ELECTRIFICATION INTERFACES AND ELECTROMAGNETIC COMPATIBILITY WITH RAILWAY CONTROL SYSTEMS

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1. Introduction

Electromagnetic Compatibility Reference [Appendix A and B]

The railway environment contains many sources of electromagnetic, electrostatic noise and electrical disturbances; and it is a hostile environment for low power control and system circuits. The railway electrification network is required to be monitored in terms of emissions and susceptibility to electromagnetic interference including, conductive [galvanic], inductive and radio frequency interference. Electromagnetic interference [EMI] will cause interference from the high power circuits of the electrification supply and traction drives into the train control systems, signalling systems, railway and publicly owned telecommunication systems, remote control and monitoring systems.

Systems Integration

Systems integration of a railway system should include all electrical systems in the supply and control of electrical traction power, supply and control of the signalling system, other train control circuits, the operation of telecommunication systems, radio communications, station and plant equipment. Electrical Systems Integration of the electrified railway should be a foundation of every railway electrification scheme. The ignorance of system compatibility means that this is often either not addressed or ignored until the designs are well established. Projects are then faced with re-engineering to ensure compatibility at significantly increased project costs.

Railway Legislation

Within the UK Rail Industry it is necessary to follow various legislation and processes with the introduction of change or novel systems to the railway infrastructure or rolling stock. These processes are designed to ensure the safety and compatibility for the systems infrastructure and rolling stock:

- Route Acceptance Safety Case for the introduction of anything new and novel onto the railway, this includes specific requirements of Railway Group Standards.

- Electromagnetic Compatibility the EEC directive 89/336 made the requirement that all electrical apparatus must not emit electro-magnetic radiation that would prevent other equipment from functioning as intended.

- Network Rail Design Approval Process and Safety Review Panels.

2. Abbreviations and Definitions

General Definitions for Electromagnetic Compatibility
Electromagnetic Compatibility [EMC]
Electromagnetic Disturbance [EMD]
Electromagnetic Interference [EMI]
Radio Frequency Interference [RFI]
Emissions [disturbance from a system]
Immunity [disturbance to the system]
Traction Feeder Station [TFS]
Technical Specification Interoperability [TSI]
Overhead Line Equipment [OLE]
Project Definition Stage [PDS]

3. The Railway and Standards

EN50238 Railway Applications Compatibility between Rolling Stock and Train Detection

The compatibility between train detection systems and rolling stock are a significant obstacle to cross acceptance of rolling stock within Europe. There is a complexity of rolling stock and different characteristics of infrastructure installed within Europe. This diversity leads Rolling Stock being restricted to specific routes with which it is compatible to avoid unnecessarily restrictive specifications.

This European Standard defines the "process to obtain the assurance that specific rolling stock operating on a specific route does not interfere with train detection systems" that are installed.

The standard seeks to identify the system characteristics that are necessary to undertake an evaluation of the compatibility of the rolling stock, infrastructure and the train detection systems. This includes the relationship between gabarit and possible interference limits. Additionally the standard addresses the characteristics of train detection, the interference signals generated by the rolling stock, traction substations and OLE system; this data is required if modelling is to be undertaken as part of the acceptance process.

GM/RT/8015 the UK Acceptance Process

This document mandates the requirements for the management of electromagnetic compatibility between railway infrastructure and train, to enable safe operation to be assured. In particular it defines the responsibilities and sets out requirements for:

1. the Infrastructure Controller to characterise the susceptibility of the infrastructure, and determine maximum allowable train emission levels
2. the provision of the infrastructure information when required
3. the process to enable compatibility between infrastructure and trains to be demonstrated in order to meet the requirements of the route acceptance process set out in the Railway Group Standard GO/RT3270

4. Project Definition and System Integration

Project Definition Stage

At the PDS system integration of the electrical systems will ensure that the system will function as intended and the project is able to deliver essential features. In many cases projects do not address facing up to systems integration until after the preliminary design stage. It is fundamental that the mutual dependence of equipment operability and electro magnetic compatibility are grasped by the project team at the PDS stage. Additionally there is the necessity that the equipment will provide a reliable and maintainable service over the anticipated life of the equipment.

Compatibility and Operability

Electrical/electronic systems may be compliant with relevant EMC standards however that will not necessarily ensure correct equipment and systems operability. Likewise the equipment may be shown to operate properly at the manufacturing stage, this does not mean compatibility with other railway systems when installed in the railway environment. Equipment operability and EMC may or may not be mutually interdependent. If this can be absorbed by projects at an early stage, a lot of the heart ache delay and cost at later stages and the cost can be alleviated. An example of this is where railway projects have shown a lack of understanding by installing equipment designed for DC railways onto AC railways and vice versa.

5. Disturbance Effects of DC Electrification

DC Short Circuit Fault Current

The DC short circuit level is an important design characteristic of the power supply system. The fault level must be of such a level that it does not interfere with normal train operation and signalling systems either due to conductive effects in the rail or by inductive effects into lineside cables.

Harmonics produced in the supply network

The rectifier works by switching the load current from one phase to the next, this process is called 'commutation'. If the transformer has leakage reactance the line current cannot switch instantaneously due to the effect of the leakage reactance, this process is called 'overlap'. During the overlap period all devices are conducting in the outgoing and incoming arms of the rectifier. This will produce a short circuit on the input and the output to the rectifier.

The input supply voltage waveform and the output DC waveform will therefore be interrupted producing a notch in the voltage waveform and oscillation due to the RLC characteristic of the supply system. This has the effect of distorting the AC supply waveform at the point of common coupling.

The input current to the rectifier produces a stepped waveform due to the switching strategy of the rectifier converter. The rectifier input line currents that are associated with a 12 pulse bridge rectifier can be shown by the Fourier Transform to be 11th, 13th, 23rd, 25th with a less amount from the 5th, 7th, 17th, 19th.

The DC output voltage waveform produces a ripple that is related to the pulse number of the converter. This will therefore produce harmonics in the load current waveform that are typically related to 300Hz, 600Hz, 900Hz etc. depending on the rectifier pulse number. There are now tendencies of using higher pulse numbers to further reduce the harmonic distortion to the supply waveform.

Additionally harmonic distortion in the supply waveform is produced by the imperfections due to unbalanced and distortion of the 3 phase voltages the supply frequency varies within a range specified by Distribution Network Operator. All of these harmonics can be seen by track circuits and are potential sources of disturbance.

Specific disturbance effects are related to rectifier arm failure when 50Hz component is produced with the subsequent disturbance to 50Hz track circuits.

6. UK Electricity Grid Supply Substation Interfaces

The National Grid Code and P24 requires the neutral of the Grid Transformer be connected to earth, this connection is also connected to the traction return systems at the TFS.

The AC railway is a single pole with neutral earth return. The traction negative at the TFS is connected to the grid substation transformer neutral. System [132kV, 275kV, or 400kV] earth faults will therefore impose a voltage on the railway ‘conductively’ through the neutral/traction negative and additionally by ‘transferred potential’ that is due to the passage of current through mother earth.

Ground Potentials and Rail Potentials

As current flows into earth during a 400kV fault to earth, the voltage of the fault location and connected parts will rise above earth. This rise of earth potential depends on the amount of current entering earth and the impedance from the local connected earthed system including the railway return current system to remote earth. Information provided for safety cases should include, as well as conduction voltages, the contours of voltage on the surface of the ground for the maximum expected fault current. The contour plots should include lines at the railway voltage thresholds [including 670V and 430 V ac]. These voltages relate to personnel safety and to apparatus reliability. The magnitude of the rise of earth potential with 400kV earth fault depends on the:

- fault current flowing into earth at the site;
- distribution of current between return paths;
- impedance to earth of the interconnected elements of the site (these acting as parallel circuits).

This voltage is only a danger if it produces a step or touch potential within the reach of people, or if the voltage imposed on the rail exceeds the level for safe operation of the signalling equipment.

7. Autotransformer and 25 kV Railway Traction Supplies [Appendix C]

Autotransformer supply 25kV schemes are increasingly used for AC electrification to take advantage of 2 x 25 kV power transmissions from the feeder station to the autotransformers, yet being able to utilise the standard 25 kV traction equipment.

The autotransformer works on the principle that the train is supplied between the contact wire [+ 25kV] and rail. The rail and earth currents are then returned to the centre tap of the adjacent auto transformers. In practice most of the train current is supplied from the two adjacent autotransformers. The traction unit current is twice the current returning through the autotransformer feed and return conductors.

The operation of classic 25kV systems is different from the autotransformer arrangements in that the booster transformer is only energised when a train is in section, whilst the autotransformer is energised whenever the supply is available in section and is independent of train position. The main advantage of the autotransformer system over the booster transformer system is that the magnitude of current and voltage drop in the supply system is less; the auto-transformer is capable of supplying more power with less voltage regulation and less system losses. Additionally the auto transformer reduces the line current by 50%, as the distribution is at 25-0-25kV. This has the benefit of reducing the voltage regulation by 50% and the distribution losses by 75%. Therefore a 6kA autotransformer railway [Network Rail proposal for WCML] is able to deliver significantly more load than a 6kA classic railway.

7.1 Degraded Modes Auto Transformer Railway

Effect of a Feeder Station Outage

Under a circuit outage at a Grid Substation only one 25-0-25kV circuit will be available, it is normal practice to ‘T’ feed the railway. This will increase the fault level by approximately 10% and is due to the component of fault current supplied by the additional autotransformers. The feeding section near the TFS can carry increased load currents. This is reduced to some extent by the reduction of voltage at remote trains and active voltage control that is incorporated in some train designs.

Outage of a Single Autotransformer.

If two autotransformer are positioned at each AT site and one is out of service, the second autotransformer at the site will continue operation without interruption. The is no consequence on EMI or induction into lineside cables.

Outage of a complete Autotransformer Transformer Site

If both ATs are out of service then the return current will flow in rails and earth wires between the two active AT sites, this will increasing the voltage V/km induced in lineside cables which run over this length. If the AT sites are spaced at 5km then for double AT outage the length of rail return area will be 10km between active AT sites. This will increase in the induction voltage into lineside cables.

Outage of an Auxiliary Feeder Wire [-25kV]

With one auxiliary feeder out of service the remaining feeder wire will continue the autotransformer operation. Note in this case the return current will be on the opposite side of the railway and the immunisation effect will not be as efficient as with a normally operating railway.

8. 25 kV Classic Railway Distribution System

The running rails of the traction return current circuit, are additionally used by the signalling engineer for train detection. Any traction 25kV faults will impinge on the rails and the signalling detection systems. It is fundamental therefore that the track circuits are immune to all operational modes of the 25kV including train loads, short circuits and degraded modes.

Traditionally we have had in the UK a 6kA system. This fault level is determined by the system voltage [27.5kV highest permanent], the impedance between the short circuit and the generating system.

This is determined by:

- Fault impedance [bird strike, conductor, insulator flashover]
- Impedance of the out and return circuit
- Impedance of any additional 25kV reactors
- Impedance of the transformer
- Impedance of the HV supply referred to the 25kV

Operation on Classic 6kA 25kV Railway [Reference Appendix C]

The UK 25kV railway has been developed for a maximum 6kA fault level; this was determined to provide the train loads required for specific services without incurring unacceptable voltage drops at the traction pantograph [EN 50163]. The classic railway including booster transformers and return conductors produces a significant voltage drop due to the impedance of the booster in normal operation [typically j3 ohms] and reduction of fault level of the 25kV system. With the increase in train loads there is a reduction in performance and efficiency of the distribution system.

When a train passes a booster transformer, the 25 kV current flows through the primary of the booster transformer. The ampere turn law states that a secondary current is required to flow in the transformer secondary and the return conductor. The booster transformer is energised when the train passes the transformer.

8.1 Degraded Modes Classic 25kV Railway,

Effect of Feeder Station Outage

Under a 25kV circuit outage at a Supply Substation only one 25kV circuit will be available, it is then normal practice to ‘T’ feed the 25 kV railway. The feeder circuit will carry increased traction load current. This is reduced to some extent by the reduction of voltage at remote trains and active voltage control that is incorporated in some train designs.

Outage of a Booster Transformer

If a booster transformer is out of service, the return current will flow in rails and return conductors, increasing the voltage induced in line side cables within this section. A study has shown that a substantial increase in induced voltage is possible if two booster transformers are out of service between two section cabins. This will increase the induction per km of lineside copper circuits.

Inoperative Return Conductor

When the return conductor is inoperative the induction into lineside cable will be determined by the traction return current in the rail or ground. This will increase the induction per km of lineside copper circuits.

9. Electrical Signalling Supplies

Signalling supplies are derived from a variety of sources including Regional Electricity Companies, standby supplies from diesel generators and the 25kV itself. There is a signalling requirement to maintain the voltage and frequency within safe limits under normal and degraded modes of operation.

Recently the introduction of commercial UPS introduced the added requirement for these to be included in signalling safety cases. This additionally will need to address all the modes of operation including normal and degraded modes of the equipment and the electrical supply networks.

10. Resonant behaviour of the Overhead Line

Series Resonance of the Overhead Line

The 25kV Classic and AT arrangement of the overhead line has the electrical characteristics of a long distributed inductance with a small series resistance with capacitance to ground. This produces natural resonant frequencies. Experience has shown that the first resonance lies in the range 500 to 1200 Hz, being governed predominantly by the length of the overhead line and the characteristics of the National Power Supplier supply; where the TFS sites have cable feeds, the cable capacitance reduces the resonant frequency.

The impact of this resonance can be observed during switching of the feeding arrangement of the overhead line and the switching current waveform of the traction unit and the overhead line.

Parallel Resonance of the Overhead Line

The resonant frequencies of the distribution system are dependant upon the power supply source impedance, supply transformer impedance and the capacitance of the catenary system to ground.

Traction AC units are a source of harmonic currents, when this is injected into the 25 kV system it may produce significant harmonic voltages. This can be generated when either the harmonic current is large, or the impedance of the system to a particular harmonic frequency is high [i.e. at resonance]. Line resonance occurs to some extent on all systems, however the higher the power levels on the system the greater the possibility that resonance will occur.

Interlaced traction pulse converters will disturb the overhead line when the traction and overhead line frequencies coincide. The overhead line may have a lowest natural frequency in the range 450-2500Hz and subsequent higher resonant frequencies. Interlaced traction pulse converters have a switching frequency of typically 3.6kHz, and harmonics at multiples of this frequencies N*3.6kHz.

Disturbances to Signalling and Electrification System:

The harmonics that are generated by the Four-Quadrant Converter may potentially interfere with train detection and signalling systems in use on the railway. Each train detection system using the rails as part of the track circuit has a characteristic frequency, those that are at particular risk to this type of converter are the audio frequency and reed track circuits. [Interlaced traction pulse converters have a switching frequency of typically 3.6kHz].

Mitigation including Filter Characteristic Design

At the parallel resonant frequency it is required that the maximum system impedance should be limited. This is required to achieve an acceptable reduction in the system over voltage. The over voltage is determined by the superposition effect of system impedances [variable frequencies] and the line current harmonic[s]. To overcome this damping may need to be installed on either the traction unit or the overhead line.

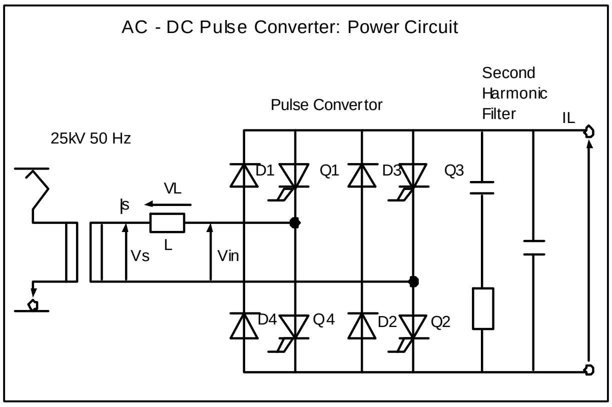
Installed on the UK rail network is a damper of resistance 300 ohms with capacitance of 0.3 µF. The UK Rail Standards [RT/E/S/270101] specifies that the 25kV distribution should ensure that the system impedance at resonance is typically below 5 kohms.

11. 25kV AC Traction Converters

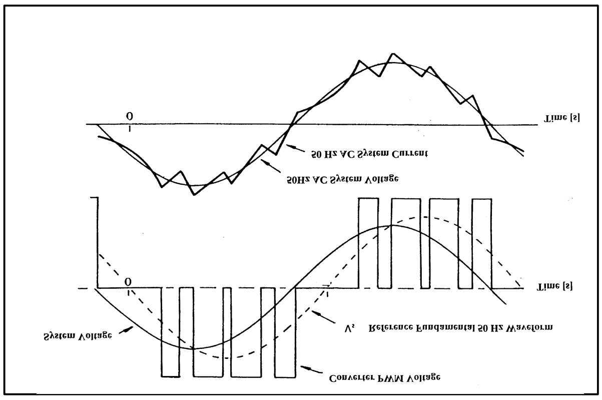
Harmonic Spectrum Four Quadrant Converters [AC Electrification]

The four-quadrant converter reduces the level of magnitude of 50Hz [3^{rd}, 5^{th} etc] harmonics that are returned to the supply system when compared with conventional diode and thyristor controlled traction converters. The number of switching per cycle of the converter determines the harmonic disturbance. The converter is normally interlaced making the line current fundamental double the operating frequency [1.8kHz] of each individual converter. The spectrum consists of the fundamental and harmonics of the switching frequency for IGBT’s this will be typically, multiples of 3.6 kHz, 7.2kHz and 10.8kHz.

Single Phase Bridge Voltage Source PWM



PWM Waveforms



Disturbances effects of Four Quadrant Converters

i. Disturbance to telecommunications systems

Electromagnetic noise is a potential area of interference, however it is expected that in most cases the interference [transverse volts] into telecommunications systems will be reduced by the introduction of Four-Quadrant Converters, due to the overall reduction in the harmonic content of the 25kV traction load current within the audio band.

ii. Disturbance to signalling detection

The harmonics that are generated by the Four-Quadrant Converter may potentially interfere with train detection and signalling systems in use on the railway. Track Circuits at particular risk to this type of traction converter are audio frequency track circuits. [2kHz -12kHz].

iii. Resonance of the 25kV Overhead Line

The harmonics of the converter can be generated at the natural characteristic frequency of the overhead line. In this case the overhead line [of Classic and AT systems] will circulate currents that produce a high system over voltage on the 25kV overhead line. Damping may be needed to be installed on either the traction unit or the overhead line.

iv. Degraded Mode of the Traction Converter

The characteristic of the converter operating under degraded mode needs to be clearly understood as there will be a change in the harmonic spectrum emitted. This is normally addressed as part of the safety case process.

v. Harmonic reduction using optimised p.w.m. scheme

Optimised p.w.m. schemes use the microprocessor technology to control the frequency of operation, so that unwanted harmonics which may interfere with signalling circuits are not produced.

The optimised sampling is achieved by specifying a switching pattern with quarter wave symmetry and which contains only odd harmonics where particular harmonics can be eliminated theoretically by the choice of suitable switching angles.

Disturbance Effects Phase of Angle Control

i. Disturbance to telecommunications systems

Phase angle control of a bridge circuit produces a relatively high level of fundamental and odd harmonics during the acceleration; this produces a high level of psophometrically weighted primary current until full conduction of the converter is reached.

ii. Harmonics produced by the converter

The mode of control may produce harmonics at the natural characteristic of the overhead line. In this case the overhead line will circulate currents that may produce high system voltage on the 25kV overhead line.

iii. Disturbance to signalling detection

The converter harmonics may potentially interfere with train detection systems and signalling track circuits. Train detection system uses the rails as part of the track circuit. There is a risk that this type of converter which produce significant harmonics [<5kHz], this may particularly affect audio and power frequency track circuits.

iv. Transient Effects

The operation of the transformer magnetic circuit will produce transient effects when the transformer is energised and during interruption of 25kV supply due to pantograph bounce. The resulting effect is an asymmetric [DC] inrush current. This switching transient will give rise to disturbances in modern jointless track circuits and conventional DC track circuits.

12. Regenerative Traction Units on 25kV Supplies

Traction units that regenerate may disturb the 25 kV and the National Grid Network. The regenerative energy will be used to supply energy to other traction units that are in the same feeding section; alternatively if no motoring units are available the energy will be distributed into the national grid.

The behaviour of the overhead line and the return conductor system will reverse. The current flow will either be between:

- regenerative traction units and motoring units;
- regenerative traction units and the Electricity Supply Point;

The current in the overhead line, boosters, return conductors and autotransformers will be exactly opposite to the flow that is observed in motoring.

Possible Disturbances that can occur with Regenerative Traction Units:

- Regenerative train runs into a dead line that is not earthed and energises the section; [note this may cause a safety and additionally an induction problem]

- The Classic Railway the ‘train in section effect’ is from the mid-point connector to the booster [1.6km]. With regenerating trains the maximum distance of ‘train in section effect’ will extend to 3.2km [where motoring and regenerative units at consecutive boosters]. This does change the peak voltage expected between two active booster transformers.

- The Auto Transformer Railway, regenerating trains the maximum distance of rail return operation is between the traction load and the regenerative unit this would equal the distance between ATs. This would change the induction behaviour but probably not significantly.

13. Regenerative Traction Units on DC Supplies

The development of traction inverters and choppers has made the recovering of kinetic energy of the train and returning it to the supply common place. The DC network is usually designed with uncontrolled rectifiers, therefore when a train enters regenerative mode the sub station diodes are reverse biased and other traction equipment that is operating in the same feeder section can use energy that is regenerated.

When the Substation diodes are reverse biased then the impedance of the supply network is determined by the traction loads and not the supply systems. The normal supply harmonics are reduced and the traction generated harmonics are dominant. There is a magnitude change of the harmonics flowing in supply system during regeneration, and this could be a change in the disturbance level to susceptible track circuits.

14. Disturbance to Communications and Telecommunications Networks

Telecommunication carrier circuits [e.g. FDM, axle counter circuits].

The railway system produces high levels of traction current which flow in the electrification system. This flow of current is responsible for producing EMI into the railways own and other telecommunication networks which are in the vicinity of the railway. The telecommunications system is required for operational reasons and therefore the level of interference is a safety issue, which must be addressed to ensure safe operation of the railway network.

The fundamental generation of EMI into telecommunication networks occurs where there is flux linkage between the electrification out and return currents with the telecommunications cables. The electrification out and return currents are normally balanced, where the current is not returning via mother earth. However if there is an imbalance in the out and return paths of the power system this will produce a loop in which there is a changing magnetic field and consequently may induce e.m.f. in any telecommunication cables within the vicinity.

The figures below are to provide an indication of the level of potential disturbances that can occur on a railway network.

The limit of power frequency magnetic field in EN 50121-4 is of 100A/M and pulsed magnetic field of 300A/M.

BS IEC 61000-5-1 1996 states that the immunity for residential equipment is 3A/m and industrial equipment is 30A/m.

As a benchmark a Cathode Ray Tube is affected by 1A/m 50Hz field and 10A/m DC field.

Disturbance Effects into Telecommunication Circuits

The induced voltage into telecommunication cables is dependent on a number of parameters including:

- Size and frequency [50Hz and harmonics] of the power circuit current
- Length of parallelism of the telecoms cables and AC electrification system
- Mutual coupling between power circuit and telecoms
- Separation of the feed and return conductors
- Separation of the cable and the power cables
- Earth proximity effects
- Intentional and unintentional screening effects.

Classic Railway mitigation of induced voltage [Appendix B]

This system utilises an out and return circuit that is mutually coupled by the Primary and the secondary windings of the booster transformer. The primary current produces a magnetic flux in the booster transformer that demands an equal and opposite flux. This is produced by the traction return current flowing in the secondary winding. The current is therefore encouraged to flow back to the feeder station via the booster secondary and the return conductors [these are mounted on the overhead line masts.] The position of the secondary is such that the magnetic field produced by the current in the catenary is partially balanced with magnetic field associated with the return current flowing in the return conductors.

Autotransformer Railway mitigation of induced voltage [Appendix A]

This system utilises an out and return circuit that is mutually coupled by the upper and the lower windings of the autotransformer. The secondary current produces a magnetic flux in the transformer that demands an equal and opposite flux; this is produced by the supply current flowing in the lower and upper winding. The return current is therefore encouraged to flow back to the feeder station via the autotransformer and the auxiliary feeder conductors [these are mounted on the overhead line masts]. The position of the auxiliary feeder wire is such that the magnetic field produced by the current in the catenary is partially balanced with the magnetic field associated with the return current flowing in the auxiliary feeder conductors.

Disturbance to Signalling Track Circuits

Many signalling systems uses the track running rails as part of the track circuit and the electrification engineer uses the same rails for the traction return current. The signalling system on electrification system may be susceptible to interference from:

- The passage of characteristic fundamental component of the electrification system, this is normally either DC or 50Hz.
- The generation of harmonics by the power system due to the characteristic switching in the DC power system,
- Generation of harmonics by complex traction control system flowing in the electrification running conductor system,
- The generation of harmonics due to the natural frequency of resonance of the AC/DC electrification power supply, distribution and loads,
- The transient operation of the electrification system due to switching of the electrification or power system or the traction system,
- Induced voltage from adjacent AC power cables used for railway and non railway purposes,
- Fault current that flows during an electrification earth fault
- Lightning Strike onto the rails, or onto the 25kV or adjacent National Grid.
- Electromagnetic or electrostatic interference into telecommunications system used in the operation of the signalling control system,
- Switching of power transformers and the generation of inrush currents,
- Earth return power circuit
- Train borne inductive sources usually associated with large chokes and power electronic equipment,
- Train borne capacitive sources in earth insulated power return systems.

Earthing and Bonding of Signalling and Traction Supplies

Rail to Rail bonds and rail to mast bonds are designed to provide a low resistance to earth. These bonds will control the rail voltages under train loads and 25kV earth faults. If these bonds become disturbed by track maintenance gangs then the voltage on the rail will increase. The absence of track bonds may increase the voltage applied to the track circuit relay.

Broken Rail

A broken rail in the traction return path will increase the voltage impressed upon the track circuit receiver. The subsequent passage of traction current will then be forced to take a more circuitous route to the traction feeder station. The length of the return path depends on the spacing of the cross bonds and the length of the track circuit.

With a broken rail the positioning and integrity of the rail to rail and track to track cross bonding is fundamental to the safe operation of the track circuit.

15. Overhead Lines and Signal Sighting.

Overhead Line Equipment [OLE] infrastructure design has to take account of signal sighting issues, in particular ensuring that no part of the OLE infrastructure [but excluding wires, etc] obscures the driver's eye view of relevant signals for more than a prescribed period of time To ensure that there is adequate visual clearance of the signal, it is necessary to create a 3D model of the railway infrastructure including rails, together with OLE, signalling and general railway infrastructure. Signals and potential obstructions [insulators, tubes, steelwork, etc] have to be detailed in full 3D to guarantee obscuration is accurately represented.

A line describing the locus of the driver's eye is constructed representing its path as the train travels down the track to the signal in question. The Cad software can perform a "fly-through" down that line with snap-shots of the perspective view of the signal from the driver's eye at specified incremental intervals. These can be analysed to identify any obscuring features and the total length of time of each obscuration can be calculated based on speed. This has to be applied to every approach route to that signal. If obscuration is outside the prescribed limits, then re-design of OLE or signalling infrastructure is required.

16. Disturbance of Radiated Effects into Signalling and Telecoms Equipment

RFI disturbance effects are largely addressed in the BSEN 50121 series of standards. It should be noted that this standard specifically addresses EMC aspect and is not 'a guarantee of satisfactory performance' [Ref EN 50121-1] or indeed Safety. That does not preclude the fact that safety and EMC may be and often are linked. As such the EN 50121 standards are a guideline of the emission levels that can be expected within the railway environment.

RFI Environmental Classification in relation to the railway

Severe	< 1m
High	1-3m
Industrial	3-30m
Commercial	>30m
Minimal	>100m

Sources of RFI and Victims

The electrified railway distribution networks and the traction unit itself are responsible for generating RFI into public and railway electrical systems. Arcing from the collection system and radiation from on board power electronic drives and control systems are the main cause of RFI.

The main RFI disturbance is due to current collection of the pantograph or the third rail shoe gear. A pantograph will create an electric arc between the pantograph head and contact wire due to the pantograph bouncing, irregularities in the overhead structure, and when the pantograph is lowered. Shoe gear on third rail systems and gapping are a major characteristic of DC conductor rail electrification systems. The gapping of the conductor rail is a major source of arcing of the DC electrification network. The arc can be produced on the high voltage or less likely on the earthed return to the sub/feeder station. The infrastructure itself is also a very good transmitter and the effects of the system are conducted along the overhead line. Radiated disturbance effects produced by the on board train systems include resonance currents, current reversal [every 10mS] in the overhead line equipment, interruptions of the current passing registration arms, switching of the 25kV system and harmonics of the traction converters.

RFI interference mechanisms may be responsible for causing the mal-operation of radio based systems, signalling track circuits control systems, train control systems, telecommunication circuits, and third party communications and control system. In any assessment both normal and fault conditions should be assessed.

Limits of emissions:

- EN 50121-2 and 3 specifies the immunity and emission limits emitted by railway vehicles [3] and the electrified railway [2] .
- EN 50121-4 specifies the immunity and emission limits of signalling and control systems.
- EN 50121-5 specifies the immunity and emission limits of power supply substations.

17. Technical Specification for Interoperability [Energy]

This specification specifically relates to equipment functionality and interoperability and does not specifically address Radio Frequency and Induction Compatibility. The assumption is that equipment RFI and Induction specification for EMC is addressed within the relevant European Norms.

TSI relating to Sub Systems

"The energy sub system of the trans European high speed rail system comprises all fixed installations that are required to supply, with respect to essentials requirements the trains from high voltage single phase or three phase networks"

Energy Sub System Comprises:

Substations, sectioning points, overhead contact lines, current return circuit.

Links concerning electrification systems

Electric interface and harmonics interface with rolling stock and control-command and signalling subsystems.

13 Acknowledgement and Disclaimer

Information and guidance given in this paper are views held by the author's. The authors, 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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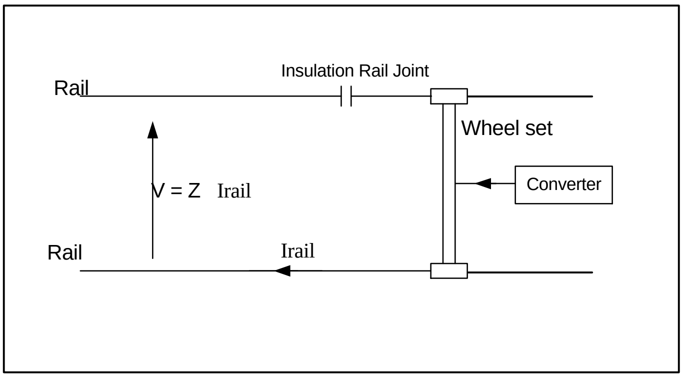
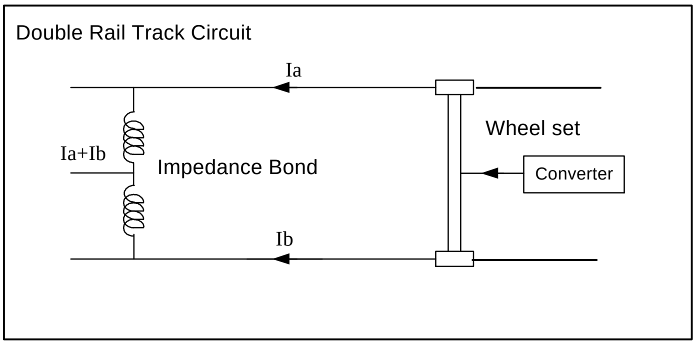
18. Appendix A Interference Mechanisms

18.1 Conductive Interference Fig 1a

Conductive interference into signalling rails can be generated by the high power circuits of the electrification supply and traction drive and is due to conduction or the passage of an electric current generating a voltage drop in the high power system.

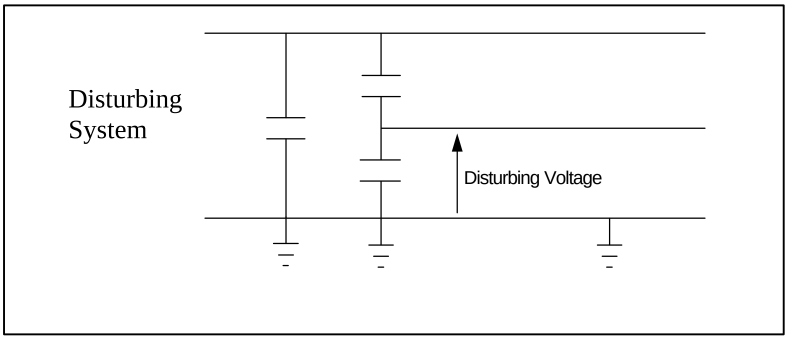
Conductive interference produced in the railway earth return and or third party installations may be responsible for causing corrosion, potentially high touch and accessible potentials under both normal and fault conditions on the electrification system.





18.1.1 Electrostatic and Capacitive Interference Fig 1b

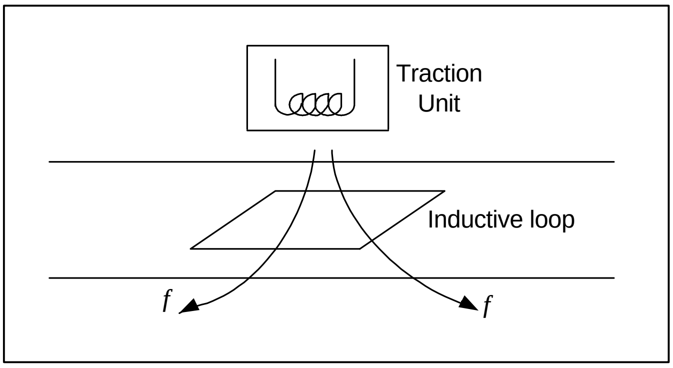
Electrostatically induced voltages due to capacitive coupling may induce high voltages on metal conductors within the vicinity of the railway. In AC supplied railways capacitive coupling must be considered in low power circuits where there is relatively high input impedance.



18.1.2 Low Frequency Magnetic Fields Fig 1c

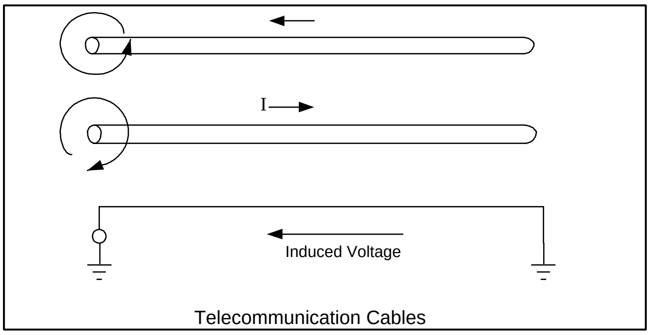
Magnetic fields surrounding the electrified railway overhead conductors and where there are large pieces of electrical equipment including transformers and switching stations.

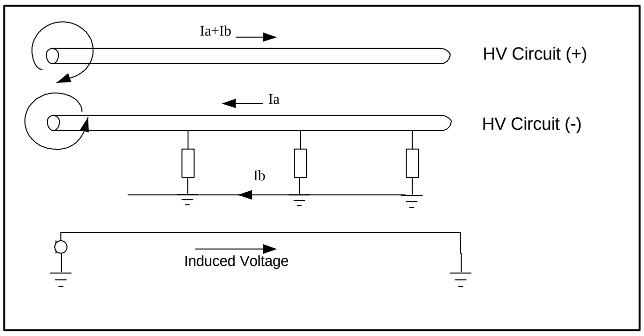
Magnetic fields are also associated with train born electrical equipment The interference will relate to the power source whether AC or DC will be either continuous or transient.
This interference will interfere with magnetically sensitive equipment including CRT.'s, Hall Effect transducers and microphones.



18.1.3 Electromagnetic Induced Voltage Fig 1d & 1e

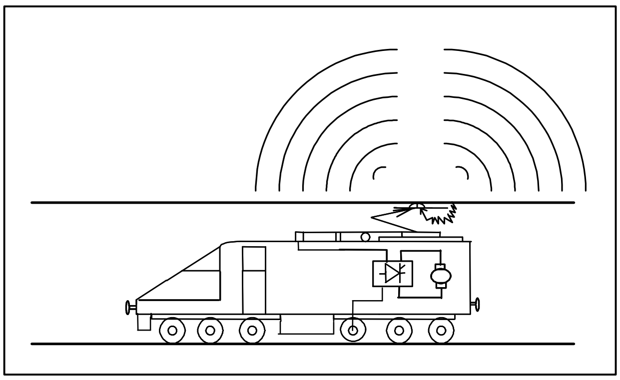
Where the magnetic field is changing due to an alternating source [ie 50Hz] or where there is a transient effect due to a high rate of change of current [DC short circuit] an emf will be induced in a conductor that is mutually coupled. The level of the induced voltage is different and dependent upon whether the return current flows via the earth or through a separate conductor.





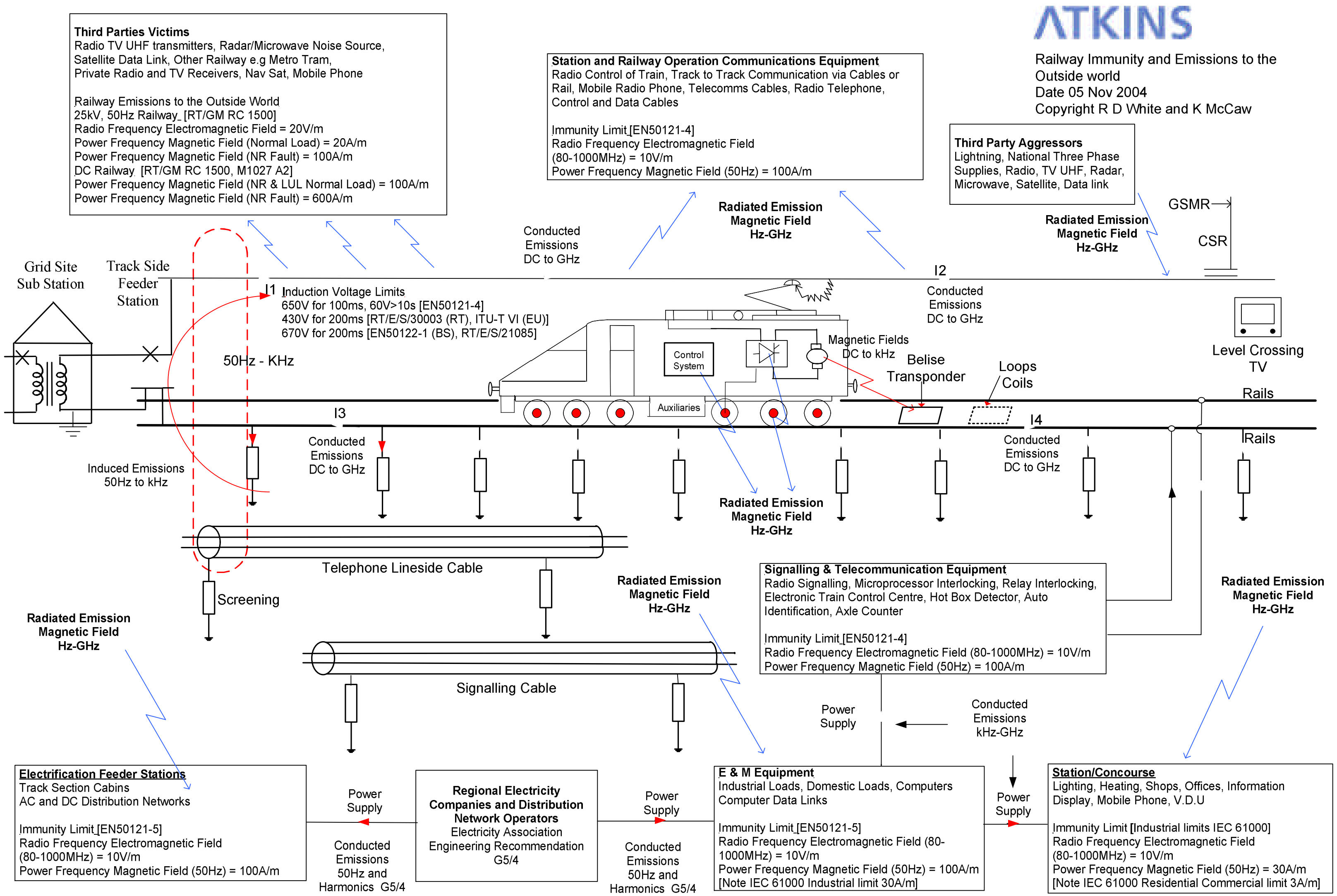
18.1.4 Radio Frequency Interference Fig 1f

The generation of radio frequency interference [RFI], electric [E] and magnetic [M] radiation, due to arcing and poor current collection from the high voltage system, may affect the railway communication systems with the generation of high frequencies.



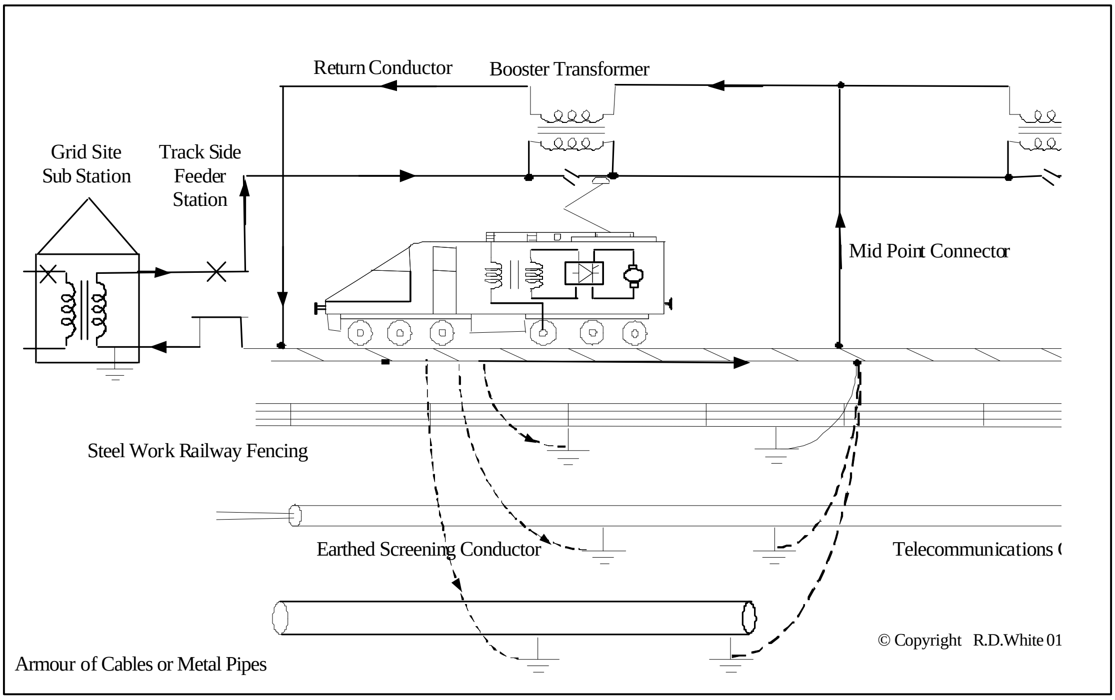
19. APPENDIX B

Figure Railway Equipment Immunity and Emissions to the Outside World



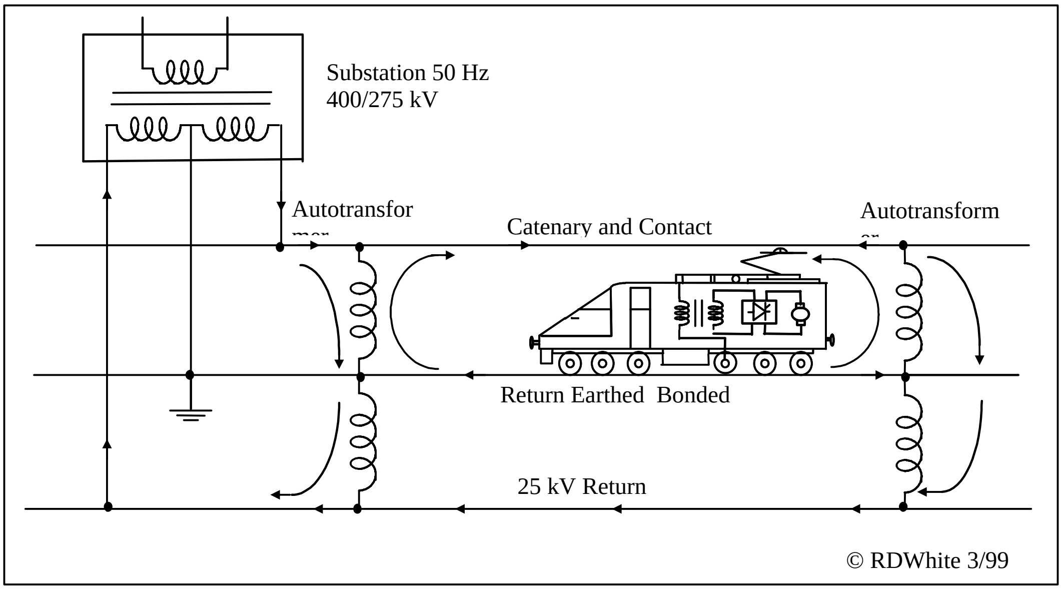
Railway Immunity and Emissions to the Outside world
Date 05 Nov 2004
Copyright R D White and K McCaw
Third Parties Victims
Radio TV UHF transmitters, Radar/Microwave Noise Source, Satellite Data Link, Other Railway e.g Metro Tram, Private Radio and TV Receivers, Nav Sat, Mobile Phone
Railway Emissions to the Outside World
25kV, 50Hz Railway [RT/GM RC 1500]
Radio Frequency Electromagnetic Field = 20V/m
Power Frequency Magnetic Field (Normal Load) = 20A/m
Power Frequency Magnetic Field (NR Fault) = 100A/m
DC Railway [RT/GM RC 1500, M1027 A2]
Power Frequency Magnetic Field (NR & LUL Normal Load) = 100A/m
Power Frequency Magnetic Field (NR Fault) = 600A/m
Station and Railway Operation Communications Equipment
Radio Control of Train, Track to Track Communication via Cables or Rail, Mobile Radio Phone, Telecomms Cables, Radio Telephone, Control and Data Cables
Immunity Limit [EN50121-4]
Radio Frequency Electromagnetic Field (80-1000MHz) = 10V/m
Power Frequency Magnetic Field (50Hz) = 100A/m
Third Party Aggressors
Lightning, National Three Phase Supplies, Radio, TV UHF, Radar, Microwave, Satellite, Data link
Conducted Emissions DC to GHz
Radiated Emission Magnetic Field Hz-GHz
Radiated Emission Magnetic Field Hz-GHz
GSMR
CSR
Grid Site Sub Station
Track Side Feeder Station
I1
Induction Voltage Limits
650V for 100ms, 60V>10s [EN50121-4]
430V for 200ms [RT/E/S/30003 (RT), ITU-T VI (EU)]
670V for 200ms [EN50122-1 (BS), RT/E/S/21085]
I2
Conducted Emissions DC to GHz
50Hz - KHz
Control System
Magnetic Fields DC to kHz
Belise Transponder
Loops Coils
Level Crossing TV
Rails
Auxiliaries
I3
Conducted Emissions DC to GHz
I4
Conducted Emissions DC to GHz
Rails
Induced Emissions 50Hz to kHz
Radiated Emission Magnetic Field Hz-GHz
Telephone Lineside Cable
Screening
Radiated Emission Magnetic Field Hz-GHz
Signalling & Telecommunication Equipment
Radio Signalling, Microprocessor Interlocking, Relay Interlocking, Electronic Train Control Centre, Hot Box Detector, Auto Identification, Axle Counter
Immunity Limit [EN50121-4]
Radio Frequency Electromagnetic Field (80-1000MHz) = 10V/m
Power Frequency Magnetic Field (50Hz) = 100A/m
Radiated Emission Magnetic Field Hz-GHz
Radiated Emission Magnetic Field Hz-GHz
Signalling Cable
Power Supply
Conducted Emissions kHz-GHz
Electrification Feeder Stations
Track Section Cabins
AC and DC Distribution Networks
Immunity Limit [EN50121-5]
Radio Frequency Electromagnetic Field (80-1000MHz) = 10V/m
Power Frequency Magnetic Field (50Hz) = 100A/m
Power Supply
Conducted Emissions 50Hz and Harmonics G5/4
Regional Electricity Companies and Distribution Network Operators
Electricity Association Engineering Recommendation G5/4
Power Supply
Conducted Emissions 50Hz and Harmonics G5/4
E & M Equipment
Industrial Loads, Domestic Loads, Computers Computer Data Links
Immunity Limit [EN50121-5]
Radio Frequency Electromagnetic Field (80-1000MHz) = 10V/m
Power Frequency Magnetic Field (50Hz) = 100A/m
[Note IEC 61000 Industrial limit 30A/m]
Power Supply
Station/Concourse
Lighting, Heating, Shops, Offices, Information Display, Mobile Phone, V.D.U
Immunity Limit [Industrial limits IEC 61000]
Radio Frequency Electromagnetic Field (80-1000MHz) = 10V/m
Power Frequency Magnetic Field (50Hz) = 30A/m
[Note IEC 61000 Residential Commercial limit 3A/m]

20. Appendix C Classic Arrangement and mitigation of induced voltage



This system utilises an out and return circuit that is mutually coupled by the Primary and the secondary windings of the booster transformer. The primary current produces a magnetic flux in the booster transformer that demands an equal and opposite flux. This is produced by the traction return current flowing in the secondary winding. The current is therefore encouraged to flow back to the feeder station via the booster secondary and the return conductors [these are mounted on the overhead line masts.] The position of the secondary is such that the magnetic field produced by the current in the centenary is partially balanced with the return current flowing in the return conductors.

20.1 Autotransformer Arrangement and mitigation of induced voltage



This system utilises an out and return circuit that is mutually coupled by the Upper and the Lower windings of the autotransformer. The primary current produces a magnetic flux in the transformer that demands an equal and opposite flux, this is produced by the traction return current flowing in the lower winding. The return current is therefore encouraged to flow back to the feeder station via the autotransformer and the auxiliary feeder conductors [these are mounted on the overhead line masts.] The position of the auxiliary feeder wire is such that the magnetic field produced by the current in the centenary is partially balanced with the return current flowing in the auxiliary feeder conductors.