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Principles of OCS And Associated Interface System

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Abstract

The Overhead Catenary System (OCS) is an important part in rail electrification, which is designed to provide continuous and dependable electrical energy to all electric rolling stock. This topic covers some of the basic principles for the OCS: its structure, components, working principle etc. Contact wire, catenary wire, droppers, insulators, and support structures are considered in order to describe how efficiency of current collection is ensured. OCS interfaces with other railway subsystems such as traction substations, signaling systems, civil structures, and rolling stock is also discussed on the topic. Specific emphasis is given to the cooperation (and integration) of these interfaces in order to maintain the safe efficient and unfettered operations of rail systems. Knowledge of these interactions is particularly important for maintenance, troubleshooting, and system adjustment.

Keywords: *25 kV AC Traction, Metro Electrification, Delhi Metro, Flexible Overhead Catenary System (FOCS), Rigid Overhead Catenary System (ROCS), Pantograph–Catenary Interaction, Contact Wire Dynamics, Electromagnetic Interference (EMI/EMC), OCS Design and Optimization.*

1. Introduction

The Overhead Catenary System (OCS) is an integral part of modern railway electrification because the network ensures continuous power to electric rolling stock. Considering the growing importance of effective and efficient urban transportation solutions, most metro rail networks have moved towards 25 kV AC electrification, owing to the advantages of the operation and economic impact. The OCS makes use of different mechanical and electrical elements, like contact wire, catenary wire, droppers, insulators and support structures which make up OCS to ensure pantographs are able to correctly capture current. Metro systems such as Delhi Metro use Flexible Overhead Catenary System (FOCS) or Rigid Overhead Catenary System (ROCS) in accordance with infrastructure demands. FOCS is typically a common system within elevated systems and ROCS is generally available in underground tunnels for space efficiency. Aspect OCS and the specific subsystems associated with it, including signaling, civil structures, and traction substations must work in sync as a single coordinated entity for safe, efficient operation. Metro rail systems run on different voltages around the globe (600 V DC, 750 V DC, 1.5 kV DC, and 25 kV AC). The old networks have 750 V DC in old networks like London and New York, and more recent high-capacity metro systems like Delhi, Chennai in the field on both the current and future ones. This should not be an exhaustive literature review. Only references required to provide the relevant background provide the most salient context that enables the readers to understand and assess the aim and results of the study without referring to previous work related to the topic. [1-4]. The Purpose of the studies reported is the subject of the Introduction, along with a discussion of their relationship to previous works in the field.

2. Literature Review

Several researches have been carried out to study the design, model and design adaptation for Overhead Catenary Systems. Studies indicate that 25 kV AC traction systems offer lower transmission losses and require fewer substations than DC systems. The use of simulation software, both MATLAB/Simulink and ETAP, has been seen to offer enhanced system performance and fault analysis support. Previous studies also highlight the significance of the dynamic interaction between pantograph and contact wire.

Quality of current collection depends on contact force, wire tension and system geometry. The usage of SCADA systems integration and predictive maintenance methods has helped to improve the reliability and the efficiency of OCS in modern metro networks

3. Methodology

This methodology consists of analyzing the structure, working principles and related interfaces of the Overhead Contact System (OCS). The approach of this study covers two systems: Flexible Overhead Contact Line (FOCL) and Rigid Overhead Contact Line (ROCL) and their design and operational characteristics. The analysis includes the configuration of contact and catenary wires, droppers, tensioning devices, insulators, and supporting structures, in addition to sectioning and isolating devices for operational flexibility and maintenance. The design considerations include line speed, train frequency, and electrical characteristics (voltage, current and system impedance). Environmental factors (in particular temperature variations and their influence on conductor performance) are considered. The study also considers pantograph characteristics and its dynamic interaction with the contact wire for effective current collection. Moreover, the process compares the interface configuration of OCS to the railway's track, civil structures, signaling, and power supply to ensure all systems operate in unison and reliably. Simulation-based analysis is integrated to investigate system behavior during various operating scenarios to enhance understanding, optimization and performance evaluation of the overall system

3.1. Typical structure of Flexible Overhead Contact Line (FOCL)

Flexible Overhead Contact Line (FOCL/FOCS) is the most widely used overhead electrification system in railway networks, especially in open and elevated sections. It is formed by a flexible connection of conductors (mainly contact wire and catenary wire) which are kept dangling through droppers and supported by masts, portals, or head-span structures. This flexibility enables the system to have constant contact with its pantograph regardless of the dynamic forces (speed, wind, temperature changes, etc.) it experiences. In metro systems, FOCS is predominantly employed in elevated corridors; however, a rigid system is more prevalent in tunnels. FOCS design provides efficient current collection by keeping proper tension, stagger, and height of the contact wire. Sectioning arrangements such as section insulators and neutral sections are introduced to isolate faulty sections or to allow maintenance activities to be performed without affecting the entire system, and hence minimize service disruptions. The application of this work allows the evaluation of its operation at several speeds and it is also easy to maintain, which makes the proposed system fit for modern railway electrification systems. The approach also examines how the interface of OCS with other railway subsystems including track, civil structures, signaling, and power supply system's functions in concert and reliability. Simulation-based modeling is being used to analyze system responses to different system operating conditions, so as to better appreciate, optimize, and assess system performance in the aggregate shown in Figure 1.

Figure 1 **Flexible overhead catenary system**

3.2. Rigid Overhead Contact Line (ROCL)

Rigid Overhead Contact Line (ROCL) is an overhead electrification line used to transport electric rolling stock, generally from an elevated position on a rigid conductor rail. Unlike flexible catenary systems, ROCL has a rigid metallic conductor (typically aluminum with a stainless-steel contact surface) supported periodically on insulators. This design permits a dense structure with a stable design, a significant advantage in underground tunnels and areas with limited clearance. A conductor rail connects the pantograph on the car directly, providing effective current acquisition. One aim of ROCL is sparkles and continuous current collection under both static and dynamic operating conditions. However, the rigid structure of ROCL system presents less maintenance which is beneficial, provides good geometric stability and reduces wear and tear as compared with flexible designs. But mainly it is not used in the high-speed areas because of lower flexibility[5-10]. In general, ROCL has strong performance in metro systems because of its reliability and space economy, as well as the stable electrical performance in limited circumstances. In addition, the approach assesses the interfaces of OCS in relation to other railway subsystems such as track, civil structure, signaling system and electrical supply system to guarantee the system operation consistent and reliable. The simulation-based analysis is used to study the performance of any system operating in various operating conditions so as to better comprehend, enhance and validate the overall system with respect to its parameters shown in Figure 2.

Figure 2 Real world ROCS/OHE.

3.3. Contact Line System

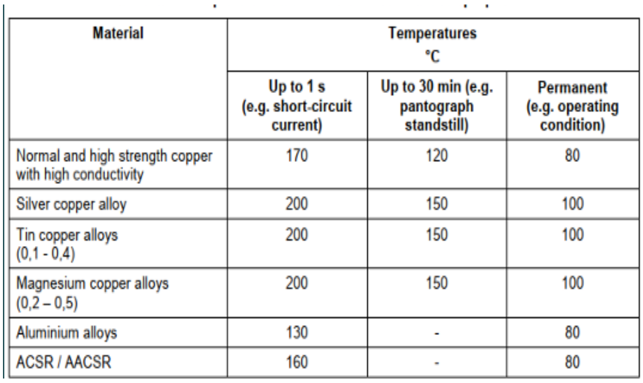
The contact line system is made up of the support system and conductors that supply electrical energy to railway vehicles through current-collecting equipment like the pantograph. The mechanical system includes all the components (contact line, supporting structures, foundations) that are required to support or register the conductors; it consists of head-spans, cross-spans, along-track feeders, negative feeders, earth wires, return conductors, and booster arrangements, as well. To keep systems secure and reliable, cross-track feeders, disconnectors (isolators), and over-voltage protection devices like surge arresters are also included. That means any additional equipment needed for the proper operation of the contact line system is included in this setup. The contact line is also comprised of all conductors that collect current and conducting rails or bars. These consist of reinforcing feeders, electrical connectors (jumpers), sectioning devices (section insulators), and tensioning devices which include spring or balance weight systems. It also comprises uninsulated supports for conductors, insulators connected to live parts, and important conductors like contact and catenary wires. Moreover, supplementary catenary wires and stitch wires enable the proper mechanical and electrical functionality of the apparatus. The results also assess OCS interfaces with other railway subsystems—track, civil structures, signaling, and power supply systems—for coordinated operation and reliability. Simulation-based analysis is used to study system behavior under different operating conditions so that the systems' overall performance can be better understood, optimized, and evaluated for efficiency.

3.3.1. Fundamental Design Data

An overhead contact system (OCS) design is based on a wide variety of fundamental parameters to allow OCS to be safe, efficient, reliable, and safe operation. These are line parameters like operating speed, performance requirements, trains as well as train types and frequencies, track alignment, and overall track conditions. Another important aspect to consider is the electrical power system's design, including voltage and frequency, continuous and short-circuit current ratings, fault current duration, permissible impedance (for AC systems) or resistance (for DC systems), and tolerance constraints. The configuration of the feeding and return systems, earthing and bonding arrangements, stray current protection, and measures to mitigate electromagnetic interference (EMI) and electromagnetic compatibility (EMC) are among other features as well. Overvoltage protection and correct insulation coordination are equally important for the safety of the system. Design considerations also depend on vehicle characteristics, such as static and kinematic profiles, structural clearances, number and spacing of pantographs, and their operational characteristics. The design also has to consider the current collectors such as pantograph profile, number of contact strips, static contact force, working height and width, lateral movement, maximum load current, dynamic interaction with the contact wire. Also the environment such as temperature, wind, humidity, and pollution are considered since it affects the performance and durability of the system. Ultimately, system overall design life is set to guarantee long-term reliability, maintainability, and economical operation. In addition, the methodology investigates the system interface of OCS with other railway subsystems such as track, civil structures, signaling, and power supply systems to work jointly and dependably. Model simulation is used to investigate system behavior under various operating conditions, for better understanding, optimization, and performance evaluation of the complete configuration shown in Table 1.

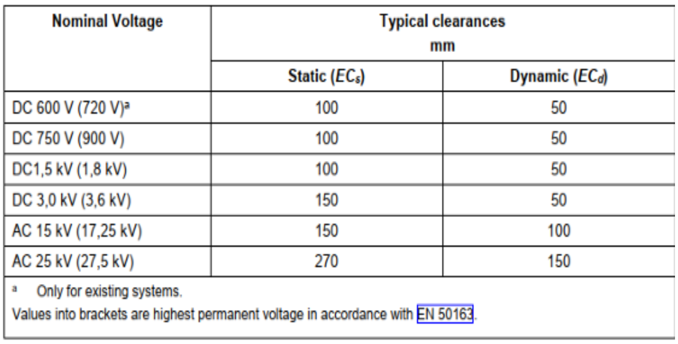
3.3.2. System Requirements

The system requirements for an overhead contact system (OCS) are primarily governed by both line and electrical characteristics to ensure safe and reliable operation. One of the key considerations is the temperature rise in conductors, which is influenced by ambient temperature, solar radiation, and heating due to electrical current flow. Excessive temperature rise can lead to increased sag in the contact wire, affecting the quality of current collection and system performance. Therefore, proper design must ensure that conductor temperatures remain within permissible limits under all operating conditions, considering both environmental and load factors shown in Table 2.



Material	Temperatures °C		
	Up to 1 s (e.g. short-circuit current)	Up to 30 min (e.g. pantograph standstill)	Permanent (e.g. operating condition)
Normal and high strength copper with high conductivity	170	120	80
Silver copper alloy	200	150	100
Tin copper alloys (0,1 - 0,4)	200	150	100
Magnesium copper alloys (0,2 – 0,5)	200	150	100
Aluminium alloys	130	-	80
ACSR / AACSR	160	-	80

Table 1 **Temperature limits for material mechanical properties**



Nominal Voltage	Typical clearances mm	
	Static (EC_s)	Dynamic (EC_d)
DC 600 V (720 V)[a]	100	50
DC 750 V (900 V)	100	50
DC1,5 kV (1,8 kV)	100	50
DC 3,0 kV (3,6 kV)	150	50
AC 15 kV (17,25 kV)	150	100
AC 25 kV (27,5 kV)	270	150

[a] Only for existing systems.
Values into brackets are highest permanent voltage in accordance with EN 50163.

Table 2 **Typical Electrical Clearances**

Clearances between adjacent live AC contact lines of different voltage phases; Design of Current Collection Systems General (line speed, performance characteristics in static & dynamic conditions). Elasticity and its variation also named "degree of non-uniformity" (normally specified by the purchaser);

$$u = \frac{e_{\max} - e_{\min}}{e_{\max} + e_{\min}} \times 100 \ [\%]$$

Vertical movement of contact point (verified by measurements or simulations) Wave propagation velocity (max. operational speed shall be less than 70% of Vc

$$v_c = \sqrt{\frac{\sum z}{\sum m}} \ [\text{m/s}]$$

Quality of current collection (dynamic behavior; interface between contact wire & contact strip(s); pantograph design; contact wire geometry & tensile load; contact forces; contact losses). Geometry (Stagger, Max. deviation, Uplift, CW Gradient, Change of Gradient, Wire Height, Span Length)

3.3.3. Traction Voltage Selection

Metro rail systems across the world operate on different traction voltages such as 600 V DC, 750 V DC, 1.5 kV DC, and 25 kV AC, depending on their design requirements and operational conditions. Earlier metro networks, such as those in London and

New York, predominantly use 750 V DC systems. However, modern high-capacity metro systems in cities like Delhi, Chennai, and Hong Kong have adopted 25 kV AC electrification due to its significant technical and economic advantages. These include lower transmission losses, suitability for longer routes with high traffic density, and the requirement of fewer substations compared to DC systems. Owing to these benefits, the 25 kV AC overhead equipment (OHE) system has been implemented in the Delhi Metro, making it a suitable and relevant system for modeling and analysis in this study.

4. Overhead Contact Line Structure and Components

4.1. Structure of an overhead contact line

The structure of an overhead contact line is designed to provide continuous and reliable electrical power to electric trains through the pantograph. It primarily consists of a contact wire, which is in direct contact with the pantograph, and a catenary wire, which supports the contact wire through droppers. These conductors are suspended from support structures such as masts, portals, or head-span arrangements, ensuring proper alignment and mechanical stability.

The system also includes insulators to electrically isolate live components, as well as tensioning devices to maintain constant wire tension under varying environmental conditions. Proper geometry, including wire height, stagger, and span length, is maintained to ensure smooth current collection and minimize wear. Overall, the overhead contact line structure is engineered to achieve efficient power transmission, mechanical stability, and safe operation under dynamic conditions shown in Figure 4.

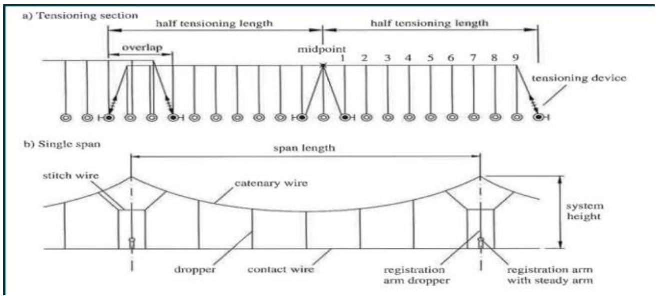


Figure 4 **Simple Structure of an Overhead Contact Line.**

4.2. Configuration of 107sq.mm Contact and catenary wire

The configuration of 107 sq.mm contact and catenary wires is commonly used in overhead contact systems to ensure efficient current collection and mechanical stability[11-15]. In this arrangement, the contact wire of 107 sq.mm cross-sectional area is positioned at the lowest level to maintain direct and continuous contact with the pantograph. It is supported by the catenary wire, which carries the mechanical load and is connected to the contact wire through droppers at regular intervals.

The catenary wire is maintained under suitable tension to support the contact wire and ensure proper geometry along the track. This configuration helps in maintaining uniform contact force, reducing wear and tear, and improving current collection performance. The 107 sq.mm size is selected to handle the required electrical load while maintaining adequate strength and conductivity, making it suitable for metro and high-density railway operations shown in Figures 5-9.

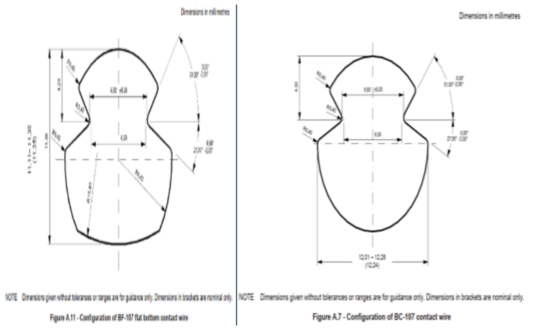


Figure 5 **High-Density Railway Operations**

Figure 6 **Simple Design of Contact and Catenary Wire**

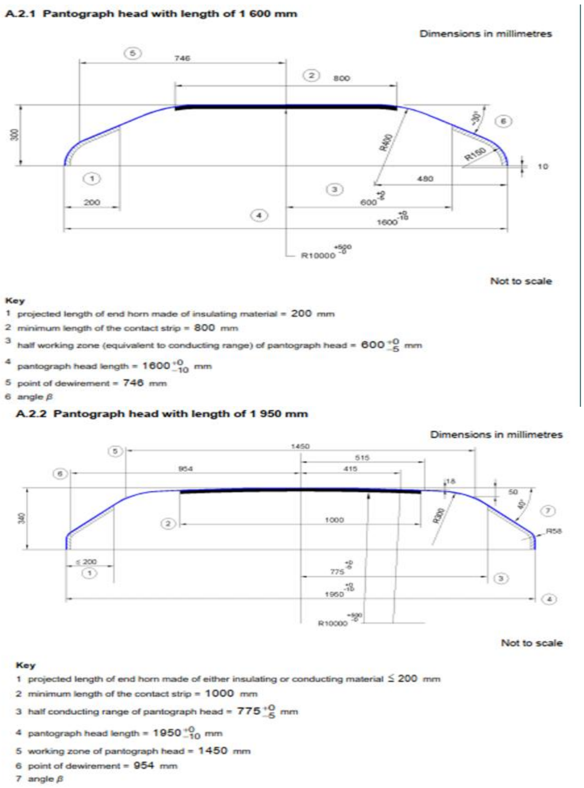
Figure 7 Simple Picture of TTC & Portals

Figure 8 Sample Pictures of Different Arrangements and Components

Figure 9 Sample Pictures of Section Insulator and Neutral Section

4.3. Profiles for Interoperable Pantograph Head

Profiles for interoperable pantograph heads are designed to ensure smooth and reliable current collection between the pantograph and the contact wire across different railway systems. These profiles define the shape, width, and material of the pantograph contact strip so that it can operate efficiently under varying conditions such as speed, voltage, and wire geometry[16-25]. Standardization of pantograph head profiles is essential to achieve compatibility with different types of overhead contact lines, reducing wear and ensuring consistent electrical contact. The design also considers factors such as contact force, lateral movement (stagger), and aerodynamic effects to maintain stable interaction with the contact wire. Proper profiling helps in minimizing arcing, reducing mechanical stress, and improving the overall performance and lifespan of both the pantograph and the contact wire. This ensures safe, efficient, and interoperable operation of electric rolling stock across different railway networks



A.2.1 Pantograph head with length of 1 600 mm

Dimensions in millimetres

Not to scale

Key

1 projected length of end horn made of insulating material = 200 mm
2 minimum length of the contact strip = 800 mm
3 half working zone (equivalent to conducting range) of pantograph head = 600 $^{+0}_{-5}$ mm
4 pantograph head length = 1600 $^{+0}_{-10}$ mm
5 point of dewirement = 746 mm
6 angle β

A.2.2 Pantograph head with length of 1 950 mm

Dimensions in millimetres

Not to scale

Key

1 projected length of end horn made of either insulating or conducting material ≤ 200 mm
2 minimum length of the contact strip = 1000 mm
3 half conducting range of pantograph head = 775 $^{+0}_{-5}$ mm
4 pantograph head length = 1950 $^{+0}_{-10}$ mm
5 working zone of pantograph head = 1450 mm
6 point of dewirement = 954 mm
7 angle β

Figure 9 Pantograph head with standard length 1600mm & 1950mm.

5. Key Interfaces with Other Disciplines

The Overhead Contact System (OCS) is closely integrated with multiple railway engineering disciplines to ensure safe, efficient, and coordinated operation. It interfaces with the track system, which includes alignment, profile, sections, points and crossings, and super elevation (cant), as these parameters directly influence the positioning and geometry of the contact line. Coordination with civil structures such as viaducts, bridges, tunnels, stations, platforms, foundations, retaining walls, and boundary structures is essential to ensure proper clearances and structural compatibility. The OCS also interacts with the signaling system, including signaling plans, signal sighting requirements, point machines, and impedance bonds, to avoid interference and ensure operational safety. Integration with electrical and power (E&P) systems is critical, covering load flow analysis, feeding and sectioning design, substations, feeding and switching posts, duct banks, electromagnetic interference and compatibility (EMI/EMC), earthing and bonding (E&B), stray current mitigation, and protection systems. Additionally, geotechnical aspects such as soil parameters are important for the design of foundations. Coordination with utilities and buried services, both existing and planned, is necessary to prevent conflicts during installation. Power line crossings must be carefully designed considering voltage levels, clearances, and safety distances. The system must also be compatible with rolling stock characteristics, including gauge, pantograph design, and vehicle dynamics. Further interfaces include electrical and mechanical (E&M) systems such as earth mat details, road crossings including level crossing (LC) gates for vehicles and pedestrians, and depot areas used for stabling, inspection, washing, and maintenance activities. Special attention is given to the transition between Rigid Overhead Catenary Systems (ROCS) and Flexible Overhead Catenary Systems (FOCS), as well as Modified Overhead Catenary Systems (MOCS) within depot inspection bays. These coordinated interfaces ensure the overall reliability and efficiency of the railway electrification system

Conclusion

The Overhead Catenary System is a critical component of railway electrification, ensuring efficient and uninterrupted power supply. The adoption of 25 kV AC systems in metro networks provides significant advantages in terms of efficiency and scalability. Proper design, integration, and maintenance of OCS and its interfaces are essential for reliable operations. Future developments may include advanced monitoring systems, predictive maintenance, and integration with renewable energy sources to enhance sustainability and performance.

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