Interfacing electrification and system reliability

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Abstract

Integration is the term given to ensuring that the different elements of an electrified railway operate together to achieve the desired result. This is particularly problematic where interfaces exist between the high power electrification distribution or traction systems, and the low power signalling and communications control systems.

The challenge of integrating electrical systems will not be made any easier as client and public expectations of new rail transit systems require railway designers to incorporate more versatile and sophisticated electrification systems.

Railway authorities in the past have found difficulty in implementing a management strategy that will ensure electrified railway systems are integrated. This is made more complex where the privatisation of railways and the procurement process divides contracts into separate engineering disciplines.

This paper seeks to explain the challenge of integrating the electrification system with the sensitive signalling, communication control and low voltage systems. Additionally the paper will review the technical necessities of integrating the electrification system with large civil structures. The paper will demonstrate how railway authorities are being challenged by the difficult task of integrating these system-wide disciplines.

Interfaces between electrical systems

The electrical systems integration process for an electrified railway should ensure that traction power, control systems, traction and rolling stock and radio based systems are integrated successfully. Specific engineering interfaces exist between rolling stock to electrification; rolling stock to signalling; electrification to signalling and communications; civil to LV and HV electrification and stray current to third parties.

Interface of earth exists between all electrical systems. This paper will review in more detail earthing of AC and DC railways, AC/DC interfaces, lightning and stray current corrosion.

Earthing of AC and DC railways [4,10,13]

Electrical transportation systems (UK) by law are required to meet specific safety requirements:

- Health and Safety at Work Act 1974.
- Electricity at Work Regulations 1989.
- Railways (Safety Critical Work) Regulations 1994
- Construction (Health, Safety and Welfare) Regulations 1996.
- Management of Health and Safety at Work Regulations 1999.
- Control of Substances Hazardous to Health (COSHH).
- Transport and Works Act, 1992
- The Railways Act 2005
- EMC Regulations 2005
- The Railways and Other Guided Transport Systems (Safety) Regulations 2006 ROGS
- Construction (Design and Management) Regulations 2007.

Responsibility for regulation of safety in 2006 moved from the Health and Safety Executive to the Office of the Rail Regulator.

Earthing design objectives: The earthing system, its components and bonding conductors should be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on back-up protection operating time.

The earthing system should maintain its integrity for the expected lifetime of the installation with due allowance for corrosion and mechanical constraints.

Earthing system performance should avoid damage to equipment due to excessive potential rise, potential differences within the earthing system and excessive currents flowing in auxiliary paths not intended for carrying parts of the fault current.

The earthing system, in combination with appropriate measures, should maintain step, touch and transferred potentials within the voltage limits based on normal operating time of protection relays and breakers.

The earthing system performance should contribute to ensuring electromagnetic compatibility (EMC) among electrical and electronic apparatus of the low-voltage system in accordance with BS IEC 61000-5-2.

Design approach to the earthing of the railway: To ensure compliance with relevant standards there is a requirement for a robust Quality Assurance process including an Earthing Management Plan, Earthing Installation Code of Practice and Earthing Test Specification.

Additionally the Earthing Management Plan must address the design, installation, operation, and maintenance aspects of the railway.

AC/DC railway interfaces [14]

An AC railway is often designed in close proximity to other DC light rail, metro and trams. Where there is parallel running, over bridges or under bridges, there may be significant interactions between the two electrified railway systems. The amount and characteristics of disturbance will be dependent on the interconnection of earths, traction loads, earth faults, the physical arrangement, the electrical systems design and the local ground conditions.

Track circuit disturbance: DC traction return current flowing in the AC traction rails can interfere with track circuits. Similarly the AC return current can interfere with track circuits used on DC electrified lines.

DC stray current: The bonds between the rails and metal structures etc. which are necessary for electrical safety in the presence of high-voltage AC railway overhead lines will provide a path for stray DC traction return current to flow to earth, and may cause electrolytic corrosion to the structures concerned, as well as neighbouring buried pipes, metal-sheathed cables etc.

Touch and accessible voltage: The impedance of the rails at 50 Hz is much greater than the resistance of the rails at DC. This means that the return current from AC trains, and from short-circuits on the AC overhead lines, would cause significant voltage drops in the rails. This would bring a risk of electric shock if suitable means were not employed to limit the voltage on the rails.

Lightning protection [11,12]

Lightning strikes on or near railway equipment can generate large voltage surges that can disturb or damage railway operations. The various ways in which a lightning strike can affect railways are:

(i) Direct strike to the overhead lines

(ii) Direct strike to the aerial earth wire or gantries

(iii) Nearby strike to ground [induced voltages]

(iv) Strike to ground further away [ground potentials].

A direct strike to the lines can generate an overvoltage surge of several million volts. This will cause a flashover across the support insulators. The surge current will then find various routes to earth depending on their surge impedance values. A lightning strike may also generate a 25kV earth fault.

Entry points for lightning to the railway control systems are numerous and some are detailed below:

(i) Radio masts

(ii) Electrical supply points

(iii) Rail and track connections to signalling circuits

(iv) Signalling data, control and indications cables

(v) Ground coupling through circulating earth loops,

(vi) Induction into power, signalling and communications circuits.

Design approach on railways: The protection of buildings, viaducts, bridges and structures from lightning is by the provision of lightning conductors and an earth electrode system. This earth is segregated from the earth path used by signalling control and the electrical and plant (E&P) systems.

In the case of the station roof structure and viaduct there is a requirement to provide lightning earthing, to control earth potentials.

Additionally there is a requirement to ensure the insulation co-ordination and any necessary segregation required for sensitive signalling and control systems that are located on or close to the station or viaduct.

Surge arrestors: Gas plasma discharge arrestors have a fast response to transient overvoltage events. This fast response and the ability to handle very high current surges effectively suppresses transients. Low capacitance and high insulation resistance [>Gohm] produce a low leakage ensuring that there is virtually no effect on the protected system.

Installation of surge arrestors: Surge arrestors can be installed on telecommunications cables or on the installation equipment. Surge arrestors for commercial installations are rated at typically 250V. This is normally too low for the railway environment.

The surge arrestor operates when a voltage between the line and remote earth exceeds the level specified. This method diverts the transient energy away from the line circuit and into the earth of the network. This is good as long as the earthed system is not coupled in any way with the telecommunications cables. The design of the earth should be such that there is no close parallel coupling with telecommunications cables.

Stray current corrosion control (DC railways) [5,7]

The overall control strategy is to follow an approach that minimises the generation of stray current, controls its 'escape' and maintains separation between the rails and associated collection systems and the metro civil structures and external structures.

The driving force for stray current can be minimised by:

- Traction power substation design and locations;
- Rail return circuit design and bonding; and minimising the longitudinal electrical conductivity of supporting structures
- Maintenance of a high rail to structure insulation.
- Construction and maintenance of stray current collection systems to provide an efficient low resistance preferential path for current collection and return.
- Maintaining an electrical separation between the collection system and other conductive parts of the structure.

Design approach on DC railways: This strategy is designed to reduce corrosion threats to the rail infrastructure and to external infrastructure by minimising stray current leakage at source and retaining this as far as practicable within the rail system.

The design process should:

- Assess the interfaces between the railway and other third party infrastructure through a Stray Current Control Survey to identify and assess stray current and corrosion risk areas. (E&M Earths, Civil Structures and Utilities)
- Utilises design philosophy that follows the guidance given in BSEN 50122-2, BSEN50162 and UK Trams ORR Tramway Guidance Notes
- Undertake modelling techniques to quantify these threats and validate the control measures
- Provide verification processes that should be designed and applied at each stage of the project to provide assurance that the strategy has been correctly applied and to identify issues for investigation and action
- Ensure a consistent approach and awareness both across the project and between the below ground and above ground sections.

Compatibility of electrical systems [3,6,8,9]

The EEC directive 89/336 made the requirement that all electrical apparatus must not emit electromagnetic radiation that would prevent other equipment from functioning as intended.

The European EMC Directive 89/336/EEC as amended by 92131/EEC has been legally adopted by UK regulations under Statutory Instrument (1992) No. 2372 'The EMC Regulations' and came into force in 28 October 1992. The Directive applies to virtually all electrical and electronic products and systems for use in the European Union.

The new EMC directive 2004/108/EC[2] includes some simplification and clarification when compared to the original Directive:

(1) Manufacturers are required to perform an EMC assessment; including the application of harmonised standards

(2) Manufacturers are required to produce a Technical File [TF] to demonstrate conformity

(3) Manufacturers may choose to obtain an independent conformity statement from a Notified Body.

(4) Manufacturers are required to make a Declaration of Conformity [DoC]

(5) A Fixed Installation [FI] at a pre-defined location is required to conform to the essential requirement but not to follow the conformity assessment procedure and therefore does not have to carry the CE Mark

(6) The FI will usually consist of equipment carrying the CE marking installed as specified by the manufacturer(s) and specific equipment not otherwise commercially available can be incorporated, accompanied by documentation which indicates precautions to be taken for incorporation into the FI; the installation shall follow ‘good engineering practice’ which must be documented.

The railway environment: contains many sources of electromagnetic, electrostatic noise and electrical disturbances; and it is a hostile environment for low power circuits i.e. remote control systems, monitoring circuits, signalling systems, telecommunication circuits and radio networks. The complete railway electrification network requires to be monitored in terms of emissions and susceptibility to electromagnetic interference, conductive interference and radio frequency interference. This includes electrical circuits in the supply of traction power, the control of traction power, the operation of signalling, train control circuits, the operation of telecommunication systems and radio communications.

Electromagnetic interference will largely cause interference from the high power circuits of the electrification supply and traction drive into the train control systems, signalling systems and railway and publicly owned telecommunication systems, remote control, and monitoring systems.

The railway authority’s responsibilities [15]

The railway authority has a responsibility to ensure that projects include design specifications that address interfaces between electrical systems and also the management process, to ensure that systems do not adversely interact or disturb each other.

Application of railway and national standards

BS EN standards are used extensively in the specification of railway projects. The projects assume that if the standards are implemented then their design will always be adequate. The basic standard for earthing railways, EN 50122-1, is very clear on safety requirements for earthing and equipotential bonding. However, the standard is not a practical guide to earthing a railway. It is a performance specification and details what is required to be undertaken by railway administration. It does not provide any detail on how installation should be undertaken.

It should also be noted that the European Standard EN50122-1 does not specifically address

(1) earthing arrangements for lightning protection

(2) provide detail design and interconnection of earthed systems

(3) system operability and the design differences between rail return, auto feeding, booster return, single rail and double rail return systems.

The complications of railway earthing are significant and the specific requirements for traction power, signalling, communications, LV and lightning earthing all have to be addressed by the project, with potentially different requirements for at grade, in tunnel and on viaduct sections. It should be noted that the IEE Wiring Regulations BS7671 is pertinent to stations, concourses and other buildings; however, track, platforms, railway traction equipment, rolling stock and signalling equipment are excluded.

It is normal practice therefore for a railway administration to produce an accompanying installation guideline for contractors and maintainers. Without such a code it is inevitable that earthing disturbances will occur. Examples of Company Code of Practice are; Network Rail NR/SP/ELP/21085, Channel Tunnel Rail Link 000-GDS-LCEEN-10041-05; Indian Railways AC Traction Manual Appendix 11 code for bonding and earthing for 25kV AC 50Hz single phase traction system.

Risk (commercial, operational, safety)

It has become the norm for railway contracts to be based along traditional engineering disciplines and interfaces; for example, wheel to rail and pantograph interfaces. Railway authorities sometimes fail to recognise the complexity of electrical interfaces and provide a solution to manage the integration between different engineering disciplines.

The major cost element of a new railway is the civils discipline; the electrical systems are a relatively small portion when compared to the civil infrastructure costs. However, failure to integrate the electrical systems will probably mean disruption to the whole project during commissioning and delay early operational service.

Major Rail Projects are largely run by the Civil Engineering Discipline. Rail Authorities often fail to provide adequate project management effort to integrate the systems, placing the whole project programme at risk.

Specify design interface specification

The railway administration should be aware of the requirements for integration, and it is their responsibility to identify and include these criteria within the project requirements at the definition stage. Interface requirements must then be included within the Particular Design Specifications for each contract. They should also make all System Wide Contractors responsible for identifying interfaces, hazards and for participating in the integration methodology of the project.

If they fail to include this within the particular specification, then the contractors will not be obliged to ensure that this integration happens. The outcome of this can be disastrous for the project programme and the railway administration, which may be powerless to ensure that their multi-million pound investment operates as intended.

Management of electrical systems

The railway authority should specify the requirement for Management Plans to address quality assurance process and installation Codes of Practice. This is to ensure compliance with railway and national electrical and safety standards. This normally becomes the responsibility of the design and build contractor and has been addressed in more detail later in this article.

Design management responsibilities

The preliminary and detailed design stages of project management plans should be prepared to address the above system interfaces. The following are examples of management plans that should be incorporated within the overall systems engineering management plan.

This is normally the responsibility of the Design and Build Contractors.

Safety Management System [15]

The Project Safety Management System (SMS) is part of the Quality Assurance process that is required to address safety of humans. In an electrified railway the topics that need to be addressed include touch and accessible potential and the risks associated with the malfunction of signalling, and control systems leading to multiple fatalities.

All potential safety hazards associated with the operation of the railway including the earthed infrastructure of the railway network should be identified. The hazards associated with electrification supply points, overhead lines, traction return paths, operation of traction and rolling stock, effects in depots and station stops etc need to be addressed.

To achieve this, experts in the fields of electrification, earthing, signalling and rolling stock are required to be brought together to assess the system behaviour under normal train operation, under system faults and all degraded modes of operation of the electrification and signalling systems and the rolling stock.

Design interface specifications

Where there are known interfaces these should be recorded in an interface matrix and a specification prepared between the two disciplines or contractors. Such interfaces could also include the co-location of several different railways at an interchange station.

An example of this is London, where various lines on the London Underground DC metro railway are in close proximity to the 25 kV AC main line infrastructure. The interface specification should identify all of the systems that may be affected.

It is necessary that the responsibilities for the identified hazards in the project are assigned an owner (and accepted) and that the designer then mitigates any potential disturbance. It should also be remembered that utilities and neighbours must be considered when addressing interface specifications within the railway environment.

Integration Management Plan [6]

The Electrical System Integration Management Plan should set out a strategy to ensure correct operation of equipment for the project life-cycle to ensure that systems are integrated successfully.

The following disciplines and systems should be included: traction power and electrification (both rail authority and public supply), signalling and control, telecommunications, rail vehicles, permanent-way and civils infrastructure, and third parties.

Failure to integrate these electrical systems properly will introduce the probability of an electrical or control system failure. This could then have a subsequent disturbance to the operation of the railway.

Earthing Management Plan [4]

The content and detail should be based on previous experience of earthing other AC/DC railways and the performance requirements of relevant national and international standards i.e. European Standard EN50122-1, and British Standards BS7671 and BS7430.

It should set out a strategy which ensures the management of interconnection of earths, including: railway electrification and distribution systems, the distribution network operator, the low voltage (LV) distribution earths, signalling earths, lightning conduction and other inter-system earths.

The requirements of utility companies' earthing practices and their connection to the railway need to be recognised and integrated.

An Earthing Management Plan should include a 'process' to cover requirements at design, installation and operational stages of the railway.

Electromagnetic Compatibility Management Plan [3,6]

An EMC Management Plan is required and should be based on the requirements of EN50121, EN61000-5 and EN61000-6. It should set out a strategy for the project to ensure EMC is achieved. It should identify a quality assurance process including hazard identification, required deliverables, roles and responsibilities, EMC certification and test specifications.

The product standards provide emission and immunity tests under controlled environments. There are additional requirements for large infrastructures that require Installation Codes of Practice; this is often bespoke to the infrastructures railway systems being designed. These Installation Codes of Practice are often ignored by individual contractors who do not consider it there responsibility.

These Codes of Practice should be based on the requirements of the railway network, best practice in EMC design, installation and the EN61000-5 series of standards. In designing a railway that operates close to another railway, it is necessary that reference is made to local railway standards and codes of practice of both railways, as their emissions will impinge on each other.

Preparation of an EMC test specification should include EMC testing of individual apparatus and at the system level. Additionally site measurements should be undertaken of radiated electric and magnetic fields of the final installed railway system along its route.

DC Stray Current Management Plan [5,7]

The 'stray current management plan' should provide guidance on the management framework, quality processes and deliverables that are required through the design and installation stages of a project. Specifically this plan should detail acceptable pass/fail criteria for the level of stray current, after construction is completed.

This plan should detail deliverables including the 'stray current code of practice', test plans and monitoring plans. The Code of Practice should provide detail of the design, based on known proven technologies and evidence of best practice e.g. attention to electrical substation connection, high rail insulation, good stray current collection, good drainage construction supervision and quality control by qualified personnel, and the necessary testing and monitoring system.

Concluding remarks

New railway projects and the privatisation of railways have divided contracts and the design process into separate engineering disciplines. Railway authorities need to recognise the importance of integrating the electrical systems. Failure to do so will have a subsequent consequence on delivering a railway free from electrical disturbances.

This paper has endeavoured to demonstrate how railway authorities are being challenged by this difficult task of integrating electrical systems. This challenge will not be made any easier as client and public expectations of new rail transit systems require the railway designers to incorporate more versatile and sophisticated electrified railway and tram networks.

Acknowledgements

Information and guidance given in this paper are views held by the author. The author would like to thank Atkins (Rail) for its support and advice in writing this paper.

The author and Atkins Rail accept no liability to anyone for any loss or damage caused by any error or omission in the work, whether such error or omission is the result of negligence or any other cause.

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