

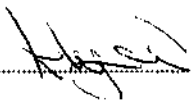
Ref	NR/GN/ELP/27010
Issue	2
Date	December 2005

Business Process Document

Guidance for compatibility between electric trains and electrification systems

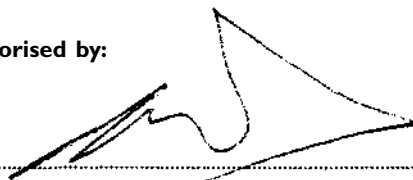
Endorsement & Authorisation

Endorsed by:



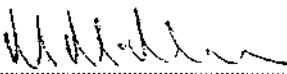
K. Lydford, Head of Electrification & Plant Engineering

Authorised by:



A. McNaughton, Chief Engineer

Accepted for issue by:



M. McManus, National Standards Manager

This document is the property of Network Rail. It shall not be reproduced in whole or part nor disclosed to a third party without the written permission of the Standard Owner.

©Copyright 2005 Network Rail

Uncontrolled copy once printed from its electronic source.

Published & Issued by: Network Rail 40 Melton Street, London NW1 2EE

Ref:	NR/GN/ELP/27010
Issue:	2
Date:	December 2005

Issue record

Issue	Date	Comments
2	December 2005	Re-issued as a SAF3 Business Process Document

Disclaimer

In issuing this document for its stated purpose, Network Rail makes no warranties, express or implied, that compliance with all or any documents it issues is sufficient on its own to ensure safe systems of work or operation. Users are reminded of their own duties under health and safety legislation.

Supply

Copies of documents are available electronically, within Network Rail's organisation. Hard copies of this document will be available to Network Rail employees on request to the Document Controller and to other organisations from IHS Technical Indexes (01344 404409)

Contents

1	Purpose	5
2	Scope	5
3	Reference documentation	5
4	A.C. electrification parameters	5
4.1	System description	5
4.2	System voltages	6
4.3	Frequency	6
4.4	Line current	6
4.5	Fault level	7
4.6	Power factor	7
4.7	System impedance	9
4.8	Harmonics	10
4.9	Regeneration	11
4.10	Neutral sections	12
4.11	System simulation	13
4.12	System performance	14
4.13	Current collector performance	14
5	D.C. electrification parameters.	15
5.1	System Description	15
5.2	System Voltage	15
5.3	Line current	16
5.4	Fault Level	17
5.5	System impedance	17
5.6	Harmonics	18
5.7	Regeneration	18
5.8	System performance	19
5.9	Current collector performance	19

Ref:	NR/GN/ELP/27010
Issue:	2
Date:	December 2005

Appendix A	Impedance of OLE versus frequency	21
	A.1 - Impedance of OLE versus frequency	21
	A.2 - Impedance of OLE versus frequency	22
	A.3 - Impedance of OLE versus frequency	23
Appendix B	Neutral section - typical detail of the insulated section	24
Appendix C	Relationship between the APC receiver and the APC track magnet	25
Appendix D	Typical electrical operating area diagram	26
Appendix E	Positioning of the conductor rail	27
Appendix F	Double slope conductor rail ramp dimensions	28
Appendix G	Single slope conductor rail ramp dimensions	29
Appendix H	Arrangement of side ramps	30

Ref:	NR/GN/ELP/27010
Issue:	2
Date:	December 2005

I Purpose

This specification details typical parameters of a.c. and d.c. electrification systems installed on Network Rail controlled infrastructure which can be used as a guide when considering the evaluation process detailed in [GM/RT1000](#) - *Compatibility between electric trains and electrification systems*.

2 Scope

The contents of this document are for information only. It is intended to give guidance on past UK practice but there is no guarantee that any of the parameters contained within this document are applicable to any existing or future electrification.

3 Reference documentation

[GM/RT 1000](#) Compatibility between electric trains and electrification systems

4 A.C. electrification parameters

4.1 System description

The a.c. electrification traction supply system forms part of the railway infrastructure owned and operated by Network Rail. The system consists of feeder stations, track sectioning cabins/locations, a 25 kV overhead line contact system and associated Supervisory Control and Data Acquisition (SCADA) systems.

The 25 kV power supply is obtained from feeder stations spaced at intervals of about 40 km along the railway. These supplies may be derived from different phases and therefore may have a phase displacement of up to 120°.

Electrical feeding and isolation of the overhead line are effected by the operation of circuit breakers and manual overhead line switches.

One pole of each 25 kV supply is connected to the running rails at the feeder stations and since the overhead line supporting structures are also connected to the running rails, this results in a multiple earth system having an overall resistance to earth of less than 1Ω.

Trains draw traction current from the overhead line contact system by means of a pantograph. The current is returned to the feeder station by way of the running rails and earth, or, where this would give rise to unacceptable inductive interference, by way of the running rails and return conductors which may also be equipped with booster transformers.

Due to the exposed nature of the a.c. electrification system, it is subject to frequent short circuits of varying severity.

The feeder stations and track sectioning cabins/locations are normally unmanned, the equipment being remotely controlled and monitored from electrical control rooms by means of the SCADA systems.

4.2 System voltages

25 kV	Nominal system voltage.
29 kV	Train equipment should be able to operate without suffering damage if the voltage rises to 29 kV for five minutes.
27.5 kV	Maximum voltage at which train equipment should operate continuously.
24 kV	Average voltage for use in train performance calculations.
20 kV	Minimum constant current voltage value.
16.5 kV	Minimum voltage in normal operation. If the voltage falls below this value it should not be possible to initiate regenerative braking.
14 kV	Minimum voltage at which a train should continue to operate for not more than ten minutes without being damaged. Also the voltage below which regenerative braking should cease.
12.5 kV	Minimum voltage at which a train should continue to operate for not more than two minutes without being damaged. Equipment energised from the overhead line need not continue to operate if the voltage falls below 12.5 kV, but should not be damaged.

Note The maximum surge voltage recorded to date had a crest value of 60 kV, lasting for 1 millisecond.

4.3 Frequency

The nominal system frequency is 50Hz. The frequency may differ from 50Hz within the limits declared by the Electricity Supply Industry (ESI). At present these limits are:

- maximum frequency: 50.5 Hz;
- minimum frequency: 49.5 Hz. (However, in extreme conditions of load shedding, the steady state frequency can drop to 48.5 Hz).

4.4 Line current

The total current taken from the overhead line by a train for traction and auxiliary loads should not exceed that shown in the table below for the conditions specified in the table.

Line Voltage	Maximum line current (A rms)
24 kV	270A for EMU's or 300A for other trains
Between 20 kV and 24 kV	Not greater than the maximum current taken by the train at 24 kV, e.g. if the maximum current at 24 kV is 220A, the train should not take more than 220A when the voltage is less than 24 kV.
Less than 20 kV	Maximum current taken at 20 kV multiplied by the ratio of line voltage to 20 kV, e.g. if the maximum current between 20 kV and 24 kV is 220A, the maximum current at 16 kV should not be greater than 176A.
Greater than 24 kV	To maintain constant power as at 24 kV

It should be possible, through action taken by the driver, to limit the line current taken by the train at any given line voltage to 50% of the maximum permitted current at that voltage. The driver should be able to introduce this facility at any speed.

The overhead lines have a current rating of approximately 600A.

4.5 Fault level

Fault level is defined as the potential short-circuit current or MVA at a given location on the traction electricity supply system, under given conditions.

For the purpose of specifying 25 kV circuit breakers on the traction unit, the maximum short-circuit current is declared as 12,000A at 27.5 kV. A short circuit of this magnitude would generally be cleared by the trackside switchgear within 90 milliseconds. If the main protection failed, it would be cleared by the trackside backup protection within 1 second.

The protective relays on the 25 kV electrification system are arranged to provide 3 Zones of protection within each electrical section. Each Zone is designated relative to its distance from the point of protections:

- Zone 1 provides rapid fault clearance, around 90 milliseconds, for 85% of the protected area;
- Zone 2 provides a time delayed protection for faults at the end of the protected section not covered by Zone 1;
- Zone 3 provides a time delayed back up protection for faults in adjacent electrical sections.

4.6 Power factor

For the purpose of this clause the term Power Factor is the quantity calculated and measured as the displacement factor.

Over the specified end to end journey time the average displacement factor should not be less than 0.85, including train auxiliaries and the effect of regenerative braking.

When a train is stationary, with traction power off, and the real power taken from the overhead line is greater than 10 kW per vehicle, the displacement factor resulting from the train load should not be less than 0.9.

A train should not export reactive power: i.e. it should not behave like a capacitor at fundamental frequency.

It is accepted that, in the “power off” condition, a small capacitive current may be drawn, by a train associated with its surge suppression networks etc. Such capacitive current should not exceed 6A for a train. If power factor correction capacitors are fitted, they should be disconnected automatically in conditions in which they would result in the export of reactive power.

Definitions of reactive power and displacement factor. For the purpose of defining the reactive power in this standard, the line voltage and the line current are represented by their fundamental-frequency components.

- a) Definition of phase angle and direction of current flow
Let the origin of time measurement be such that:

$$u = \sqrt{2} \cdot U \cdot \sin(2\pi ft)$$

$$i = \sqrt{2} \cdot I \cdot \sin(2\pi ft - \Phi)$$

where: f is the fundamental frequency in Hz

u is the instantaneous voltage

i is the instantaneous current

U is the RMS voltage

I is the RMS current

Φ is the phase angle difference

$\cos(\Phi)$ is the displacement factor

Let the polarities of the voltage and current be such that when $\Phi=0$ and $u \cdot i > 0$ real power flows from the overhead line to the train.

- b) Imported and exported real and reactive power
The magnitude of the real power, averaged over one cycle, is: $P = U \cdot I \cdot \cos\Phi$

The magnitude of the reactive power, averaged over one cycle is:
 $Q = U.I.\sin\Phi$

With Φ and the polarities of voltage and current, as defined above, the directions of real and reactive power flow are as follows:

If $U.I.\cos\Phi > 0$ the train imports real power

If $U.I.\cos\Phi < 0$ the train exports real power

If $U.I.\sin\Phi > 0$ the train imports reactive power

If $U.I.\sin\Phi < 0$ the train exports reactive power

c) Average displacement factor

Over an arbitrary number of cycles N:

Average real power = $P_n = (1/N) \cdot \sum U.I.\cos\Phi$

Average reactive power = $Q_n = (1/N) \cdot \sum U.I.\sin\Phi$

Average displacement factor = $1/\sqrt{(1 + Q_n^2/P_n^2)}$

4.7 System impedance

Source impedance is the impedance as seen by a traction load, measured at its point of connection with the electricity supply. This is sometimes quoted as the impedance of the electricity supply industry system measured at the input to the Network Rail transformer.

All overhead line sections have resonant frequencies. The natural frequencies and damping ratios vary from site to site depending on the lengths of the electrical sections, the power supply feeding arrangements, etc. At a given location the conditions can vary from time to time, when power supply feeders are out of service for maintenance.

The lowest natural frequency is in the range 450-2500 Hz, and is associated with the power supply source impedance, the impedance of the transformer, and the capacitance to ground of the overhead lines (i.e. a parallel resonance as seen from a train). The next higher frequency is typically in the range 1000 to 3000 Hz, and is associated with travelling waves reflected between the ends of the overhead line sections (a series resonance as seen from a train).

See Appendix A for typical examples of an impedance versus frequency plot obtained from practical measurements at low voltage.

The following are typical values of impedances of equipment at 50 Hz.

- a) Source impedance of 132 kV power supply:
in the range 0.5Ω to 1.2Ω , referred to 25 kV;
- b) Impedance of 132 kV/25 kV transformer: there are two basic types:
 - i. 10MVA, naturally cooled, or 14MVA, force cooled: impedance referred to 25 kV is 6.9Ω (in some places, two of these are run in parallel).
 - ii. 18MVA, naturally cooled or 26.5MVA, force cooled; impedance referred to 25 kV is 4.2Ω (these transformers are never run in parallel).
- c) Overhead lines: a typical value for one track of a double track line, with booster transformers and return conductors, is $0.29 + j0.81\Omega$ per km at 50Hz. Using only the rails and earth wire as the return path, a typical impedance for one track of a double track route is $0.19 + j0.48\Omega$ per km (these figures are based on measuring the current and voltage drop in one track, when both tracks are connected in parallel). The capacitance to earth is typically 11 nanofarads per single track km.

4.8 Harmonics

A harmonic is a sinusoidal voltage or current whose frequency is an integral multiple of the fundamental supply frequency (nominally 50 Hz).

Harmonics are present in the 25 kV supply due to traction rectifiers and thyristors on the trains.

A single EMU should not exceed the following maximum harmonic currents. These are expressed in the table below as a percentage of the maximum 50Hz current of a single unit:

Frequency (Hz):	150	250	350	450	550
Percentage of the maximum 50Hz current	15.0	7.0	3.5	1.5	1.0
For speeds below 55km/h the percentage may be increased to	22.0	11.5	6.5	3.5	2.0