced by the Stemmann Technik Company to apply to the contact wires. Also other applications and services can be affected by icing: airports, highways, etc. Chemical solution means applying the de-icing agents to contact wires and creates some environmental pollution with chemicals and should be taken in consideration.

Resistive wire heating de-icing – There are specialized some companies: Alston from France and Hitachi from Japan, developed a de-icing system for overhead contact wire using built-in wire with insulation resistance characteristics, and applied it to railway and tram systems, for example in Japan, France, South Korea and the UK. The system for remove icing is similar to process with composite conductors used in de-icing of high-voltage transmission lines.

This is a good example of taking a technology from a different domain and adapting to the railway applications.

Negative effects of contact lines when icing:

- **Quality and performance of the contact wire are decreased** - The ice weight added to the contact will increase the tension of the wires; this would cause the clamp dropper for messenger wire to break, the mid-anchor clamps are deformed. In glaze ice conditions, ice will grow at the bottom of the clamps for suspension; this will may provoke the increasing of the variation of the elasticity and lead to the increasing the contact force, vertical component, between pantograph collector strip and the contact wire. If there are icicles at the bottom of the contact wires, a damage may occur when the collect strip runs; the locomotive collect strip will be major damaged for the high-speed running locomotives.
- **Divergences of the contact wire -** The changed shape of cross-section after icing, of the contact wire and lines, will change aerodynamic characteristics. The supplementary loads when wind could make the contact wire to diverging. In order to make the contact wire wear in a uniform manner as in the design, the installation of the overhead contact wire should be in the shape of a "Z". If the contact wire diverts, it may break the smooth contact between the collect strip and the contact wire. This event will affect the current collection quality, but also will increase the wear rate of collect strip and contact wire.
- **Icing causes an electric arc –** When ice covers the contact wire, will reduce the conductivity at contact point between the contact wire and the collect strip; will result electric arc and if is current intense will burn out the contact wire and will damage the

collect strip. Appearance of icing means it is glaze icing or border edge icing, named also rim icing. If the thickness of icing is compact and big, the contact wire will not make contact with collect strip, resulting in no power supply and the locomotive will stop. Sometimes are comparing situations of railway contact wire icing and icing of high voltage lines; there is a huge difference between them because, for high voltage lines, as long as the tower will not collapse and the line is not effectively broken, it still can transmit power to public or industrial consumers, even to railway substations, with ice on lines.

- **Icing causes the insulators to flashover -** Ice accretion will coat on the high-speed locomotive's roof surface insulators, and will deposit on the upwind side. The higher the speed the thickness of icing will be increased. When the locomotive uplift the pantograph, the ice will melt due to contact heating, and the melted ice will form a conductor, which will cause electrical short circuit, will produce flashover and cause damage to electrical equipment and insulators. For the affected electrification railway, the major problem is flash-over of insulator on the roof of electrical power locomotive.
- **Icing leads to large balance of the contact wire –** This phenomenon is very rare, but when happens can cause large damages. The damage caused to the parts of contact wire in the area influenced by the large balancing mainly includes the breakage of positive power supply cable, steady-arm, and dropper clamp, deformation of mid-anchor clamp, and even the breakage of cantilever insulators, etc. The balancing amplitude could have from few centimetres to tens of centimetres and could cause large amounts of damage to equipment.

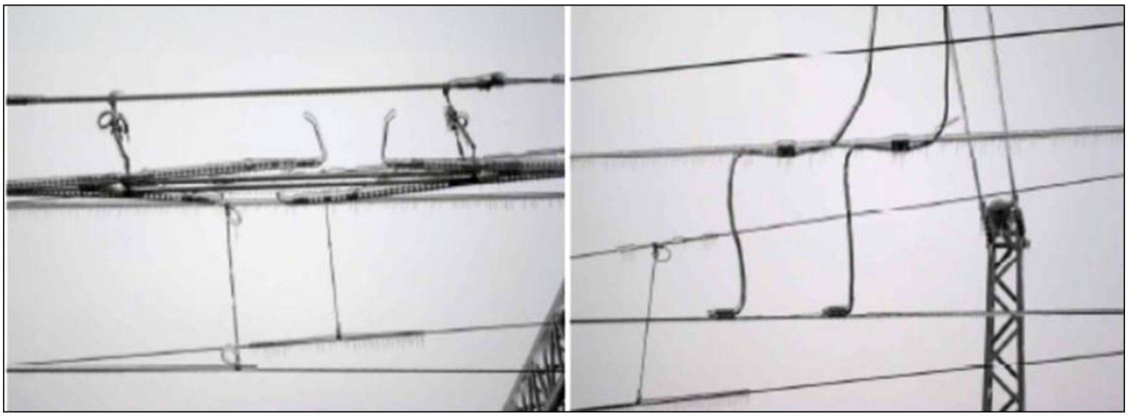


Figure 4.27 – Icing of overhead contact wire (26)

Example of overhead components icing are presented in Figure 4.27

The icing of the structures - icing or ice accretion, happens in cold and very cold regions. It can be classified into categories: precipitation icing, in-cloud icing and sublimation icing.

Icing is influenced by factors, such as micro-climate, wind speed, micro-terrain, temperature and content of cooled water in air, etc. Relating to these factors, icing on aerial wires can be divided into several categories according to different aspects.

Ice classification based on density and appearance:

- **Glaze**: transparent vitreous, unbreakable and strong in texture with density between 0.6 and 0.9 g/cm^3, can also be called ice slush or clear ice which covers wires with strong adhesive power and never easy to shed.
- **Granular Rime**: ivory opaque with density between 0.1 and 0.3 g/cm^3, loose and crisp in texture with air bubble voids inside, sinuous surface and irregular shape.
- **Crystalline Rime**: white crystal with many air bubbles inside, loose and soft in texture with density between 0.01 and 0.08 g/cm^3, weak adhesive power on wires and easy to shed.
- **Wet Snow:** ivory or off white, usually soft in texture with density between 0.1 and 0.7 g/cm^3. Wet snow on wires will turn into hard frozen body when the temperature continues to decrease.
- **Mixed Rime:** ivory, large with many voids, is formed by the alternate freezing of glaze and rime on wire surface, and the density ranges from 0.2 to 0.6 g/cm^3. (26)

Classifications of ice based on formation mechanism:

- **Precipitation:** This type of ice is formed by freezing rain (super cooled water) or snow falling on the wire surface when atmospheric temperature is around to 0^0 C. Usually the bigger drops are correlated with the lower temperature degree. The super cooled degree of little water drops can be several centigrade, while the degree for fog droplets can even be more than ten degrees. Once touching the wires, the super cooled water droplets would freeze. Because the speed of releasing latent heat is slow during the process of freezing, a thin surface of water would appear on the wire surface, and so the glaze appears. The most dangerous to aerial wires is the glaze formed by icing precipitation; this is because of its high density and strong adhesive power. Freezing rain often happens in America, Canada, Russia China, etc., while icing from the snow covering is more common in Japan and the Europe – Alps and Carpathians.
- **Cloud or fog in the air:** Frozen ice by these sources mainly depends on humidity, air velocity etc. This type of icing happens with high frequency in many places and is possible to do simulation study with artificial weather model, which is one feature of in-cloud icing. Another is that in-cloud icing can be formed as long as super cooled water drop exists. Small in size, the fog droplets can release the latent heat quickly when freezing. Thus, it won’t form a water layer on wire surface but usually produces rime shape ice.
- **Sublimation:** This process forms frost when air water vapours freezes on the surface of overhead wires, installation surface, etc., and is called crystalline rime. Formed through sublimation, it is called sublimation icing. Because of its weak adhesion and easy to shed, it won’t represent danger to the overhead wire. But this type of icing can represent a start support for glaze, mixed rime and wet snow, etc. and in this way can increases the risk of danger for railway power supply system.

The icing of overhead wires is mainly influenced by micro-climate and micro-terrain. The size, rigidity and shape of the wires may also affect the icing thickness and density.

Micro-climate includes the next factors: temperature, wind speed, wind direction, and liquid water content in the air (LWC). These parameters are useful in the prediction model of icing. They can be acquisitioned through specialised sensors and their values can control the flow and heat transfer in icing and de-icing processes.

Micro-terrain includes next elements: altitude of the wire, topography of the local area, water presence in the region and water distribution, etc. Their major functions are to affect in heterogenic way and will cause different icing phenomenon; results can be used in modelling as historical and statistics range values.

Temperature is the main influencing factor of icing. Generally, the temperature of icing is always below 0^0 C, but if it is too cold (below -10^0 C), icing won't occur.

If water drops at cooled degree and high quantity, icing would happen even slightly over 0^0 C, and this will form dense glaze.

Speed of wind is an important factor of icing because of it characteristics to decrease atmospheric temperature. It will create ice when the cooled water droplets touch the wire surface. The wind sends the cooled water drops to the wire surface; the wind speed also affects the heat transfer in the process of icing.

Therefore, the higher the speed of wind is, the more cooled water drops can touch the wire surface; the more easily the latent heat released in the process of icing to be lost, and the more icing on the wire surface.

Direction of wind also has certain influence on icing. The wind direction mainly affects the effectiveness of super cooled water drop delivery. If the wind direction is perpendicular to the wires, the delivery is the most effective; if the wind direction is parallel to the wires, the delivery is the least effective, hence less icing.

Liquid water content (LWC) has an important influence on icing. It will not only influence the speed of icing but also the types of icing. If LWC is low and diameter of the droplets is small, rime is formed and icing develops slowly, whereas if LWC is relatively high and diameter of the droplets is relative large, glaze is formed and icing develops quickly. If the LWC is very high and diameter of the droplets is very large, rain is formed. (26)

4.2.9 Comparison between icing on contact wires and on aerial network of high-voltage lines:

Structure Differences – High voltage transmission wires related to public electric grid or industrial network are steel with aluminium core while most contact lines of electrification railway are copper alloy wires. For this reason, when difference in wire surface, the icing will be different. The contact line has several points of bearing and a shorter (less than 65m). In this way, the suspension is well distributed, can be seen as a straight line, that will not twist when will freeze; high voltage transmission line is stranded with very long (300m - 500m), which will twist when glaze and icing occurs and will cause high waves in the wind (see Figure 4.28 and Figure 4.29).

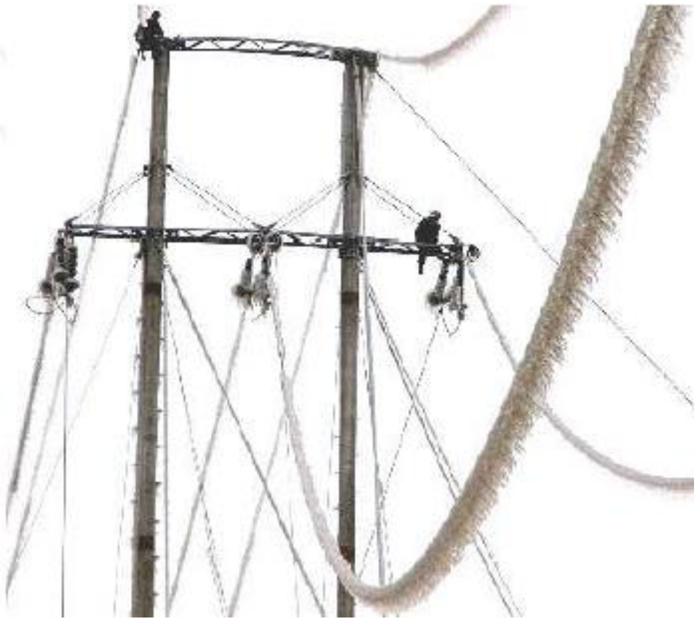


Figure 4.28 – Icing of high-voltage line (26)

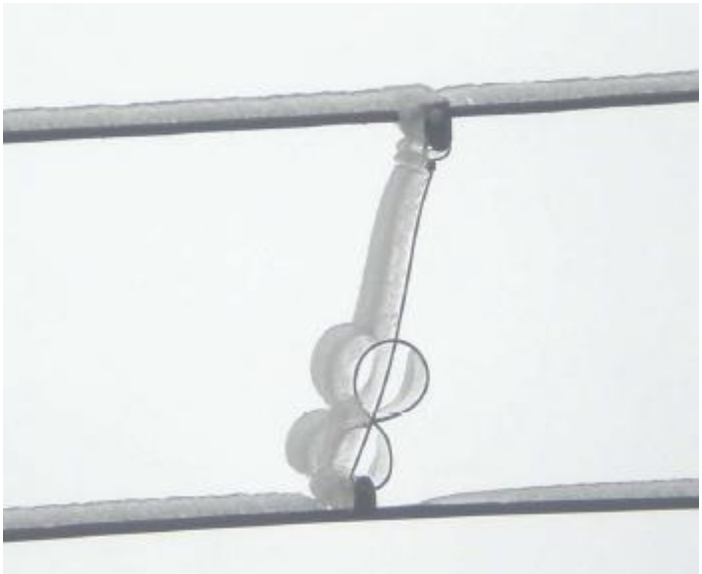


Figure 4.29 – Icing of overhead contact wire (26)

Height Differences - There is a big difference in height between electrification railway contact wires – around 6 m - and high-voltage lines that have heights up to tens of meters. The influence of wind speed varies and is very important. The speed of surface wind is weaker than that of high-altitude wind; the icing of contact wire will be weaker than that of high-voltage line under the same meteorological parameter and geographical factors.

There are many theoretical models used to predict icing formation, as glaze and rime. These include the Imai model - based on wet growth process; Lenhard model – a formula to calculate the weight of the ice; Goodwin model – based on dry growth process; Chaine model - dry growth process, but shape of the icing is the uneven oval and Makkonen model - considering the existence of ice cycles. (26)

Conclusions related to ice accretion:

- The wind speed has important influence on icing; when the wind speed is higher, the ice will become high density.
- Temperature air increasing leads to increasing ice density but decreasing ice thickness.
- Ice type begins to change around -4^{0} C. When the temperature is higher than -4^{0} C, large mixed glaze ice or glaze ice will form; when the temperature is below -4^{0} C, rime ice will form.
- The type of the ice is influenced and affected by air temperature but not influenced by wind speed; the wind speed will lead to the increasing of adhesion of the ice to contact wires;

4.3 Modern practices and components selection for new railway electric traction systems

4.3.1 Overview

As definition, power supply systems for railway cover all aspects of the electricity supply, needed for operation of electric locomotive motors. It consists mainly of technology and infrastructure to energy conversion at substations, power transmission circuits to supply electrical power to consumers' systems; these transport systems can be DC or AC. In the composition of power supply systems for railway have to be included also fixed structures, measurement and inspection materials, overhead lines maintenance equipment.

Sending electric power through the overhead line and pantograph introduced nearly 100 years ago in electric railways and remains basically unchanged as main principles. However, technological developments have concentrated to increase the current capacity, speed, and safety; nowadays the current capacity is more than sufficient to drive modern super high-speed trains.

As detailed and structured the overhead contact line system (OCS) comprises overhead contact line, cantilevers, poles, foundations and return conductors to supply current for use by electric railways. The overhead contact line (OCL) consists of contact wire, catenary wire, droppers, stitch wires, fixed points and tensioning devices.

Figure 4.30 illustrates a typical overhead contact line system design with individual poles on both sides of the tracks. This is the preferred design for main line traffic at all usual voltages and for urban transportation. The components such as contact line, cantilevers, poles, traction power feeder lines, return current conductors and rail bonds are shown in this schematic diagram.

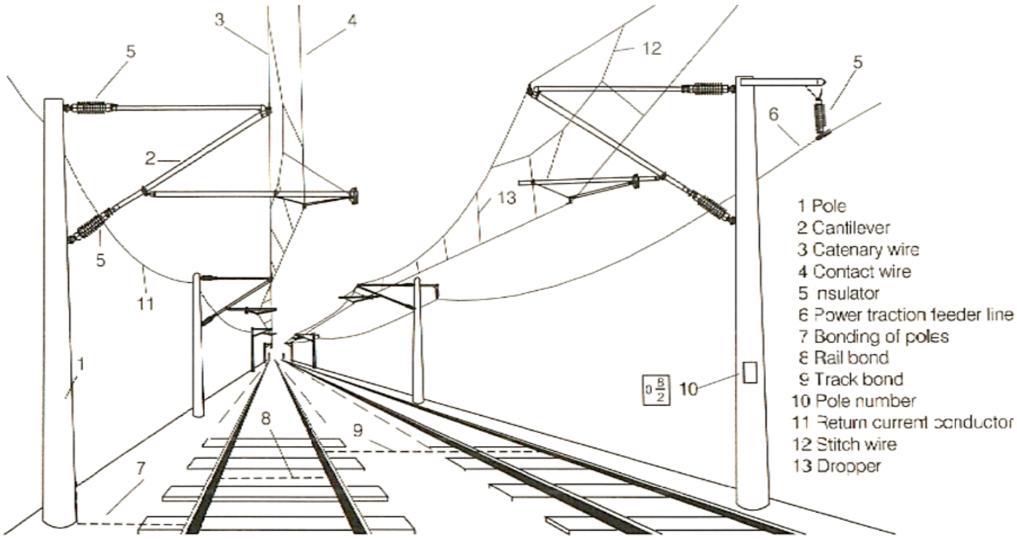


Figure 4.30 - Overhead contact lines on individual supports using concrete poles (7)

The elements considered part of the overhead contact line system are the following:

Pole (1); Cantilever (2); Catenary wire (3); Contact wire (4); Insulator (5); Power traction feeder line (6); Bonding of poles (7); Rail bond (8); Track bond (9); Pole number (10); Return current conductor (11); Stitch wire (12); Dropper (13)

Electric operation is always preferred on railways with long tunnels or on underground railways because the energy efficiency is higher than steam or diesel locomotives and does not involve on board combustion. The high traction force also makes electric operation suitable for lines running through geographical highest regions.

Electric train operation started first with direct-current power supply systems capable of driving a DC motor directly and offering high traction force and easy speed control; 3 kVdc power systems are used in many other countries as powerful DC system.

Low frequencies such as 25 Hz and 16.67 Hz were introduced in Austria, Germany, and other countries to minimize rectification failures. Further technological advances made possible the use for commercial 50 Hz frequencies as most prevalent system. The 25 kVac system is now used around the world and also Japan relies on 25 kVac for Shinkansen as highest technology railway network and 20 kVac power supply systems for other conventional railways.

System Type			Worldwide
DC	< 1.5 kV		Germany, UK, Switzerland, USA, Japan
	1.5 kV – 3 kV (predominant 1.5 kV)		France, Spain, Netherlands, Australia, Japan
	≥ 3 kV (predominant 3 kV)		Russia, Poland, Italy, Spain, South Africa
Single - phase AC	50 Hz & 60 Hz	< 20 kV	France, USA
		20 kV	Japan
		25 kV	Russia, France, Romania, Japan, India, China
		50 kV	USA, Canada, South Africa
	25 Hz; 11 kV - 13 kV		USA, Austria, Norway
	16.67 Hz	11 kV	Switzerland
		15 kV	Germany, Sweden, Switzerland
Three-phase AC			Switzerland, France, Japan

Table 4.3 - Railway Electricity Systems Dispersion

4.3.2 Overhead Line Systems

The structure of an overhead line can be seen in Figure 4.31 and consists of individual spans, which are designed according to the application of the contact line. The contact line is divided into individual tensioning sections.

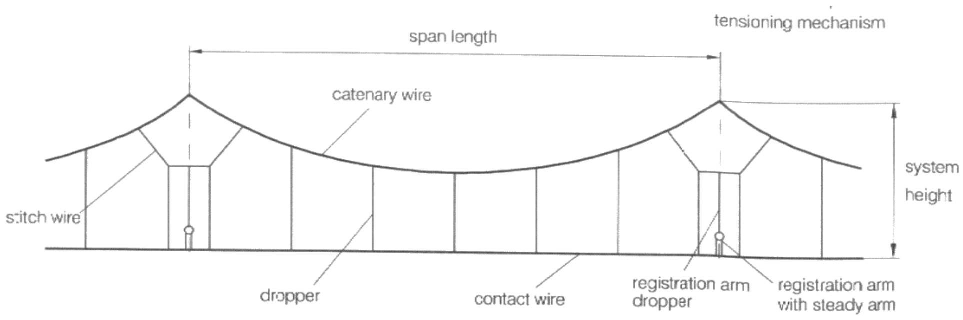
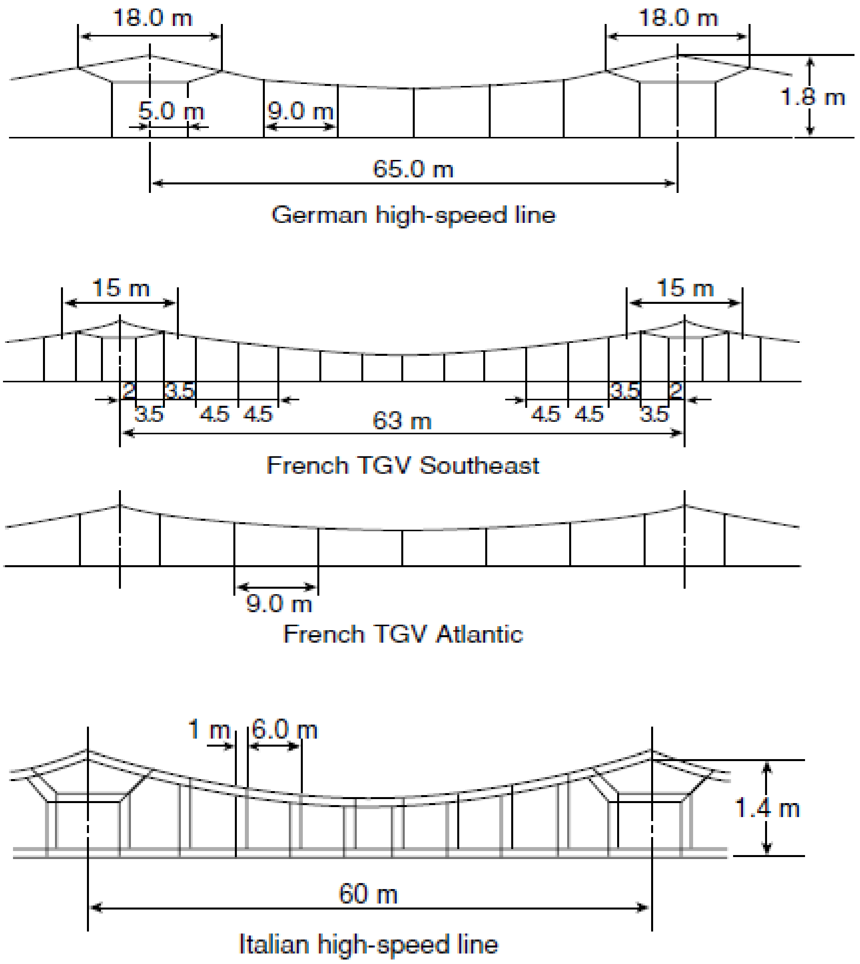


Figure 4.31 - Design of a contact line section and a span.

Terminations or tensioning equipment are found at the ends of these sections. The tensioning equipment maintains the tensile forces in the contact wire and the catenary wire approximately constant at varying temperatures. The contact line must be designed to satisfy the static, dynamic, thermal and electrical requirements for each application.

Overhead line systems have role to transfer electric power from substations to moving vehicles on the railway; these are necessary for electric motors, lights, air conditioning, etc., The energy used by locomotives are collected from the overhead line using the pantograph on the vehicle roof. The pantograph should be in direct and constant contact with the overhead contact wire. Therefore, the overhead line must always be located within the pantograph range, and the pantograph must always maintain contact with the overhead line to supply uninterrupted, good-quality power at all times. To accomplish these conditions, the overhead line system is generally designed with these requirements:

- Should be considered general characteristics generated by speeds at which trains will run.
- The height above ground must be uniform as possible to optimize pantograph electrical power collecting, so entire equipment must have uniform spring forces and rigidity.
- Have to be affected by minimum vibration and motion to ensure pantograph passage as smooth as possible during high-speed running or when strong winds
- Need to have enough strength to withstand vibration, corrosion, heat, etc., that means reliability on operational life.



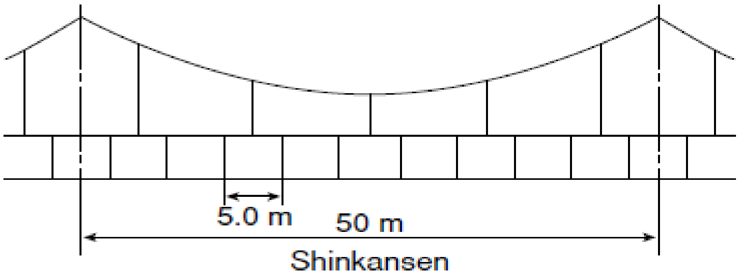


Figure 4.32 – Synthetic Layout Overhead Lines of world high speed railways (24)

Figure 4.32 compares the catenary equipment for high-speed trains in different countries. In Japan, compound catenary equipment consisting of three longitudinal wires is used for Shinkansen, while simple or stitched catenary equipment is used in Europe. Also, the Italian high-speed line uses twin catenary equipment to supply the large current for the electrification with 3 kVdc. Compound catenary systems feature less pantograph vertical motion and less vibrations but larger current capacity and require a larger number of components, resulting in a more complex design, see Figure 4.33.

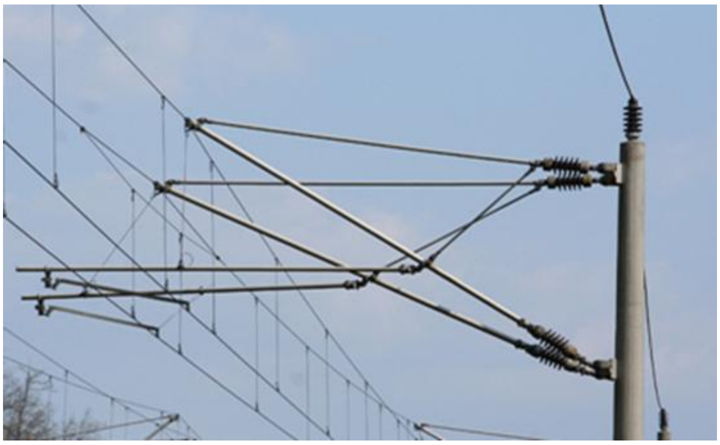


Figure 4.33 – Compound overhead line[13]

[13] http://www.aeg-ie.com/englisch/rolling_stock.htm

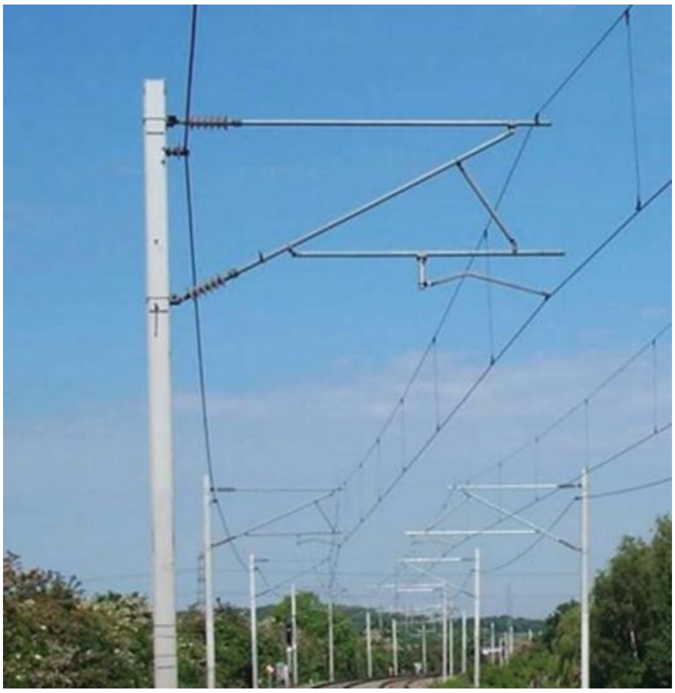


Figure 4.34 – Simple catenary equipment[14]

Simple catenary system is used in Europe and pre sag has role to compensate large vertical motion of the pantograph (see Figure 4.34). Pre sag means to design feature in which the height of the contact wire is lower at the centre of the span by an amount equal to around 1/1000 of the span. In real terms, generally, the contact wire height is 20 or 30 mm lower at the centre of the span than at supports, suppressing the pantograph vertical motion. This design is effective for the overhead lines on the French and German high-speed lines which have large amplitude, but is less effective for overhead lines with small amplitudes like the Italian high-speed line, also for Shinkansen line.

The Naganobound - Shinkansen (Takasaki-Nagano section), which started operations in October 1997, uses the simple catenary overhead equipment; that is commonly for Europe. This system was chosen for economy because the less-frequent train operation consumes only a small proportion of the current-carrying capacity. This high speed line uses a 110 mm^2 copper - clad steel wire; the wire tension is 20 kN to resist for the train 260 km/h operating speed. This is a particularly simple catenary system for high speed operation in Japan.

4.3.2.1 Lateral wave propagation

The most critical constants for the performance of the overhead line, mechanical point of view, are the weight and tension per unit length. The tension is linked by the push force pantograph against the contact line. These tension direct influences vertical motion of the overhead line. The values are: 54 kN for Shinkansen and 28 kN to 34 kN for the French and German overhead systems. The Italian

[14] http://www.eurobricks.com/forum/index.php?showtopic=76552

system accepts a total tension of 66 kN because it uses a twin catenary system with a larger wire size. The pantograph push-up force is roughly 70 N to 80 N for Japan, 130 N to 250 N for France and Germany, and 200 N to 300 N for Italy. This means France and Germany have overhead contact line tension amplitude about four times greater than that of Japan. Generally, greater stability results from smaller overhead line amplitude. It also reduces the fault frequency and damage to components.

As definition, the square root of the ratio of the contact wire tension to the weight per unit length represents the velocity of the lateral wave propagating along the wire. This is the most important parameter in overhead line design. In railway technology, this velocity is called the wave propagation velocity.

Table 4.4 shows the velocity for wave speed and the ratio of the train speed related to the wave propagation velocity. Experiments have tested that if the train speed approaches the wave propagation velocity, the overhead line amplitude and local bending are increased; the contact of the pantograph and overhead line will be difficult to maintain. When the train speed exceeds 70% to 80% of the wave propagation velocity, risk of pantograph contact loss increases greatly; overhead line itself can be destroyed.

Item		France		Germany	Italy	Japan
		TGV Southeast	TGV			
Catenary type		Stitched and simple	Simple	Stitched and simple	Twin stitched and simple	Heavy compound type
Standard span [m]		63 (Stitched wire 15)	63	65 (Stitched wire 18)		50
Standard wire height [m]		4.95	4.95	5.3	4.85	5.0
System height [mm]		1400	1400	1800	1400	1500
Wire grade	Suspended	Bz 65 mm^2 (0.59 kg/m)	Bz 65 mm^2 (0.59 kg/m)	Bz11 70 mm^2 (0.63 kg/m)	CdCu 153.7 m^2 (1.42 kg/m)	St 180 mm^2 (1.450 kg/m)
	Auxiliary suspended	Bz 35 mm^2	-	Bz11 35 mm^2 (0.31 kg/m)	(0.30 kg/m)	Cu 150 mm^2 (1 .375 kg/m)
	Contact wire	CdCu 120 mm^2	Cu 150 mm^2 (1.33 kg/m)	CuAg Ri 120 mm^2 (1.08 kg/m)	CuAg 151.7 mm^2 (1.35 kg/m)	Cu 170 mm^2 (1 .511 kg/m)

Item		France		Germany	Italy	Japan
		TGV Southeast	TGV			
Contact line total density [kg/m]		1.65	1.92	1.71	2.77 x 2	4.34
Catenary wire tension	Suspended [N]	14,000	14,000	15,000	18,400	24,500
	Auxiliary suspended [N]	4,000 (Stitched wire)	-	2,800 (Stitched wire)	2,900 (Stitched wire)	14,700
	Contact wire [N]	14,000	20,000	15,000	14,700	14,700
	(Total tension) [N]	(28,000)	(34,000)	(30,000)	(33,100 x 2)	(53,900)
Wave propagation velocity of contact wire [km/h]		414	441	424	376	355
β (train speed/wave propagation velocity)		0.65 (= 270/414)	0.68 (= 300/441)	0.59 (=250/424)	0.66 (= 250/376)	0.68; 0.76 (= 240, 270/355)
Pre-sag		1/1,000	1/1,000	1/1,000	1/1,000	None

Table 4.4 – Comparison of Overhead Line Constants on Dedicated High-speed Lines (27)

The constant for contact wire have to be set so that the propagation velocity is significantly faster than the train speed. The propagation velocity could be improved using a light wire with higher tensioning force. In the case of a pure copper contact wire, the maximum achievable speed is around 500 km/h. Increasing of the wave velocity can be done by using wires with a higher tensile resistance and special composition for less wearing.

In Table 4.4**,** the **β** values are 0.7 or lower; that indicates that all countries have selected values within the above-mentioned stable velocity range for train speeds.

4.3.2.2 Selection of the overhead contact line design

An overhead contact line type is defined by the design and thus by the configuration of its components for a given application. It follows that the overhead contact line should also be configured to provide minimum operational life cycle costs. The verification of the suitability of a design of overhead contact line for a given purpose can be performed by simulation of the interaction between the overhead line and the pantograph or by carrying out a track test. Table 4.5 contains applications for typical overhead contact line designs.

Type	Design	Properties	Application
1	Simple overhead contact line without continuous catenary wire, fixed termination or flexible tensioning, horizontal registration arrangements	Contact wire height changes with temperature, Limited span length and current carrying capacity	Light rail systems (tramways) With low electrical load, sidings on mainline railways, speed up to 100 km/h
2	Vertical contact line without stitch wire, tensioned contact wire, catenary wire fixed or tensioned	Contact wire height independent of temperature, span lengths up to 80 m are possible, current-carrying capacity can be adapted by selecting suitable catenary wire and contact wire cross sections, large variation of elasticity between mid-span and support	Tramways with high electrical load, main-line railways at speeds up to 120 km/h, two parallel contact wires are often employed with DC traction supplies
3	As (2), but with or without stitch wire, automatically high tensioned contact wire and catenary wire	As (2), however lower elasticity differences between mid-span and support	Main-line railways with high electrical loading and speeds up to 350 km/h
4	Vertical contact line with auxiliary catenary wire automatically tensioned	As (3), however higher current-carrying capacity and more uniform elasticity	Main-line railways with very High electrical loading and very high speeds

Table 4.5 - Typical applications for types of overhead line system designs

4.3.2.3 Selection of conductor cross sections and tensile forces

The contact wire and catenary wire cross sections are to be kept as small as possible for economic reasons. They should be designed to satisfy requirements at the lowest investment. The traction power supply system, the traffic timetable and the route profile determine the magnitude of the current flowing through the overhead contact lines. There are major differences between the conductor cross sections for high density lines and lines with low density of traffic; also, are larger differences between conventional lines and high speed lines.

4.3.2.4 Selection of span lengths

Long span lengths are desirable in view of keeping investment down. Contact wires that are displaced by wind from their still air position have to guarantee an uninterrupted power transfer. Determination of span length must consider the wind loading per unit length for the contact wire and the catenary wire for the anticipated regional wind velocity. The height of the overhead contact lines above the surrounding terrain together with maximum regional wind velocity determines the wind velocity to be applied.

4.3.2.5 Selection of system height

The regular system height, being the distance between the contact wire and the catenary wire at supports should allow for the installation of minimum design length droppers at the centre of the span.

The minimum lengths of flexible dropper ($L_{Hmin)}$ are dependent upon running speed. Recommended minimum dropper lengths for design are:

v <= 120 km/h; L_{Hmin} = 300mm;

v > 120km/h; L_{Hmin} = 500 mm;

If this is not possible, shorter flexible droppers, and finally sliding droppers have to be employed. These transfer the contact wire lift directly to the catenary wire and, therefore, generate force peaks in the contact force profile. To respect the minimum dropper length is important in view of dynamic behaviour. Shorter droppers in combination with inflexible material increase the probability of dropper failures, especially at higher speeds and larger contact wire lift.

System heights in stations are usually greater than those employed on the interstation line, because of the installation of section insulators, and the need to avoid electrical clearance problems between crossing contact lines of different electrical sections, especially under dynamic uplift conditions.

4.3.2.6 Design of contact lines in tunnels

In addition to the general requirements, there is a need to minimise the installation space for tunnel overhead contact lines in order to keep the overall tunnel cross section as small as possible.

The contact wire height should be kept as low as possible to minimize the tunnel cross section and the associated construction investment. However, contact wire gradients are not permitted on high-speed lines, so that the same contact wire heights has priority, as found on the open line sections. To keep the tunnel cross section low, a low system height should be provided within the tunnel; this requires shorter span lengths e.g. 50 m. Depending by the operating speed, alternative contact line equipment are possible, could be used overhead contact lines with elastic or overhead contact rail systems and with short support intervals, e.g. 10m.

4.3.2.7 Adoption of contact wire pre-sag

For some designs of overhead contact lines, the contact wire is not threaded at a constant height above the top of rail. For example, the TGV overhead line for SNCF, the contact wire is provided with a contact wire pre-sag of 0.1 % of the span length, so that the contact wire is lower at the centre of the span than at the supports. The provision of pre-sag is based on the premise that the overhead contact line has a lower resilience at the supports than at mid span, and the pantograph, therefore, lifts the contact wire at the supports to a lesser degree than at mid span. In order to achieve an almost constant pantograph operating height during the passage of a train, a pre-sag is provided at mid span, which should compensate for the difference in lift at the support compared to that at mid span. The dynamic components of contact wire lift, however, increase with increasing speed and the pantograph is pressed downwards by the pre-sag at mid span. Tests performed during the development of the overhead contact lines for the new high-speed line sections at DB showed that a pre-sag is not necessary for high-speed overhead contact line systems, and can even be negative from the viewpoint of running characteristics. According to SNCF's experience a pre-sag is also useful for high-speed contact lines without stitch wires as proven by studies and tests. An initial pre-sag can also contribute to compensate the effect of wear which could result in a negative sag. When installing the contact wire, a pre-sag of 0 to 0.05 % of the span length should be aimed at.

A pre-sag can provide running quality for overhead contact line systems up to 200 km/h with their relatively large elasticity differences along the line, whereby the static behaviour in the interaction between the overhead line and the pantograph is predominant.

4.3.2.8 Selection of dropper spacing

The catenary wire supports the contact wire via the droppers (hangers). Dependent upon the contact wire tensile force, the dropper intervals determine the contact wire sag between droppers. To limit this sag, the dropper intervals should be less than 12 m. The dropper intervals are also chosen with the objective of allowing contact between the contact wire and the track after a contact wire failure, thus activating the tripping of the section feeder circuit breaker. However, this safety requirement will be satisfied even if the dropper intervals are less than double the contact wire height and the contact wire fails in the middle of two droppers, since the adjacent droppers also fail, allowing the contact wire to make contact with the track, creating a short circuit.

Following consideration of these aspects, dropper intervals between 5 m and 12 m have been used.

4.3.2.9 Using of a stitch wire

In the case of contact lines with a fixed catenary wire, stitch wires compensate for changes in contact wire height at the supports and at mid-span caused by varying temperatures. In the case of automatically tensioned contact and catenary wires the stitch wires equalise the elasticity at the supports and in mid span. The vertical movement of the contact point where the collector strip touches the contact wire should be as low as possible within a span. Low differences in the elasticity result in nearly constant contact point height and a higher current transmission quality. According to the TSI Energy the difference between the highest and lowest dynamic contact point within a span should be:

In the case of contact lines for AC lines:

- 80 mm for line design speeds of 250 km/h and above;
- 100 mm for line design speeds below 250 km/h;

In the case of contact lines for DC lines:

- 80 mm for line design speeds of 250 km/h and above;
- 150 mm for line design speeds below 250 km/h;

The compliance of the contact wire height variation within a span has to be verified on the installed system.

Elasticity differences between the support and at mid span result in varying contact forces and uneven wear of the contact wire

The lengths and tensile forces of the stitch wires are the results of optimisation processes, whose objectives were to achieve, as far as possible, the same elasticity near the support as at mid span.

When commissioning the AC contact line type Sicat H1.0 as installed on the high-speed line HSL Zuid in the Netherlands, the maximum difference in the height of the contact point was recorded as 18 mm at 330 km/h.

SNCF used stitch wires on the Paris-Lyon high-speed line and experienced that they were difficult to be installed and maintained. Therefore, the contact lines for the other high-speed lines in France were designed without stitch wires.

4.3.2.10 Selection of tensioning section length

The temperature range of the overhead contact line, the operating range of the tensioning mechanism, the variation of the contact wire tensile force along the section, and the permitted tolerances for the contact wire stagger and contact wire height, determine the tensioning section length, (see Figure 4.35). Higher tensile forces require longer weight stacks and, therefore, reduce the operating range.

Overhead contact lines are normally automatically tensioned at both ends. Tensioning section lengths shorter than 750 m that are automatically tensioned at one end and rigidly anchored at the other, are adopted in station areas and at special locations on the interstation track. Single ended, tensioning sections offer advantages especially for contact lines in transitions between open track and a tunnel. There, longitudinal displacements of the contact line and loadings on the midpoint anchor can occur. These are caused by different ambient temperatures in the tunnel and in the open, when double-ended flexibly tensioned contact lines are adopted. These displacements are avoided by single ended tensioning sections.

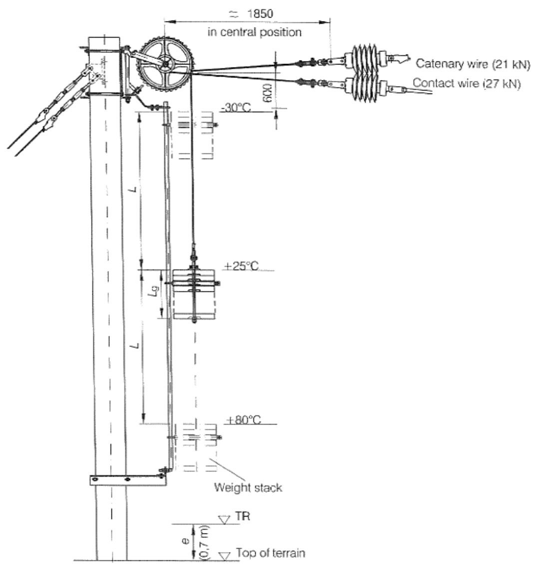


Figure 4.35 - Example of operating of the tensioning device (7)

Mechanical mid points, fixed anchor points or other kind of restraints should be used in a tensioning section length of an overhead contact line that is tensioned automatically at both ends, to ensure the conductors do not migrate towards both ends of the tensioning section length with changes in the loading conditions. This may be provided for by the installation of an anchoring arrangement at approximately the midpoint of the tensioning section length or at such a location which balances the along track forces at the midpoint. Midpoint anchors restrict the travel of the contact line during temperature variations and after failing of contact wire, catenary wire, or contact line.

The design of the catenary wire fixed point takes into account the different tension loads of either the catenary wire or the contact wire. The highest value should be applied. The fixed point for cantilevers should be designed to prevent their movement. For head spans, measures should be taken to ensure the upper cross span wires can withstand the required longitudinal load. Also, several adjacent head spans may act as the fixed point.

If a contact wire fixed point is required, this can be achieved in several ways. For example, the contact wire is connected to the catenary wire by a conductor installed close to the catenary wire fixed point. Thus, the contact wire is fixed in its position along the track. The design of the contact wire fixed point should take into account the difference of the operating tensioning forces of the contact wire on both sides of the fixed points.

The midpoint anchor fixes two-ended automatically terminated overhead contact lines. Two types of midpoint designs are considered, those with a hinged tubular cantilever and those in cross spans. For cantilever designs, a midpoint anchor manufactured from bronze or steel conductors fixes both sides of the catenary wire support. The stabilisation of the midpoint anchors is performed by the neighbouring poles, which are often provided with anchors. The contact wire is anchored to the catenary wire on both sides of the midpoint to ensure the conductors do not migrate. The cross-span wires also provide stabilisation of the midpoint in cross-spans. The rating of the midpoint complies with the sum of the contact wire and catenary wire tensile forces.

Automatic flexible tensioning. The tensioning mechanism and devices serve the task of maintaining the magnitude of the tensile forces in the contact line, and therefore the position of the contact wire, as constant as possible after length changes in the contact wire and catenary wire as a result of temperature variations. The device should be designed to achieve an efficiency defined in the specification over the specified design temperature range of the contact line. The efficiency, measured as the ratio of the actual to the intended tensile force, should be as high as possible, so that the horizontal tensile forces do not vary by more than 3%.

Designs with tensioning weights and gear wheels or pulley blocks, as well as hydraulic or electromechanical devices are employed as tensioning mechanisms. Particular attention should be given to the corrosion protection of any bearing arrangement in tensioning devices and suitable maintenance instructions made available to maintain the design efficiency of the tensioning arrangement.

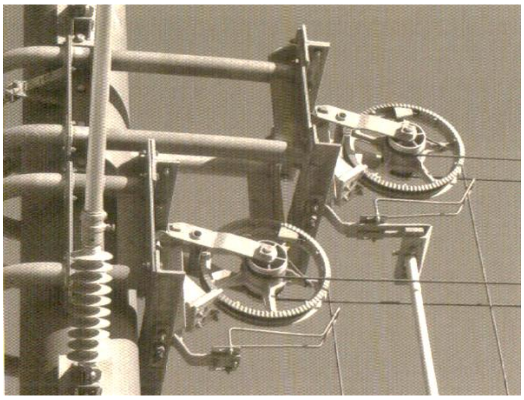


Figure 4.36 - Wheel tensioning design with separate tensioning of contact wire and catenary wire

To ensure that the tensioning device does not fail in the case of an incident, the breaking load of the tensioning device should be higher than the breaking load of the tensioned conductor.

The wheel tensioners consist of a tensioning wheel with two rope drums on a common axle and a blocking device. The overhead contact line to be tensioned is attached to the small split drum by means of flexible steel ropes, while the weights of the tensioning masses act on the large drum. The latch-in devices lock after a wire break preventing the concrete or cast iron weights from impacting with the ground, stopping further distortion of the contact line and avoiding the danger of dropper breakage. This is the main advantage of wheel tensioners over tensioners using the pulley block principle. The contact wire and catenary wire are tensioned separately (Figure 4.36) on high-speed overhead contact line systems. The separate tensioning ensures the planned tensile forces even when differing length changes occur in the contact wire and catenary wire. Separate tensioning also allows different tensile forces to be specified for the catenary and contact wires.

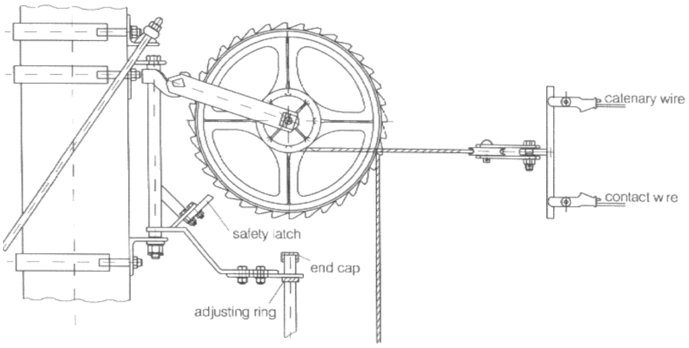


Figure 4.37 - Jointed tensioning device with articulated lever.

Combining of the contact wire and the catenary wire with the same tensioning device is shown in Figure 4.37 and has the disadvantage that after rupture of either the contact wire or the catenary wire the wheel tensioner does not always latch-in as a result of the articulated lever. This can result in the intact part of the contact line being tensioned with a doubled tensile force.

Figure 4.38 shows a tensioning device with compact design.

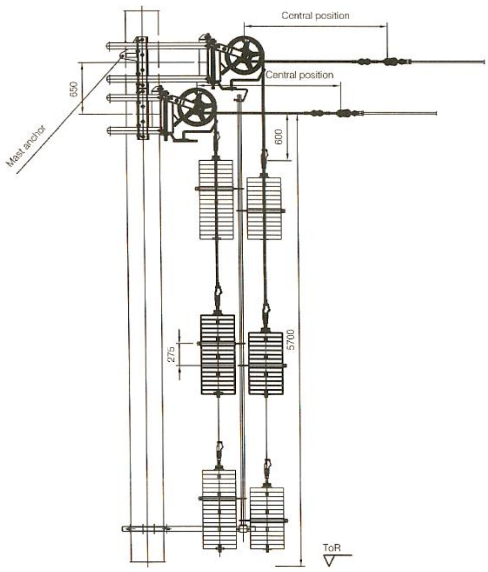


Figure 4.38 - Tensioning devices with compact design (Siemens AG)

Pulley tensioners operate on the pulley block principle. The weight force is transmitted to the contact line via several pulley wheels as a horizontal tensile force, as shown in Figure 4.39. The efficiency of these tensioning devices should be more or equal than 97%. Figure 4.39 shows such a tensioning device designed by SNCF as used on the Paris-Strasbourg line.

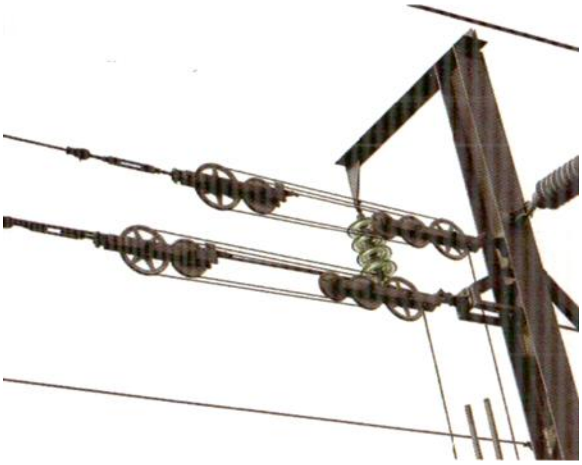


Figure 4.39 - Pulley-wheel tensioner used on the Paris – Strasbourg line; SNCF

Pulley tensioners without stoppers can cause large distortions and additional dropper failures after damage to the contact line as there is no safety latch-in to restrict the travel after a fault. Some railway companies use additional anchor ropes to avoid this problem.

The hydraulic tensioner controls the tensile force in the contact lines by means of the change in volume of a gas and fluid in a cylinder. This causes an axial movement of a piston, which adjusts the tensile force in the contact line as illustrated in Figure 4.40.

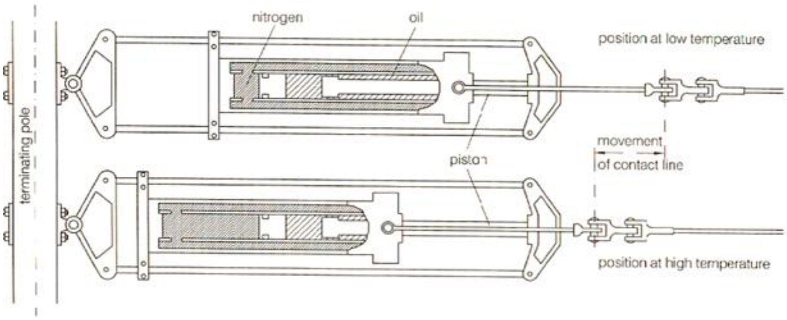


Figure 4.40 – Principle of Hydraulic tensioning device

The tensile force, as required according to the specific condition of a contact line, is set by adjusting the gas pressure in the cylinder when installing the equipment. This device reacts only to changes in the ambient temperature but not to changes of the contact line temperature.

The electromechanical tensioning device compensates tensile force changes resulting from temperature - dependent contact line length changes, via an electrically driven spring, whose reaction threshold can be adjusted. The electromechanical tensioning device requires an electricity supply.

Only the wheel and pulley tensioners have become accepted for mainline railways. Urban transportation systems also use spring-type tensioning devices for short tensioning section lengths, up to 180 m.

4.3.3 Inspection and Maintenance of Overhead Lines

Overhead line is a long linear structure and is subject to wear caused by slipping pantograph at the contact point. Another wear source is the environment that influences baseline characteristics by rain, wind, snow, ice and other natural phenomena. Because of these sources acting entire operational life, the overhead line could be considered a potential source of accidents involving broken wires due to corrosion and wear. Such accidents require several hours to repair, so maintenance is essential.

Maintenance activities begin with an accurate diagnosis on the current state of the airline, often made out of a moving car with specialized equipment. For example, overhead lines from Shinkansen are inspected every 10 days, using the "Doctor Yellow" train, a seven-car with electrical facilities and track diagnostic system. For the conventional lines, Japanese railroads authorities use a two inspection units. Items measured include contact wire height above rails, the longitudinal deviation; wire wear, pantograph vibrations at the contact point, frequency of losing contact. For Shinkansen line, measured data are processed by a central computer and the results are sent to specialized maintenance crews.

Although the use of increasingly more automated technologies are elements that cannot be checked automatically from a moving train. These factors include the degree of corrosion of power wires and screws where they are weak or opened. They must be manually inspected during maintenance activities.
When needed replacing lines or fastening elements, work is carried out using special machines. Automatic diagnosis and repairs are subject to continuous improvement in railway engineering; efforts are made to achieve fully robots to replace human inspection and intervention.

4.3.4 Technologies for Overhead Contact Line Inspection

As we know, overhead wires show a horizontal zigzag pattern to provide a uniform contact with the pantograph. A modern control system for power supply lines must be able to perform fast and accurate measurements of wear of wire, longitudinal and vertical deviation of the contact line; also must be able to display the results in real time.

Parameters to inspect for overhead contact line:

- Wear grade of contact line;
- Longitudinal deviation of contact line;
- Transversal height deviation of contact line;
- Other characteristics inspected;

4.3.4.1 Contact Line Wear Inspection

Electric overhead contact lines ensure electricity supply for railway rolling stock through pantograph that transfers energy to the locomotive. Wear of the overhead line due to contact with the pantograph can be divided into mechanical wear caused by friction and wear caused by electrical arcing when the pantograph and overhead line are separated from each other, even for a short period of time. Because of these adverse events there is a risk that the contact line to break, if the wear exceeds a certain limit.

To prevent this event that is extremely costly and dangerous for the entire railway network that includes that segment, it is essential that the inspection and maintenance of the electric supply system to be done before reaching this destructive limit.

4.3.4.2 Contact Line Deviation Inspection

The overhead line is in direct contact with the pantograph device; if this contact is limited to a small area relative to the pantograph, this part of the pantograph will be worn in accentuated grade. To prevent concentrated wear in a certain area and thus reduce the life of the pantograph, by fixing overhead line from the supporting pillars will create a horizontal zigzag pattern; in this way will ensure even wear on contact with the pantograph.

This technique produces a supplementary risk, if overhead line exceeds the pantograph length and passes beyond the edge, then the line will be caught and blocked on the pantograph edge and it will break. This risk can be greatly reduced if will be set a safe limit for the horizontal zigzag line of the contact, bellow the smallest length of a pantograph that cross that section. Obviously this measure must be accompanied by a scheduling program of inspections and maintenance that should confirm that this limitation is not exceeded in operational time.

4.3.4.3 Height Inspection

In case of overhead power supply lines there are events as length changes: stretching or contracting; these situations are associated with temperature changes as seasons changing but also from day to night. Besides the rapid wearing contact lines these phenomena cause changes in longitudinal profile lines and changes in their height.

The risk that arises is to cause jumps and frequently disconnection between overhead contact line and pantograph due contact voltage changes in the distance between the two supporting pillars. This is why inspections for electrical infrastructure, along the railway, have to include in the protocol also checking the real height of the contact line. Because of the interaction characteristics between pantograph and overhead line, these measures needed to be carried out under real working conditions.

4.3.5 Future Development

Maintenance and inspection activities are becoming increasingly importance with increasing travel speed on railway networks. The current trend of increasing safety of passenger transportation makes these activities to gain an even greater importance. Inspection activities are the first step in establishing the needed maintenance. If these checks are accurate, it can intervene only at times when needed. Thus, substantial savings can be made with both the materials and components that need replacing but also reducing downtime for passenger traffic congested segments.

In the near future it is anticipated that the frequency of inspections will be higher because the request railway infrastructure will be higher.

At present special vehicles are used for regular inspections; these vehicles contain special equipment that makes the evaluation of the functionality and wear of the railways.

Hitachi High-Technologies Corporation has developed various track inspection and overhead contact line inspection systems that use the technologies described above. For example, a top technology for inspections is “Doctor Yellow”- car inspection for Shinkansen line. The inspection cars for use on the Tokaido and Sanyo Shinkansen consist of a 7-car configuration. Each car is completed with a line of inspection equipment. With these cars a total of 25 different railway track inspection measurements are performed, including noise and axle-box accelerations. The overhead contact line inspection system, meanwhile, performs a total of 13 measurements at 5 cm intervals. Inspection can be performed at speeds similar to those used by regular high speed train services (270 km/h).

Figure 4.41 – Railway Inspection Train Class 923, for Shinkansen Lines

A theory gaining credibility is to fit the inspection systems to the trains used for commercial service, so that measurements can be performed during normal operation. In this kind of solution, Hitachi High-Technologies Corporation has already developed systems for railway track inspection, and can be mounted on the commercial vehicles and is working, even on high speed travel.

5 Power supply systems for existing infrastructure and components

Existing power supply systems, specific for railway infrastructure from partners will be presented.

This includes technical and technological performance related to the railway lines from partner's countries, as generalities and practice, and also, it includes the list of case study lines adopted by NeTIRail-INFRA project and presented in detail.

5.1 Technical characteristics and performance for power supply systems used in United Kingdom

Network Rail has approximately 8000km of OLE (Overhead Line Equipment) electrified AC routes and 4800km of DC electrified tracks. Energy consumption per km of route was mostly on the DC systems rather than AC during last year.

5.1.1 25kV AC Overhead line

The majority of NR AC traction system is 25kV OLE which is installed on WCML (West Coast Main Line), ECML and the suburban areas of Glasgow, Leeds, Birmingham & Anglia, including:

- HV Transformer substation (nominal 132/25kV or 400/25.0.25kV);
- Feeder station and along track distribution buildings;
- Mid-Point distribution buildings with neutral sections;
- OLE contact wire and catenary;
- OLE structures, associated track bonds;
- The ECR and SCADA system which control the status of ac and dc circuit breakers, and other remote operated devices.

The rail return system induces currents which may interfere with the track circuit signalling systems, when the load of the traction system goes up, the voltage induced into telecoms circuit increases.

In order to boost the return current into the return conductor, booster transformers were installed; their vicinity to the OLE provides an electric field cancellation effect. Therefore, more than 85% of the ac network is equipped by booster transformers.

However, booster transformers decrease system capacity by imposing impedance in the electrical system. To retrofit existing infrastructure, autotransformer technology has been developed by Network rail, which successfully omits the system impendence. Besides, adding an anti-phase conductor, increases the transmission voltage as twice as much and improves the efficiency further. (28)

5.1.2 750V DC Third rail

This traction system is based on a nominal 750 V, top contact, and third rail system. Over 4800 km of railway tracks of south of London, plus North London Line, Northern City Lines, Euston to Watford and Mersey-Rail are powered with this system. The third rail system include the following major parts:

- The 3-phase high voltage AC Grid supply points
- The 3-phase high voltage AC distribution cables and switching stations
- The DC distribution track paralleling huts and substations including the transformer rectifiers
- The ETE (Electrical Transformer Equipment) and associated return current equipment, like impedance bonds.
- The ECR and SCADA system which control the status of AC and DC circuit breakers, and other remote operated devices.

Track paralleling and substation huts are installed every 2-5km through the electrified route.

As the power requirements have increased a number of TPHs (Track paralleling huts) have been converted to SS (substation huts) resulting in double end fed sections.

Around 370 DC SS and 260 TPH are used to protect the ETE by means of circuit breakers which allow most roads to be independently controlled.

The loop impedance of the electrical sections has a significant effect on overall system capability. Originally 100 & 106 lb/yd steel conductor was installed, however since 1960's the policy changed to use 150 lb/yd steel rail. Similarly running rails sizes increased from 95 and 109 lb/yd to 113 lb/yd and recently UIC 60.

The return system which currently been used are available for running rails and are cross-bonded around 800m, to reduce the impedance of the system by letting the current sharing. To have continuity in dc traction return current, impedance bonds are used while keeping segregating of the ac track circuits. Loop impedance varies significantly as the lengths, conductors/ running rails, plus the number of running rails are varying. (28)

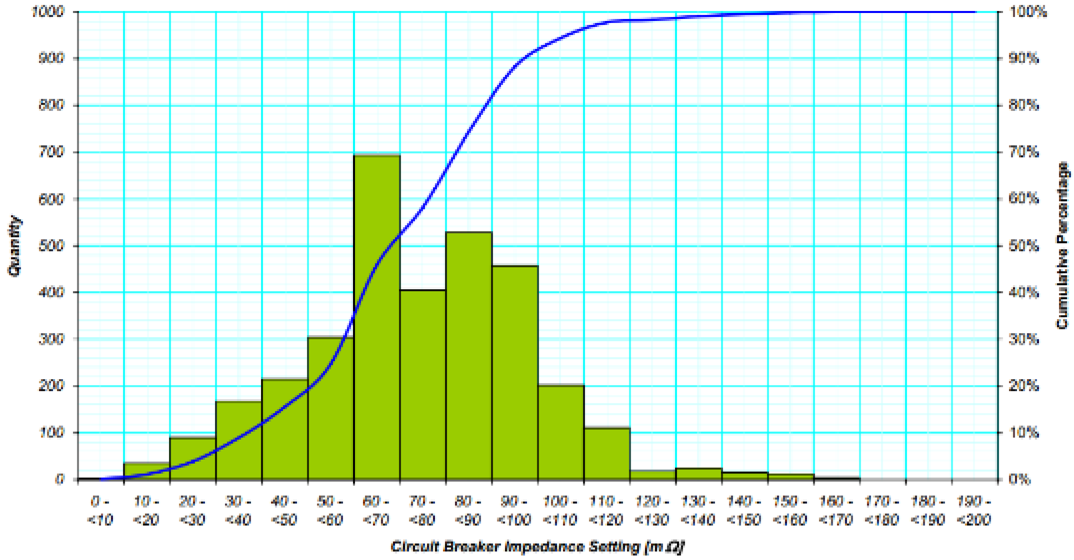


Figure 5.1 - Southern Circuit Breaker Impedance Settings

5.1.3 New Equipment

By increasing the number of trains utilizing the WCML as well as the introduction of faster services between major stations, the current OLE system/equipment will get instantly close to its maximum electrical load capacity.

To provide a safe and reliable railway as part of Network Rail's commitment in the 21st Century and to meet future increases/demand for rail services on the WCML, updating the system is required.

The solution was an autotransformer (AT) arrangement, in the UK and EU robust electrical supply on the WCML has been provided by successful installation and operation of this arrangement, which meets today's requirements and increases further capacity for the future

The classic existing OLE system and the AT system are nearly identical; but the introduction of the AT system added the following: Two single 400mm^2 aluminium 'along track conductors', one on each side of the railway which form the ATF. They are typically positioned at high level on the back or inside of each structure

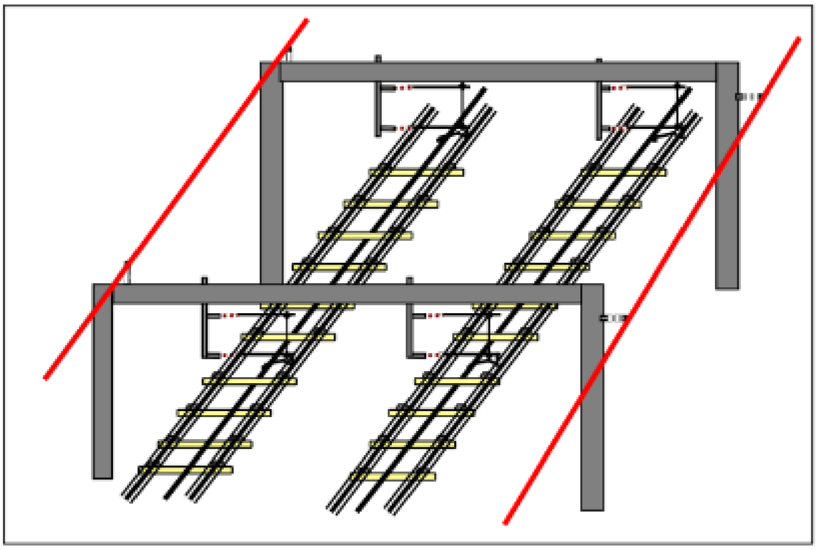


Figure 5.2 Typical ATF arrangement

Notes: the approximate placement of the ATF, which is dependent on the type of OLE structure, is shown by Red line, Booster Transformers have been removed. Return conductor removed. Existing contact wire also is illustrated by black line

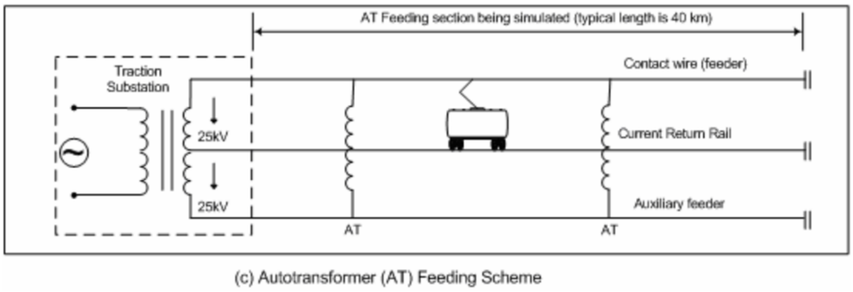


Figure 5.3 Autotransformer system [15]

5.1.4 Mileages of the different systems in the UK [16]

The length of electrified track is measured in kilometres in the below bands:

- Overhead line at 25 kVac.
- Overhead line at 1.5kVdc.
- Third rail 650 Vdc/ 750Vdc.

The length of running track and loops are considered in the measurement; however, the sidings and depots are excluded.

[15] Ref**:** Estimation of electrical losses in Network Rail Electrification Systems V1.0, 20.01.10

[16] Ref: Annual Return 2013

Lengths of track with dual electrification are separately taken into account. In addition, earthed line which is not energized is considered as non–electrified.

For England, Wales, Scotland and the whole network, electrification capabilities are listed in Table 5.1 to Table 5.3 also the breakdown by operating route for 2012/13 compared to previous years

Based on the line speed capability measure's report, the alterations of Network size mainly cause the changes of electrification data. An error was made with the AC OHL electrified track kilometres reported for Scotland in 2011/12. The number reported should have been 1,495 kilometres. This has now been corrected.

In 2012/13, additional 19km of electrified reported track were completed at Paisley Canal (9km) and Paisley Corridor (10km). Because of double tracking at Tanners Hill Flydown, the total kilometres of DC electrified track has gone up in Kent and the Route Asset Managers need to update their data throughout the year to consider some of these changes.

	March 2009	*March 2010*	*March 2011*	*March 2012*	*March 2013*
25 kV AC overhead	6,747	6,761	6,757	6,739	6,750
Third rail 650/ 750V DC	4,481	4,475	4,470	4,469	4,473
Dual AC, overhead/third rail DC	40	37	37	35	34
1500V DC overhead	39	39	39	39	39
Total electrified	11,307	11,312	11,303	11,282	11,296
Non-electrified	15,632	15,572	15,573	15,560	15,543
Total	**26,939**	**26,884**	**26,876**	**26,842**	**26,839**

Table 5.1 - Electrification capacity (km of electrified track) England & Wales

	March 2009	*March 2010*	*March 2011*	*March 2012*	*March 2013*
25 kV AC overhead	1,253	1,255	1,302	1,495	1,514
Third rail 650/ 750V DC	0	0	0	0	0
Dual AC, overhead/third rail DC	0	0	0	0	0
1500V DC overhead	0	0	0	0	0
Total electrified	1,253	1,255	1,302	1,495	1,514
Non-electrified	2,927	2,934	2,930	2,726	2,722
Total	**4,180**	**4,189**	**4,232**	**4,221**	**4,236**

Table 5.2 Electrification capacity (km of electrified track) Scotland

	March 2009	March 2010	March 2011	March 2012	March 2013
25 kV AC overhead	8,000	8,016	8,059	8,234	8,264,
Third rail 650/ 750V DC	4,481	4,475	4,470	4,469	4,473
Dual AC, overhead/third rail DC	40	37	37	35	34
1500V DC overhead	39	39	39	39	39
Total electrified	12,560	12,567	12,605	12,777	12,810
Non-electrified	18,559	18,506	18,503	18,286	18,265
Total	**31,119**	**31,073**	**31,108**	**31,063**	**31,075**

Table 5.3 Electrification capacity (km of electrified track) Network-wide

5.1.5 Regenerative braking [17]

Conventional mechanical disc brakes, electrical braking without regeneration and electric regenerative braking are types of braking systems commonly used in modern electric and diesel-electric passenger rolling stock.

Regenerative braking systems decreases the net energy consumption, and it is assumed as a cost-effective system for the train operators. The regenerative braking system contains a discount to the modelled traction electricity charge. The available discounts are listed in Table 4.

Type of infrastructure / service frequency	CP4 discount
AC, long distance (more than 10 miles between stations)	16%
AC, regional and outer suburban (less than or equal to 10 miles between stations)	18%
AC, local and commute (less than or equal to 2.1 miles between stations)	20%
DC	15%

Source: ORR, Periodic review 2008: determination of Network Rail's output and funding 2009-14

Table 5.4 Regenerative braking discounts in CP4

Comparing a train with a bicycle provides a better understanding why for regenerative braking is needed and how it works. Both cases need more energy to start off or in times of accelerating or climbing, but less effort is required to keep pace on level ground. On downhill sections, both cases consume negligible energy and they need to apply the brakes to lower speed by friction and attenuation of extra energy as heat form.

Dynamo lighting which is used in many bicycles, is a small electricity generator powered through the wheels. Dynamo lighting creates more loads and causes extra energy to speed up. Similarly, in a train with regenerative braking system when it needs to slow down, the operation of the electric motors will reverse, so that they generate power rather than using it. The power reduces the momentum of the train to such an extent that it will stop the train.

[17] Ref: Traction electricity consultation – Sep 2012

A measure of the effectiveness of regenerative braking is that in slippery conditions, it is capable of causing the wheels to skid in the same way that over application of a mechanical brake will cause the wheels to lock and slide.

The electrical power exported from the train feeds back into the electricity traction network where it will either be used by another train nearby that is drawing power, or dissipated through network losses or, in the case of the AC network, fed back into the national grid system, if the network transformers allow it. As an alternative, it is also technically feasible to store some of this surplus energy either on board the train or line-side in batteries or fly wheels.

5.1.6 The regenerative braking discount

There was little financial motive to invest in regenerative braking during the decades of relatively cheap energy. Environmental issues become more important by increasing the energy prices, the viability of regenerative braking increases.

However, installation of regenerative braking on new trains was still expensive for train operators.

Train operators were proposed discount in the modelled traction electricity charges for trains equipped with regenerative braking to encourage the installation of regenerative braking. Since local commuter trains stop more they would use their regenerative braking more frequently compared to inter-city trains and return more power to the network. Based on route type and some number of assumptions, which influence the amount of regenerated power, the regenerative braking discount varies which did not take account of the impact of the different variables. Historically this was not a major concern, as any imbalance due to these assumptions between the modelled and actual consumption was resolved through the annual volume wash-up.

It is important to revisit the way we encourage the use of regenerative braking for operators; since more operators fit meters to their trains. Based on information gathered from metered operators Virgin and London Midland the current AC regenerative braking discounts for modelled operators are in approximately the right range. Similarly, a very small sample of metered data from Southern Trains shows that the average regenerated energy, as an average percentage of the gross consumption the regenerated energy was between 16% and 20%. This suggests that the current 15% discount offered is broadly appropriate; it seems that this data is robust enough to see changing the current levels.

5.1.7 Factors affecting regeneration

An advantage of moving trains at speed is their low rolling resistance and the disadvantage occurs when trying to stop a high speed train. A key factor in braking performance is rail adhesion; therefore, avoid sliding in poor conditions such as ice or leaves, drivers can override the regenerative braking. This manual intervention means there is no control or check that regenerative braking is in service even if installed.

Based on train designing and the blending of mechanical braking with regenerative braking, the level of deceleration and regeneration varies. Some train designs operate friction and electric braking simultaneously, whereas, some others only have friction system to supplement the electric braking when the driver calls for increased retardation. The factors which affect regeneration are shown in Table 5.5. We have found that these issues often result in a few days where no regenerative energy is being produced, and many days when the output is not maximised.

Factors affecting regeneration	Influencing factors
The degree of timetable optimisation	A timetable that is optimised to reduce energy consumption by enabling trains to operate at a steady average speed with few signal stops will use less energy and also reduce regenerated brake energy.
Robustness of train operating service Passenger Performance Measures (PPM)	To maintain PPM a train operator may have to maintain a high average speed achievable only by aggressive driving. This will consume more energy but also due to reduced coasting create greater regenerative energy.
Number of electrically braked axles	The amount of regenerated power that a train can generate is partly dependent on the number of braked axles; the power that can be generated per axle is limited due to the wheel adhesion per axle.
Rail Adhesion / Weather	In poor conditions (leaves, ice) then regenerated power is reduced, often to zero.
Coasting policy	A coasting train is using no energy and is gradually reducing speed, braking and regenerated power when required to stop.
Train braking control logic	The braking of modern trains is determined by their software. The balance between mechanical and regenerative braking varies according to train class.
Driving style	An economical driving style avoids harsh braking and reduces regeneration energy.
Type of service	As indicated by the current range of regeneration discounts, the type of service influences the amount of regenerated energy.
Line design	A line with gradients, curves and junctions will require the train to brake and accelerate thereby increasing both the power consumption and power regeneration.

Table 5.5 Factors affecting regeneration

Reduction of gross energy consumption, which can be done through on-train metering itself has been considered as a first priority. When we are keen for operators to exploit the full savings that can be made through regenerative braking. We believe the priority should be to incentivise and reward those savings ahead of the secondary recovery of energy through regeneration.

Regenerated energy as well as the gross energy consumption are measured by on-train meters. Therefore, operators using on-train metering are charged based on metered energy consumption net of any regenerated power returned to the rail network. This net consumption is then uplifted to take account of losses.

5.1.8 Quantifying and reducing electrical losses [18]

5.1.8.1 AC network

Train B will use up the power which is regenerated by another motoring train A nearby. The short distance between the trains causes little loss in transferred power and in all probability much less loss than had train B been supplied by the normal feed.

If there is no other train to consume energy which is regenerated by train A, the surplus energy will return to the National Grid through the normal grid supply point. In this case, the cost of supply losses will not be incurred by the train operator; the cost of losses will return for the regenerated and it will pass through to the volume wash-up and be shared by all parties in that ESTA who are subject to the year-end volume wash-up.

5.1.8.2 DC network

In the case that there is another motoring train B near train A which regenerates energy, then train B will consume the regenerated power. Because of short distance little loss will take place in transferring the power and in all probability much less loss than had train B been supplied by the normal feed.

However, if train A regenerates energy while there is no other train to use this energy up, the extra energy cannot be taken back to the National Grid through the normal grid supply point without the installation of prohibitively expensive inversion equipment. Therefore, the regenerated energy is leaked and produces heat. Under this scenario, the train operator will not incur the cost of losses in supply and return for the regenerated energy; all parties in that ESTA are subject to the year-end volume wash-up and they will share the cost of these losses, which will pass through to the volume wash-up. As a result, in both the AC and DC networks, overall energy consumption will be decreased and the current flowing in the electrification system will be increased by regenerative braking system; therefore, electrification losses will rise. Given the scenarios described above, it is apparent that there is difference between gross energy consumption loss and energy regenerated loss.

DC regenerative braking systems have to be introduced on all DC electrified routes in Wessex, Sussex and Kent. The reduction of electric current for traction (EC4T) consumption, reductions in energy costs and consequent improvement in industry energy efficiency will be achieved through using this technology. In this modernisation project, also the nominal system voltage has been increased to 750V across the three routes, which makes marginally increment of the available traction supply capacity.

[18] Ref: Traction electricity consultation – Sep 2012; Ref: CP5 Enhancements Delivery Plan

5.1.8.3 Scope of works

In Wessex, Sussex and Kent routes DC regenerative braking is now in operation and no further work is required to meet this obligation. To enable the increase of Network Rail system voltage without risk to LUL rolling stock and systems, Segregation of 660V DC traction supplies to the LUL Waterloo & City line from Network Rail Infrastructure need be accomplished. The circuit breakers will also have to be modified to raise traction supply outputs on all inner London routes to 750V DC nominal in Wessex, Sussex and Kent, which will be completed in two parts:

- Phase 1 - by March 2014, all inner London traction supply outputs other than the areas surrounding the LUL District line interfaces at Richmond and Wimbledon will be completed;
- Phase 2 -In December 2016, once the LUL rolling stock change programmer has completed, the remaining inner London traction supply outputs will be increased.

5.1.8.4 Significant interfaces

- LUL – agreement of commercial and technical arrangements, train interfaces, introduction of S Stock trains and removal of C&D stock trains.
- South West Trains - agreement of commercial and technical arrangements and train interfaces in Wessex.
- South East Trains / Southern Trains - agreement of commercial and technical arrangements and train interfaces.
- Power supply enhancements required for introduction of longer trains.
- Asset traction power renewals.
- Renewal of Waterloo substation equipment.

5.1.9 Electrical efficiency of system in UK and Netherlands [19]

Below, three pieces of work are summarized here, which have been identified as publishing an estimation of 25 kVac system resistive losses.

The efficiency of the system using both single and multiple trains without timetabled service pattern were studied and calculations of the resistive losses in Network Rail Electrification Systems for a multi train simulation is as below:

- Rail Return 1%-2.5%
- Booster Transformer 1.5% - 3.2%
- Autotransformer 1.8% - 2.2%

5.1.10 UIC Rail energy

In addition, following work for the UIC Rail energy project done by Enotrac have been listed:

- High-speed EMU traffic, 2x25 kVac AC (France), Electrical efficiency = 97.6%

[19] Ref: Estimation of electrical losses on 25 kV ac Electrification Systems V1.0 17 December 2010

- High-speed EMU traffic, 1x15 kV AC (Germany), Electrical efficiency = 93.7%
- Intercity locomotive traffic, 1x15 kV AC (Austria), Electrical efficiency = 96.5%
- Intercity EMU traffic, 1x15 kV AC (Austria), Electrical efficiency = 82.9%
- Intercity & freight Loco/EMU, 15 kV AC (Austria), Electrical efficiency = 96.8%
- Intercity locomotive traffic, 3 kV DC (Italy), Electrical efficiency = 92.3%
- Regional EMU traffic, 15 kV AC (Sweden), Electrical efficiency = 95.6%
- Regional EMU traffic, 1.5 kV DC (Netherlands), Electrical efficiency = 84.3%
- Intercity EMU traffic, 1.5 kV DC (Netherlands), Electrical efficiency = 90.6%

It can be concluded that the most efficient electrification system is the 25 kV; besides, the sensitivity of train service pattern on the resistive system efficiency has been highlighted.

5.1.11 Vision / OSLO

To understand the losses more study was carried out by Network Rail. A proprietary software programme called OSLO is developed and it works in conjunction with another signalling software simulation programme known as VISION. VISION includes a train movement simulator, which provides the train movement and OSLO solves the resultant electrical equations.

In 5 second time steps the electrical circuit equations are solved and for various designated system nodes, the outputs are current, voltage; phase angle and power. When available voltage is insufficient, the tractive effort is reduced, and therefore, the train speed is reduced and the iterative process is needed.

Originally VISION /OSLO was developed by British Rail and improved by AEA Technology (now Delta Rail); it is considered as the industry standard and is used by a number of consulting engineers in the UK; it also has been validated a number of times.

5.2 Technical characteristics and performance for power supply systems used in Netherlands

In the Netherlands, around 6500 km of tracks are available for railway traffic. Thereof a 76% is electrified. Most of this electrified track is equipped with a 1500V DC traction power supply system. Most of the Dutch railways are conventional lines with speed limited up to 160km/h. As the power used by conventional trains is fairly independent of the traction system, high currents are required in case of a low voltage system. Therefore, the Dutch catenary was designed with a double contact wire. Also pantographs are relatively robust to accommodate the high current flow in comparison to higher voltage systems. Both the Schiphol-Antwerp high-speed line and the Betuwelijn (a freight line) provide traction power by means of a 25kV AC system operating at 50Hz. (29)

5.3 Technical characteristics and performance for power supply systems used in Turkey

5.3.1 Power supply system requirements and specifications

At İskenderun-Divriği track line, 154kV AC voltage, which is supplied from TEİAŞ, is converted to 27.5 kVac voltage by 2x12.5 MVA power transformers located in transformer station. This voltage is transferred to catenary lines to operate trains at electricity lines. There is no alternative energy type to operate trains at these lines.

5.3.2 Interaction between trains and the power grid systems, feedback to grid, the effect of reliability and safety on the lines (common failures in the power line)

At this track section, required energy and traction power are supplied from 27.5 kVac voltage which is drawn from catenary line. Return of the current drawn from catenary line to transformer station is done through rails. Due to breaking, kinetic energy converted to electricity energy cannot be feed backed to main network for the current trains.

Common failures at catenary systems for TCDD network:

- Dirty pantograph insulator located on electric powered trains;
- Breaking off the pantograph at electric powered trains;
- Dirty insulator based on environmental pollution due to industrial regions;
- Failures due to climate conditions;
- Injuries from 3rd Party;
- Failures due to track works;
- Broken Catenary wire;
- Energy cut off;
- Broken contact wire;
- Failed feeding wire;
- Short circuit of porter;

Within TCDD's track network, 12485 km line in total, 2535 km in conventional lines and 1213 km in the HSL are electrified lines which sum up to 3748 km (%30). In the electrified network there are 35 transformer centres and 10 tele/command centres that control these transformer centres remotely.

Length of Electrified Lines / 2014 (km)

Railway line	Single Line [km]	2, 3, 4 Main Lines [km]	Total [km]	Subsidiary Line [km]	Grand Total [km]	Year
Malatya - Narlı	182		182	23	205	1996
Narlı - Fevzipaşa	69		69	17	86	1996
Fevzipaşa - Toprakkale	63		63	17	80	1996
Toprakkale - İskenderun	60		60	15	75	1996
Divriği - Çetinkaya	66		66	26	92	1996
Çetinkaya-Hekimhan	72		72	20	92	1996
Hekimhan - Malatya	73		73	21	94	1996
Sincan - Behiçbey	16	32	48	4	52	1972
Behiçbey - Ankara	9	27	36	35	71	1972
Ankara - Kayaş	12	12	24	2	26	1972

5.4 Technical characteristics and performance for power supply systems used in Slovenia

Length of electrified lines	503.5 km
• double-track lines	330.9 km
• single-track lines	172.6 km
Number of power supply stations	17

Table 5.6 - Basic data with electrification system [20]

For electrified lines in the Slovenian railway network, there are adopted technical specifications for interoperability (TSI) relating to the subsystem ‘energy’ of the railway system across the European Union, as set out in the Annex “Commission Regulation (EU) No. 1301/2014 of 18 November 2014 concerning the technical specification for interoperability relating to the subsystem ‘energy’ of the railway system in the European Union ".

TSI is applicable to any new, upgraded or renewed "energy" subsystem of the rail system in the European Union, as defined in section 2.2 of Annex II to Directive 2008/57 / EC. TSI does not apply to existing infrastructure of the railway system in the European Union on 1 January 2015 are already in operation throughout the network, or part of a network of any Member State, unless renewed or upgraded in accordance with Article 20 of Directive 2008/57 / EC and Section Annex 7.3.

Slovenia applies the voltage and frequency subsystem energy as 3 kVdc. Overhead contact lines DC systems shall be designed to withstand 200 A (for a 3 kV supply system), per pantograph when train is stationary.

[20] Source: Statistical data SŽ

Figure 5.4 - Slovenian railway network [21]

Electric power devices are stable electric traction devices enabling the undisturbed transmission of electric power from the public distribution network to electric traction units and other energy devices like low-voltage transformer stations, external lighting, heating of switch-points and energy devices in buildings. The stable devices are composed of sub-stations with connection power lines and cable conduits, and the catenary, and within the construction of the most recent sub-station a system for the remote control of devices is being set up. Almost all electrified lines of Slovenske železnice are electrified by a one-way system with a rated voltage of 3 kVdc, only in near-border sections are the systems of neighbouring Austria (15 kV / 16.67 Hz) and Croatia (25 Hz / 50 Hz) built in (see Table 5.6 and Figure 5.4).

By using power lines or cable conduits, electric power is transmitted from the medium-voltage network to the sub-stations where it is transformed and rectified, and distributed to sections of the catenary. With regard to demands of the line, two rectifier aggregate units with a rated current of 667 A, 1000 A or 1500 A are installed in each of the 17 sub-stations.

The catenary transmits power to the vehicles and is electrically divided into longitudinal and transversal sections with more than 700 switches. An individual section is the catenary of one track between stations, or of a group of tracks at a station. Due to the relatively high traction currents, two contact wires with a cross-section of 100 mm2 and a support wire with a cross-section of 120 mm2 are mounted on the main tracks, which makes the total cross-section of the catenary of the

[21] http://en.slo-zeleznice.si/en/company/infrastructure/rail_network/electric_power_system

main tracks 320 mm^2. Together, all electrified tracks are over 900-km long, involving more than 24,000 poles to support the catenary.

The development of stable devices for electric traction is oriented at the modernization of existing devices, as well as in electrification of new tracks on existing and envisaged new lines. In the area of sub-stations, the installation of newer devices and the remote control system is envisaged to continue, while the development of the catenary is aimed at the use of better materials and equipment, and the reduction of impacts from the environment.

5.5 Comparative table for the five electrified case studies chosen in the NeTIRail Project

Rail Line identification /name	Divača – Koper	Pivka - Ilirska Bistrica	Kayaş - Sincan	Divriği - Malatya	Malatya - İskenderun
Line Category	Freight dominated route	Low density rural / secondary line	Busy passenger	Low density rural / secondary line	Freight dominated route
Type of electric power supply:					
Voltage levels	3 kVdc	3 kVdc	25 kVac / 50Hz	25 kVac / 50 Hz	25 kVac / 50 Hz
Current types for electricity power supply	DC	DC	Alternating Current , Single Phase	Alternating Current , Single Phase	Alternating Current , Single Phase
Contact system type	Overhead contact lines	Overhead contact lines	At TCDD electrified lines there are two system are used, new system and conventional system. At **Sincan-Kayaş** line, conventional type system is used. Within new	At TCDD electrified lines there are two system are used, new system and conventional system. At **Divriği - Malatya** line, conventional and new type system is used.	At TCDD electrified lines there are two system are used, new system and traditional system. At **İskenderun - Divriği** line, new type system is used. Within new system

Rail Line identification /name	**Divača – Koper**	**Pivka - Ilirska Bistrica**	**Kayaş - Sincan**	**Divriği - Malatya**	**Malatya - İskenderun**
			system, feedback current is loaded to the substation It had been drawn. Of 65% feedback current through the conductor rails and the rest through feedback conductor.	Within new system feedback current is loaded to the substation It had been drawn. Of 65% feedback current through the conductor rails and the rest through feedback conductor.	feedback current is loaded to the substation It had been drawn. Of 65% feedback current through the conductor rails and the rest through feedback conductor.
Primary electrical energy for railway power supply:					
Voltage values	20 kV or 110 kV	20 kV	27.5 KV	27.5 KV	27.5 KV
Source of energy	Public Grid Network	Public Grid Network	Public Grid Network	Public Grid Network	Public Grid Network
Type of energy generated	Public Grid Network	Public Grid Network	Thermo energy Hydro energy	Thermo energy Hydro energy	Thermo energy Hydro energy

Rail Line identification /name	**Divača – Koper**	**Pivka - Ilirska Bistrica**	**Kayaş - Sincan**	**Divriği - Malatya**	**Malatya - İskenderun**
Substations:					
Classification by functional types	AC/DC converter substation	AC/DC converter station	Power transformer	Power transformer	Power transformer
Distance between substation	Average 10 km	22 km	Depending on the field conditions it is about between 50km -60km	Depending on the field conditions it is about between 50km -60km	Depending on the field conditions it is about between 50km -60km
Return current circuit solution:					
Type of circuit return	running rails	running rails	Return Wire, running rail	Return Wire, running rail	Return Wire
Overhead contact lines system characteristics:					

Rail Line identification /name	Divača – Koper	Pivka - Ilirska Bistrica	Kayaş - Sincan	Divriği - Malatya	Malatya - İskenderun
Maximum speed designed	140 km/h	100 km/h	160 km for conventional lines	160 km for conventional lines	160 km for conventional lines
Static contact forces designed	90N	90 N			
Dynamic contact force designed	140N	140 N			
Adopted pre-sag [% by span length]	0.1%	0	0.15% V>120km/h 0.2% 100<V=<120km/h 0.3% V=<100km/h	0.15% V>120km/h 0.2% 100<V=<120km/h 0.3% V=<100km/h	0.15% V>120km/h 0.2% 100<V=<120km/h 0.3% V=<100km/h
Standard height adopted	5.35	5.35 m	5.75m	5.75m	5.75m

Rail Line identification /name	Divača – Koper	Pivka - Ilirska Bistrica	Kayaş - Sincan	Divriği - Malatya	Malatya - İskenderun
(from the ground);			(6,20 hemzemin)	(6,20 hemzemin)	(6.20 hemzemin)
Type of suspension	Catenary supported type	Catenary supported type	Trolley type	Trolley type	Trolley type
With/ Without stitch	Without stich	Without stitch	With stitch	With stitch	With stitch
Contact wire characteristics:					
Contact wire standard	AC-100	AC-100	BC-105; AC-120; AC-150	BC-105; AC-120; AC-150;	
Cross wire section[mm2]	2x100 mm^2	2x100mm^2	105mm^2;	105mm^2;	

Rail Line identification /name	Divača – Koper	Pivka - Ilirska Bistrica	Kayaş - Sincan	Divriği - Malatya	Malatya - İskenderun
			120 mm²; 150 mm²;	120 mm²; 150 mm²;	
Material Composition	CuAg 0.1	Cu-ETP	0.1% Au Alloy (AC-120 and AC-150)	0.1% Au Alloy (AC-120 and AC-150)	
Tensioning characteristics:					
Tensioning type	separate	separate	Separate (=>120km/h); Jointed (<120km/h);	Separate (=>120km/h); Jointed (<120km/h);	Separate (=>120km/h); Jointed (<120km/h);
Tensioning section length	Average 1000m	Average 1000m	Max. 1350m; Nominal 1250m	Max. 1350m; Nominal 1250m	Max. 1350m; Nominal 1250m;
Tensioning device type	Pulley-wheel	Pulley-wheel	Pulley-wheel;	Pulley-wheel;	Pulley-wheel;

Rail Line identification /name	**Divača – Koper**	**Pivka - Ilirska Bistrica**	**Kayaş - Sincan**	**Divriği - Malatya**	**Malatya - İskenderun**
			Spring in tunnels	Spring in tunnels	Spring in tunnels;
Tensioning force applied	7500 N	7500 N	If Separate 1200 kg; If Jointed 2000 kg;	If Separate 1200 kg; If Jointed 2000 kg;	If Separate 1200 kg; If Jointed 2000 kg;
Catenary suspension characteristics:					
Catenary Type	Simple	Single	Single	Single	Single
Standard height	1.40m	1.4 m	5.75 m	5.75 m	5.75 m

Rail Line identification /name	**Divača – Koper**	**Pivka - Ilirska Bistrica**	**Kayaş - Sincan**	**Divriği - Malatya**	**Malatya - İskenderun**
Material composition	Cu	Cu - ETP			
Droppers:					
Droppers current type	Current caring	Non-current caring	Current caring	Current caring	Current caring
Droppers mechanical type	Rigid	Sliding	Rigid	Rigid	Rigid
Material composition	Bz II	Cu	Cooper Cadmium Alloy	Cooper Cadmium Alloy	Cooper Cadmium Alloy
Poles for supports of contact line:					
Structural materials	Steel	Steel	Concrete	Concrete	Concrete

Rail Line identification /name	**Divača – Koper**	**Pivka - Ilirska Bistrica**	**Kayaş - Sincan**	**Divriği - Malatya**	**Malatya - İskenderun**
Structural design	Lattice	Tube	Section shape	Section shape	Section shape
Hinged cantilever:					
Design type	Pull-off	Pull- off	There is no hinged cantilever at TCDD networks. So Dimensions of the cantilever are variable depending on the conditions of the field.	There is no hinged cantilever at TCDD networks. So Dimensions of the cantilever are variable depending on the conditions of the field.	There is no hinged cantilever at TCDD networks. So Dimensions of the cantilever are variable depending on the conditions of the field.
Material composition	Steel	Steel	Al alloy EN-10204, EN1706, EN515, EN573-3 and EN755	Al alloy EN-10204, EN1706, EN515, EN573-3 and EN755	Al alloy EN-10204, EN1706, EN515, EN573-3 and EN755

Rail Line identification /name	Divača – Koper	Pivka - Ilirska Bistrica	Kayaş - Sincan	Divriği - Malatya	Malatya - İskenderun
Neutral sections:					
Design destination	-		Separate Phases Separate energy supply	Separate Phases Separate energy supply	Separate Phases Separate energy supply
Maximum speed designed	-	100 km/h	160 km/h	160 km/h	160 km/h

5.6 Slovenia - case studies lines

5.6.1 Rail line Divača - Koper

Line category:

Freight dominated route

Functionalities:

The line is categorized as a Main Line related to national consideration, it is single track, electrified line with 3 kVdc and has almost only freight traffic trains. There are only few passenger trains and full of freight trains per day.

Length line by sections: Divača – Prešnica: 16.5 km; Prešnica – Koper: 31.5km.

It is in the category D3, the maximal permissible axle load is 22.5 tons with gauge dimension: 1435 mm and clearance gauge: UIC B 505, which is compatible with intermodal transport.

The Divača – Koper line has the characteristics of a mountain railway, with high slopes and small radii. The starting point of the line is in Divača at 431.1 m above sea level. The line reaches sea level at Koper Freight station. The highest altitude station of the line is the station Rodik, at 537.6 m. The maximal gradient is 25.8 ‰ over 300 m between Hrastovlje and Rižana, while the minimal radius of the curve is 250 m (in section Črnotiči – Hrastovlje).

Performances:

Average number of passenger trains per day is 11. Average number of freight trains per day is 79. Capacity of the line is 82 trains per day. Maximal speed is 90 km/h.

The maximal line speed is between 65 km/h and 75 km/h for freight trains and 90 km/h for passenger trains.

In year 2014 the following parameters were registered: 4 684 PT (passenger trains) – 0.1 MP (millions passengers) and 20 375 FT (freight trains) – 11.04 Mt (millions of tons).

Economic aspects:

There are only short (few hours) possessions for maintenance works. The main problem is wearing of rails, because of heavy trains and steep slopes (inclination). Maintenance is difficult also because of no accessibility by road and of course, before mentioned heavy traffic. During summer there are also considered fire precautions.

The Divača–Koper railway line is particularly important for international rail freight traffic, given the role of the Port of Koper in linking the Slovenian hinterland with the European economy.

Need to upgrade from single to double tracks line. Second track will be shorter and with less inclination.

Other characteristics:

Year of construction related to sections: Divača – Prešnica: 1876; Prešnica – Koper: 1967.

The railway line consists of two line sections. The line section Divača - Prešnica junction was constructed in 1876 in the scope of “Istrian state railways”, when the railway line Divača – Pula was being constructed. The line section from Prešnica junction to Koper was constructed in 1967. Passenger traffic started in 1972 and, in 1979, a new passenger station in Koper was built.

The line was electrified in 1976. The catenary is supplied from electrical substations (ESS) at Divača, Črnotiče and Rižana. In the course of modernization, two electrical substations were set up in Dekani and Hrpelje - Kozina.

Need to upgrade from single to double tracks line. Second track will be shorter and with less inclination.

Quality of the track is according to national regulations. There are several types of inspections to control the quality of the track from personal inspections, hand measurement, and land survey measurement, geometrical parameters measuring by train inspection, dynamic parameters measuring train inspection.

5.6.2 Rail line Pivka - Ilirska Bistrica

Line category:

Low density rural / secondary line

Functionalities:

This particular electrified single track line with 3 kVdc, has mixed traffic, some passenger trains and some freight trains. There are only few passenger and freight trains per day.

Length of railway line: 24.5 km

Gauge dimension and clearance gauge: 1435 mm; UIC B 505.

Contrary to it high economic importance, the axle load category of line is rather limited (category C, i.e. 20 t/ axle loads).

Performances:

Average number of passenger trains per day is 14. Average number of freight trains per day is 6. Capacity of the line is 63 trains per day.

Maximal speed is 75 km/h.

In year 2014 the following parameters were registered: 10 276 PT (passenger trains) – 0.4 MP (millions passengers) and 506 FT (freight trains) – 0.08 Mt (millions of tons).

Economic aspects:

The railway line Pivka - Ilirska Bistrica - Šapjane (HŽ – Croatian Railways) is extremely important for the port of Rijeka. It also serves an alternative route that of Rijeka-Zagreb. With the liberalization of the rail transport market in Croatia, this railway line will also became a major force, because it provides the shortest route from the port of Rijeka to Central Europe.

Other characteristics:

The border station for traffic exchange is Šapjane in Croatia (HŽ), which is fitted with two systems of electrification, namely 3 kVdc (SŽ) and 25 kVac/ 50 Hz (HŽ).

Quality of the track is according to national regulations. There are several types of inspections to control the quality of the track from personal inspections, hand measurement, land survey measurement, geometrical parameters measuring train inspection, dynamic parameters measuring train inspection (not on this particular line).

5.7 Turkey – case studies

5.7.1 Rail line Kayaş - Sincan

Line category:

Busy passenger

Functionalities:

This line is an electrified line with automatic block system. The length of the line is 37km

The gauge of the line is standard (clearance gauge UIC B 505, track gauge 1435mm).

Current type for power supply system is alternating current, single phase: 25kVac / 50 Hz.

Number of tracks between sections:

- Kayaş-Ankara: 3 lines
- Ankara-Marşandiz: 4 lines
- Marşandiz-Sincan: 3 lines

The maximum gradient on the line is 17.8 ‰. A block system with 3-aspect signals is used; block section length is the same for all lines, namely 700 meters.

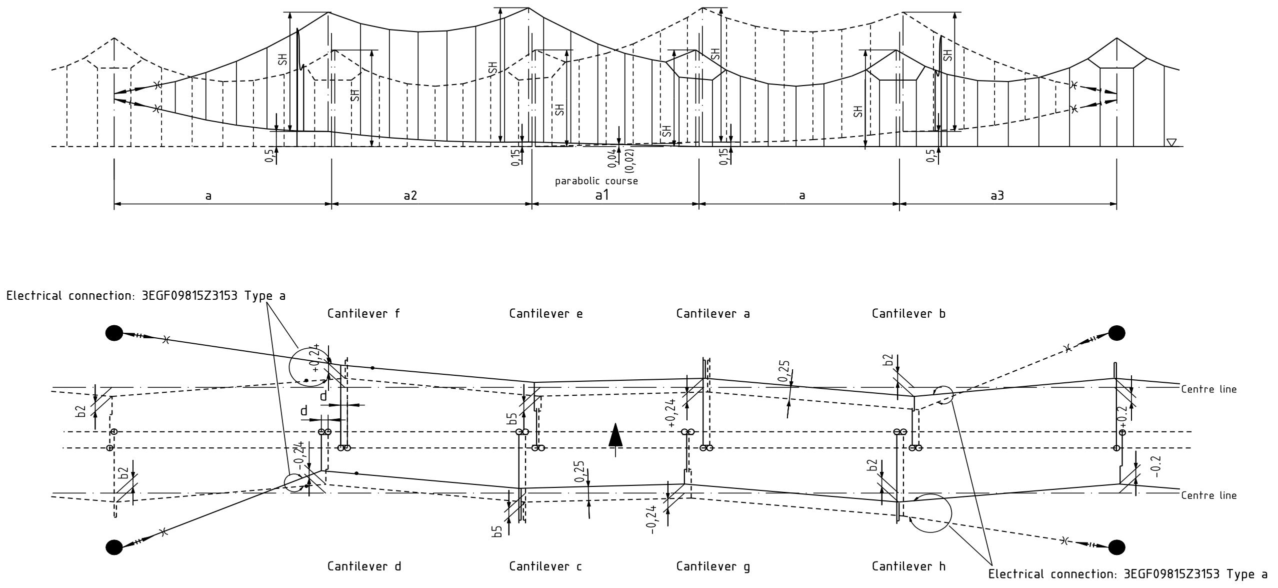


Figure 5.5 - Ankara – Kayaş: Layout standard design for overhead contact line system

Performances:

Average number of passenger trains per day is 28. Average number of freight trains per month is 148. Capacity of the line is 50 trains per day. Maximal speed is 80 km/h.

This line manages with 2,809,040 passenger train.km/year and 1,161,430 freight train.km/year. Gross-Tonnage.km are 16,222 for Ankara-Marşandiz, 30,968 for Marşandiz-Sincan and 22,014 for Ankara-Kayaş. The Sincan-Kayaş railway line comes second for passenger transportation amongst TCDD lines.

The maximum speed of the line is uniformly set at 120 km/h.

At level of year 2014 was registered next parameters: 196 599 PT (passenger trains) – 16 MP (millions passengers) and 7174 FT (freight trains).

Economic aspects:

For this line, related to 2014, were identified and separated two revenue categories:

- Revenue from passenger transportation component: 884381 €/year. On this line are used the following passenger trains: DOĞU EKSPRESİ; GÜNEY – VANGÖLÜ; İZMİR-MAVİ; POLATLI EKSPRESİ; ÇUKUROVA; KIRIKKALE EKSPRESİ; BANLİYÖ.
- Revenue from freight transportation component, by sections of the line:
    - Ankara-Marşandiz: 341650 €/year;
    - Marşandiz-Sincan: 652215 €/year ;
    - Ankara-Kayaş: 463635 €/year

5.7.2 Rail line Divriği - Malatya

Line category:

Low density rural / secondary line

Functionalities:

This line is an electrified and signalled single-track line, with length of 207 km

The gauge of the line is standard (clearance gauge UIC B 505, track gauge 1435mm). The traction system is 25kVac/ 50 Hz**.**

The line is in axle load category of D4 (22.5 t/axle, 8.0 t/m) and the maximum speed of the line is 120 km/h.

The maximum gradient on the line is 24, 12‰.

A block system with 3-aspect signals is used; block section length is the same for all lines: 700 meters.

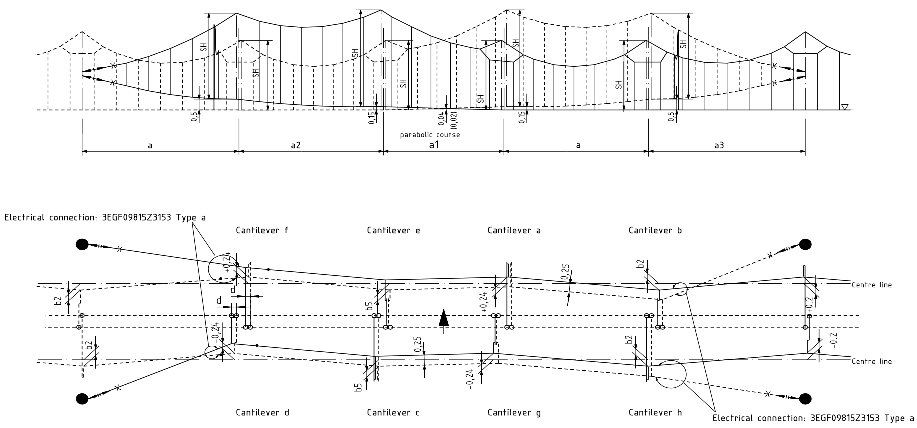


Figure 5.6 - Divriği - Malatya: Layout standard design for overhead contact line system

Performances:

At level of year 2014 was registered next parameters: 5 691 PT (passenger trains) – 0.49 MP (millions passengers) and 22 597 FT **(**freight trains) – 0.37 Mt (millions of tons)

The overall passenger train traffic represents 915,420 ton.km per year, and 5,797,660 ton.km per year for freight. The gross freight ton.km between Divriği and Çetinkaya amount to 407,683; between Çetinkaya and Hekimhan, to 438 379, and between Hekimhan and Malatya to 561 806.

At level of year 2014 was registered next parameters: 691 PT (passenger trains) – 0.49 MP (millions passengers) and 22 597 FT (freight trains).

Economic aspects:

For this line, related to 2014, were identified and separated two revenue categories:

- Revenue from passenger transportation component: 359064 €/year. On this line are used the following passenger trains: DOĞU EKSPRESİ; GÜNEY-VANGÖLÜ; 4EYLÜL.
- Revenue from freight transportation component, by sections of the line:
    - Divriği-Çetinkaya: 8586191 €/year;
    - Çetinkaya-Hekimhan: 9232678 €/year
    - Hekimhan-Malatya: 11832168 €/year

The main expenses for this line is considered to be the maintenance operations and the rent.

Divriği-Malatya line section is low-density line. Regarding that it is not possible to increase the traffic density it will be possible to decrease the maintenance cost and the line section will be more economic.

Other characteristics:

The main problematic of the line section is winter condition is very hard. It snows more than other sections and due to snowing and icing, some problems on track and S&C occurs.

5.7.3 Rail line Malatya - İskenderun

Line category:

Freight dominated route

Functionalities:

This line is an electrified and signalled single-track line, with length of 374 km.

The gauge of the line is standard (clearance gauge UIC B 505, track gauge 1435mm). The traction system is 25kVac/ 50 Hz**.**

The line is in axle load category of D4 (22.5 t/axle, 8.0 t/m) and the maximum speed of the line is 120 km/h. The maximum gradient on the line is 21‰.

A block system with 3-aspect signals is used; block section length is the same for all lines: 700 meters.

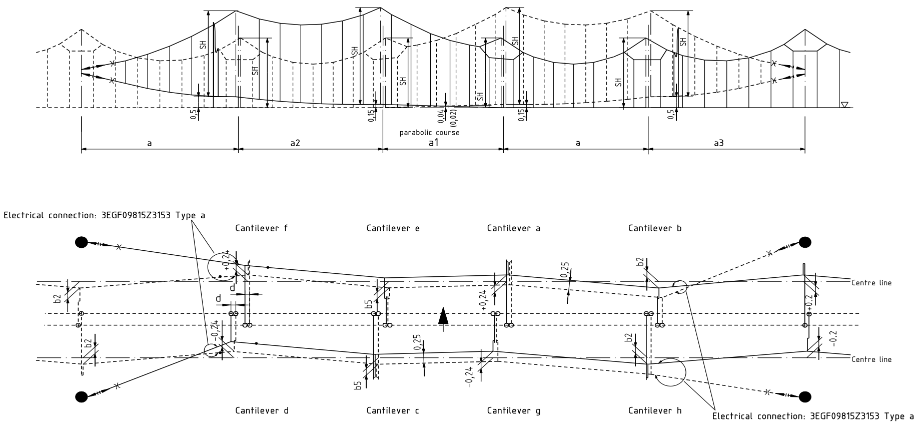


Figure 5.7 - Malatya - İskenderun: Layout standard design for overhead contact line system

Performances:

At level of year 2014 was registered next parameters: 3 593 PT (passenger trains) – 0.58 MP (millions passengers) and 38 088 FT **(**freight trains)

The number of Passenger Train-km / year is 591,300 and, the number of Freight Train - Km / Year is 16,260,750. The Gross-Tonnage-Km between Malatya and Narlı is 1,522,527, between Narlı and Fevzipaşa is 675,174, between Fevzipaşa and Toprakkale is 613,954 and between Toprakkale and Iskenderun is 425,459.

The overall passenger train traffic represents 915,420 ton.km per year, and 5,797,660 ton.km per year for freight. The gross freight ton.km between Divriği and Çetinkaya amount to 407,683; between Çetinkaya and Hekimhan, to 438 379, and between Hekimhan and Malatya to 561,806.

At level of year 2014 was registered next parameters: 3 593 PT (passenger trains) – 0.58 MP (millions passengers) and 38 088 FT (freight trains).

Economic aspects:

For this line, related to 2014, were identified and separated two revenue categories:

- Revenue from passenger transportation component: 782208 €/year. On this line are used the following passenger trains: DOĞU EKSPRESİ; FIRAT EKSPRESİ.
- Revenue from freight transportation component, by sections of the line:
    - Malatya-Narlı: 32065864 €/year;
    - Toprakkale-İskenderun: 14219806 €/year;
    - Toprakkale-Fevzipaşa: 12930454 €/year;
    - Fevzipaşa-Narlı: 8960571 €/year;

This line is of significant importance, due to the connection with Iskenderun Port and Iskenderun Iron and Steel Plant. As per 2011 statistics, the number of loaded goods is 489,000 t and unloaded goods, 1,044,000 t at the port. The revenue of the İskenderun Port is over 12.5 million TL annually.

Line capacity enhancement is expected to increase the revenue of the port by increasing the capacity of usage of the hinterland, by means of decreasing the downtime related to maintenance. The connection to the iron and steel plant is also of significant importance for freight transportation. In particular, iron ore is mined from Divriği and transported to İskenderun by rail.

The main expenses for this line is considered to be the maintenance operation.

6 Design of data repository support for analyses for existing power supply installations

6.1 Design of conceptual model of data repository

The entity relationship diagram (ERD) designed to database support for analysis of existing installations (power supply for high and low density lines) is presented below.

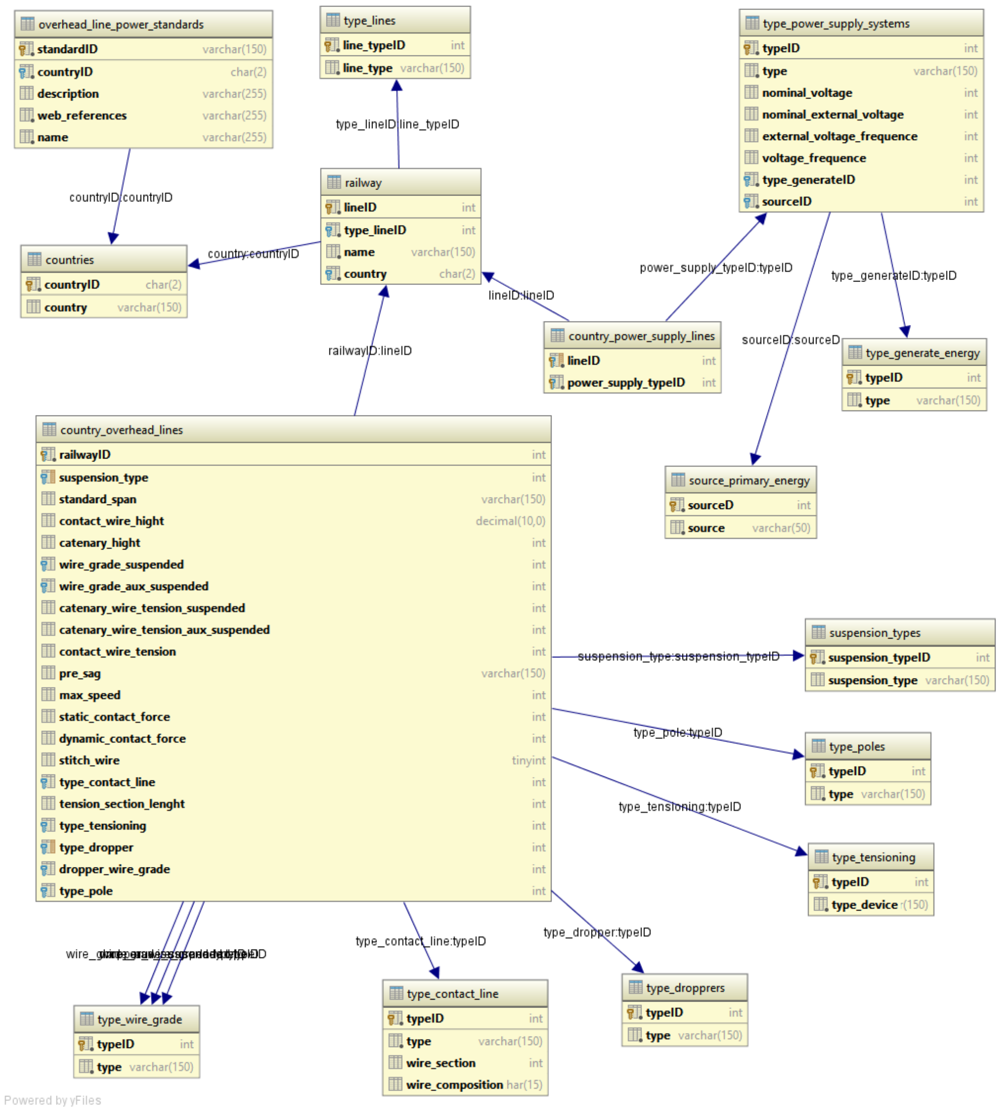


Figure 6.1 Structure of database support for analysis of existing installations: power supply for high and low density lines

The structure of the database consists of principal entities (entities on which will make analysis) and secondary entities that support the characterization of principal entities (lists of attributes for the principal entities).

The database "Support for analysis of existing installations" was conceived as an add-on for database created in Task 2.1, in order to collect additional data relating to the power supply system for electrified railway lines.

6.2 Summary of database

In this section, presents the list of the entities constituting the database support for analysis of existing installations: power supply for high and low density lines.

Name	Description
countries	In this table is managed information on the countries for which you wish to perform analysis
type_lines	In this table is managed information on the railway types for which you wish to perform analysis
type_poles	In this table is managed information regarding the classification and characteristic of different types of poles
source_primary_energy	In this table is managed information regarding the source of primary energy
type_power_supply_systems	In this table is managed information regarding the classification and characteristic of different types of power supply systems
type_generate_energy	In this table is managed information regarding the classification and characteristic of different types of generate energy
type_droppers	In this table is managed information regarding the classification and characteristic of different types of droppers
suspension_types	In this table is managed information regarding the classification and characteristic of different types of suspension
type_contact_line	In this table is managed information regarding the contact line type systems
type_wire_grade	In this table is managed information regarding the classification different types of wire grade
type_tensioning	In this table is managed information regarding the classification different types of tensioning device
railways	In this table is managed information regarding the railways network at country level

Name	Description
country_overhead_lines	In this table is managed information regarding the overhead line types at country level
country_power_supply_lines	In this table is managed information regarding the power supply systems at country level
overhead_line_power_standards	In this table is managed information regarding the overhead line power standards

7 Conclusions

Electrification systems are classified by three main parameters: voltage level of electricity power supply; current types used for electricity power supply; contact system type with electricity power supply.

The most common DC voltage power supply systems are 600 Vdc and 750 Vdc - for trams and metros. Other important categories, for intercity lines are: 1.5 kVdc and 3 kVdc.

The lower voltages are often used with third or fourth rail systems, whereas voltages levels above 1kV should be raised up to overhead lines, for safety reasons.

Alternative current (AC) - This category represents with no exception, the overhead power supply system. This allows much higher voltages and therefore smaller currents along the line, which means smaller energy losses for long railways, lesser components renewal.

Taking in consideration the variety of railway electrification systems, which can vary even within a country, trains often have to pass from one system to another. In Europe, it is common to use four system locomotives (1.5 kVdc; 3 kVdc; 15 kVac / 16.7 Hz; 25 kVac / 50 Hz).

Reliability in operation electrified railway networks depends by the availability and reliability of the electricity traction supply system. Contact line requirements – overhead line or third rail – have to take in consideration the contact line cannot be installed redundant, from economic and technical reasons.

Main disadvantages of electric power supply system are the high cost as initial investment and continuous addition maintenance; these could be uneconomic on low traffic routes. Bringing electric power supply as an upgrade for a railway line has opposite effect as the one desired: the maintenance costs will grow. The cost reduction is not an objective, even if all infrastructure managers and rolling stock operators claim lower maintenance costs as principal condition for new investments and upgrades.

Main benefits of electrification are increased productivity of railway infrastructure as well as rolling stock: locomotives and wagons.

Overhead lines represent a transporting system used to transmit electrical energy to trains from the energy supply point.

The contact line, as wire, is grooved to allow a clamp to attach the dropper wire and to be fixed on the top side. The tension of the wire is maintained by weights suspended (most usual solution) at each end of its length.

Interoperability is the most important requirement for existing and newest railway power supply systems, not only for present period but more important for the futures; this became a political goal of the European Community (EC).

Overhead contact line systems include: catenary wire, contact wire, return current conductors, earthed conductors, lightning protection conductors, feeder and parallel feeder lines, foundations, supporting structures and other components which serve to hold and support contact wire and conductors, switchgear equipment, monitoring and protective equipment.

To achieve good high-speed current collection, it is necessary to keep the contact wire geometry within defined limits; this is responsibility by a second wire known as the messenger wire (US & Canada) or catenary (Europe). This catenary wire is attached to the contact wire at regular intervals by vertical wires known as droppers.

The contact wire is zigzagged slightly to the left and right of centre at each successive support poles, so that the pantograph wears evenly.

Compound overhead contact line system uses a second support wire – auxiliary wire - between the catenary wire and the contact wire, and represents an improvement of the system.

The pantograph is the most important external component which influences the performance and the life cycle of the contact line system. For this reason, its characteristics and performance are described in this report.

The contact lines should be at constant mechanical tension to prevent pantograph oscillations in the electrical lines and to avoid producing waves of contact lines; tensioning the line makes these functions.

An electric multiple unit or EMU is a multiple unit train consisting of self-propelled carriages, using electricity as the motive power; most EMUs are used for passenger trains.

Neutral sections usually consist of an earthed section of wire which is separated from the contact lines on either side by insulating material; the pantograph will not collect power traction from one section to the other. Main roles are: section insulator; phase separation.

Systems from "third rail" category are implementing railways lines that are supplying electricity through a rigid conductor placed continuously near or between the railroad tracks; it is mostly used in systems for transport passengers, where the system has its own alignment. The main disadvantage of third rail systems is that they present the hazard of electric shock because higher system voltages; for this reason all voltages used, above 1500 V are not considered safe and present higher resistive losses compared to higher voltage overhead line systems.

The world speed record for a third rail train is 174 km/h reached on 11 April 1988 by a British Class 442 EMU.

There are systems that use a combination of power supply systems using third rail for part of the system, and overhead catenary system or diesel power engine for the rest of the track section.

However, the best technical solution is to achieve full compatibility of entire networks. This is the cause of conversions from third rail to overhead contact line supply (or vice versa).

The most representative and high performance existing overhead contact lines (OCL) systems are presented as technical characteristics and related to their category of voltage and frequency used. These categories are: OCL for 3kVdc; OCL for 1.5 kVdc; OCL for 15kVac/ 16.7Hz; OCL for 25 kVac/ 50Hz.

The operating requirements and the power supply systems of long-distance main line traffic are the factors leading to the use of overhead contact lines as traction energy supply installations for railways with low and medium traffic density, capable to provide high energy with high voltage to traction vehicles. Lines with low density traffic give opportunity to improve the infrastructure for becoming high speed lines.

Traffic lines for high density and short distance are mostly considered suitable for local area traffic, commuters' traffic, etc., where the railway traffic solution can decrease traffic congestions in high populated areas.

Designing new railway power supply systems have to consider climatic requirements: outdoor temperature; wind velocities and wind loads; corrosive substances from environment; lightning voltage surges; snow and icing of contact lines and infrastructure.

For designing new overhead power supply systems, as modern practice, compound catenary systems feature less pantograph vertical motion and less vibrations but larger current capacity and require a larger number of components, resulting in a more complex design.

Simple catenary system is used especially in Europe and pre sag has role to compensate large vertical motion of the pantograph. This design can be effective for the overhead lines on the French and German high-speed lines which have large span amplitude, but is less effective for overhead lines with small amplitudes like the Italian high-speed line, also for Shinkansen line. When designing new power supply systems, concerns should be considered selecting components and technologies will be used: selection of the overhead contact line design; selection of conductor cross sections and tensile forces; selection of span lengths; selection of system height; design of contact lines in tunnels; adoption of contact wire pre-sag; selection of dropper spacing; using of a stitch wire; selection of tensioning section length.

Maintenance process is direct dependent by inspection activities. Parameters to inspect for overhead contact line: wear grade of contact line; longitudinal deviation of contact line; transversal height deviation of contact line; other characteristics inspected.

At present special vehicles are used for regular inspections; these vehicles contain special equipment that makes the evaluation of the functionality and wear of the railways.

A theory gaining credibility is to fit the inspection systems to the trains used for commercial service, so that measurements can be performed during normal operation.

In the last part technical characteristics and performance for systems used in United Kingdom, Netherlands, Turkey, and Slovenia are presented.

Seven railway lines were chosen to complete a list with case studies for next tasks of the project. Five from these are electrified lines and a comparative table with detailed technical characteristics, related to their power supply systems, are provided. Also, are presented description related to functionalities, performance, economic aspects, etc.

These lines are for Slovenia: Divača - Koper (as freight dominated route) and Pivka - Ilirska Bistrica (as low density rural / secondary line). For Turkey, the INTADER were selected railway lines: Kayaş - Sincan (as busy passenger), Divriği - Malatya (as low density rural / secondary line) and Malatya - İskenderun (as freight dominated route).

Main objectives when railways are modernized: allowing heavier trains to run safely and economically at faster speeds; improving productivity; providing better customer service to rail users.

Framing a railway line in one of the three categories, defined in project analysis, it is subjective; a line of high-density transport for one region could be a low-density transportation line for other infrastructure manager, in another geographic region. In this way, wear of rail infrastructure and maintenance activities costs are more pronounced, in the same period of time, for one situation than for the other, although both cases are qualified as high density transport.

Current strategies for railways modernization are focused on:

- Track and power supply infrastructure modernization for high speed lines.
- Railway modernization adopting strategies focused for designing of dedicated freight routes which means for carrying freight traffic at higher speeds and increased axle loads.

In case of the railway power supply systems, the most important improvement is the upgrading from systems based on DC voltage to high-voltage systems with alternating current; and as a default will also change the type of contact from third rail to overhead contact line. This modernization will bring significant extra traction power for locomotives, which implies a higher travel speed and larger capacity of transportation. Also, the loss of electric power will be lower in AC power supply systems than in DC variant. Other improvements are related to selecting the best options, as presented in deliverable, for each component or subsystem that make up power supply systems: overhead quality wire, tensioning line devices, neutral sections provided, type of catenary, type of droppers, using of a stitch wire, inspection and maintenance quality, etc.

For the situation of busy passenger line, infrastructure modernization is necessary to serve in good conditions the social demands. Meanwhile, expenses incurred by infrastructure improvements are economic feasible as this investment will be recovered from covering increased demand of passenger traffic; so, this situation a good return on investment should be realised. The main target of modernization is to increase the speed of trains in this category of line. However, with the upgrade from third rail to overhead line the investment cost also need to include potential modifications to structures and tunnels to allow electrical clearances between the structures and the high voltage overhead line. In many cases the changes to existing structures can be a very expensive part of any new electrification scheme or the upgrade from third rail systems to AC overhead line systems.

Freight category dominated route also has the advantage that the investments to be recovered on the basis of covering the transport needs. Most important improvement for better utilisation of freight category dominated route is to increase the axle loads on the routes, with immediate result to increase railway capacity. The objectives could be summarised as to have axle loads of 30 tonnes for new lines because that could be designed according to highest technical requirements, and for the current lines to increase loading capacity up to 25 tonnes per axle, obvious with improvements even for tracks and wagons.

Low density rural/ secondary line represents a different situation. Increasing traffic density is mainly dependent on external factors. Modernisation of line involves costs that may not be recovered. In this way, increasing efficiency could be possible through decreasing the maintenance cost; with this strategy, the line section will become more economic. Any improvement proposed at the others categories will contribute to decreasing maintenance expenses but any investment would only be realised if an economic assessment proved the scheme worthwhile. For low density rural/secondary lines other technologies may provide effective returns, for example if on train energy storage could be used in combination with electrification so that less infrastructure investment is required and the on board energy storage is used for carrying the train along lesser used sections and can be used to avoid expensive alterations to structures.

8 References

1. *Overhead Contact Line Systems for Main-line Railways.* **AG, Siemens.** s.l. : www.siemens.com, 2012.

2. **Bartels, S, Herbert, W. and Seifert, R.** *High-speed pantograph for the ICE .*

3. **Braun, E.** Connection of railway substations to the nationa three-phase power supply for the Madrid-Seville high-speed line. *Elektrische Bahnen.* 5/1990, 1990.

4. —. Power supply of the high-speed line Madrid - Seville. *Elektrische Bahnen.* 12/1990, 1990.

5. **Frey, Sheilah.** Railway Electrification Systems & Engineering. 2012.

6. **Harprecht, W.** Modern installations for traction power supply. *Die Bundesbahn.* 7/1986, 1986.

7. **Kiessling, Puschmann, Schmieder, Schneider.** Contact Lines for Electric Railways - Planning, Design, Implementation, Maintenance; Second Edition. 2012.

8. **Herbert, W.** Development and operating experience with the DSA 350S high speed pantograph for the ICE.

9. **Horstman, D. Budzinski, F. Pirwitz, J.** The dual system traction equipment of the high speed train Velaro for Russia. *ETG-Fachberichte.* 107 /108 (2007), 2007.

10. **Hardmeier, W., Schneider, A.** Direttissima Italy, high-speed lines Bologna-Florence and Florence-Rome. 1989.

11. **Wittke, V. and Bauer, G.** Standardised traction power substations without central compressed air supply at German Railway. *Elektrische Bahnen.* 8/1985, 1985.

12. **Grimrath, H. and Reuen, H.** Electrification of line Elmshorn-ltzehoe with overhead contact line system Sicat S1.0. *Elektrische Bahnen.* 10/1998, 1998.

13. **Ungvari, S. and Paul, G.** Overhead contact line Sicat Hl.O for the new high-speed line Cologne-Rhine/Main. *Elektrische Bahnen.* 7/1998, 1998.

14. **Kohlhaa.s, J., et al.** Interoperable overhead contact line Sicat H1.0 for high-speed line Cologne-Rhine/Main . *Elektrische Bahnen .* 7/2002 , 2002 .

15. **Thoresen, Th. E. and Gjertsen, E.** New overhead contact lines for Norges Statsbaner. *Elektrische Bahnen.* 4/1996, 1996.

16. **Hahn, G.** Overhead contact line design of the Loetschberg base tunnel. *Elektrische Bahnen.* 5/2007, 2007.

17. **Lortscbei, M., Aeberhard, Z. and Scbiu, R.** Demand on traction power for the Loetschberg lines. *Elektrische Bahnen.* 11/2007 , 2007 .

18. **Kocher, M.** The new overhead contact line system "BN 160" of Bern-Neuenburg Railway. *Information brochure of BLS.*

19. **Vega, T.** High-speed line Madrid-Sevilla completely operated with AC 25 kV 50Hz. *Elektrische Bahnen.* 3/2003, 2003.

20. **Roldan, S. and Vega, T.** New high-speed line Madrid-Toledo. In Elektrische Bahnen. 2/2006, 2006.

21. **Chambron, E.** Construction of the TGV atlantique project and the civil engineering works. In: Revue Generale des Chemins de Fer. *Revue Generale des Chemins de Fer.* 12/1986, 1986.

22. **Luppi, J. and Lamon, J.-P.** History of 25kV contact lines . *Revue Generale des Chemins de Fer .* 3/1992 , 1992 .

23. **Watanabe, K.** Review and perspektive of Shinkansen. *Elektrische Bahnen.* 5/1985, 1985.

24. **Junsheng, L. and Zimmert, G.** Electrification of the line Harbin - Dalian within the Peoples Republic of China. *Elektrische Bahnen.* 3/2001 , 2001 .

25. **Altmann, A., Matthes, R. and Rister, S.** Electrification of the high-speed line HSL Zuid. *Elektrische Bahnen.* 5/2005, 2005.

26. **Liu Heyun, Gu Xiaosong, Tang Wenbin.** Icing and Anti-Icing of Railway Contact Wires. 2012.

27. **Yasu Oura, Yoshifumi Mochinaga, Hiroki Nagasawa.** Railway Electric Power Feeding Systems (Japan Railway & Transport Review). *Japan Railway & Transport Review.* 16/1998.

28. Estimation of electrical losses in Network Rail Electrification Systems V1.0, 20.01.10.

29. P. Ramaekers, T. de Wit, M. Pouwels,. "Hoe druk het is nu werkelijk op het Nederlandse spoor?” Centraal Bureau voor de Statistiek . s.l. : Den Haag/Heerlen. , February 2009.

30. DESIGN GUIDELINES. Guide to Station Planning and Design Issue 1; Network Rail. 2011.

31. SKIBICKI, Jacek. The new version of contact-less method for localisation of catenary contact wire – theoretical assumption. *PRZEGLĄD ELEKTROTECHNICZNY.* 7/2013, 2013.

32. K. Lee, Y.H. Cho, Y. Park, S. Kwon. Improvements of Existing Overhead Lines for 180 km/h operation of the Tilting Train.

4 ANNEX 1: Power supply systems related to power supply voltage and type of current

4.1 Electrification system 600 Vdc

This voltage is mostly used by older tram systems worldwide but by a few new ones as well.

Country	Name of system	Location
Australia	Adelaide Metro tramway	Adelaide
	Yarra Trams	Melbourne
Belgium	Belgian Coast Tram	Antwerp
	Brussels trams	De Panne to Knokke
	Ghent Tram	Brussels
	Calgary Transit C-Train	Ghent
Canada	Edmonton Transit LRT	Calgary
	Toronto Transit Commission	Edmonton
	most tram lines	Toronto
Czech Republic	Blackpoll Tramway	
England	Tallinn tram	Blackpoll
Estonia	Helsinki tram	Tallinn
Finland	Augsburg tram	Helsinki
Germany	BKV	Augsburg
Hungary	DKV	Budapest
	MVK Zrt.	Debrecen
	Public transport in Szeged	Miskolc
	BKV	Szeged
	Most tram lines	Budapest
Italy	Most tram lines	

Country	Name of system	Location
Japan	Chōshi Electric Railway	
	Eizan Electric Railway	Chōshi, Chiba
	Enoshima Electric Railway	Kyoto, Kyoto
	Iyotetsu Takahama Line	Kanagawa
	Shizuoka Railway	Matsuyama, Ehime
	Tokyu Setagaya Line	Shizuoka, Shizuoka
	Amsterdam Tram	Tokyo
Netherlands	Rotterdam tram	Amsterdam
	Trams in The Hague	Rotterdam
	city tram networks	The Hague
	Suburban trams in Łódź, Konstantynów Łódzki, Lutomiersk, Ozorków, Pabianice and Zgierz	Warszawa and suburbs
	city tram networks	Łódź
	Arad tramway system	Bydgoszcz, Częstochowa, Elbląg, Gdańsk, GOP, Gorzów Wielkopolski, Grudziądz, Kraków , Poznań, Szczecin, Toruń, Warszawa (Warsaw), Wrocław
Romania	Botoşani tramway system	Arad
	Craiova tramway system	Botoşani
	Iaşi tramway system	Craiova
	Oradea tramway system	Iaşi
	Sibiu-Răşinari Narrow Gauge Railway	Oradea
	Timişoara tramway system	Sibiu county
	Belgrade tram system	Timişoara
Serbia	Trenčianska elektrická železnica (TREŽ)	Belgrade
Slovakia	Basel Trams (BVB)	Trenčianska Teplá – Trenčianske Teplice

Country	Name of system	Location
Switzerland	Bern Trams (Bernmobil)	Basel
	Dolderbahn	Bern
	Geneva Trams (TPG)	Zürich
	Regionalverkehr Bern-Solothurn (RBS)	Geneva
	Zürich Trams (VBZ)	Canton Bern
	Kenosha Streetcar	Zürich
United States	MBTA	Kenosha, Wisconsin
	RTA Rapid Transit	Boston
	San Diego Electric Railway & San Diego Trolley	Cleveland, Ohio
	San Francisco Muni	San Diego
	SEPTA	San Francisco

4.2 Electrification system 750 Vdc

This voltage is used for most modern tram systems.

Country	Name of system	Location
Argentina	PreMetro line E2	Buenos Aires
	Tranvía del Este	Buenos Aires
Australia	GoldLinQ	Gold Coast, Queensland
	Light rail in Sydney	Sydney
Austria	Local lines of Stern & Hafferl	
Austria/ Switzerland	Internationale Rheinregulierungsbahn	River Rhine / Lake Constance
Brazil	MetrôRio	Rio de Janeiro
Germany	Albtalbahn	Rhein-Haardtbahn
	Cologne-Bonn Tram	Cologne to Bonn and its suburbs.
Greece	Athens Tram	Athens

Country	Name of system	Location
Hong Kong	Light Rail (MTR)	Hong Kong
India	Kolkata Metro Line 1	Kolkata
	Namma Metro	Bangalore
Ireland	LUAS	Dublin
Italy	Metropolitana di Genova	Genova
Japan	Enshū Railway	Hamamatsu, Shizuoka
	Hakone Tozan Railway Line	Hakone, Kanagawa
	Iyotetsu Yokogawara Line and Gunchū Line	Ehime
	Yokkaichi Asunarou Railway Utsube Line, Hachiōji Line	Yokkaichi, Mie
Malaysia	Kelana Jaya Line (RapidKL Rail)	Kuala Lumpur
Netherlands	Randstadrail	The Hague, Zoetermeer, Rotterdam and adjacent cities
	Rotterdam Metro	Rotterdam
	Utrecht sneltram	Utrecht, Nieuwegein and IJsselstein
Norway	Oslo Tramway	Oslo
	Bergen Light Rail	Bergen
Philippines	Manila LRT Line 1 (Light Rail Transit System)	Metro Manila
	Manila Metro Rail Transit System	Metro Manila
	Metro do Porto	Oporto
Portugal	Metro Transportes do Sul	Almada, Seixal
	Manila LRT Line 1 (Light Rail Transit System)	Metro Manila
Sweden	Trams in Stockholm and Saltsjöbanan	Stockholm
	Gothenburg tram	Göteborg
	Trams in Norrköping	Norrköping
Switzerland	Wynental- und Suhrentalbahn (WSB)	Aargau

Country	Name of system	Location
Turkey	Eskişehir Tramway System	Eskişehir
United Kingdom	Edinburgh Trams	Edinburgh
	Manchester Metrolink	Manchester
	Midland Metro	Birmingham to Wolverhampton
	Nottingham Express Transit	Nottingham
	Sheffield Supertram	Sheffield
	Tramlink	South London
United States	Baltimore Light Rail	Baltimore, MD
	Dallas Area Rapid Transit (DART)	Dallas, TX and adjacent suburbs
	Denver Regional Transportation District (RTD)	Denver, Colorado
	Houston Metrorail	Houston, TX
	Hudson-Bergen Light Rail	Hudson County, New Jersey
	Los Angeles Metro Rail	Los Angeles County, California
	Lynx Rapid Transit	Charlotte, North Carolina
	MAX, TriMet	Portland, Oregon
	METRO	Minneapolis-Saint Paul
	Newark Light Rail	Newark, New Jersey
	Portland Streetcar	Portland, Oregon
	Sacramento Regional Transit (RT)	Sacramento, California
	Santa Clara Valley Transportation Authority	San Jose, California
	South Lake Union Streetcar	Seattle, Washington
	St Louis Metrolink	St Louis, Missouri
	Sacramento Regional Transit (RT)	Sacramento, California
	Tacoma Link	Tacoma, Washington
	Tide Light Rail	Norfolk, Virginia

Country	Name of system	Location
	TRAX	Salt Lake City, Utah
	Valley Metro	Phoenix, AZ

4.3 Electrification system 1.2 kVdc

Country	Name of system	Location
Cuba	Ferrocarriles Nacionales de Cuba	Havana – Matanzas and branches
Germany	Lusatian	Lusatian
Hungary	Budapest Suburban Railway lines	Budapest
Spain	Barcelona Metro	Barcelona, Catalonia
	Sóller Railway	Palma – Sóller, Majorca
Switzerland	Aare Seeland mobil (ASm)	Canton Bern / Canton Solothurn
	Bremgarten-Dietikon-Bahn	Dietikon, Canton Zürich – Wohlen, Aargau
	Forchbahn	Zürich – Esslingen, Canton Zürich
	Frauenfeld-Wil-Bahn	Frauenfeld, Thurgau – Wil, Canton St. Gallen
	Meiringen–Innertkirchen Bahn	Meiringen – Innertkirchen, Canton Bern
	Sihltal Zürich Uetliberg Bahn	Zürich – Üetliberg, Canton Zürich

4.4 Electrification system 1.5 kVdc

Country	Name of system	Location
Argentina	Buenos Aires Metro	Buenos Aires
	Tren de la Costa	Buenos Aires
Australia	Sydney Trains	Sydney
	Melbourne Suburban Railways	Melbourne
Brazil	São Paulo Metro	São Paulo

Country	Name of system	Location
China	Shanghai Metro	Shanghai
	Guangzhou Metro	Guangzhou
	Shenzhen Metro	Shenzhen
Czech Republic	Czech Railway Infrastructure Administration (SŽDC)	
Denmark	Copenhagen S-train	Copenhagen
Dominican Republic	Santo Domingo Metro	Santo Domingo
Egypt	Cairo Metro	Cairo
France	Société Nationale des Chemins de fer (SNCF)	
Hong Kong	Mass Transit Railway Corporation	Hong Kong
Hungary	Budapest Cog-wheel Railway	Budapest
India	Mumbai Suburban Railway	Mumbai
Indonesia	KRL Jabotabek	Jakarta
Ireland	Dublin Area Rapid Transit	Dublin
Italy	Metropolitana di Roma	Roma
Italy	Metropolitana di Roma	Roma
Japan	Japan Railways (JR) lines	
	Most private railway lines	
	Most subway lines	
Philippines	Manila MRT Line 2 (Light Rail Transit System)	Metro Manila
Netherlands	Nederlandse Spoorwegen - Dutch Railways (NS)	
New Zealand	Wellington Suburban	Wellington
	Wellington Suburban	Wellington
Portugal	Cascais Line	Cascais
Singapore	Mass Rapid Transit	Singapore

Country	Name of system	Location
South Korea	Seoul Subway	Seoul National Capital Area
	Incheon Subway	Incheon
	Daegu Subway	Daegu
	Busan Subway	Busan
	Daejeon Subway	Daejeon
	Gwangju Subway	Gwangju
Slovakia	Tatra Electric Railway	
Spain	Ferrocarrils de la Generalitat de Catalunya	Catalunya
	RENFE	
	Euskotren	
	FEVE	
	Ferrocarrils de la Generalitat Valenciana	valencia
Switzerland	Chemin de fer Aigle–Leysin (AL)	Aigle – Leysin, Vaud
	Chemin de fer Aigle–Ollon–Monthey–Champéry (AOMC)	Aigle, Vaud – Champéry, Valais
	Chemin de fer Aigle–Sépey–Diablerets (ASD)	Aigle – Les Diablerets, Vaud
	Berner Oberland Bahn (BOB)	Interlaken – Lauterbrunnen / Grindelwald, Canton Bern
	Chemins de fer du Jura (CJ)	Canton Jura
	Chemin de fer Lausanne–Échallens–Bercher (LEB)	Lausanne – Bercher, Vaud
	Chemin de fer Nyon-St-Cergue-Morez (NStCNM)	Nyon – La Cure, Vaud
	Rigi-Bahnen (VRB/ARB)	Vitznau / Goldau – Rigi
	Schynige Platte Bahn (SPB)	Wilderswil – Schynige Platte, Canton Bern
	Waldenburgerbahn (WB)	Liestal – Waldenburg, Basel-Landschaft

Country	Name of system	Location
	Wengernalpbahn (WAB)	Lauterbrunnen – Grindelwald, Canton Bern
	Chemin de fer Aigle–Ollon–Monthey–Champéry (AOMC)	Aigle, Vaud – Champéry, Valais
Sweden	Roslagsbanan	Stockholm
Turkey	Bursa LRT	Bursa
United Kingdom	Tyne and Wear Metro	Newcastle, Sunderland, Gateshead and Tyneside
	Manchester-Sheffield-Wath	Manchester to Sheffield
	Manchester, South Junction and Altrincham Railway	Manchester
	Great Eastern Main Line	London (Liverpool Street) to Shenfield (then Chelmsford)
	Shildon to Newport	County Durham
United States	Metra Electric District Service	Chicago
	Chicago SouthShore and South Bend Railroad NICTD Line	Northern Indiana & Chicago
	Central Link	Seattle

4.5

4.6 Electrification system 3 kVdc

Country	Name of system	Location
Belgium	Belgium National Railways (SNCB)	
Canada	Deux-Montagnes Line	Montreal
Czech Republic	Czech Railway Infrastructure Administration (SŽDC)	
Estonia		
Georgia	Georgian Railway LLC	
Italy	RFI - Rete Ferroviaria Italiana (Italian Railways Network)	
Latvia	Latvian Railways (LDz)	

Country	Name of system	Location
Luxembourg	Chemins de fer luxembourgeois (CFL)	The line between Luxembourg and Arlon
Poland	Polish State Railways (PKP)	
Russian Federation	Russian Railways (RZD)	
Slovakia	Slovak Republic Railways (ŽSR)	
Slovenia	Slovenian Railways (SŽ)	
South Africa	Transnet Freight Rail (TFR); MetroRail	
Spain	Spanish National Railways (RENFE)	
Ukraine	Ukrainian Railways	
United States	Morris & Essex Lines	New Jersey, lines towards New York City

4.7 Electrification system 15 kVac/ 16.7 Hz

Country	Name of system	Location
Austria	Austrian Federal Railways	
Germany	German National Railways	
Norway	Norwegian National Rail Administration	
Sweden	Swedish Transport Administration	
Switzerland	Chemin de fer Bière-Apples-Morges (BAM)	Vaud
	BLS	Canton Bern
	Sihltal Zürich Uetliberg Bahn	Canton Zürich
	Swiss Federal Railways	Throughout the country
	Zentralbahn	Central Switzerland and Bernese Oberland

4.8 Electrification system 25 kVac/ 50 Hz

Country	Name of system	Location

Country	Name of system	Location
Argentina	Ferrocarril General Roca	Buenos Aires
Australia	Queensland Rail, Citytrain	Brisbane, North Coast Line, Coalfields
	Transperth	Perth
	Adelaide Metro	Adelaide
Belgium	Belgium National Railways (NMBS/SNCB)	High-speed lines and some other lines
Bulgaria	Bulgarian State Railways BDZ	
Croatia	Croatian Railways (HŽ)	Nationwide
Czech Republic	Czech Railway Infrastructure Administration (SŽDC)	
Denmark	Banedanmark	See rail transport in Denmark
Finland	Finnish Railway network	
France	French National Railways (SNCF)	
Germany	Rübelandbahn	Harz
Greece	Hellenic Railways Organisation (OSE)	Nationwide
Hong Kong	Mass Transit Railway Corporation (East Rail Line) (West Rail Line) and (Ma On Shan Line)	Hong Kong
Hungary	Hungarian State Railways (MÁV) and Raab-Oedenburg-Ebenfurter Eisenbahn AG (GYSEV)	
India	Indian Railways (IR)	
	Delhi Metro	Delhi
Israel	Israel Railways	
Japan	JR East Tōhoku, Jōetsu, and Hokuriku Shinkansen	
Latvia	Latvian Railways (LDz)	
Lithuania	Lithuanian Railways (LG)	Naujoji Vilnia-Kaunas and Naujoji Vilnia-Trakai
Luxembourg	Chemins de fer luxembourgeois (CFL)	National standard
Macedonia	Macedonian Railways	

Country	Name of system	Location
Malaysia	KTM Komuter Keretapi Tanah Melayu Berhad	Sungai Gadut - Tanjung Malim / Port Klang - Batu Caves
Montenegro	Railways of Montenegro	Belgrade - Bar railway and Podgorica - Nikšić
Namibia	Proposed line to Botswana	
Netherlands	Used on new High Speed Lines and Freight Lines	
New Zealand	North Island Main Trunk Railway	
	Auckland suburban	Auckland
Poland	Linia Hutnicza Szerokotorowa	
Portugal	Portuguese Railways (CP)	
Romania	Romanian Railways (CFR)	
Russian Federation	Russian Railways (RZD)	
Serbia	Serbian Railways	
Slovakia	Slovak Republic Railways (ŽSR)	
South Africa	Transnet Freight Rail (TFR), Gautrain	
Thailand	Suvarnabhumi Airport Link	Bangkok
Turkey	Turkish State Railways (TCDD)	Nationwide
UK	Network Rail	
Ukraine	Ukrainian Railways	
Zimbabwe	National Railways of Zimbabwe (NRZ)	Gweru-Harare

4.9 Electrification system 25 kVac/ 60 Hz

25 kVac/ 60 Hz is not standardized by BS EN 50163 and IEC 60850 and is the logical equivalent of 25 kVac/ 50 Hz in countries where 60 Hz is the normal grid power frequency.

Country	Name of system	Location
Canada	Deux-Montagnes Line	Montreal
Japan	Tōkaidō-Sanyō Shinkansen	Western Japan, Central Japan, Eastern

Country	Name of system	Location
	Hokuriku Shinkansen Kyushu Shinkansen	Japan, JR Kyushu
Mexico	Ferrocarril Suburbano de la Zona Metropolitana del Valle de México	Mexico City
Pakistan	Pakistan Railways	
South Korea	Korail	South Korea
	A'REX	Incheon, Seoul
Taiwan	Taiwan Railway Administration (TRA)	All electrified lines
	Taiwan High Speed Railway (THSR)	Western Taiwan Corridor
United States	Morris & Essex Lines, New Jersey Transit	New Jersey
	North Jersey Coast Line, New Jersey Transit	Aberdeen-Matawan to Long Branch, New Jersey
	Northeast Corridor (NEC), Amtrak	New Haven to Boston
	FastTracks, Denver RTD	Denver

5 ANNEX 2: Entities details of database support for analyses for existing power supply installations

This section presents the details of each entity and relationship of them in the database.

Entity “countries”

Columns Summary

Name	DataType	Constraints	Nullable	Description
countryID	char(2)	PK	No	Primary key or identifier of country
country	varchar(150)		No	Name of country

Relationships

railway_ibfk_2 : Relationship	
To	railways
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "contries" and "railways" because the a specific railway belongs a country

overhead_line_power_standards_ibfk_1 : Relationship	
To	overhead_line_power_standards
Identifying	false
On Delete	No action

overhead_line_power_standards_ibfk_1 : Relationship	
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "contries" and "overhead_line_power_standards" because analysis of the overhead line power standards is made belong to a country

Entity “type_lines”

Columns Summary

Name	DataType	Constraints	Nullable	Description
line_typeID	int(11)	PK	No	Primary key or identifier of line type
line_type	varchar(150)		No	Name of line type - railway NeTIRail-INFRA line types (busy passenger, low density rural/secondary line, and a freight dominated route)

Relationships

traction_power_supply_characteristics_ibfk_2 : Relationship	
To	railways
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes

traction_power_supply_characteristics_ibfk_2 : Relationship	
Description	Ensure the relationship between tables "type_line" and "railways" because specific railways shall be a particular type.

Entity “type_poles”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of poles
type	varchar(150)		No	Name of type of poles (Structural design and materials (e.g. concrete, steel, section shape, etc.))

Relationships

country_overhead_lines_ibfk_12 : Relationship	
To	country_overhead_lines
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_poles" and "country_overhead_lines" because analysis of overhead line is done also on a type of poles.

Entity “source_primary_energy”

Columns Summary

Name	DataType	Constraints	Nullable	Description
sourceID	int(11)	PK	No	Primary key or identifier of specific source of primary energy
source	varchar(50)		No	Source of primary energy (e.g. from public grid network, from dedicated power plants)

Relationships

type_power_supply_systems_ibfk_2 : Relationship	
To	type_power_supply_systems
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_power_supply_systems " and "source_primary_energy" because analysis of type of power supply system can be done on a source primary energy

Entity “type_power_supply_systems”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of power supply system
type	varchar(150)		No	Name of type of power supply system
type_generateID	int(11)	FK (type_generate_energy.typeID)	No	Foreign key which defines the type of energy generated (e.g. thermo, hydro, nuclear, etc.).
sourceID	int(11)	FK (source_primary_energy.sourceD)	No	Foreign key which defines the source of energy (e.g. from public grid network, from dedicated power plants)
nominal_voltage	int(11)		Yes	Voltage level for railway power supply system (DC or

Name	DataType	Constraints	Nullable	Description
				AC)
voltage_frequence	int(11)		Yes	Frequency value for railway power supply system when AC (alternative current)
nominal_external_voltage	int(11)		Yes	Voltage level for primary energy
external_voltage_frequence	int(11)		Yes	Frequency value for primary energy when AC (alternative current)

Relationships

coutry_power_supply_systems_ibfk_2 : Relationship	
To	coutry_power_supply_systems
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_power_supply_systems " and "coutry_power_supply_systems" because analysis of traction power supply characteristics is done on a type of power supply system belong a country.

type_power_supply_systems_ibfk_1 : Relationship	
From	type_generate_energy
Identifying	false
On Delete	No action
On Update	No action

type_power_supply_systems_ibfk_1 : Relationship	
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_power_supply_systems" and "type_generate_energy" because analysis of type of power supply system can be done on a type generate energy.

type_power_supply_systems_ibfk_2 : Relationship	
From	source_primary_energy
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_power_supply_systems " and "source_primary_energy" because analysis of type of power supply system can be done on a source primary energy

Entity "type_generate_energy"

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of energy generated
type	varchar(150)		No	Name of type of energy generated (e.g. thermo, hydro, nuclear, etc.)

Relationships

type_power_supply_systems_ibfk_1 : Relationship	
To	type_power_supply_systems
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_power_supply_systems" and "type_generate_energy" because analysis of type of power supply system can be done on a type generate energy.

Entity “type_droppers”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of droppers
type	varchar(150)		No	Name of type of droppers (e.g. current caring, non-current caring, etc.)

Relationships

country_overhead_lines_ibfk_10 : Relationship	
To	country_overhead_lines
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1

Sync To Association	Yes
Description	Ensure the relationship between tables "type_droppers" and "country_overhead_lines" because analysis of overhead lines can be done on a type of droppers.

Entity “suspension_types”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of suspension
type	varchar(150)		No	Name of type of suspension (e.g. trolley type, catenary supported type, etc.)

Relationships

country_overhead_lines_ibfk_8 : Relationship	
To	country_overhead_lines
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Sync To Association	Yes
Description	Ensure the relationship between tables "suspension_types" and "country_overhead_lines" because analysis of overhead lines can be done on a type of suspension.

Entity “type_contact_line”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of contact line system type
type	varchar(150)		No	Name of contact line system type (e.g. Overhead contact lines; Conductor third rail; Overhead conductor rail, etc.)
wire_section	int(11)		Yes	Wire section of contact line
wire_composition	varchar(15)		Yes	Wire composition of contact line

Relationships

country_overhead_lines_ibfk_6 : Relationship	
To	country_overhead_lines
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_contact_line" and "country_overhead_lines" because analysis of the overhead lines systems is done also on a type of contact line system.

Entity “type_wire_grade”

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of type of wire grade
type	varchar(150)		No	Name of type of wire grade (wire composition material)

Relationships

country_overhead_lines_ibfk_11 : Relationship country_overhead_lines_ibfk_4 : Relationship country_overhead_lines_ibfk_3 : Relationship	
To	country_overhead_lines
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_wire_grade" and "country_overhead_lines" because analysis of the overhead lines systems is done also on a type of wire grade suspended or wire grade auxiliary suspended or dropper wire grade.

Entity "type_tensioning"

Columns Summary

Name	DataType	Constraints	Nullable	Description
typeID	int(11)	PK	No	Primary key or identifier of tensioning device type
type_device	varchar(150)		No	Name of tensioning device type (e.g. pulley-wheel, hydraulic, spring, etc.)

Relationships

country_overhead_lines_ibfk_9 : Relationship	
To	country_overhead_lines
Identifying	false

country_overhead_lines_ibfk_9 : Relationship	
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_tensioning" and "country_overhead_lines" because analysis of overhead lines can be done on a type of tensioning device.

Entity “railways”

Columns Summary

Name	DataType	Constraints	Nullable	Description
lineID	int(11)	PK	No	Primary key or identifier of specific railway line
type_lineID	int(11)	FK (type_lines.line_typeID)	No	Foreign key which defines the type of railway line
name	varchar(150)		No	Name of railway line
country	char(2)	FK (countries.countryID)	No	Foreign key which defines the country of railway line

Relationships

country_power_supply_lines_ibfk_1 : Relationship	
To	country_power_supply_lines
Identifying	true
On Delete	No action
On Update	No action

To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "country_power_supply_lines" and "railways" because analysis of power supply lines is made on a specific line.

country_overhead_lines_ibfk_13 : Relationship	
To	country_overhead_lines
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	1
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "country_overhead_lines" and "railways" because analysis of overhead lines is made on a specific line.

railway_ibfk_2 : Relationship	
From	countries
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "contries" and "railways" because the a specific railway belongs a country

railway_ibfk_3 : Relationship	
From	type_lines
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_line" and "railways" because specific railways shall be a particular type.

Entity “country_power_supply_lines”

Columns Summary

Name	DataType	Constraints	Nullable	Description
lineID	int(11)	PK/FK (railway.lineID)	No	Composited Primary key for identifier of specific railways and a specific type of power supply. Foreign key which defines of line.
power_supply_typeID	int(11)	PK/FK (type_power_supply_systems.typeID)	No	Composited Primary key for identifier of specific railways and a specific type of power supply. Foreign key which defines the type of power supply.

Relationships

country_power_supply_lines_ibfk_2 : Relationship	
From	type_power_supply_systems
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_power_supply_systems " and "coutry_power_supply_systems" because analysis of traction power supply characteristics is done on a type of power supply system belong a country.

country_power_supply_lines_ibfk_1 : Relationship	
From	railways
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "country_power_supply_lines" and "railways" because analysis of power supply lines is made on a specific line.

Entity “country_overhead_lines”

Columns Summary

Name	DataType	Constraints	Nullable	Description

Name	DataType	Constraints	Nullable	Description
railwayID	int(11)	PK/FK (railway.lineID)	No	Primary key or identifier of specific railway line. Foreign key which defines of line.
suspension_type	int(11)	FK (suspension_types.suspension_typeID)	Yes	Foreign key which defines the type of suspension (e.g. trolley type, catenary supported type, etc.).
standard_span	varchar(150)		Yes	Standard span length adopted.
contact_wire_hight	decimal(10)		Yes	Standard height adopted (from the ground)
catenary_hight	int(11)		Yes	Standard height from the contact line
wire_grade_suspended	int(11)	FK (type_wire_grade.typeID)	Yes	Foreign key which defines the contact wire composition material
wire_grade_aux_suspended	int(11)	FK (type_wire_grade.typeID)	Yes	Foreign key which defines the material stranded conductors
catenary_wire_tension_suspended	int(11)		Yes	Tensioning catenary
catenary_wire_tension_aux_suspended	int(11)		Yes	Tensioning auxiliary catenary (compound catenary)
contact_wire_tension	int(11)		Yes	Tensioning contact line
pre_sag	varchar(150)		Yes	Adopted pre-sag [% by span length]
max_speed	int(11)		Yes	Maximum speed designed for electric power supply system
static_contact_force	int(11)		Yes	Static contact forces designed
dynamic_contact_force	int(11)		Yes	Dynamic contact force designed

Name	DataType	Constraints	Nullable	Description
stitch_wire	tinyint(4)		Yes	With/without stitch suspension improvement
type_contact_line	int(11)	FK (type_contact_line.typeID)	Yes	Foreign key which defines the contact line system type (e.g. Overhead contact lines; Conductor third rail; Overhead conductor rail, etc.)
tension_section_length	int(11)		Yes	Tensioning section length
type_tensioning	int(11)	FK (type_tensioning.typeID)	Yes	Foreign key which defines the tensioning device type (e.g. pulley-wheel, hydraulic, spring, etc.)
type_dropper	int(11)	FK (type_dropprers.typeID)	Yes	Foreign key which defines the droppers type (current caring, non-current caring, etc.)
dropper_wire_grade	int(11)	FK (type_wire_grade.typeID)	Yes	Foreign key which defines the material stranded conductors for dropper wire
type_pole	int(11)	FK (type_poles.typeID)	Yes	Structural design and materials (e.g. concrete, steel, section shape, etc.)

Relationships

country_overhead_lines_ibfk_8 : Relationship	
From	suspension_types
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1

country_overhead_lines_ibfk_8 : Relationship	
Sync To Association	Yes
Description	Ensure the relationship between tables "suspension_types" and "country_overhead_lines" because analysis of overhead lines can be done on a type of suspension.

country_overhead_lines_ibfk_12 : Relationship	
From	type_poles
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_poles" and "country_overhead_lines" because analysis of overhead line is done also on a type of poles.

country_overhead_lines_ibfk_10 : Relationship	
From	type_dropprers
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_droppers" and "country_overhead_lines" because analysis of overhead lines can be done on

country_overhead_lines_ibfk_10 : Relationship	
	a type of droppers.

country_overhead_lines_ibfk_11 : Relationship country_overhead_lines_ibfk_4 : Relationship country_overhead_lines_ibfk_3 : Relationship	
From	type_wire_grade
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_wire_grade" and "country_overhead_lines" because analysis of the overhead lines systems is done also on a type of wire grade suspended or wire grade auxiliary suspended or dropper wire grade.

country_overhead_lines_ibfk_6 : Relationship	
From	type_contact_line
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_contact_line" and "country_overhead_lines" because analysis of the overhead lines systems is

country_overhead_lines_ibfk_6 : Relationship	
	done also on a type of contact line system.

country_overhead_lines_ibfk_13 : Relationship	
From	railway
Identifying	true
On Delete	No action
On Update	No action
To Multiplicity	1
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "country_overhead_lines" and "railways" because analysis of overhead lines is made on a specific line.

country_overhead_lines_ibfk_9 : Relationship	
From	type_tensioning
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	0..1
Sync To Association	Yes
Description	Ensure the relationship between tables "type_tensioning" and "country_overhead_lines" because analysis of overhead lines can be done on a type of tensioning device.

Entity “overhead_line_power_standards”

Columns Summary

Name	DataType	Constraints	Nullable	Description
standardID	varchar(150)	PK	No	Primary key or identifier of catenary type
countryID	char(2)	FK (countries.countryID)	No	Foreign key which defines the country to which it belongs standard
name	varchar(255)			Standard name
description	varchar(255)		No	Standard description
web_references	varchar(255)		No	Web references

Relationships

overhead_line_power_standards_ibfk_1 : Relationship	
From	countries
Identifying	false
On Delete	No action
On Update	No action
To Multiplicity	0..*
From Multiplicity	1
Sync To Association	Yes
Description	Ensure the relationship between tables "overhead_line_power_standards" and "countries" because analysis of overhead line power standard belong to a country