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Surtensions dans les systèmes d'alimentation de la traction

Overvoltages in traction supply systems

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En ce qui concerne la terminologie générale, le lecteur se reportera à la CEI 60050: *Vocabulaire Electrotechnique International* (VEI), qui se présente sous forme de chapitres séparés traitant chacun d'un sujet défini. Des détails complets sur le VEI peuvent être obtenus sur demande. Voir également le dictionnaire multilingue de la CEI.

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– la CEI 60617: *Symboles graphiques pour schémas;*

et pour les appareils électromédicaux,

– la CEI 60878: *Symboles graphiques pour équipements électriques en pratique médicale.*

Les symboles et signes contenus dans la présente publication ont été soit tirés de la CEI 60027, de la CEI 60417, de la CEI 60617 et/ou de la CEI 60878, soit spécifiquement approuvés aux fins de cette publication.

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- **IEC Bulletin**
- **IEC Yearbook**
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Terminology

For general terminology, readers are referred to IEC 60050: *International Electrotechnical Vocabulary* (IEV), which is issued in the form of separate chapters each dealing with a specific field. Full details of the IEV will be supplied on request. See also the IEC Multilingual Dictionary.

The terms and definitions contained in the present publication have either been taken from the IEV or have been specifically approved for the purpose of this publication.

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– IEC 60027: *Letter symbols to be used in electrical technology;*

– IEC 60417: *Graphical symbols for use on equipment. Index, survey and compilation of the single sheets;*

– IEC 60617: *Graphical symbols for diagrams;*

and for medical electrical equipment,

– IEC 60878: *Graphical symbols for electromedical equipment in medical practice.*

The symbols and signs contained in the present publication have either been taken from IEC 60027, IEC 60417, IEC 60617 and/or IEC 60878, or have been specifically approved for the purpose of this publication.

IEC publications prepared by the same technical committee

The attention of readers is drawn to the end pages of this publication which list the IEC publications issued by the technical committee which has prepared the present publication.

RAPPORT TECHNIQUE – TYPE 3

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Overvoltages in traction supply systems

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

SURTENSIONS DANS LES SYSTÈMES D'ALIMENTATION DE LA TRACTION

AVANT-PROPOS

1) La CEI (Commission Electrotechnique Internationale) est une organisation mondiale de normalisation composée de l'ensemble des comités électrotechniques nationaux (Comités nationaux de la CEI). La CEI a pour objet de favoriser la coopération internationale pour toutes les questions de normalisation dans les domaines de l'électricité et de l'électronique. A cet effet, la CEI, entre autres activités, publie des Normes internationales. Leur élaboration est confiée à des comités d'études, aux travaux desquels tout Comité national intéressé par le sujet traité peut participer. Les organisations internationales, gouvernementales et non gouvernementales, en liaison avec la CEI, participent également aux travaux. La CEI collabore étroitement avec l'Organisation Internationale de Normalisation (ISO), selon des conditions fixées par accord entre les deux organisations.

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3) Les documents produits se présentent sous la forme de recommandations internationales. Ils sont publiés comme normes, rapports techniques ou guides et agréés comme tels par les Comités nationaux.

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La tâche principale des comités d'études de la CEI est d'élaborer des Normes internationales. Exceptionnellement, un comité d'études peut proposer la publication d'un rapport technique de l'un des types suivants:

- type 1, lorsque, en dépit de maints efforts, l'accord requis ne peut être réalisé en faveur de la publication d'une Norme internationale;
- type 2, lorsque le sujet en question est encore en cours de développement technique, ou lorsque, pour une raison quelconque, la possibilité d'un accord pour la publication d'une Norme internationale peut être envisagée pour l'avenir mais pas dans l'immédiat;
- type 3, lorsqu'un comité d'études a réuni des données de nature différente de celles qui sont normalement publiées comme Normes internationales, cela pouvant comprendre, par exemple, des informations sur l'état de la technique.

Les rapports techniques de type 1 et 2 font l'objet d'un nouvel examen trois ans au plus tard après leur publication afin de décider éventuellement de leur transformation en Normes internationales. Les rapports techniques de type 3 ne doivent pas nécessairement être révisés avant que les données qu'ils contiennent ne soient plus jugées valables ou utiles.

La CEI 61374, rapport technique de type 3, a été établie par le comité d'études 9 de la CEI: Matériel électrique ferroviaire.

INTERNATIONAL ELECTROTECHNICAL COMMISSION

OVERVOLTAGES IN TRACTION SUPPLY SYSTEMS

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.
3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical reports or guides and they are accepted by the National Committees in that sense.
4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.
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The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical report of one of the following types:

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

IEC 61374, which is a technical report of type 3, has been prepared by IEC technical committee 9: Electric Railway Equipment.

Le texte de ce rapport technique est issu des documents suivants:

Projet de comité	Rapport de vote
9/390/CDV	9/424/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de ce rapport technique.

Les annexes A, B, C, D et E, en anglais seulement, font partie intégrante du présent rapport technique.

The text of this technical report is based on the following documents:

Committee draft	Report on voting
9/390/CDV	9/424/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

Annexes A, B, C, D and E form an integral part of this technical report and appear only in English.

INTRODUCTION

Il convient de concevoir les convertisseurs de puissance embarqués à bord de véhicules ferroviaires de telle sorte qu'ils fonctionnent à l'intérieur des limites spécifiées des tensions d'alimentation. Les valeurs en régime établi des tensions d'alimentation sont spécifiées dans la CEI 60850.

Il n'existe pas de spécifications pour les surtensions transitoires. C'est la raison pour laquelle il a été décidé de créer un groupe de travail avec la tâche de spécifier les surtensions dans les systèmes d'alimentation de traction. Il s'avéra impossible de préparer les spécifications de surtension sur la base des connaissances existantes et, de ce fait, un questionnaire fut diffusé.

De nombreux pays répondirent au questionnaire. Les réponses sont de nature à constituer une source valable d'informations importantes. Elles sont compilées et diffusées conjointement avec le questionnaire pour constituer le présent rapport technique, avec l'espoir que ce dernier contribuera aux futurs travaux sur les surtensions.

INTRODUCTION

Power convertors on board railway vehicles should be designed for operation within the specified limits of the supply voltages. Steady-state values of traction supply voltages are specified in IEC 60850.

For transient overvoltages no specifications exist so far. This is why it was decided to set up a working group with the task of specifying overvoltages in traction supply systems. Overvoltage specifications on the basis of existing knowledge were not able to be produced and therefore a questionnaire was circulated.

The questionnaire was answered by many countries. The answers are considered to be a valuable source of important information. They were compiled and issued together with the text of the questionnaire to form this IEC technical report. It is hoped that this report will help future work on overvoltages.

SURTENSIONS DANS LES SYSTÈMES D'ALIMENTATION DE LA TRACTION

0.0 Domaine d'application

Ce rapport technique constitue une information utile sur les surtensions transitoires dans les systèmes d'alimentation de la traction. Les informations contenues dans ce rapport ont été rassemblées à l'issue de la circulation d'un questionnaire. Ce rapport devrait contribuer à l'avancement des travaux menés dans le domaine des surtensions. Il convient d'adresser tous les commentaires sur ce rapport au Bureau Central de la CEI.

0.1 Documents de référence

CEI 60038: 1983, *Tensions normales de la CEI*

CEI 60310: 1991, *Transformateurs de traction et inductances de traction*

CEI 60349: 1971, *Règles applicables aux machines électriques tournantes des véhicules ferroviaires et routiers*

NOTE – Remplacé par la deuxième édition, 1991: *Traction électrique – Machines électriques tournantes des véhicules ferroviaires et routiers.*

CEI 60850: 1988, *Tensions d'alimentation des réseaux de traction*

OVERVOLTAGES IN TRACTION SUPPLY SYSTEMS

0.0 Scope

This technical report establishes useful information concerning transient overvoltages in electrical traction supply systems. The information contained in this report was complied from the circulation of a questionnaire. It is hoped that this report will help progress the work being carried out in the area of overvoltages. Comments of the content of this report should be sent to IEC central office.

0.1 Reference documents

IEC 60038: 1983, *IEC standard voltages*

IEC 60310: 1991, *Traction transformers and inductors*

IEC 60349: 1971, *Rules for rotating electrical machines for rail and road vehicles*

NOTE – Now superseded by the second edition, 1991, *Electric traction – Rotating electrical machines for rail and road vehicles.*

IEC 60850: 1988, *Supply voltages of traction systems*

QUESTIONNAIRE

Généralités

Le questionnaire a été lancé en 1987 avec le texte qui suit.

Le Comité d'études 9 de la CEI a entamé une activité pour établir des spécifications pour les tensions transitoires dans les systèmes d'alimentation de traction. Il convient que ces spécifications soient fondées sur des informations sur des conditions réelles à travers le monde et sur la pratique de l'ingénierie dans divers pays. Il est de ce fait attendu que les compagnies et organisations ferroviaires internationales remplissent ce questionnaire aussi précisément que possible. Pour le cas où une même organisation utiliserait différents systèmes de traction, il convient de remplir un formulaire séparé pour chaque système.

1 Identification du système

1.1 *Description du système*

1.1.1 *Compagnie ferroviaire*

1.1.2 *Tension et fréquence nominales*

1.1.3 *Tolérances sur la tension*

1.1.4 *Tensions maximale et minimale de sous-station au repos*

1.1.5 *Impédances maximale et minimale de sous-station à la fréquence assignée*

1.1.6 *Paramètres de distribution de la ligne de contact:*

- résistance par kilomètre;
- inductance par kilomètre;
- capacitance par kilomètre.

1.1.7 *Distances maximale et minimale entre sous-stations*

1.1.8 *Impédance de contact des lignes de contact à simple bout à la fréquence assignée*

1.1.9 *Moyens d'ajustement de la tension*

1.1.10 *Installations de régénération d'énergie dans les sous-stations*

1.1.11 *Réseaux de correction de facteur de puissance*

1.1.12 *Type de ligne de contact (aérienne ou troisième rail)*

1.1.13 Décrire les matériels de traction principalement utilisés dans votre système (par exemple puissance assignée, freinage récupératif ou non, courant maximal d'alimentation de la traction et du freinage, type et courant maximal d'alimentation des convertisseurs auxiliaires, quantité de voitures ou de locomotives dans la composition d'un train).

QUESTIONNAIRE

General

The questionnaire was launched in 1987 with the following text.

IEC technical committee 9 has started an activity to set up specifications for transient overvoltages in traction supply systems. These specifications should be based on information from real world conditions and engineering practice in the various countries. It is therefore most desirable that the international railway companies and organizations fill in this questionnaire as precisely as possible. If there are different traction systems within one organization, separate forms should be filled in for each system.

1 System identification

1.1 *System description*

1.1.1 *Railway company*

1.1.2 *Nominal voltage and frequency*

1.1.3 *Voltage tolerances*

1.1.4 *Maximum and minimum substation no-load voltage*

1.1.5 *Maximum and minimum substation impedance at rated frequency*

1.1.6 *Distributed contact line parameters:*

- resistance per kilometre;
- inductance per kilometre;
- capacitance per kilometre.

1.1.7 *Maximum and minimum distance between substations*

1.1.8 *Terminating impedance of single-ended contact lines at rated frequency*

1.1.9 *Means of voltage adjustment*

1.1.10 *Installations for the regeneration of energy in the substations*

1.1.11 *Power factor correction networks*

1.1.12 *Type of contact line (overhead or third rail)*

1.1.13 Describe the traction equipment mainly used in your system (e.g. rated power, regenerative braking or not, maximum input current by traction/braking, type and maximum input current of auxiliary converter, quantity of coaches or locomotives in a train composition).

1.2 *Informations complémentaires*

1.2.1 Appliquez-vous une des spécifications suivantes de la CEI?

– CEI 60038 (tableau II: Systèmes de traction à courant continu et à courant alternatif).

– CEI 60349, édition de 1971, (tableau V ou annexe B: Tension d'alimentation des systèmes de traction).

1.2.2 Quelles autres normes de tension, internationales, nationales ou de société appliquez-vous? (Fournir la copie des documents qu'on ne peut généralement pas se procurer). Quels niveaux limites de surtension utilisez-vous?

2 Spécifications de surtensions

2.1 *Questions relatives aux surtensions*

Les questions qui suivent se réfèrent à diverses surtensions telles que classifiées au 2.2. Dans la mesure du possible, affecter vos réponses aux différentes causes de surtensions. Indiquer également si les surtensions se rapportent à une sous-station ou si elles sont localisées au niveau du pantographe.

2.1.1 Niveau, durée et énergie des surtensions calculées ou estimées. Spécifier les méthodes de calcul.

2.1.2 Niveau, durée, énergie et taux de répétition des surtensions mesurées. Spécifier les conditions de mesure et le matériel de mesure.

2.1.3 Avez-vous constaté des défauts ou des dommages, y compris le dommage de parafoudres dû à des surtensions?

2.1.4 Avez-vous observé des surtensions aussi bien positives que négatives?

2.1.5 Pouvez-vous décrire la forme d'onde des surtensions mesurées? (Si possible, fournir des copies des enregistrements à l'oscilloscope).

2.1.6 Durée de remise à zéro en cas d'activation de dispositifs de protection contre les surintensités ou les surtensions.

2.2 *Classification des surtensions*

2.2.1 *Surtensions temporaires*

Sont considérées comme surtensions temporaires les surtensions en fréquence de ligne ou de nature continue d'une durée allant de quelques secondes à l'état permanent. Laquelle des raisons qui suivent retenez-vous pour vos surtensions temporaires?

2.2.1.1 Défauts de terre d'un système triphasé alimentant un réseau ferré à l'aide de transformateurs. Comment le transformateur est-il relié au système (phase à phase ou phase au neutre)?

2.2.1.2 Chutes de charge en relation avec les stations d'alimentation à tension de sortie régulée. (Chutes de charge dans les lignes de contact qui sont alimentées par des stations d'alimentation à tensions de sortie régulées).

2.2.1.3 Résonances de bancs de filtres sur la ligne de contact.

2.2.1.4 Distorsion de la tension de ligne due aux commutations de convertisseurs ou aux harmoniques.

1.2 *Additional Information*

1.2.1 Do you follow one of the following IEC voltage specifications?

- IEC 60038 (table II: d.c. and a.c. Traction Systems).
- IEC 60349, edition 1971 (table V of appendix B: supply voltage of traction systems).

1.2.2 Which other international, national or company voltage standards do you apply? (provide copies of documents not generally available.) Which overvoltage limit levels do you use?

2 Specification of overvoltages

2.1 *Questions concerning overvoltages*

The following questions refer to various overvoltages as classified in 2.2. Allocate your answers as far as possible to the different causes of overvoltages. Indicate also whether the overvoltages refer to a substation or to the location of the pantograph.

2.1.1 Level, duration, and energy of calculated or estimated overvoltages. Specify the calculation methods.

2.1.2 Level, duration, energy and repetition rate of measured overvoltages. Specify the measurement conditions and measurement equipment.

2.1.3 Did you experience failures or damage, including damage to arresters, due to overvoltages?

2.1.4 Did you see positive as well as negative overvoltages?

2.1.5 Can you describe the waveshape of measured overvoltages? (If possible provide copies of oscillograms.)

2.1.6 Time to clear in case of activating overcurrent or overvoltage protection devices.

2.2 *Classification of overvoltages*

2.2.1 *Temporary overvoltages*

As temporary overvoltages we consider overvoltages of line frequency or d.c. nature with duration of a few seconds up to continuously. Which of the following reasons do you consider for your temporary overvoltages?

2.2.1.1 Earth faults of the three-phase system supplying a railway network though transformers. How is the transformer connected with the system (phase-to-phase or phase-to-neutral)?

2.2.1.2 Load dropping in conjunction with supply stations with regulated output voltage. (Load dropping in contact lines which are supplied by supply stations with regulated output voltages.)

2.2.1.3 Resonances of filter banks on the contact line.

2.2.1.4 Line voltage distortion due to convertor commutations or current harmonics.

2.2.1.5 Résonances de tension sur la caténaire, en particulier pour les lignes à simple bout.

2.2.1.6 Surtensions en régime établi dépassant les niveaux spécifiés par la CEI 60038:

– acceptez-vous dans votre système des niveaux plus élevés de surtension en régime établi?

– les sur-tolérances sont-elles le fait du freinage récupératif?

2.2.1.7 Surtensions dues à la surcompensation causée par les filtres embarqués dans les véhicules ou présents dans le système d'alimentation.

2.2.1.8 Surtensions causées par les résonances de filtre dues aux changements de fréquence de convertisseurs.

2.2.1.9 Connaissez-vous d'autres causes de surtension temporaire?

2.2.2 *Surtensions de commutation*

Des surtensions de commutation peuvent apparaître corrélativement à des opérations de commutation et à des défauts dans le système. Normalement elles sont représentées par une impulsion normalisée de commutation de 250/5 000 µs, même si leur forme d'onde peut varier considérablement. Laquelle des conditions suivantes s'applique-t-elle à votre cas?

2.2.2.1 Débranchement de transformateurs qui ne sont pas en charge dans les véhicules, en particulier immédiatement après la mise sous-tensions.

2.2.2.2 Interruption des circuits, en particulier court-circuits sur le véhicule.

2.2.2.3 Modification de la configuration d'alimentation du fait d'actions de commutation.

2.2.2.4 Résonances de filtres de lignes.

2.2.2.5 Résonances de filtres embarqués à bord d'un véhicule, en particulier la charge de filtres d'entrée.

2.2.2.6 Saut de pantographe.

2.2.2.7 Passage d'une section d'alimentation à une autre.

2.2.2.8 Connaissez-vous d'autres causes de surtensions de commutation?

2.2.3 *Surtensions de foudre*

Les surtensions de foudre sont habituellement d'origine atmosphérique mais elles peuvent également survenir corrélativement à des décharges d'isolement et des réamorçages de coupe-circuit.

Les surtensions atmosphériques sont généralement limitées au moyen de parafoudres ou de contournements sur la ligne de contact. La forme d'onde peut varier mais peut être représentée par une impulsion 1,2/50 µs.

2.2.3.1 Spécifier le type, le niveau de protection et l'espacement des parafoudres sur vos lignes d'alimentation.

2.2.3.2 Indiquer le niveau de contournement de vos lignes d'alimentation.

2.2.1.5 Voltage resonances on the catenary, especially for single-ended lines.

2.2.1.6 Steady-state overvoltages exceeding the levels specified by IEC 60038:

- do you accept in your system higher steady-state overvoltage levels?
- are there extra tolerances for regenerative braking?

2.2.1.7 Overvoltages due to over-compensation caused by filters on board vehicles or in the supply system.

2.2.1.8 Overvoltages caused by filter resonances due to convertor frequency changes.

2.2.1.9 Do you know other causes of temporary overvoltages?

2.2.2 *Switching overvoltages*

Switching overvoltages may occur in conjunction with switching operations and faults in the system. Normally they are represented by a standard switching impulse of 250/5 000 μs, even if their waveshape may vary considerably. Which of the following reasons apply in your case?

2.2.2.1 Disconnection of unloaded transformers on vehicles, especially immediately after energization.

2.2.2.2 Interruption of circuits, especially short circuits on the vehicle.

2.2.2.3 Modification of the supply configuration by switching actions.

2.2.2.4 Resonances of line filters.

2.2.2.5 Resonances of filters on board of a vehicle, especially loading of input filters.

2.2.2.6 Pantograph jumping.

2.2.2.7 Passing from one feeding section to another.

2.2.2.8 Do you know other causes of switching overvoltages?

2.2.3 *Lightning overvoltages*

Lightning overvoltages are usually of atmospheric origin but they may also occur in conjunction with insulation discharges and circuit-breaker restrikes.

The atmospheric overvoltages are usually limited by surge arresters or by flashovers on the contact line. The waveshape may vary but can be represented by a 1,2/50 μs impulse.

2.2.3.1 Specify type, protection level and spacing of surge arresters on your feeding lines.

2.2.3.2 Indicate the flashover level of your feeding lines.

3 Questions complémentaires

3.1 Quel est le matériel de protection contre les surtensions utilisé à bord des véhicules?

Spécifier le type et le niveau de protection pour les différents types de véhicules.

3.2 Quelles sont les méthodes d'essai utilisées pour tester la capacité de surtension de l'équipement du véhicule?

3.3 La surtension dépend-elle de la configuration réelle de la ligne, c'est-à-dire de la position de commutation dans votre système.

3.4 Serait-il possible de spécifier des niveaux acceptables de comportement ou de dommage de l'équipement pour différents niveaux de surtensions? vos suggestions?

3.5 Avez-vous connaissance de spécifications raisonnables ou de méthodes de calcul pratique:

- de l'impédance interne de la source de surtension,
- du niveau d'énergie de la surtension?

3.6 Avez-vous connaissance d'autres causes de surtensions qui n'entrent pas dans la classification temporaires, de commutation ou de foudre?

NOTE – Le présent questionnaire se réfère aux spécifications de tension de la CEI 60038 et de la CEI 60349. Cependant la norme applicable est la CEI 60850.

3 Additional questions

3.1 Which overvoltage protection equipment is used on board of the vehicles? Specify type and protection level for different types of vehicles.

3.2 Which test methods are used to test the overvoltage capability of vehicle equipment?

3.3 Does the overvoltage depend on the actual line configuration, i.e. switch position in your system?

3.4 Would it be possible to specify acceptable levels of behaviour or damage to the equipment at different levels of overvoltages? Your suggestions?

3.5 Do you know reasonable specifications or practical calculation methods for:

- the internal impedance of the overvoltage source,
- the overvoltage energy level?

3.6 Do you know other causes of overvoltages which cannot be classified as temporary, switching or lightning overvoltages?

NOTE – This questionnaire refers to the voltage specifications of IEC 60038 and IEC 60349. However, the relevant standard is IEC 60850.

Annex A

Table A1: Answers to DC systems: nominal voltage 600 V/ 630 V/ 660 V/ 750 V/ 800 V

number	CHINA	FRANCE	GERMANY	GERMANY	GERMANY	GERMANY	ITALY	UNITED KINODOM	UNITED KINODOM
1.1.1	underground railway motor car	RATP	BVG Berlin	HHA Hamburg	ÜSTRA Hannover	SWS Solingen	A.T.M.	London Underground	BR
1.1.2	750 V dc	750 V dc	800 V dc	750 V dc	600 V dc	660 V dc	750 V dc	630 V dc	750 V dc
1.1.3	550 V - 975 V	500 V - 900 V	560 V - 960 V	525 V - 900 V	420 V - 720 V	362 V -792 V	750 V - 800 V	450 V - 750 V	900 V - 450 V
1.1.4	-/-	850 V / 760 V	960 V / 850 V	900 V / 800 V	720 V / 680 V	720 V	-/-	780 V / 750 V	900 V / 850 V
1.1.5	-/-	0.01 Ω	-/-	9.1 - 129 mΩ	-/-	-/-	-/-	8.2 mΩ - 32.6 mΩ	2 mΩ - 27 mΩ
1.1.6	r -/- l -/- e -/-	r = 18.6 mΩ/km l = 1 mH/km e unknown	r = 9 - 55 mΩ/km l = 1.5 - 2 mH/km e unknown	r = 26 mΩ/rail l = 1 mH/rail e unknown	r = 45 mΩ/km l = 1 - 2 mH/km e unknown	r = 220 mΩ/km l = 2 mH/km e = 0.23 nF/km	r = 0.05 Ω/km l = 1.5 mH/km e -/-	r = 26 mΩ/km l = 1.5 mH/km e unknown	r = 12 - 17.9 mΩ/km l = 2.5 - 4 mH/km e unknown
1.1.7	2 - 4 km	0.65 - 3.4 km	1.5 - 8 km	1.5 - 3.7 km	1.5 - 3 km	1 - 2.65 km	2 - 3 km	2 - 7 km	0.9 - 7.6 km
1.1.8	-/-	8 - 12 mΩ	-/-	-/-	-/-	-/-	-/-	not applicable	not applicable
1.1.9	-/-	transformer tape	transformer tape	transformer tape	transformer tape	transformer tape	-/-	transformer tape	transformer tape
1.1.10	-/-	no	no	no	no	no	no	no	none
1.1.11	-/-	no	-/-	-/-	-/-	-/-	no	no	none
1.1.12	overhead / 3rd rail	3rd rail	3rd rail	3rd rail	overhead	2 wire overhead	3rd rail	3rd and 4th rail	3rd rail top cont.
1.1.13	-/-	equipment with and without regenerative braking, basic composition of a train : 3 motor carriages + 2 trailers in fixed installations : auxiliary rectifier groupes 1750, 2300, 2800, 4000kV for more information see annotation 1)	regenerative braking Imax,in =1200 A/veh[1] Imax,br =1400 A/veh auxiliary rectifier 15-18 A/veh	regenerative braking P = 640 kW/veh[1]	regenerative braking Imax,in =600 A/veh[1] Imax,br =1200 A/veh auxiliary rectifier 60 A/veh	regenerative braking P = 150 kW auxiliary rectifier 6 kW	rheostatic braking P = 360 kW Imax,in = 900 A Imax,br = 550 A 4 or 5 motor carriages plus 2 or 1 trailers	some equipment with purely rheostatic braking and other with regenerative braking Imax,in =450 A/motorcar aux. converter 60 A 6–8 cars of multiple unit stock, 50 -75 % motorcars	no regenerative braking P = 186 kW/coach Imax,in = 500 A/coach aux. equipment 20 kW/coach 1 - 13 coaches compositi
1.2.1	in principle IEC 38, IEC 349	IEC 38	-/-	-/-	-/-	-/-	IEC 38, IEC 349	no	IEC 38,IEC 349, but not for lowest voltage
1.2.2	-/-	-/-	DIN VDE 0115	DIN VDE 0115	DIN VDE 0115	DIN VDE 0115	no	no	BR internal stand.
2.1.1	-/-	-/-	-/-	-/-	-/-	-/-	-/-	overvoltage 420 V, duration 50 ms, energy LI²	-/-
2.1.2	-/-	overvoltage -2700 V in short-circuited modell , duration about 20 ms, traction system modelled as a R-L circuit	-/-	-/-	unknown	unknown	overvoltage level 2 kV, duration 20 - 30 ms	overvoltage level 800 V, duration 50 ms, oscillografic measurement	overvoltage level 1.2-1.8 kV, duration 10 ms, UV recorder, resistor voltage divider and non-inductive shunts
2.1.3	-/-	-/-	-/-	damages by lightnings	no problems except lightnings	no problems	-/-	no	no
2.1.4	-/-	yes	yes, but seldom	unknown	yes	unknown	-/-	only positive	yes
2.1.5	-/-	nearly square form	no	no	no	no	no	see Figure A1	see Figure A2
2.1.6	-/-	20 to 80 ms	-/-	-/-	minutes till days	-/-	-/-	75 to 150 ms detection	15 to 150 ms
2.2.1.1	-/-	-/-	-/-	-/-	-/-	phase to phase	-/-	not considered	not considered
2.2.1.2	-/-	-/-	-/-	-/-	-/-	output voltage =const	-/-	not considered	not considered
2.2.1.3	-/-	-/-	-/-	-/-	-/-	-/-	-/-	not applicable	not applicated
2.2.1.4	-/-	yes, 300 Hz or 600 Hz depending on rectifiers feeding phase (300 or 600 Hz)	yes, 300 Hz by rectifier	yes, 300 Hz by rectifier	yes, 12-pulse rectifier and chopper	-/-	-/-	not considered	not considered
2.2.1.5	-/-	-/-	-/-	-/-	-/-	unknown	-/-	not applicable	not applicable
2.2.1.6	-/-	no, 500 - 900 V	960 V limit for regeneration	920 V limit for regneration	800 V limit for regeneration	720 V limit for regeneration	-/-	no, no extra tolerances	no, no extra tolerances
2.2.1.7	-/-	-/-	-/-	-/-	-/-	-/-	-/-	not applicable	not applicable
2.2.1.8	-/-	-/-	unknown	-/-	unknown	unknown	-/-	not appicable	not appicable
2.2.1.9	-/-	-/-	-/-	fault of charging equipment of the input filter	no	no	-/-	no	no

Annex A

Table A2: Answers to DC systems: nominal voltage 600 V/ 630 V/ 660 V/ 750 V/ 800 V

2.2.2.1	-/-	-/-	-/-	-/-	-/-	-/-	-/-	not applicable	not applicable
2.2.2.2	i/-	yes	-/-	yes	yes, main cause	yes	-/-	yes	yes
2.2.2.3	-/-	-/-	-/-	-/-	no problems	no	-/-	yes	yes
2.2.2.4	-/-	-/-	-/-	no	-/-	no	-/-	not applicable	not applicable
2.2.2.5	-/-	yes	-/-	yes (see 2.2.1.9)	unknown	no	-/-	not splicable	not splicable
2.2.2.6	-/-	-/-	-/-	no	very often, but over-voltages are limited connecting both sides	no problems	-/-	yes, shoe bounce	yes, shoe bounce
2.2.2.7	-/-	-/-	-/-	no		no interruption necessary	-/-	yes	yes
2.2.2.8	-/-	-/-	-/-	no	no	no	-/-	no	no
2.2.3.1	-/-	no arresters	-/-	Siemens 3EC 2010 2..2.4 kV ≤ 10 kA	Siemens 3EC 1010 1.55 kV	SEM 4.5 kV	-/-	Metrosil surge arresters at sub-stations, 4 kV	surge arresters at each substation Bowthorpe EMP MHVBM 07 DC
2.2.3.2	-/-	--	-/-	-/-	unknown	unknown	-/-	not applicable	not applicable
3.1	-/-	filter for chopper	-/-	no	Siemens 3EC 1010	Siemens 3EC 2	no	not used	not used
3.2	-/-	only test of dielectric insulation	-/-	-/-	test every 8 years	-/-	test of insulation resistance	routine testing of car wiring and collection equipment	routine testing of car wiring and collection equipment
3.3	-/-	-/-	yes	no	unknown	-/-	-/-	yes	yes
3.4	-/-	-/-	-/-	level 3·U	-/-	-/-	-/-	on train no permanent damage at 4.5 kV level	not considered
3.5	-/-	-/-	no	no	no	-/-	-/-	no	no
3.6	-/-	-/-	no	no	no	-/-	-/-	no	no
number	CHINA 750 V dc	FRANCE 750 V dc	GERMANY 800 V dc	GERMANY 750 V dc	GERMANY 600 V dc	GERMANY 660 V dc	ITALY 750 V dc	UNITED KINGDOM 630 V dc	UNITED KINGDOM 750 V dc

legend

-/-	:	question was not answered
unknown	:	answer cannot be given exactly , because of data-lecking or other reasons
U	:	rated voltage
P	:	rated power
Imax, in	:	maximum input or traction current
Imax, br	:	maximum braking current

annotations

1) classical equipment without regenerative braking and with rheostatic controlled starting
P = 1100 kW/train
Imax, in = 1450 A/train
auxiliary converter 40 A/train
equipment with regenerative braking and with rheostatic controlled starting
P = 1590 kW/train
Imax, in = 3000 A/train
auxiliary converter 60 A/train

2) per vehicle unit

Annex A

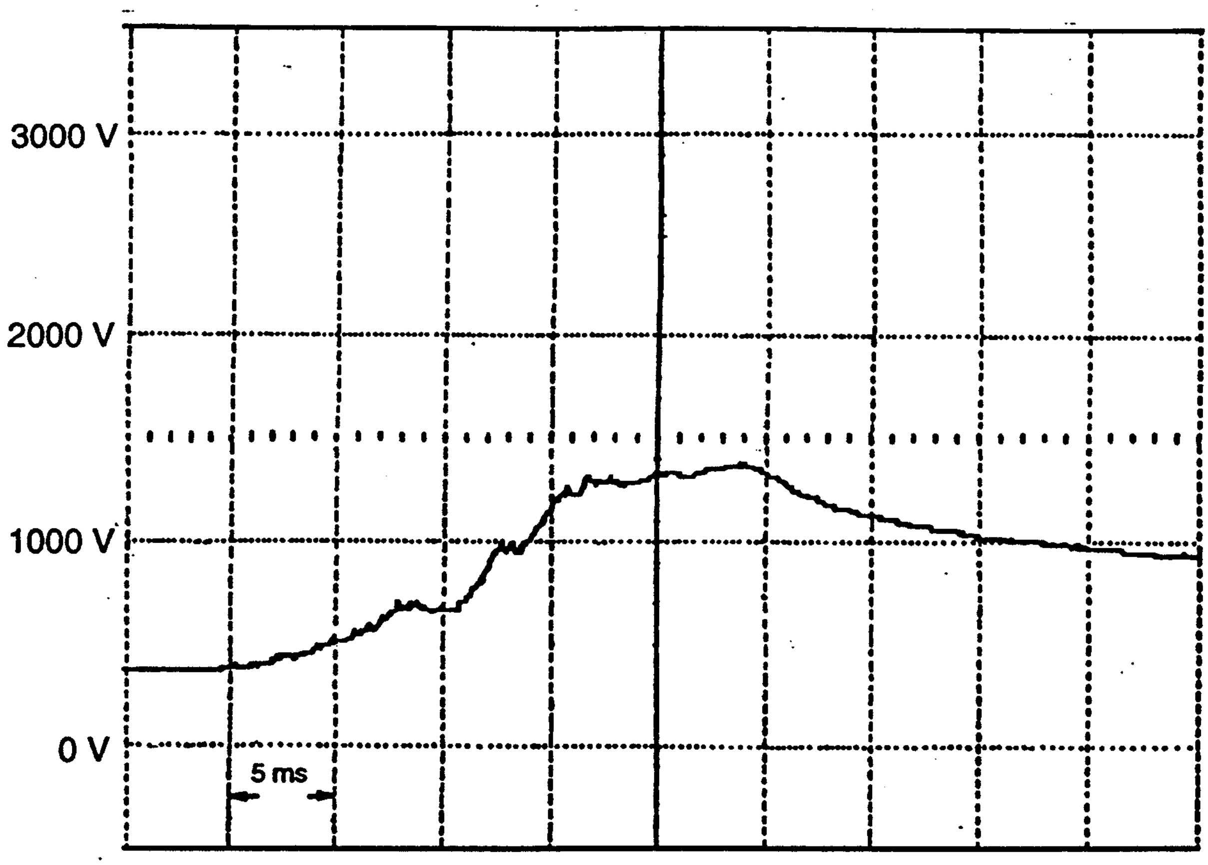

Figure A1: Overvoltage in 630 V traction power supply

Source: London Underground / UNITED KINGDOM
Switching overvoltage created by an eight-car train of A60/62 stock, shutting off at maximum traction current

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Annex A

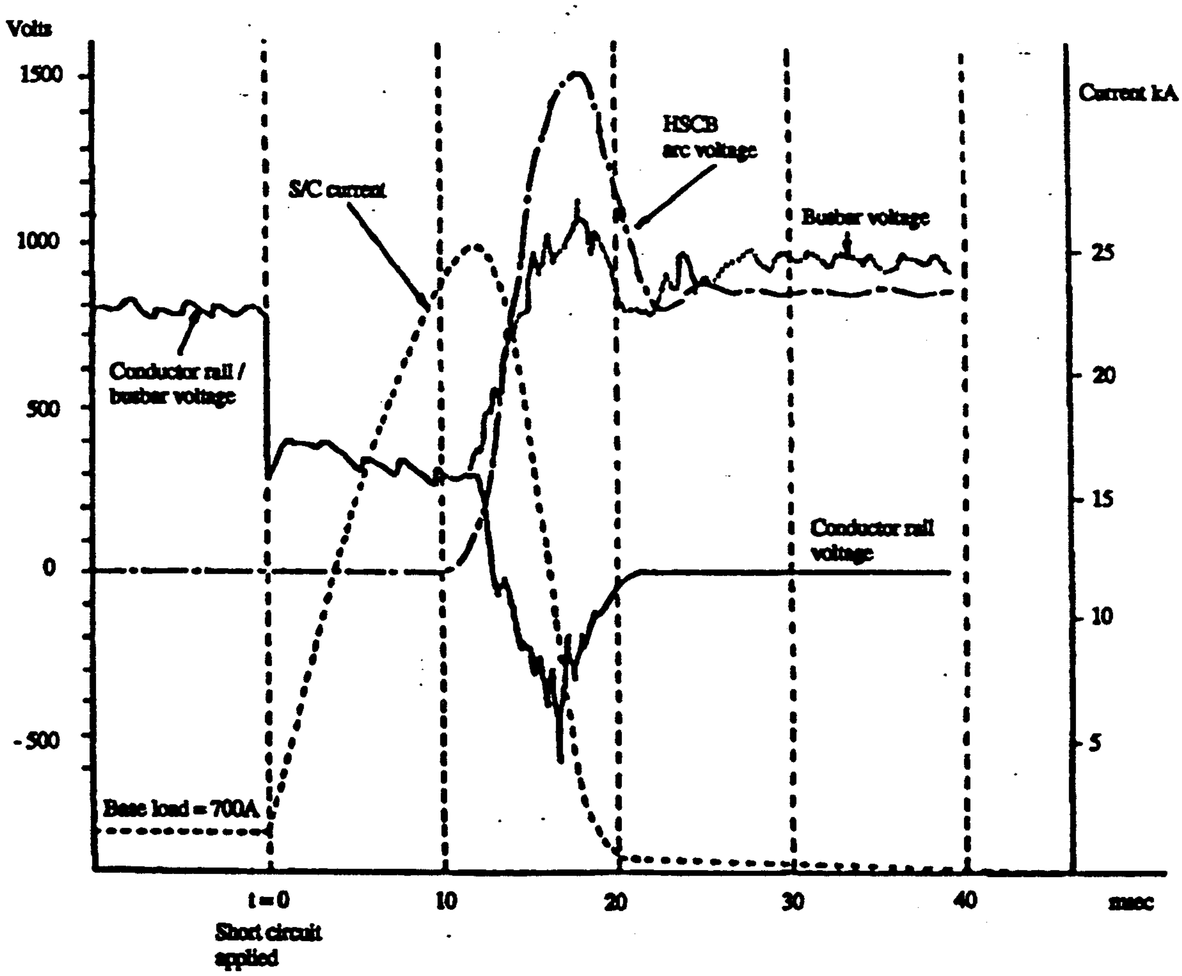

Figure A2: Current / Voltage Profiles of a 750 V Traction Power Supply

Source: British Railways / UNITED KINGDOM
H.S.C.B. Clearance of short circuit applied adjacent to
750 V, 2.5 MW recitifier substation
Prospective current ≈45 kA

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Annex B

Table B1: Answers to DC systems: nominal voltage 1.5 kV

number	CHINA	FRANCE	FRANCE	ITALY	JAPAN	NETHERLANDS	UNITED KINGDOM
1.1.1	(mine locomotives)	SNCF/RATP	SNCF/RER	A.T.M.	JRG (former JNR)	NS	Tyne and Wear Metro
1.1.2	1.5 kV dc	1.5 kV dc	1.5 kV dc	1.5 kV dc	1.5 kV dc	1.5 kV dc	1.5 kV dc
1.1.3	1000 V - 1800 V	1400 V - 1700 V	1000 V - 1800 V	1500 V - 1620 V	1000(900)V - 1800 V	1050 V - 1800 V	1000 V - 1800 V
1.1.4	-/-	1500 V - 1740 V	1510 V - 1600 V	-/-	1220 V - 1700 V	-/- - 1875 V	-/- - 1900 V
1.1.5	-/-	15 - 45 mΩ	0.03 Ω	-/-	-/-	20 - 150 mΩ	25 mΩ - 113 mΩ,
1.1.6	r -/- l -/- c -/-	r = 65 mΩ/km l = 1.5 mH/km c = 18 nF/km	r = 23 - 29 mΩ/km l = 1.2 mH/km c -/-	r = 70 mΩ/km l = 2 mH/km c -/-	r = 33.3 mΩ/km l = 0.9 - 1.1 mH/km c -/-	r = 35 - 50 mΩ/km l = 0.65 - 1 mH/km c = 15 nF/km	r = 104 - 122 mΩ/km l = 0.2 + j 0.5 Ω[1] c = 15 nF/km[2]
1.1.7	-/-	8 km - 30 km	1.2 km - 4.9 km	2 km - 3 km	1.3 km - 17.8 km	4 km - 22.1 km	4.6 km - 7 km
1.1.8	-/-	-/-	35 mΩ	-/-	-/-	-/-	not applicable
1.1.9	-/-	transformer taps	transformer taps	-/-	thyristor rectifier, transformer	manual operated switching devices	on-load tap changers, manual tap changing
1.1.10	-/-	inverter	no	no	inverters	not applicable	no
1.1.11	-/-	no	no	no	-/-	not applicable	no
1.1.12	overhead	overhead	overhead	overhead/third rail	overhead	overhead	overhead
1.1.13	-/-	equipment with and without regenerative braking, see Table B4	equipment with and without regenerative braking, in fixed installations : auxiliary rectifier groups 3000, 4500, 6000 kW see annotation [3]	rheostatic controlled starting rheostatic braking, auxiliary converter 28 A, train composition : 4 motor carriages + 2 trailers Imax,in = 600 A/motorcar Imax,br = 350 A	-/-	no regenerative braking, electrical locomotives do not ride multiple, maximum of coupled railcars 7 for 2-articulated train sections and 5 for 3-articulated train sections, Imax,in = 4000 A, auxiliary rotating converter 13.3 A and electronic converter 26.6A	in substations 1, 2 or 3 rectifiers, 90.9 A or 126.4 A, ratings 1000 W or 1500 W operating singly or in pairs, outer bogies motored, P = 187 kW, no regenerative braking
1.2.1	IEC 38, IEC 349	EC 38, UIC 600 (1981)	IEC 38	IEC 38, IEC 349	IEC 38, IEC 349	IEC 38	IEC 38, IEC 349
1.2.2	-/-	CF 60000 (1981) , french standard	-/-	no	-/-	NEN 400 national standard	British standards
2.1.1	-/-	-/-	-/-	-/-	-/-	-/-	-/-
2.1.2	-/-	rare short overvoltages, caused by fuse damages, but more often long overvoltages, resulting from load reductions on the line, level 10-12 kV see annotation[4]	overvoltage 9 kV with a duration of 3 ms and 1.9 kV with a duration of 20 ms, both on the catenary and caused by a catenary overvoltage	overvoltage 2000 V with a duration about 20 - 30 ms	overvoltage 2430 V at midpoint between DC substations, duration 10 ms	overvoltage > 10 kV with a front time < 1 μs, rate of a lightning counter : 300/year with currents > 100 A	overvoltages up to 3.5 kV during short-circuit testing, duration 20 - 75 ms

Annex B

Table B2: Answers to DC systems: nominal voltage 1.5 kV

number	CHINA	FRANCE	FRANCE	ITALY	JAPAN	NETHERLANDS	UNITED KINGDOM
2.1.3	-/-	damages on transformers in fixed installations by lightnings	cable damage caused by a catenary overvoltage, in fixed installations damages by lightnings	-/-	failures when one silicon-rectifier had been working and another was started to work	this seldom appears	-/-
2.1.4	-/-	yes	yes	-/-	-/-	yes	yes, particulary during abnormal feeding
2.1.5	-/-	see Figure B2	exponential form with rising time 50 μs for overvoltage 9 kV, duration 3 ms	-/-	see Figure B1	-/-	see Figures B3 / B4
2.1.6	-/-	-/-	clear : 5 s	-/-	detection: 40 - 200 ms clear: 30 - 100 ms	-/-	close-up faults 20 ms distant faults up to 75 ms
2.2.1.1	-/-	-/-	-/-	-/- ; -/-	-/- ; primary side neutral and not grounded	-/- ; phase to phase	yes ; 1500 V negative not deliberately earthed
2.2.1.2	-/-	-/-	-/-	-/-	-/-	-/-	-/-
2.2.1.3	-/-	-/-	-/-	-/-	-/-	-/-	not applicable
2.2.1.4	-/-	yes, 300 Hz or 600 Hz	yes, 300 Hz , 600 Hz, 900 Hz depending on feeding rectifier	-/-	yes	-/-	-/-
2.2.1.5	-/-	-/-	-/-	-/-	-/-	max 900 Vrms at 300 Hz	not applicable
2.2.1.6	-/-	-/- ; -/-	no ; no	-/- ; -/-	no ; no	yes ; 1875 V for 5 min	no ; not applicable
2.2.1.7	-/-	-/-	-/-	-/-	parallel condensers are disconnected in case of no load (night)	-/-	not applicable
2.2.1.8	-/-	-/-	-/-	-/-	-/-	-/-	not applicable
2.2.1.9	-/-	-/-	-/-	-/-	no	switching or control faults of the distribution bord in the supply networks	no
2.2.2.1	-/-	-/-	-/-	-/-	yes, at limit voltage of arrester and below	-/-	not applicable
2.2.2.2	-/-	yes	yes, see 2.1.2	-/-	yes, at limit voltage of arrester and below	yes, highspeed breakers in trains cause overvoltages up to 4 kV	yes, by live breaker trip on the car or OLE short circuit trip, occasionally car equipment flashovers may occur, but not OLE flashovers
2.2.2.3	-/-	yes	-/-	-/-	-/-	-/-	yes, rectifier switching is sometimes done in traffic
2.2.2.4	-/-	-/-	-/-	-/-	no influence (small capacity)	yes	not applicable
2.2.2.5	-/-	-/-	yes, with 2 trains on distinct rails when one of them was urgently braking	-/-	-/-	yes	not applicable
2.2.2.6	-/-	-/-	-/-	-/-	-/-	yes	no
2.2.2.7	-/-	-/-	-/-	-/-	-/-	-/-	yes, but only during abnormal feeding
2.2.2.8	-/-	line defects (picking-up)	-/-	-/-	no		no

Annex B

Table B3: Answers to DC systems: nominal voltage 1.5 kV

number	CHINA	FRANCE	FRANCE	ITALY	JAPAN	NETHERLANDS	UNITED KINGDOM
2.2.3.1	-/-	lightning arresters type GADRAT-SOULE 6 kV sometimes in serie with a capacitance 40 μF, at every substation	lightning arresters type GADRAT-SOULE 6 kV, set up in serie with a capacitance 40 μF and a fuse type EMPIRE BAGS, spacing 700 -1500 m	-/-	lightning arrester, every 500 m from feeder : types gapped and gapless 28 kV	spark-gap with SiC - resistance (SOULE cZ) 2 kV, spacing 1500 m	surge diverter EMP type MHBM15DC 1.8 kV, spacing 7 km
2.2.3.2	-/-	10 kV, 50 Hz	40 kV	-/-	100 kV	35 KV at 1/50 μs	insulator : 60 kV, substation and cable test : 6 kV
3.1	-/-	lightning arresters type SOULE 6 kV for global protection, static converters	arresters (one per pantograph) 8.5 kV 1/50 μs with a discharging current of 10 A	arrester 3.9 kV type CGE 9LAM-6Ab-28 with capacitance 4 μF	arrester 5 kV	capacitor 4 μF between pantograph and vehicle, except of "Elok 1600" having an arrester type SOULE 8500	capacitor ASEA-BICC type EHJ to BS 1650, 4μF working at 3 kV and insulated to 22 kV
3.2	-/-	-/-	dielectric test at 5750 V and test of devices at 4900 V for 1 min	insulation resistance measurement at 2.5 kV: ≥ 1 MΩ IEC 9-10(IV-1967)	-/-	hand-craked generator overvoltage test ("Megger")	flash test for resistance banks at 5 kV, Megger tests for cables and other components
3.3	-/-	-/-	-/-	-/-	-/-	-/-	yes, but only during abnormal feeding
3.4	-/-	-/-	-/-	-/-	-/-	no, at voltage 1875 V the rolling stock shall work normally	no
3.5	-/-	-/-	-/-	-/-	-/-	-/-	no
3.6	-/-	-/-	-/-	-/-	-/-	-/-	no

legend

-/-	:	question was not answered
unknown	:	answer cannot be given exactly, because of data-lecking e.g.
P	:	rated power
Imax,in	:	maximum input or traction current
Imax,br	:	maximum braking current

annotations

1) frequency for calculation unknown
2) estimate from tests
3) classical equipment without regenerative braking and with rheostatic controlled starting
   P = 1500 kW/element, Imax,in = 1800 A/element, auxiliary converter 40 A/element
   equipment with regenerative braking and rheostatic controlled starting
   P = 2800 kW/element, Imax,in = 2400 A/element, auxiliary converter 90 A/element
4) measured using a potentiometer combined with a resistance transformer, a memory oscilloscope, further specialized instruments like an electronic voltmeter to measure energy and a "perturbograph", see 2.1.5

Annex B

Table B4: Electric characteristics of some traction vehicle types / SNCF France (1.5 kV) Reference: Question 1.1.13

vehicle type	set into service	rated power kW	maximum input current A	maximum regenerative braking current A	traction equipment
CC 6501 - 74	1969	5500	4000	without	rheostatic controlled locomotive
BB 22201 - 405	1976	4400	4200	without	transformer + mixed bridge + rectifier + dc current motors
BB 7201 - 410	1976	4400	4200	without	rectifier + dc current motors
BB 7411 - 440	1986	4400	4200	1400	identical to BB 7200 but especially regenerative braking
TGV-PSE - 101 trains - trains often run associated by 2 (4 motor carriages)	1981	3100 per train	2700	without	mixed bridge in ac, converted in dc by rectifiers and choppers + dc current motors
TGV-A - 2 motor carriages per train	1988	3880 per train	3600 per train	without	chopper + ondulators + synchron motors

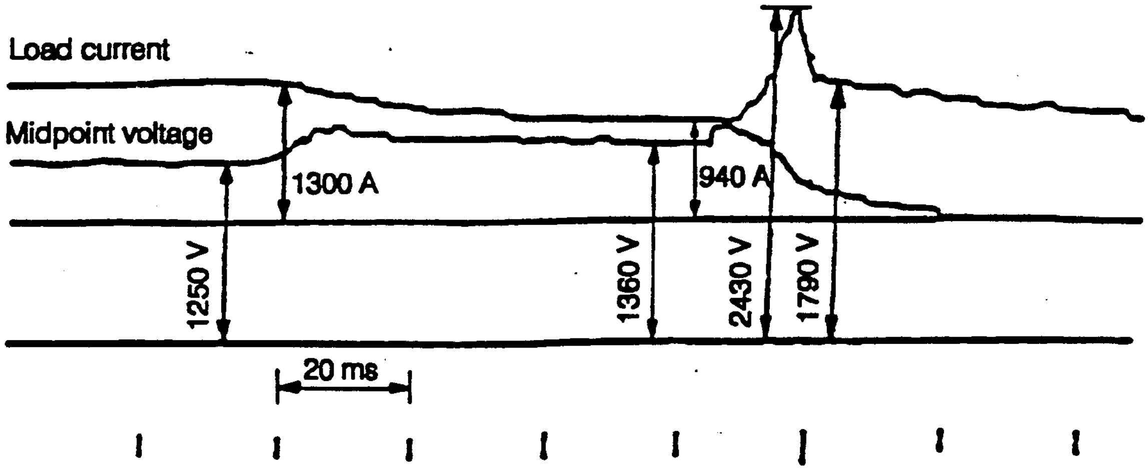

Figure B1: Overvoltage in 1,5 kV DC traction power supply

Source: JAPAN
Line voltage at midpoint between DC substations, measured at notch-off after departure from station.

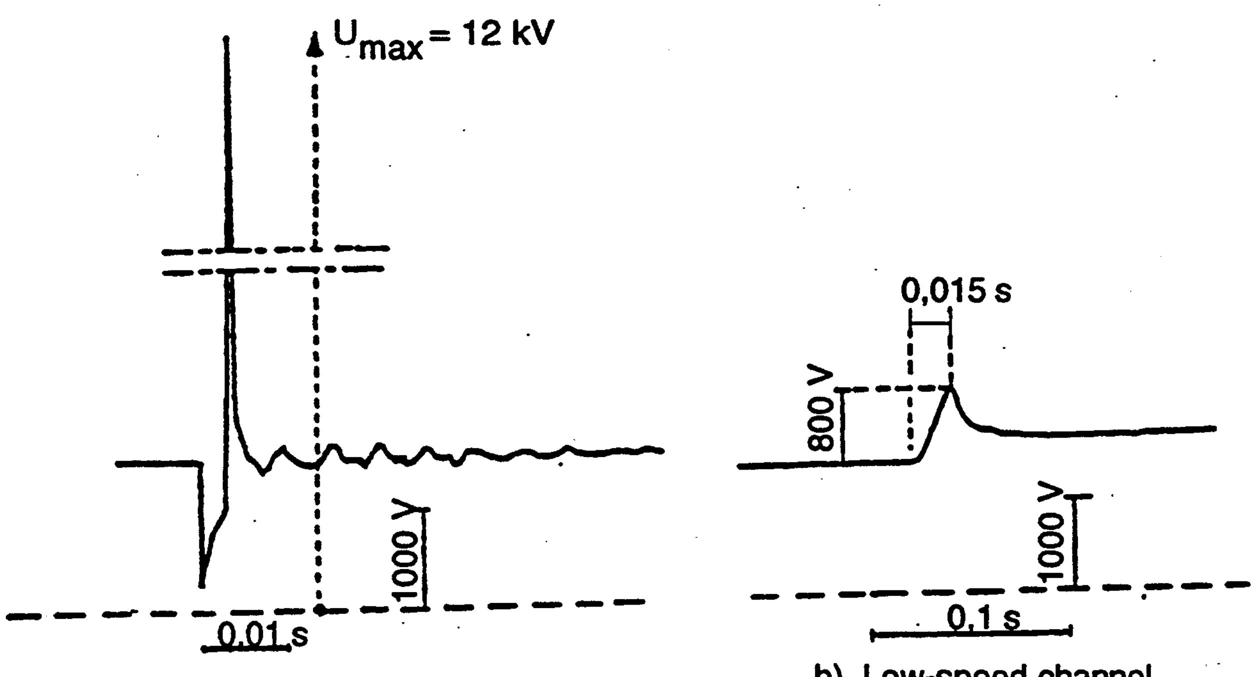

Figure B2: Overvoltages on a 1,5 kV DC power supply line

Source: RATP / SNCF / FRANCE

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Annex B

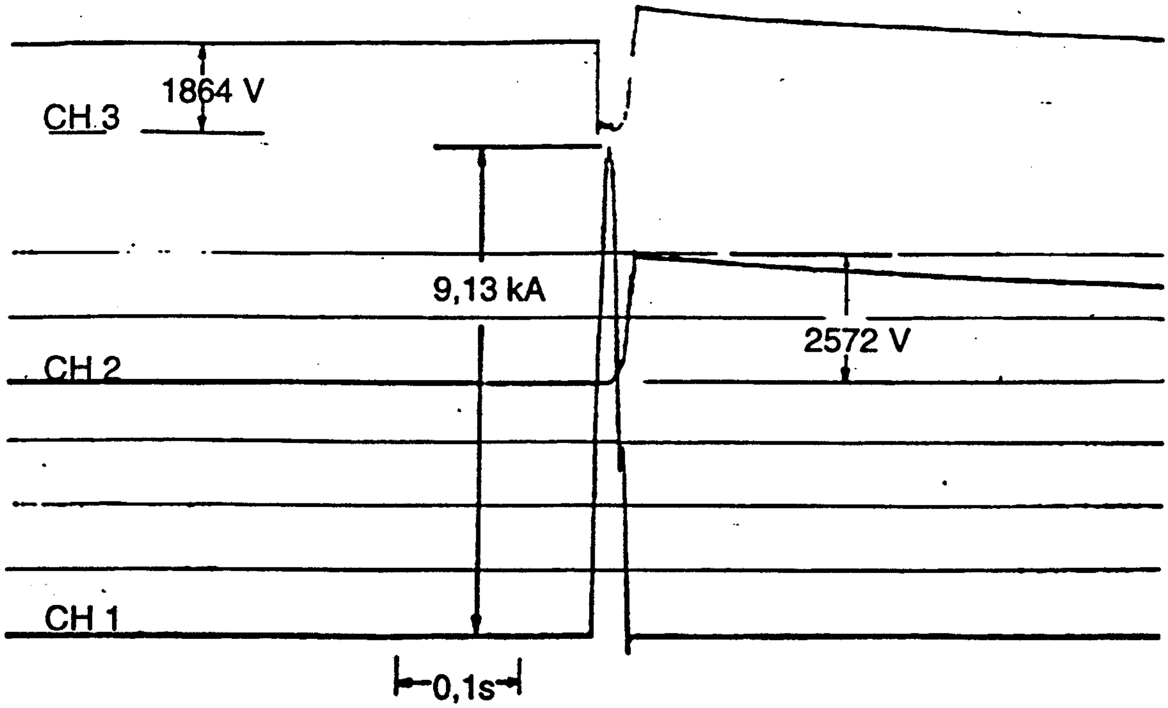

Figure B3: Overvoltage in 1,5 kV DC traction power supply

Source: UNITED KINGDOM
Short circuit applied at the point of a cable connection for feeder
CB O/L set at 1200 A
CH1: DC current CH2: Voltage across CB CH3: Busbar voltage

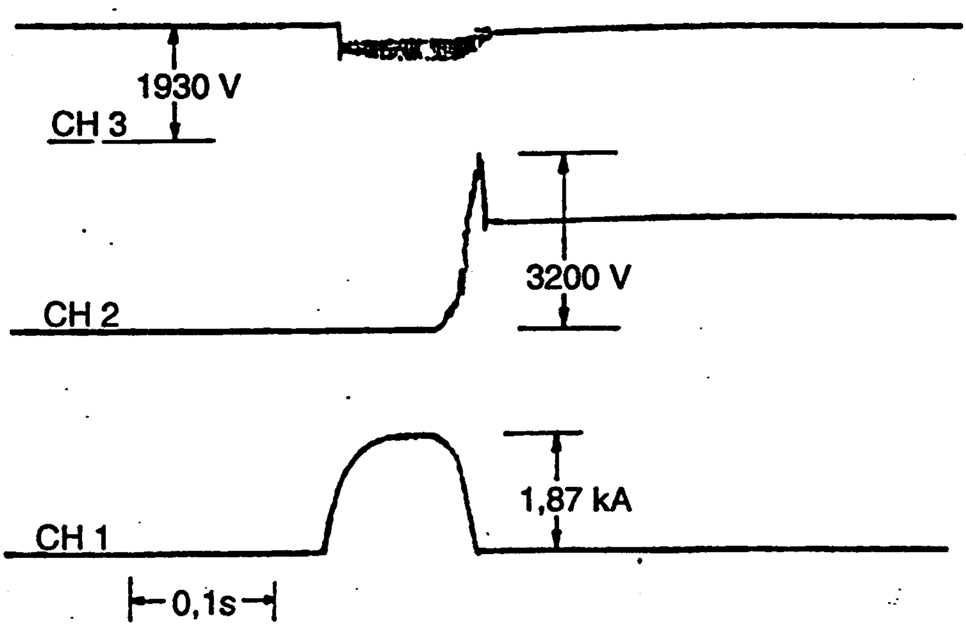

Figure B4: Overvoltage in 1,5 kV DC traction power supply

Source: UNITED KINGDOM
Short circuit applied at the end of track feed
CB O/L set at 1800 A
CH1: DC current CH2: Voltage across CB CH3: Busbar voltage

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Annex C

Table C1: Answers to DC systems: nominal voltage 3 kV / 3.3 kV

number	BELGIUM	CZECHOSLOVAKIA	ITALY	POLAND	USSR	YUGOSLAVIA
1.1.1	SNCB	CSD	FS	PKP	SZD	ZJZ
1.1.2	3 kV dc	3 kV dc	3 kV dc	3.3 kV dc	3 kV dc	3 kV dc
1.1.3	2 kV - 3.6 kV	2 kv - 3.6 kV	2.4 kV - 3.6 kV (±20 %)	2.1 kV - 3.9 kV	2.2 kV - 3.85 kV	-/-
1.1.4	3.42 kV- 3.78 kV (±5 %)	-/- - 3.6 kV	3.0 kV - 3.6 kV	3.0 kV - 3.6 kV	3.85 kV maximum, minimum not standardized	-/-
1.1.5	300 V voltage drop at rated load	1 mH per rectifier group	0.1 Ω - 0.25 Ω	0.1 Ω - 0.25 Ω depending on number and kind of converters	0.07 Ω - 0.18 Ω	-/-
1.1.6	r = 0.05 Ω/km l = 1.5 mH/km c unknown	r = 0.048 - 0.06 Ω/km l = 0.73 - 1.94 mH/km c = 15 - 24 nF/km	r = 0.045 Ω/km l = 1.3 - 1.4 mH/km c = 11 - 12 nF/km	r = 0.062 - 0.112 Ω/km l = 1.5 mH/km[1], 1.8mH/km[2] c unknown, but surely small	r = 0.034 - 0.067 Ω/km l = 1.0 - 1.3 mH/km c unknown	r -/- l -/- c -/-
1.1.7	5 - 41 km	15 - 30 km	15 - 40 km	18 - 22 km average maximum 30 km	4.5 - 6 km	-/-
1.1.8	(0.05 + 0.01(rail)) Ω/km	-/-	-/-	-/-	1.17 Ω/km - 1.75 Ω/km	-/-
1.1.9	automatic voltage adjustment under load	transformer taps, ± 10 % and ± 20 %	transformer taps	no	transformers, converters, see annotation[5]	-/-
1.1.10	no	no	no	no	inverters	-/-
1.1.11	no	no	no	no	yes	-/-
1.1.12	overhead	overhead	overhead	overhead	overhead	-/-
1.1.13	-/-	P = 5000 kW per rectifier group, up to 5 groups in a substation, no regenerative braking Imax,in = 1300 A auxiliary drives 30 A 4 railcars or 1 or 2 locomotives on the train	rheostatic and regenerative braking, for more information see annotation[4] auxiliary converters for - locomotives 110 A - coaches 45 A maximum number of coaches 22	P = 1850 - 4480 kW pneumatic and rheostatic, but no regenerative braking Imax, in = 2500 A auxiliary converter 40 A max 3 coaches, 2 locomotives in a train composition	in traction substations three-phase 6.3 and 12 MVA transformers	-/-
1.2.1	IEC 349	IEC 349 (1971)	IEC 38, IEC 349	IEC 38	IEC 38 (1983)	IEC 38
1.2.2	-/-	leaflet UIC 600 , leaflet OSShD R 611/1982	IEC 9.2 (1973)	Polish standard	state standard	-/-
2.1.1	unknown	-/-	-/-	unknown	see technical literature in USSR	-/-
2.1.2	-/-	no test overvoltages available	in case of simultaneous under load clearance of two or more high-speed breakers maximum overvoltage level (5 - 6) U	unknown	overvoltages up to 9 kV with duration of 5-20 ms, energy 150 kJ if a short-circuit is cleared up by a coupled high speed breaker of type AE - 2/4, measured by oscillographs	voltage level 6.6 kV with duration < 10ms in case of a short-circuit interruption, on locomotive (1.5 - 5) U because of condenser groups
2.1.3	yes, damages of diodes in substations	-/-	yes, failures to substation components by switching and to insulation lines by lightning overvoltages	unknown	-/-	-/-
2.1.4	only positive	-/-	yes, lightning impulses negative, switching pulses both	unknown	yes, in case of a.c shunt compensation devices	-/-
2.1.5	no	-/-	-/-	unknown	mainly isoceless triangle, 5-20 ms duration,	250/5000 µs (switching overvoltage) see Figure C1
2.1.6	interlocking sequence of substation breakers : 10 s	-/-	protection devices only clear overcurrents in 20 - 30 ms	unknown	2 - 5 ms	-/-
2.2.1.1	no	no influence	-/-	phase to phase	-/-	-/-
2.2.1.2	no	no influence (manual adjustment)	-/-	no regulation	-/-	-/-
2.2.1.3	no	12 pulse rectifier and no filters	-/-	no filters	-/-	-/-

Annex C

Table C2: Answers to DC systems: nominal voltage 3 kV / 3.3 kV

number	BELGIUM 3 kV	CZECHOSLOVAKIA 3kV	ITALY 3kV	POLAND 3.3kV	USSR 3kV	YUGOSLAVIA 3kV
2.2.1.4	no	yes, due to a distorsion of feeding voltage of 22 kHz	-/-	yes; the permitted value is 5% for constant and 10% for periodical distorsions	-/-	-/-
2.2.1.5	yes	no	-/-	no	-/-	-/-
2.2.1.6	no ; no	no ; not used	no ; no	no ; not used	-/-	-/-
2.2.1.7	no	no filters used	-/-	not applicable	-/-	-/-
2.2.1.8	no	no filters used	-/-	no	-/-	-/-
2.2.1.9	no		-/-	no	-/-	-/-
2.2.2.1	no	no	-/-	no	no	-/-
2.2.2.2	yes	yes;filter protection at 4.4kV	yes	yes	-/-	yes, hurtfullest overvoltages, maximum level 11.4 kV
2.2.2.3	no	no	yes	yes	-/-	-/-
2.2.2.4	no	no filters used	yes	no	-/-	-/-
2.2.2.5	yes, but not especially loading of input filters	no (on vehicles with pulse converters use of L-C filter)	-/-	no	-/-	-/-
2.2.2.6	no	yes, but very seldom	-/-	yes	yes, but only with transformer in idling conditions	-/-
2.2.2.7	no	no	-/-	yes	-/-	-/-
2.2.2.8	no	yes, during a function of fuses	-/-	no	-/-	-/-
2.2.3.1	arresters, sparkgap 12 kV at spacing 1400 m	surge arrester type GZM or VDM 3.6 with starting voltage in the range 6.4-7 kV	insulator flashover "sky wires" surge arresters only in correspondance to substations	lightning arresters level of polish standard BN-75/9317-87 for feeding lines (14 kV), and type GZM-4/10 of polish standard BN 70/3086-13 for supply cables, spacing 600-1200 m	-/-	-/-
2.2.3.2	15 kV	-/-	150 kV	> 30 kV	-/-	-/-
3.1	arrester, sparkgap type SOULE 12 kV	arrester 9.5 -10 kV/50 Hz	sparkgap and capacitor 9 kV, metallic oxid arrester 7kV, controlled arrester using non-linear resistors 4.3 - 6 kV	magnetic-valve type lightning arresters type GZM-4/10 7.5 kV and condenser type lightning arresters 4 µF type KOT, in locomotives EU07 additionally double air sparkgap JRG-3 (16 ±0.5) kV	lightning arrester and zink-oxid based R-C-chains	-/-
3.2	reception of lightnings on arresters, dielectric test on the machine	superposed voltage test and surge voltage test	application of impulse waveshapes, simulation with inductive circuits	according to Polish standard	-/-	minimum 20 pulses of both polarities in 1s intervals
3.3	yes	unknown	no	yes	-/-	-/-
3.4	no	cannot be answered	test at 12 kV for 60 s	no, but directives for coordination of insulation design shall be drawn	-/-	-/-
3.5	no ; -/-	cannot be answered	no ; energy level 10 - 35 kJ	no ; no	-/- ; -/-	-/- ; $0.5CU^2$ (C capacitance of the object), for maintainance more important near energy level : total duration and repetition frequency of overvoltage
3.6	no	unknown	no	no	-/-	-/-

Annex C

Table C3: Legend and Annotations to Tables C1 and C2

legend

-/-	question was not answered
unknown	answer cannot be given exactly , because of data-lacking or other reasons
P	rated power
U	rated voltage
Imax, in	maximum input or traction current
Imax, br	maximum braking current

annotations

1) on single line one side supply

2) on double line two sides supply

3) -transformers for on-board voltage step-type control
-transformers with auxiliary winding for voltage chopper control
-controlled voltage adding units for d.c substations
-controlled thyristor converters
-controlled devices for transverse capacity compensation
-compensated converting sets

4) rheostatic locomotives and EMUs without electric braking
up to P = 4800 kW
rheostatic locomotives with non regenerative braking
up to P = 4000 kW
electronic locomotives and EMUs with chopper drives, electric regenerative braking
in case of maximum rated power engins
-- Imax,in = 2000 A
-- Imax,br = 700 A

Annex C

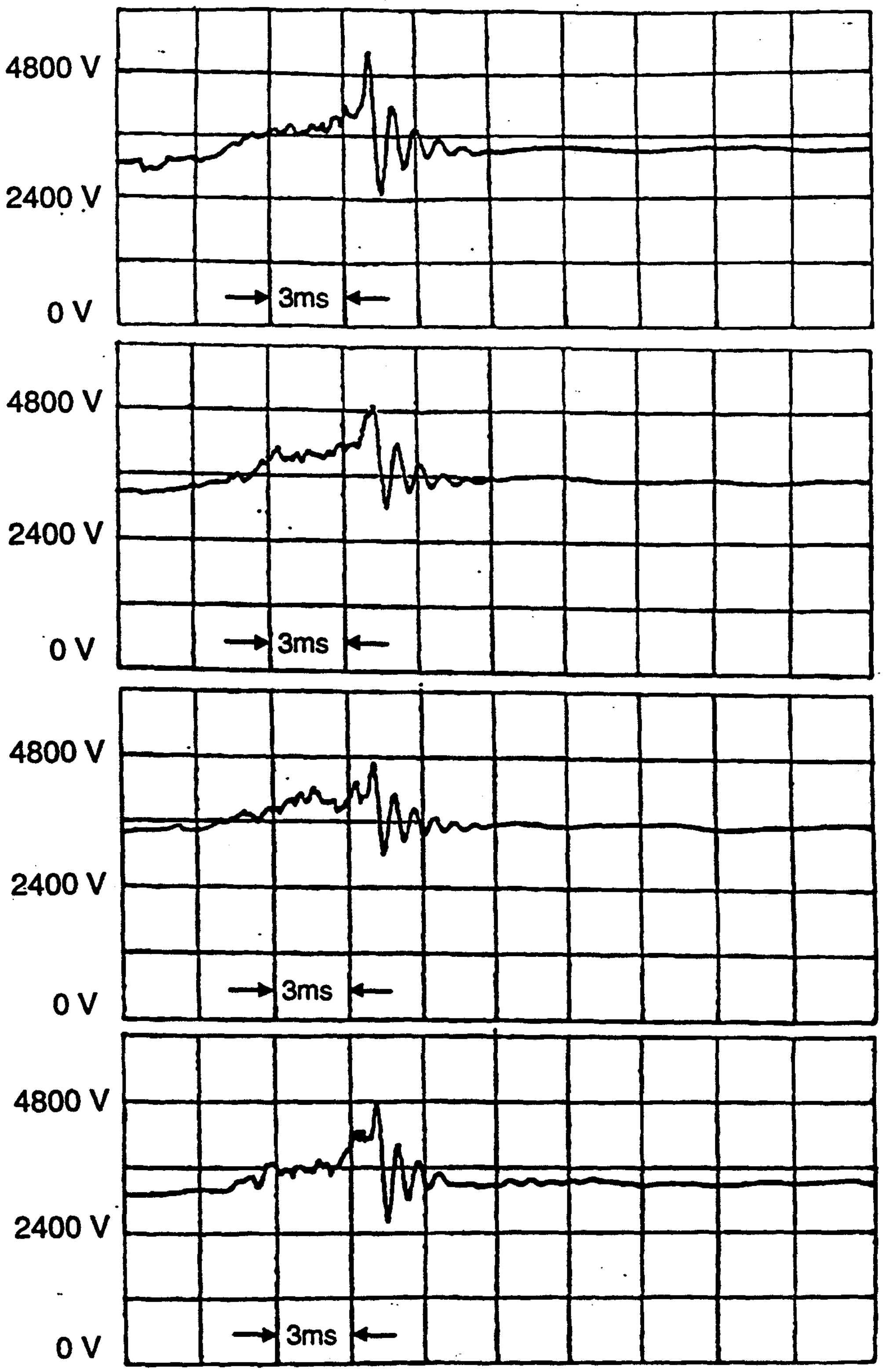


Figure C1: Overvoltages in 3 kV DC traction power supply

Source: YUGOSLAVIA

Gr15.DRW

Annex D

Table D1: Answers to AC systems: nominal voltage 15 kV / 16 $^{2}/_{3}$ Hz | 12 kV / 25 Hz

number	GERMANY	NORWAY	SWEDEN	SWITZERLAND	AUSTRIA	UNITED STATES
1.1.1	DB	NSB	SSR	SBB	ÖBB	NRPC
1.1.2	15 kV / 16 2/3 Hz	15 kV / 16 2/3 Hz	15 kV / 16 2/3 Hz	15 kV / 16 2/3 Hz	15 kV / 16 2/3 Hz	12 kV / 25 Hz
1.1.3	12 kV - 17,25 kV	12 kV - 16.5 kV	12 kV - 16.5 kV	12 kV - 17.25 kV	12 kV - 17.25 kV	8 kV - 13.7 kV
1.1.4	16.5/17.25/18 kV	16.2 kV constant	16.27 kV - 16,83 kV rms	16.5/17.25/18 kV	15 kV - 18 kV	11 kV - 13.2 kV
1.1.5	0.4 Ω - 5 Ω	synchronous 34.6 Ω - 62.4 Ω	subtransient 1 Ω - 15 Ω syncronous 1 Ω - 4 Ω	0.7 Ω - 1.4 Ω	from 0.16 Ω + j0.38 Ω to 0.07 Ω +j0.96 Ω	0.33 Ω - 0.8 Ω
1.1.6	r = 86.9 mΩ/km l = 0.92 mH/km c = 11 nF/km[1)]/20 nF/km[2)]	r = 210 mΩ/km l = 2 mH/km c = -/-	r = 140 - 300 mΩ/km l = 1.52 - 2.2 mH/km c = -/-	r = 110 mΩ/km double track l = 1 mH/km c = 20 nF/km	r = 140 mΩ/km l = 1.2 mH/km c = -/-	r = 173.1 mΩ/km l = 2.5 mH/km c = unknown
1.1.7	< 110 km	12 km - 114 km	40 km - 160 km	20 km - 40 km	14 km - 55 km	3.58 km - 18.6 km
1.1.8	unknown	Bergen 4.5 + j 4.5 Ω Stavanger 3.54 + j 3.54 Ω Gjovik 13.3 + j 13.3 Ω Trondheim 7.95 + j 7.95 Ω	open line	unknown	8 Ω	no
1.1.9	voltage of generator	transformer taps and automatical adjustment	constant voltage control	transformer taps	transformer tabs	transformer taps, no load (manual) tap changer
1.1.10	no	inverters	actually not applicable	no	-/-	no
1.1.11	local capacitors	yes, by phase compensation at Oslo central station	yes, in connections with static converter stations (integrated with harmonic filter)	yes, in great converter-plants possibility of phase-shifting with synchron-generators	1 compensation station used, 15 kV - 4 Mvar	no
1.1.12	overhead	overhead	overhead	overhead	overhead	overhead
1.1.13	no regenerative braking, but rheostatic controlled braking, see table 2	for types and characteristics see table 1, distinguishing in locomotives and motor coaches	no regenerative braking, P = 3600 kW thyristor con-trolled, Imax,in = 500 A, static auxiliary converter 750 V, 160 V	line-regenerative braking in locomotives P = 4650 kW, Imax,in= 530 A, Imax,br = 220 A, in locomotives with asynchron-motors and converters P = 3200 kW, Imax,in = 290 A, Imax,br=200 A and in motor-cars with DC-controlled rectifiers P = 1750 kW, Imax,in = 290 A, Imax,br = 200 A	Imax,in = 600 A, no regenerativ braking; composition of max. 3 locomotives and 16 coaches or 2000 to load	no regenerative braking, P= 5600 kW, Imax,in= 577 A, Imax,br= 50 A ,compositions of 1or 2 locomotives with 6 or 14 coaches, static, single wave, single thryistor converter, bridge, full waver rectifier 185 A
1.2.1	IEC 38, but not IEC 349	-/-	no	IEC 38, IEC 349	IEC Publications	IEC 38, IEC 349
1.2.2	DIN VDE 0115	UIC page 600	15 kV +10% / -20%	44 kV	ÖVE-T 1/1979 §30 and §40	GOST (state standard)
2.1.1	unknown	unknown	-/-	unknown	-/-	-/-
2.1.2	voltage 40 kV on the basis of sparkover marks on replica spark gaps of surge arresters	no measurements available	no measurements available	overvoltage 29 kV with duration 0.1 ms	short circuit test: max 18,5 kV, 2periods	-/-
2.1.3	yes, 31 failures by 1000 lightnings per year	yes, transformer due to lightning impulses	-/-	50 short-circuits per year due to lightnings	spark over in the high voltage switch group	-/-
2.1.4	yes	yes	-/-	yes	-/-	-/-
2.1.5	see Figure D1, D2	no measurements available	-/-	see Figures D3 to D 12	-/-	-/-
2.1.6	total average time for eliminating failures 175 min	output lines from substations have auto-reclosing after 5 s	-/-	60 ms - 300 ms depending on overcurrent amplitude	-/-	-/-
2.2.1.1	-/-	not relevant: the supply to contact line is done through rotating conv.	not applicable	-/-	-/-	phase to neutral, solidly grounded neutral
2.2.1.2	no ; tap changers of transformers are disconnected only under no-load conditions	principly yes, but the voltage regulator of the converter gives a corresponding limitation	yes, but not for more than 10 s and with a maximum of 17.5 kV to 18 kV	-/-	-/-	-/-
2.2.1.3	filter banks are firmly set to 42 Hz	no filters used	not applicable	no filters used	-/-	-/-
2.2.1.4	unknown	unknown	yes, factor up to 40 %	yes, especially on the far end of a single-ended line	-/-	-/-
2.2.1.5	unknown	not relevant	no	-/-	-/-	-/-

Annex D

Table D2: Answers to AC systems: nominal voltage 15 kV / 16 $^{2}/_{3}$ Hz | 12 kV / 25 Hz

2.2.1.6	unknown	max. voltage normally set to 16.5 kV, for braking limited to17 kV	no ; regenerative braking does not give any voltage rise	-/- ; -/-	-/-; -/-	-/- ; -/-
2.2.1.7	unknown	no	yes, 5 % rise in voltage	-/-	-/-	-/-
2.2.1.8	-/-	no, because frequency is kept constant	not applicable	-/-	-/-	-/-
2.2.1.9	no	no	-/-	-/-	-/-	yes, in case of loss on neutral ground (rail return) or mal-function of voltage regulation and the generating stations
2.2.2.1	yes, unloaded transformers on rail-borne vehicles are disconnected immediately after energization in rare cases only	no	unknown	-/-	yes, e.g. near by section point	-/-
2.2.2.2	yes, see 2.1.5	no	unknown	-/-	yes	-/-
2.2.2.3	in case of traction supply systems yes, in case of of rail-borne vehicles no	no	unknown	yes, see copies 2-6	-/-	-/-
2.2.2.4	unknown	no filters used	unknown	-/-	-/-	-/-
2.2.2.5	unknown	no	unknown	-/-	-/-	-/-
2.2.2.6	yes, for example in case of contact lines covered with ice	no	unknown	-/-	-/-	-/-
2.2.2.7	no, normally substations sections are interconnected	no	unknown	-/-	yes, during regeneration	-/-
2.2.2.8	no	no	unknown	-/-	-/- -/-	-/- -/-
2.2.3.1	surge arresters are no longer installed in overhead lines	arresters type ASEA XBA 26 (71 kV- 1.2/50), from converter to contact line by means of cable and by arrester at the termination	no lightning arresters	-/-	Sprecher & Energie type BHF 6d, 24 kV, 10 kA, 16 2/3 Hz	standard lightning arresters rating for 18 kV class
2.2.3.2	power-frequency withstand voltage 70 kV and impulse withstand voltage (positive) 170 kV	spacing normally > 250 mm, but > 175 mm is permitted	150 kV to 225 kV depending on type of insulator	power-frequency withstand voltage 70 kV, impulse withstand voltage 170 kV	old feeding lines 15 kV new feeding lines 30 kV	25 kV minimum insulation class
3.1	surge arresters with resistor discs and spark gaps did not prove successful in practical use, so that they are removed in part : sparkover voltage 35-40 kV rated voltage 15 kV	arresters XBD 26 or XAD 230 S/XAD 245 24 kV, 55 kV maximum flashover voltage	lightning arrester ASEA type XAD 20S, 60 kV	new locomotives mostly equipped with metaloxyd-arresters type MWA 4 kV, older machines have surge arresters with resistor discs and spark gaps	Siemens Teb-Sub 1061-1, 813-1, 2625-2x, Siemens UC 1050 P2400/200 E; BBC BZU 35 (1 kV), AEB 050333, HML 18, MWA 18; Sprecher & Energie BHF 6c (9 kV, 18 kV), BHF 6d (19,5 kV)	standard lightning arrester rating for 18 kV class, some locomotives with 15 kV lightning arresters reported failures with this unit, 18 kV lightning arresters have been proven satisfactory protection
3.2	according to DIN VDE 0535 part 2 that corresponds to IEC publication 310	on traction vehicles no tests performed, high voltage equipment tested by the manufacturer	-/-	-/-	UIC specifications	IEEE standard transient and withstand capability test with 2.5 kV , 1.5 MHz waveform
3.3	no; off-load cables may, however cause overvoltages within substations	yes	-/-	-/-	unknown	-/-
3.4	no ; unknown if there is a causality between the removal of surge arresters and an increase in failure rate of power thyristers and diodes	damage by overvoltage should be limited to break down the arrester itself	-/-	-/-	unknown	-/- ;
3.5	no	no	-/-	-/-	-/-	-/-
3.6	no	no	-/-	-/-	-/-	-/-
number	GERMANY 15 kV	NORWAY 15 kV	SWEDEN 15 kV	SWITZERLAND 15 kV	AUSTRIA	UNITED STATES 12 kV

Annex D

Table D3: Legend and Annotations to Tables D1 and D2

legend

-/-	question was not answered
unknown	answer cannot be given exactly , because of data-lecking or other reasons
P	rated power
U	rated voltage
Imax, In .	maximum input or traction current
Imax, br	maximum braking current

annotations

1)	for single line
2)	for double line

Table D4: Electric characteristics of some traction vehicle types / NORWAY (15 kV / 16 $^{2}/_{3}$ Hz) Reference: Question 1.1.13

locomotive type	number	rated power kW	maximum input current A	maximum regenerative current A	train compositions	remarks
El 11	40	1676	140	no	passenger train :	
El 12	7	2400	200	no	1 locomotive and 3 to	3 locomotives per train (Ore-train locomotive)
El 13	37	2650	220	no	14 coaches	
El 14	31	5082	450	no		
El 15	6	5406	500	no	freight train :	2 locomotives per train (Ore-train locomotive)
El 16	17	4400	550	no	1 to 2 locomotives	
El 17	12	3400	280	100		

Annex D

Table D5: Electric characteristics of some traction vehicle types / GERMANY (15 kV / 16 $^{2}/_{3}$ Hz)

line of product	rated power kW	maximum input/traction current A	maximum braking current A	remarks and braking type
140	3620	400	-/-	conventional locomotive with rheostatic controlled starting, without rheostatic braking
141	2300	340	-/- (85)	conventional locomotive with rheostatic controlled starting, mostly without rheo-static braking, except 5 locomotives (85 A)
103	7080	880	-/-	
110/111/112	3620	480	-/-	conventional locomotives with rheostatic controlled starting, with rheostatic braking
150	4440	550	-/-	
151	6000	720	-/-	
181.2	3200	560	-/-	multiple system locomotive with rheostatic braking
120	5600	550	200	three-phase motored locomotive with rheostatic braking
420/421	2400 per train	380	-/-	motor coaches with rheostatic braking trains of 3, 6 or 9 vehicle units

Annex D

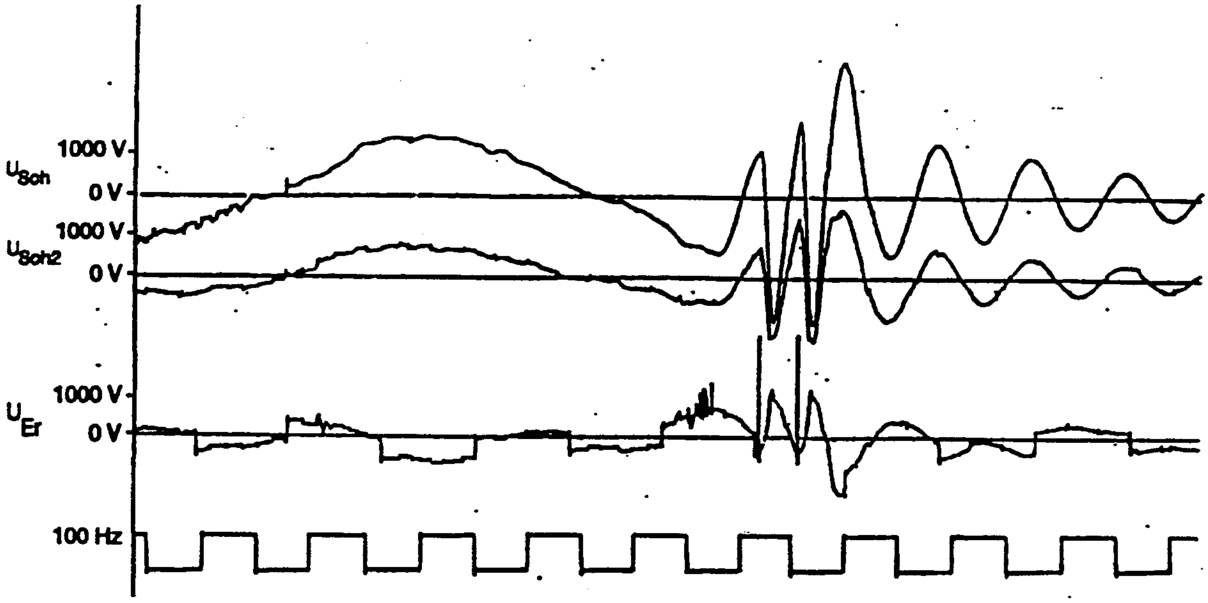


Figure D1: Overvoltages at the terminals of a load

Source: DB / GERMANY (15 kV / 16 2/3 Hz)
Switching-off a fully excited main-transformer
(U_N = 885 V AC; $\hat{U}$≈3200 V)

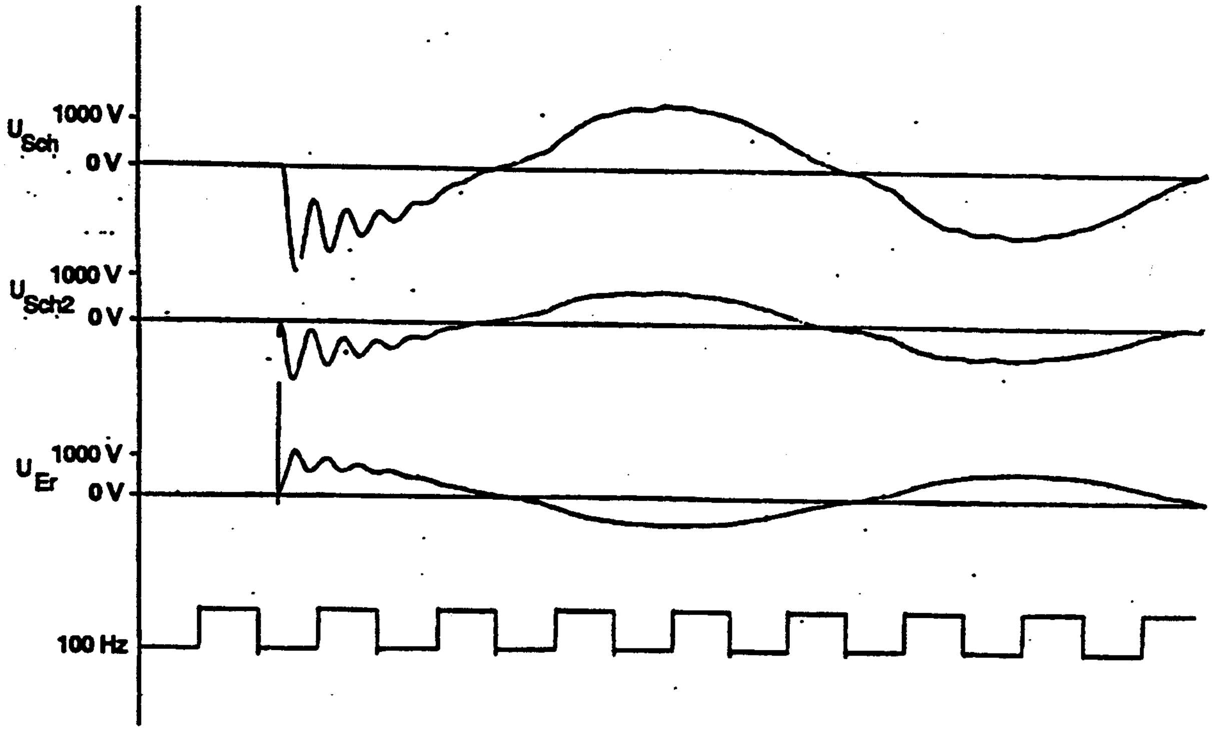


Figure D2: Overvoltages at the terminals of a load

Source: DB / GERMANY (15 kV / 16 2/3 Hz)
Switching-on the main-transformer
(U_N = 885 V AC)

GR13.DRW

Annex D

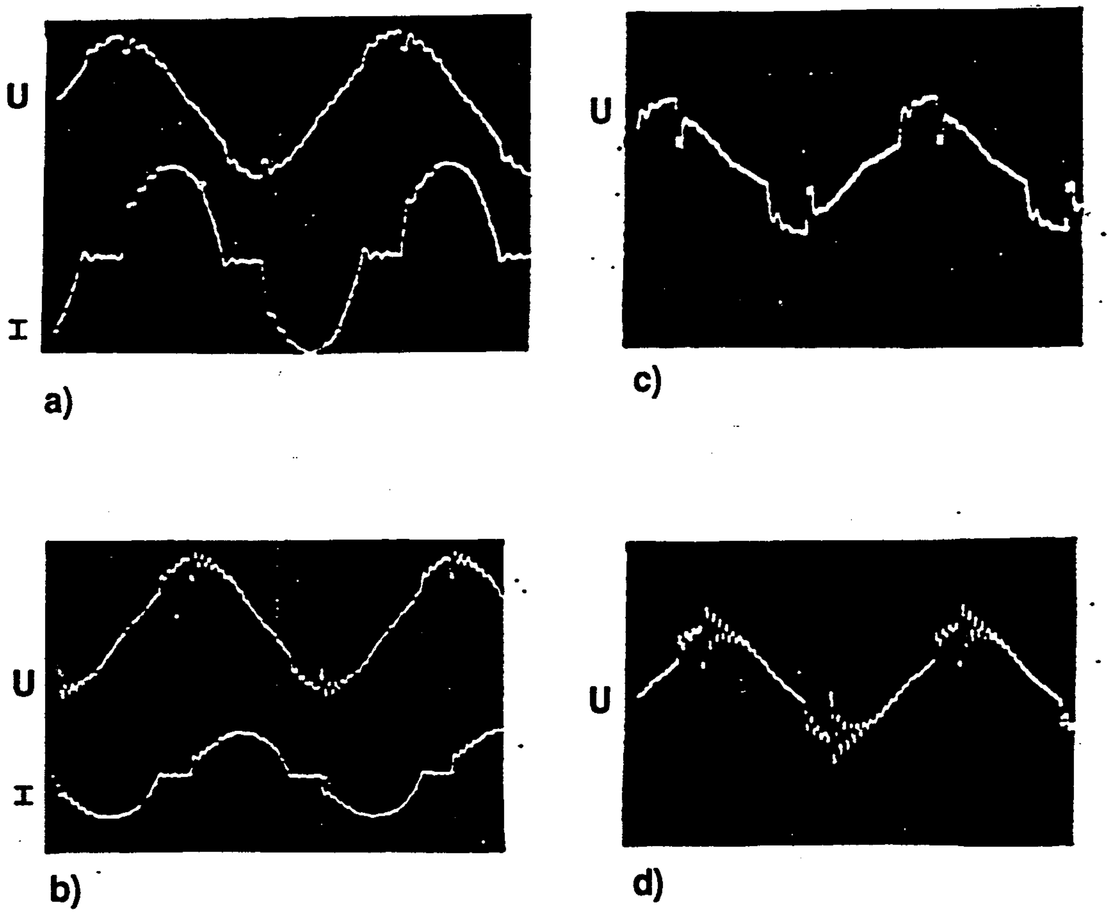
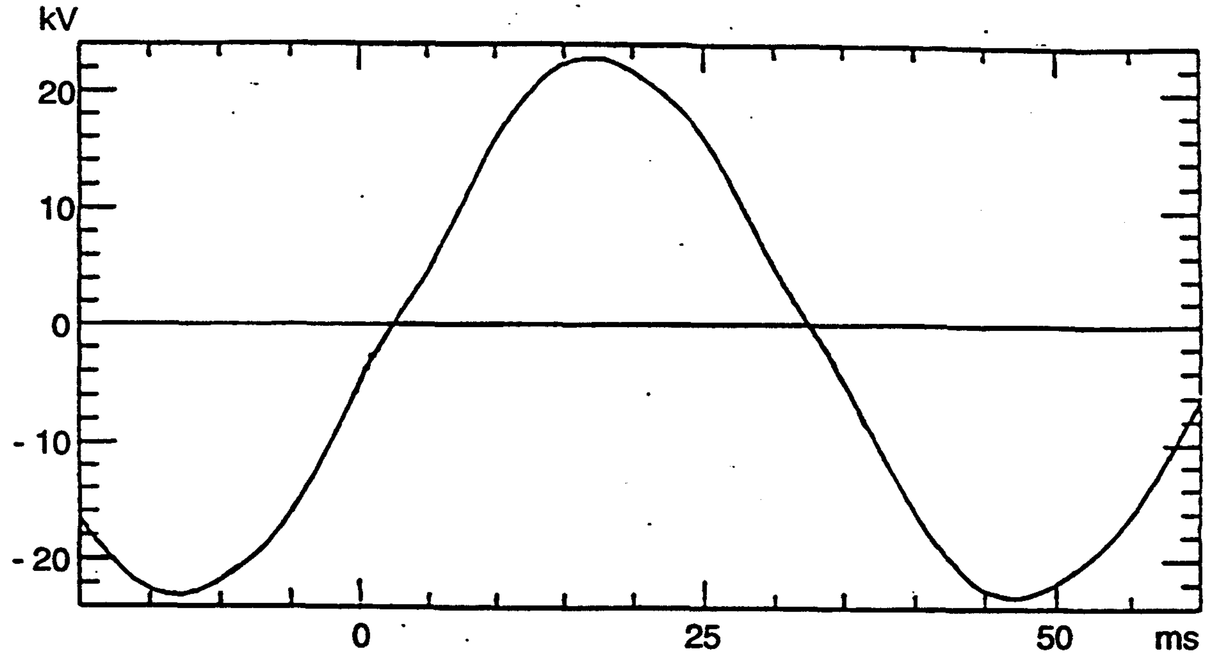


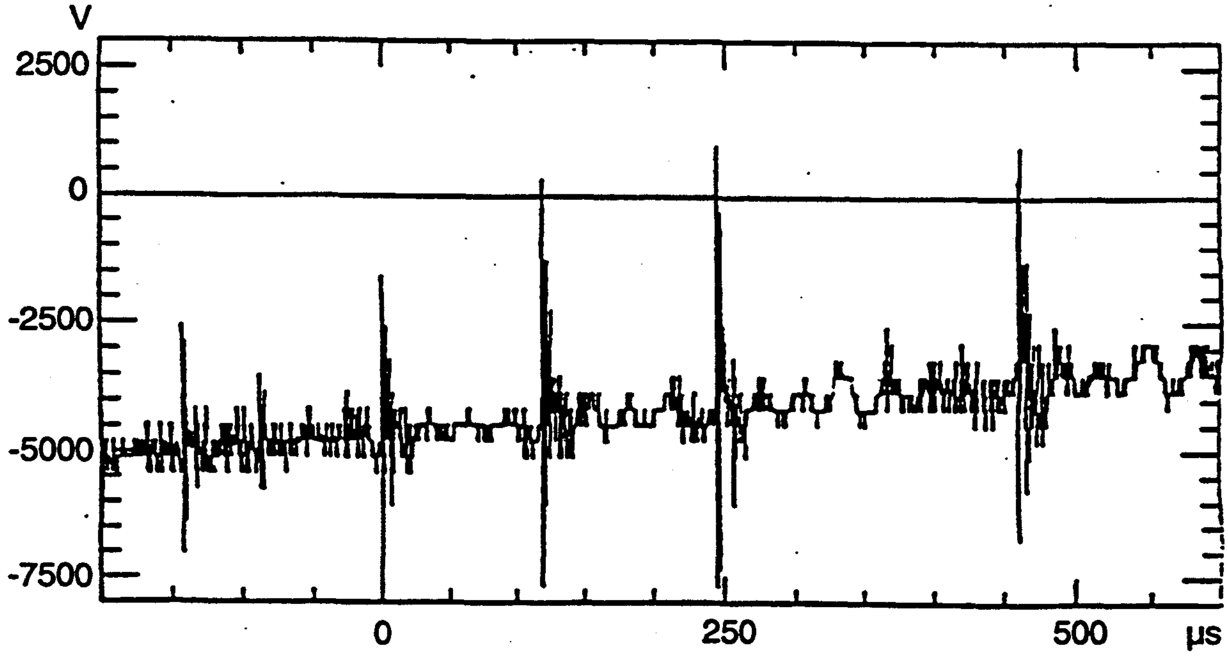
Figure D3: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB
a) measured at transformer-substation
U = 15 kV I = 400 A
b) measured at transformer-substation
U = 15 kV I = 800 A
c) + d) measured at end of line
U = 16,1 kV

Gr9.DRW



a) low speed channel



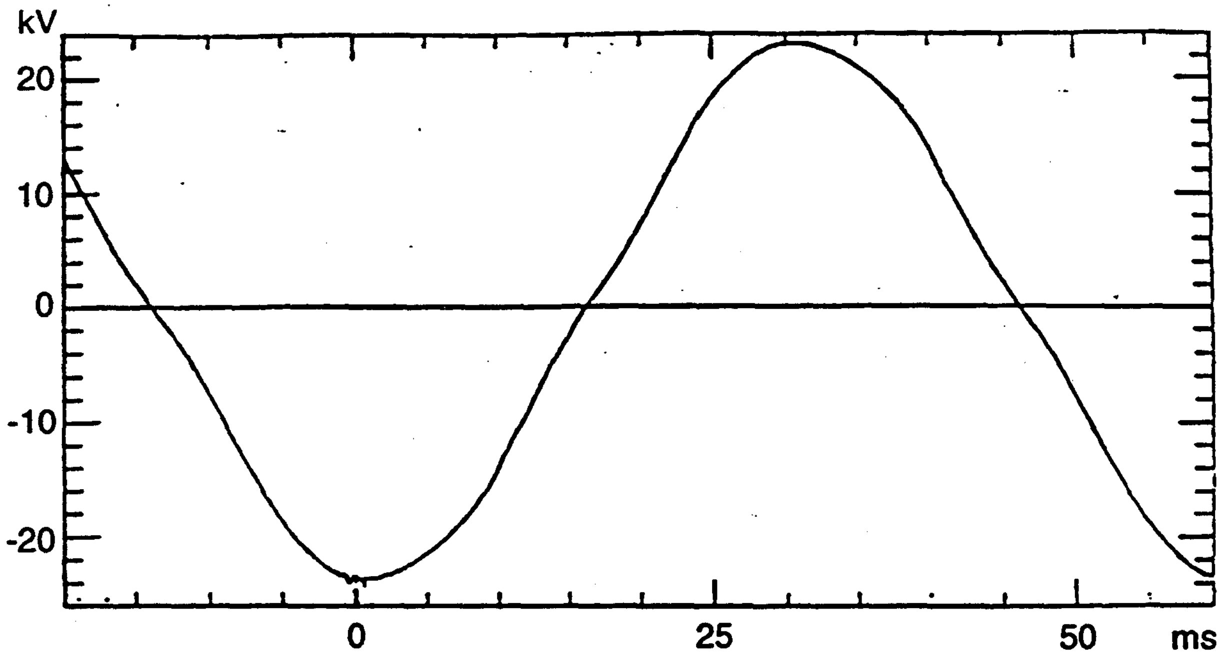
a) high speed channel

Figure D4: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

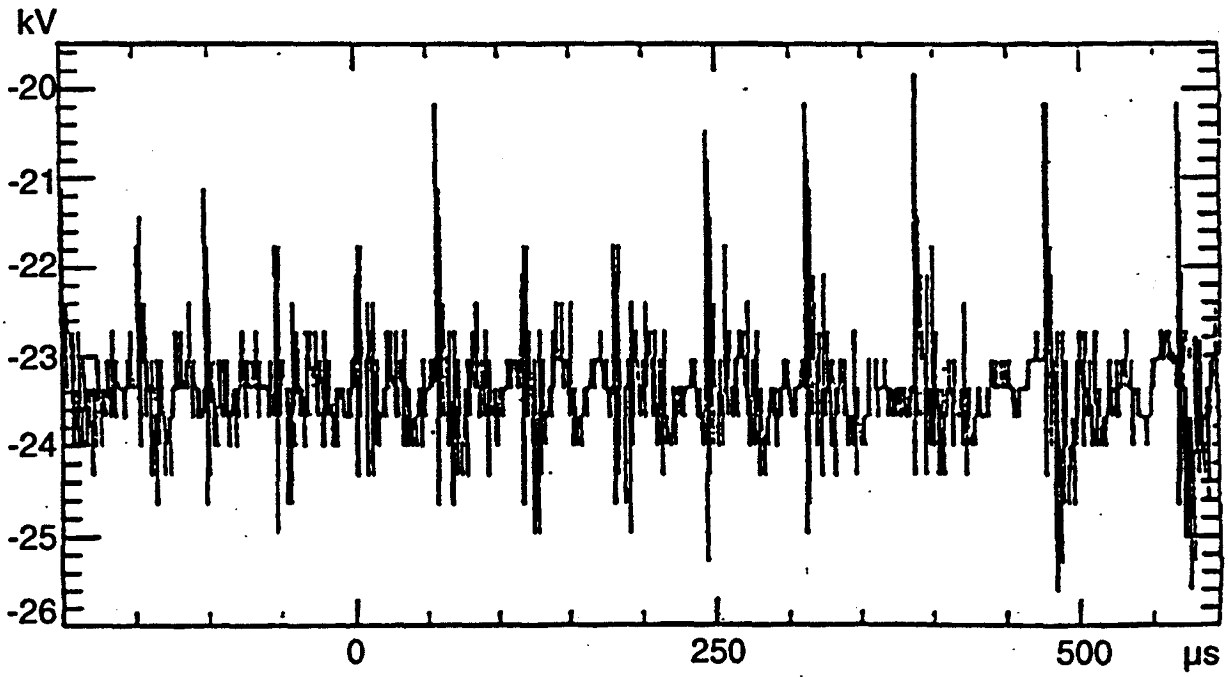
Source: SWITZERLAND / SBB

GR19.DRW

Annex D



a) low speed channel



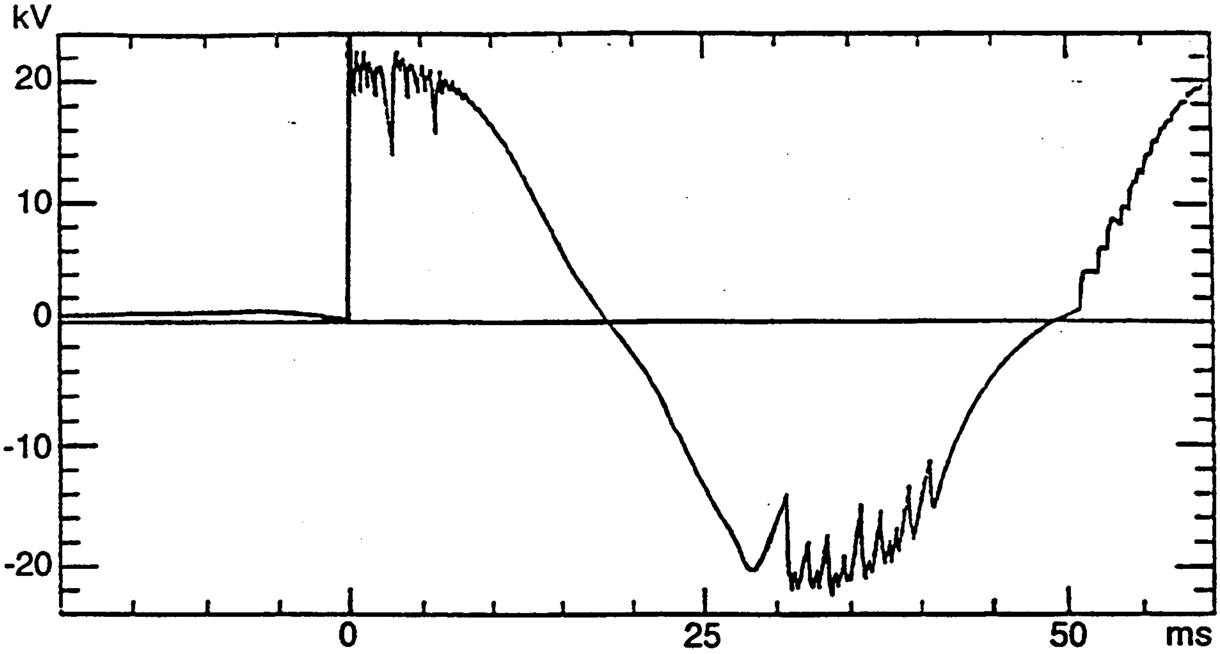
b) high speed channel

Figure D5: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

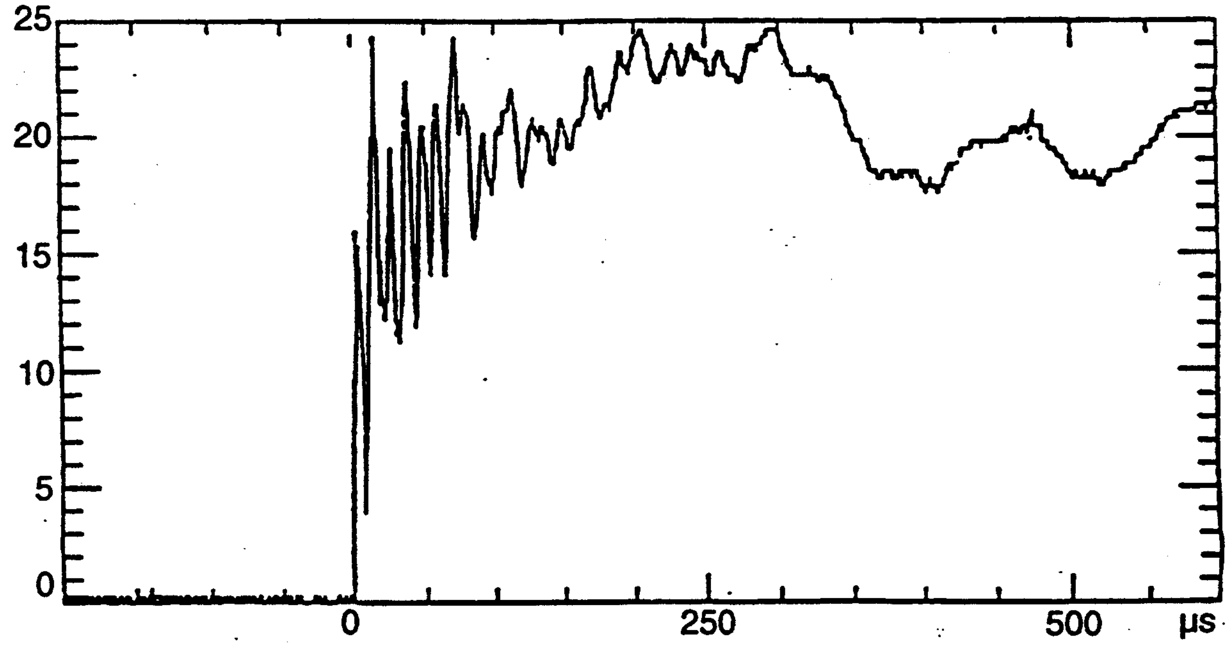
Source: SWITZERLAND / SBB

Gr5.DRW

Annex D



a) low speed channel



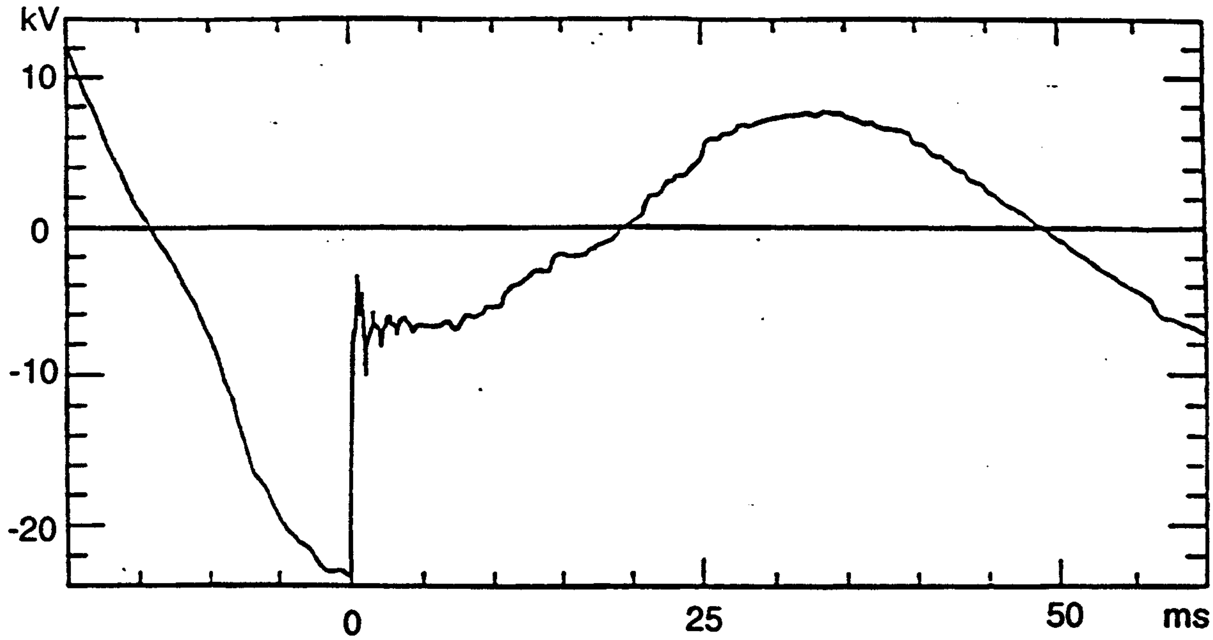
b) high speed channel

Figure D6: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

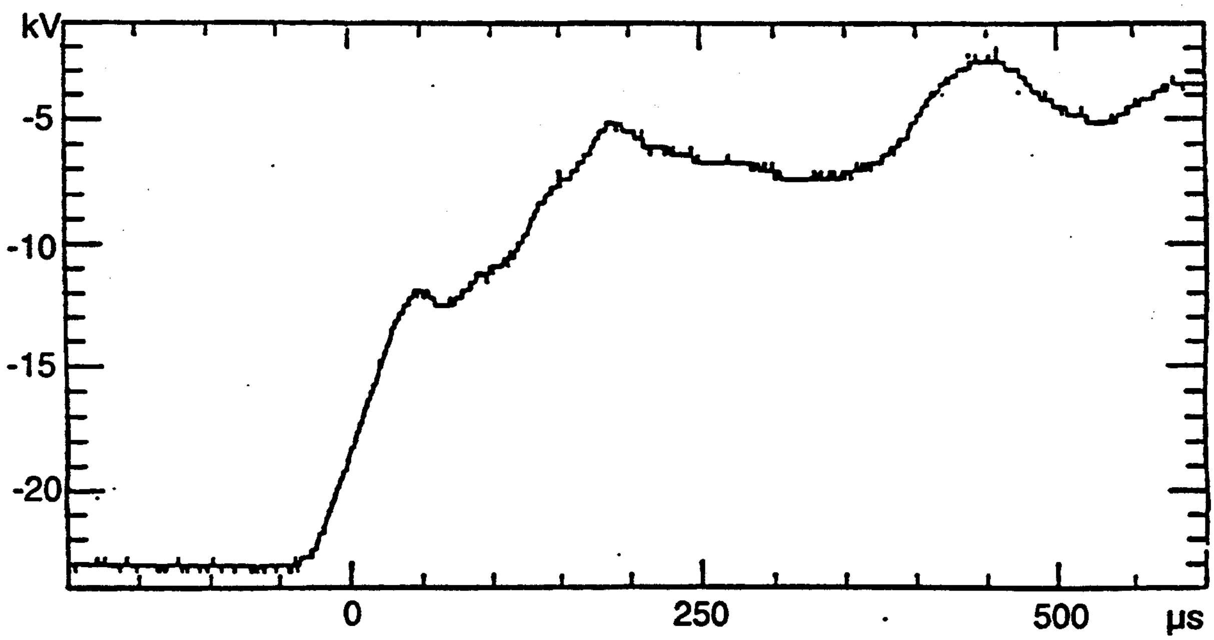
Source: SWITZERLAND / SBB
Background unknown

GR3.DRW

Annex D



a) low speed channel

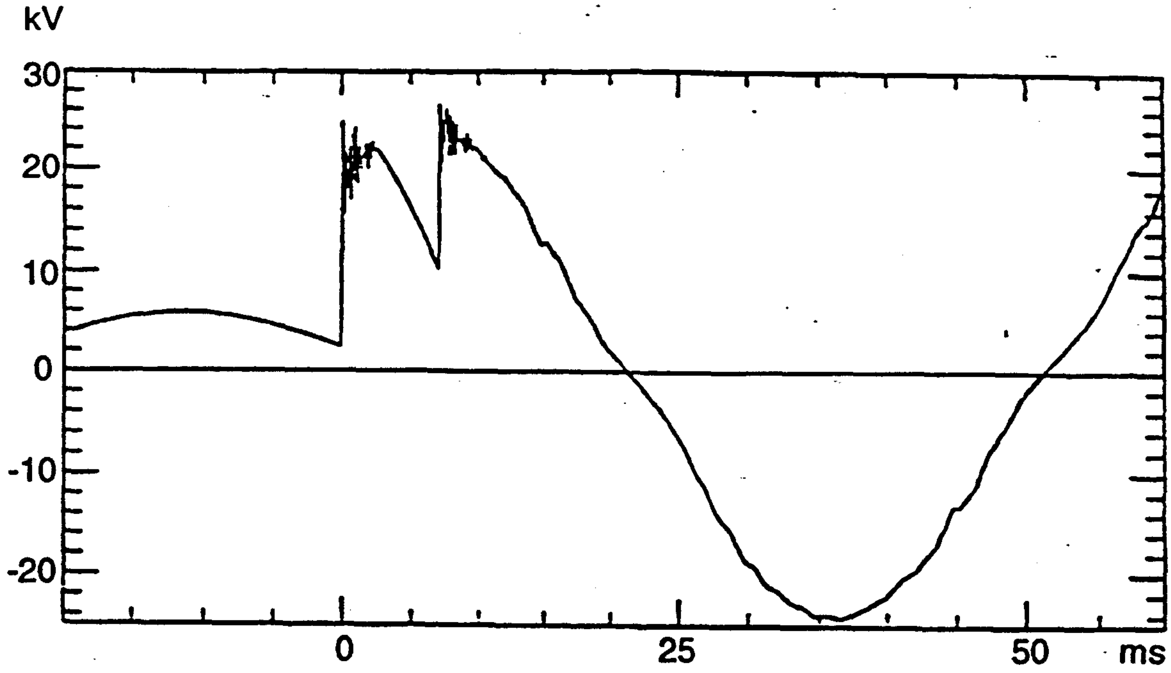


b) high speed channel

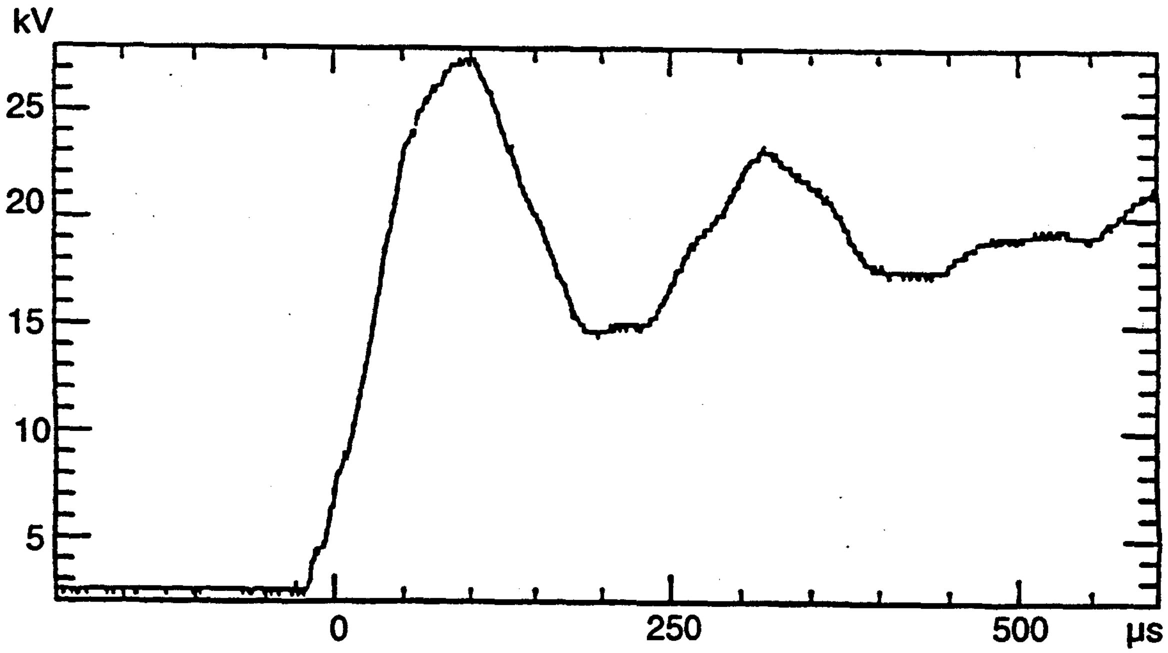
Figure D7: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB
Background unknown

Gr4.DRW



a) low speed channel

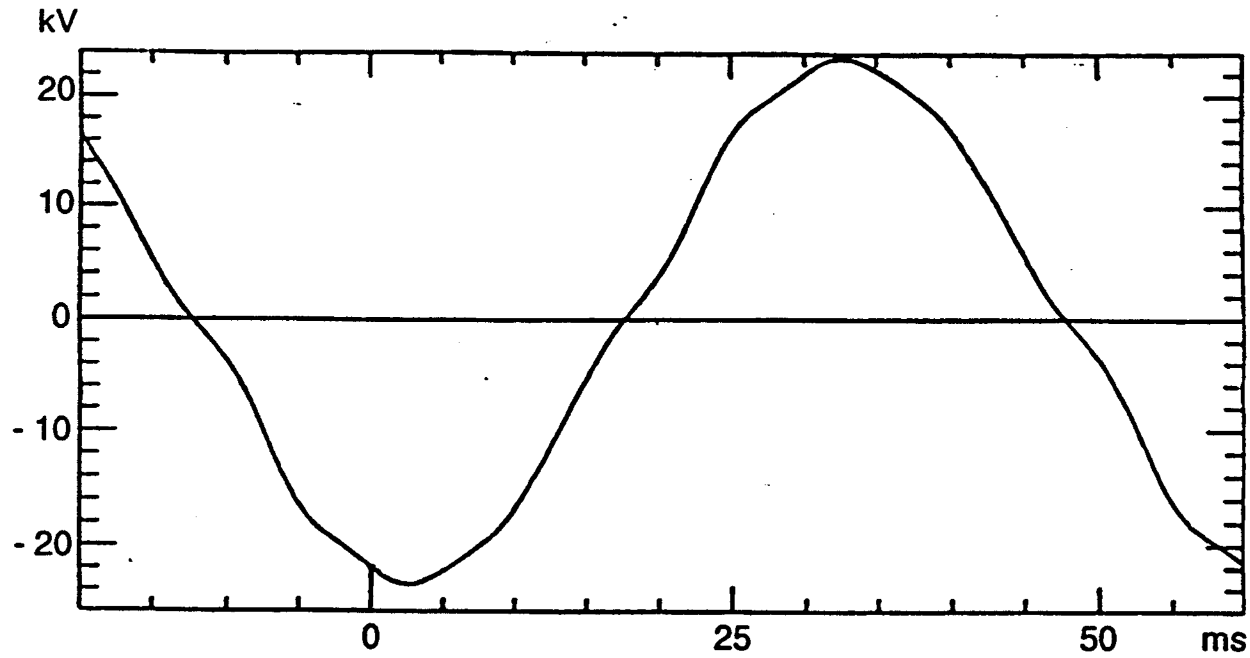


b) high speed channel

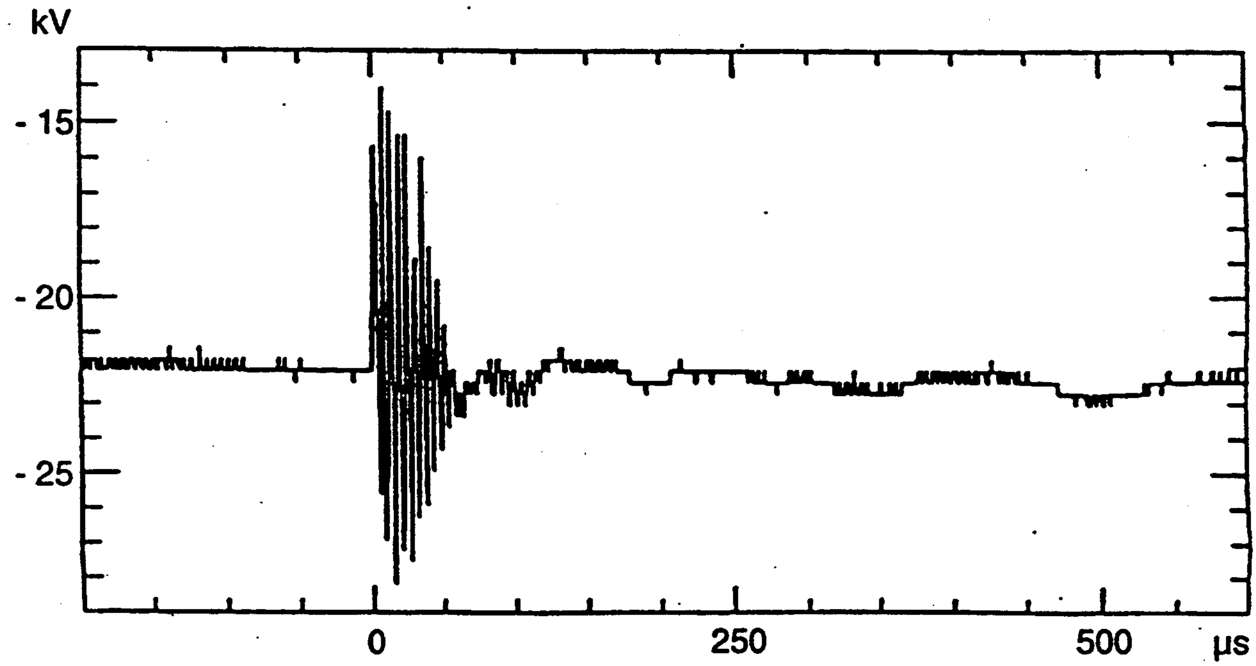
Figure D8: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB
Background unknoen, refeeding of line after short-circuit

Gr8.DRW



a) low speed channel

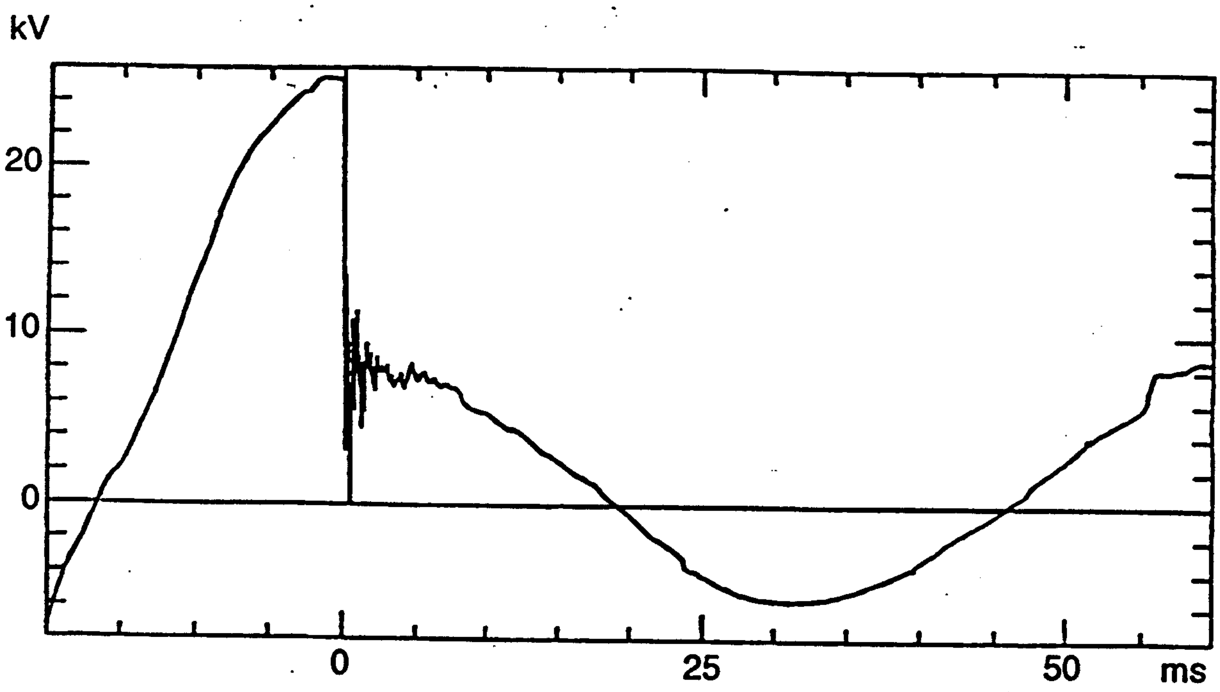


b) high speed channel

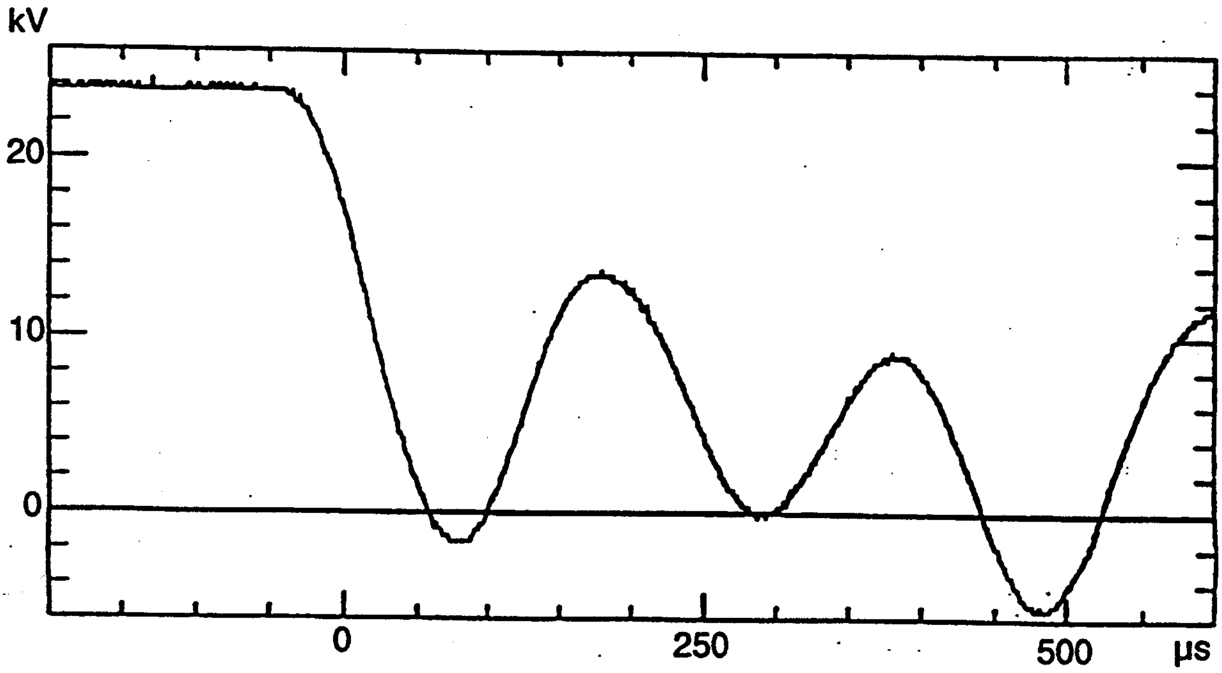
Figure D9: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB
Background unknown

GR22.DRW



a) low speed channel

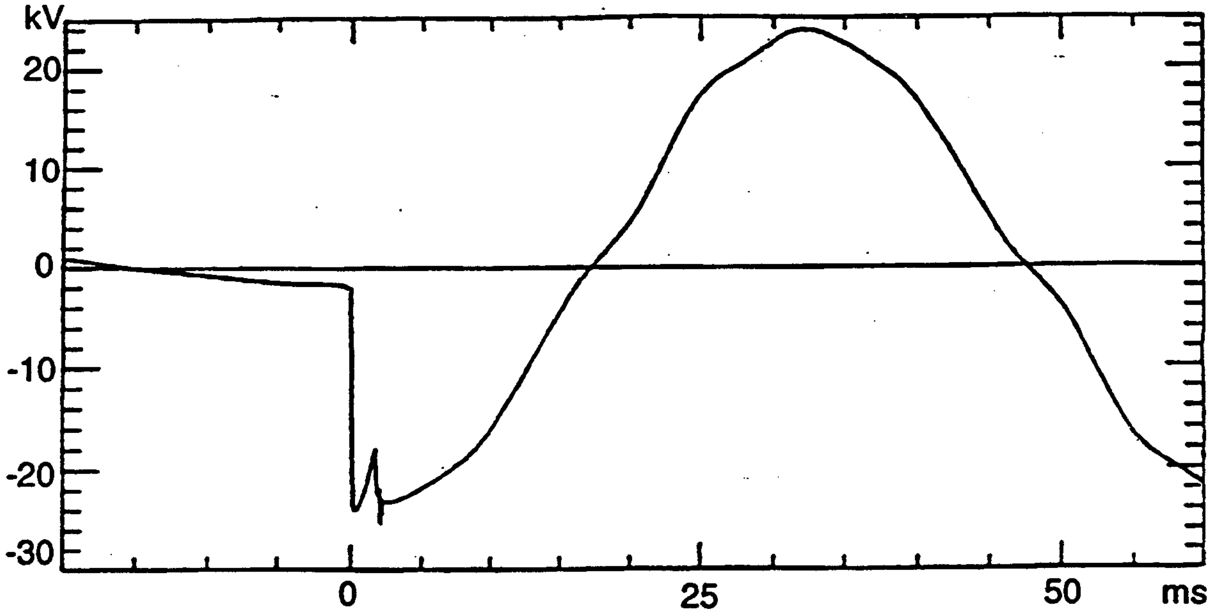


b) high speed channel

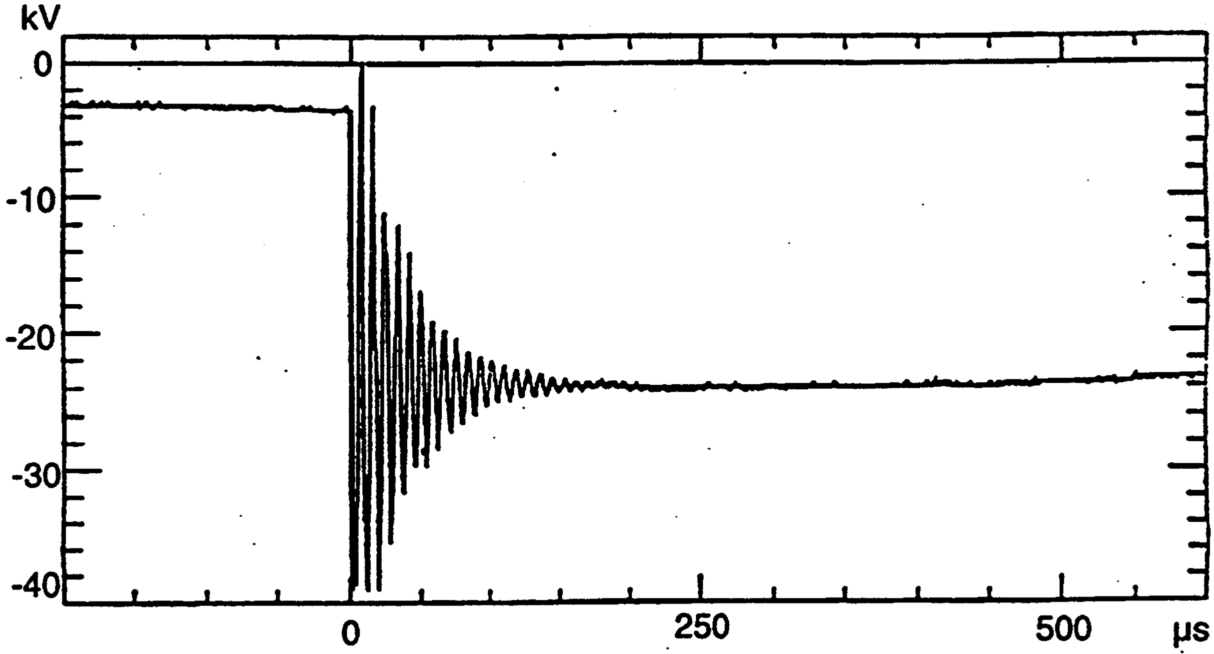
Figure D10: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB
Background unknown, probably short circuit

Gr21.DRW



a) low speed channel



b) high speed channel

Figure D11: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB
Background unknown, probably after short circuit

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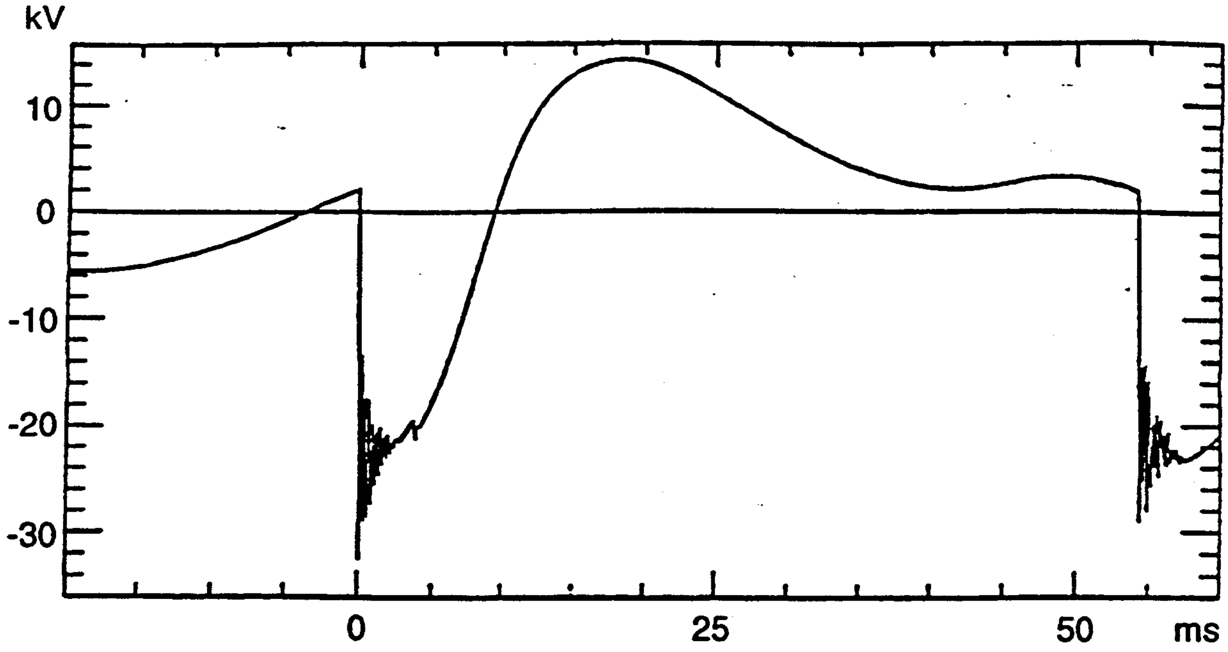
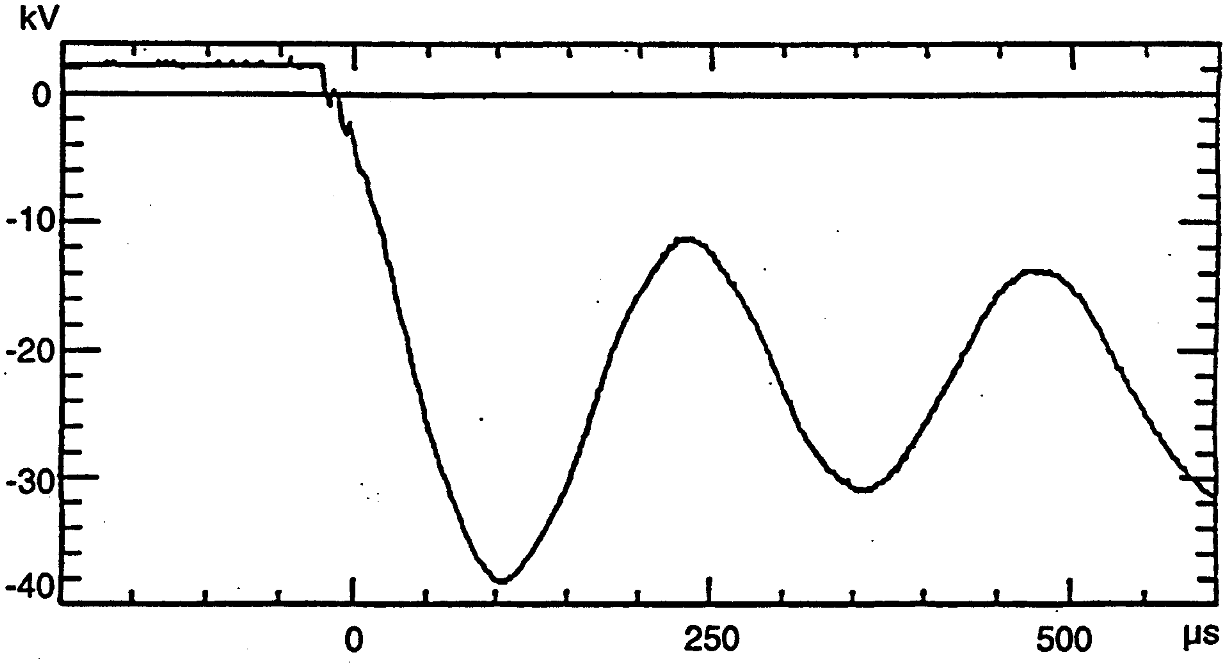


a) low speed channel



b) high speed channel

Figure D12: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB
Background unknown

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Annex E

Table E1: Answers to AC systems: nominal voltage 25 kV / 50 Hz

number	CHINA	CZECHOSLOVAKIA	FRANCE	UNITED KINGDOM	USSR	YUGOSLAVIA
1.1.1	China Railways	CSD	SNCF	BR	SZD	ZJZ
1.1.2	25 kV / 50 Hz	25 kV / 50 Hz	25 kV / 50 Hz	25 kV / 50 Hz	25 kV / 50 Hz	25 kV / 50 Hz
1.1.3	19 kV - 29 kV	27.5 kV - 19 kV	23 kV - 27 kV	16.5 kV - 27.5 kV	19 kV - 29 kV	-/- - -/-
1.1.4	26 kV - 29 kV	-/- - 27.5 kV	25 kV - 27.5 kV	2.5 kV - 27.5 kV	-/- - 29 kV	-/- - -/-
1.1.5	3.18 Ω - 11.9 Ω (on the side of 27.5 kV)	8 Ω - 10 Ω	2.5 Ω - 8 Ω	4.4 Ω - 8 Ω	2 Ω - 8 Ω (on the side of 27.5 kV)	-/-
1.1.6	r = -/- l = -/- c = -/-	r = 0.12 - 0.34 mΩ/km l = 0.73 - 1.94 mH/km c = 15 - 24 nF/km	r = 0.09 mΩ/km l = 0.89 mH/km c = 27 nF/km	r = 51-266 nΩ/km l = 0.436-2.266 mH/km c = 10 nF/km per single track[1]	r = 65-220 nΩ/km l = 0.5-1.4 mH/km c = 40-50 mF/km	r -/- l -/- c -/-
1.1.7	30 - 100 km	30 - 50 km	6 - 74 km	3.4 - 73.6 km	20 - 98 km	-/-
1.1.8	325 Ω	infinity	10 Ω	not used	25 Ω - 50 Ω	-/-
1.1.9	under no-load condition	transformer taps (2 x 16 taps 2 %)	load adjustment	off load tap change where fitted	inverters, see annotation[2]	-/-
1.1.10	no	no	-/-	no	yes	-/-
1.1.11	parallel capacitor compensation with compatibility of the third harmonic filter on secondary winding of the transformer in the substation	no	yes, in substations by filters,but depending on type of feeded engin and necessity of compensation	no	-/-	-/-
1.1.12	overhead	overhead	overhead	overhead	overhead	-/-
1.1.13	see Table E6	no regenerative braking P = 10/13.5 MVA for traction transformer, trains consisting of one locomotive and 4 rail-cars, Imax,in=20 A, auxiliary drives 5 A	see Table E7	P typically for EMC 1-1.5 MW, for AC locomotive 3-6 MW, Imax,in = 350 A, trains consisting of 9 to 16 coaches locomotive hauled, auxiliary units : static inverters, mainly motor/alternator sets	-/-	-/-
1.2.1	IEC 38, IEC 349	IEC 349 (1971)	UIC 600 for voltage IEC 38 for frequency	IEC 38, IEC 349, but for lowest voltage	IEC 38, IEC 349	IEC 38
1.2.2	natinal standard GB 1402-78 Electric railways-trunk lines	leaflets UIC 600 and ShD R 611/1982	CF 60000 (1981)	British Railways standard	GOST (state standard)	-/-
2.1.1	-/-	-/-	-/-	-/-	see literature in USSR	-/-
2.1.2	interrupting the no-load current on vehicle : 2.65-3.3 U, duration 6 ms, oscilloscope and capacitance divider, closing up (2 U) or breaking off (1.7 U) the no-load contact line, length 18 km, measured with a vacuum circuit breaker	overvoltages on transformers in a substation 180 kV, on board of the vehicle 150 kV and on the contact line 200 kV	overvoltage 72 kV under exceptional circumstances : powerful engin and weak feeding, duration up to 5 min, memory oscilloscope	maximum surge level 60 kV, duration 1ms, frequency < 1 per day, surge monitoring and use of a capacitor divider	overvoltage 100 kV when turning-on devices with shunt-compensation, 150 kV at duration 10 ms by cutting them off, cutting off the air-break switch causes 80 kV overvoltage with duration about 2 ms	overvoltage 2-3 U, when current is cut off by a switch on board of the locomotive in course of 30 ms after a vainly manual attempt to restablish the current, no load transient duration shorter than underload duration in case of power cut
2.1.3	damages of arresters on contact lines and in substations due to lightning overvoltages	-/-	no damages on vehicles, since spark-gaps are used, but in fixed installations damages of arresters by lightnings, of transformers by ferroresonances and of switches located at the other end of long feeded sectors	no	-/-	-/-
2.1.4	-/-	yes	-/-	yes	yes	-/-
2.1.5	-/-	-/-	see Figure E1	see Figures E2 – E4	-/-	-/-
2.1.6	< 75 ms on vehicles 0.1-1.5 s in substations	-/-	-/-	no clearance required - no flashovers	2 - 5 ms depending on type and protection	-/-

Annex E

Table E2: Answers to AC systems: nominal voltage 25 kV / 50 Hz

number	CHINA	CZECHOSLOVAKIA	FRANCE	UNITED KINGDOM	USSR	YUGOSLAVIA
2.2.1.1	yes, short circuit between phases or flashover of insulator towards earth	no ; phase to phase connection	-/- ; phase to phase	-/- ; phase to neutral	-/- ; -/-	-/- ; -/-
2.2.1.2	yes	no	yes, but only 2 kV overvoltages	not applicable	-/-	-/-
2.2.1.3	yes	not used	yes	not applicable	-/-	-/-
2.2.1.4	yes	yes	yes, often and principally odd harmonics of 50 Hz	yes, gives rise to a repetitive 2.2kV transient overvoltage	-/-	-/-
2.2.1.5	yes	yes	yes, often and lead to destruction of transformers	unknown	-/-	-/-
2.2.1.6	-/- ; -/-	no ; no	-/- ; -/-	no ; no	-/-	-/-
2.2.1.7	yes	not used	yes, but tolerable	not applicable	-/-	-/-
2.2.1.8	-/-	not used	-/-	no	-/-	-/-
2.2.1.9	-/-	no	-/-	no	-/-	-/-
2.2.2.1	yes	no	-/-	yes	no	-/-
2.2.2.2	yes	yes, but not exceeding repeatable cut-off voltages	yes, switching condenser batteries at energy distributor	no	-/-	-/-
2.2.2.3	yes	no	-/-	not applicable	-/-	-/-
2.2.2.4	yes	not used	-/-	not used	-/-	-/-
2.2.2.5	yes	not used	-/-	not used	-/-	-/-
2.2.2.6	yes	yes, but very seldom	-/-	yes, but small surges	yes, but only with transformer in idling condition	-/-
2.2.2.7	yes	no	-/-	no	-/-	-/-
2.2.2.8	-/-	switching on of compensating stations situated along the track	-/-	no	-/-	-/-
2.2.3.1	surge arresters type Valve FZ-20x2 and FZ-35 30 kV, spacing 1.5-4 km, ZnO arrester YWT-30 30 kV and tube GX35/0.5 to 4 30 kV	surge arrester type VRA 30 54 kV (113 kV for impulse voltage) on outputs of feeding and at head parts of railway stations	-/-	no surge arresters, other than rod gaps on track-side are used due to poor reliability of gapped arresters	-/-	-/-
2.2.3.2	> 300 kV to 400 kV (negative)	-/-	81 kV, for wave forms 1.2/50 μs 190 kV	impulse flashover 1/50 μs 115 - 150 kV	-/-	-/-
3.1	air gap discharger on the line side 90 kV and R-C protective devices 2.5 Ω /12 μF - 5 Ω /6 μF	Valve type lightning arrester type GZSa 30 t 30 kV, surge voltage for wave 1.2/50 μs situated on the roof of a vehicle	lightning arresters and a R-C circuit 4 Ω, 20 μF for TGV and 94 Ω,1 μF for BB 22000	R-C networks on transformer secondary and some roof mounted arresters	zink-oxid based R-C chains, power transformer shunt secondary of ac electric locomotive, lightning arresters	-/-
3.2	methods directly applying voltages to pantigraph, lightning and switching overvoltage standard impulse waves	superposed voltage test and surge voltage test	-/-	circuit breakers, cables, transformers etc are tested to typically 175 kV, 1.2/50 μs impulse and 75 kV one minute a/c withstand	test of commutation overvoltages under actual operation conditions and atmospheric overvoltages simulated by supplying an atmospheric voltage pulse	-/-
3.3	-/-	-/-	-/-	unknown	-/-	-/-
3.4	-/-	-/-	-/-	-/-	-/-	-/-
3.5	-/- ; -/-	-/- , -/-	Zh = ahZcc with Zh harmonic network impedance, Zcc short-circuit impedance at 50 Hz on loop-line, h order of the harmonic and a=2 for hvn, a=3 for mvn and a=1 for lvn[2)]	no ; no	-/- ; -/-	-/- ; -/-
3.6	-/-	no	-/-	no	-/-	-/-

Annex E

Table E3: Answers to AC system JAPAN: nominal voltage 20 / 25 kV

1.1.1 1.1.2	JNR 20 kV ac		JNR 25 kV ac	
	substation BT system	substation AT system	substation BT system	substation AT system
	50/ 60 Hz	-/-	60 HZ	50 / 60 Hz
1.1.3 1.1.4.	16 kV - 22 kV 20 kV - 22 kV		22.5 kV - 30 kV 24.7 kV - 30 kV	
1.1.5	4 Ω - 10 Ω	12 Ω - 29 Ω	2 Ω - 4 Ω	6 Ω - 7 Ω
1.1.6 1.1.7	r = 0.286 Ω/km l = 2.18 mH/km c = 10 nF/km 20.8 km - 49.7 km	r = 0.111 Ω/km l = 0.56 mH/km c = 6 nF/km 84.3 km - 108.5 km	r = 0.286 Ω/km l = 2.18 mH/km c = 10 nF/km -/- - -/-	r = 0.111 Ω/km l = 0.56 mH/km c = 6 nF/km 30.9 km - 58.6 km
1.1.8	unknown	300 Ω	unknown	300 Ω
1.1.9	ac substation voltage regulator consisting of voltage regulators, tap-changing thyristor switches, a series-connected output transformer and a central controlling thyristor switch, compensation by sum and difference of the transformer taps when 8 thyristor switches are operated if necessary			
1.1.10	inverters tentatively used, on lines on which regenerative braking is used filters abate inductive interferences			
1.1.11	parallel condensers connected to the substations			
1.1.12	overhead			
1.1.13	P = 1840 kW for two car unit, traction motor 230 kW, SEA dynamic brake or electric signal air brake, Imax,in = 750 A/train, trains of 12 cars			
1.2.1	no			
1.2.2	conform to narrow-gauge and Skinhansen line standards			
2.1.1	-/-			
2.1.2	voltage of 8U in the series reactor and 2 U at the condenser, when the parallel condenser circuit is turned on			
2.1.3	failures when one silicon rectifier had been working and another was started to work			
2.1.4	-/-			
2.1.5	-/-			
2.1.6	detection : 40 ms - 200 ms, to clear : 30 ms - 100 ms			
2.2.1.1	primary-side neutral of the transformer not grounded for special high voltage network (Scott-connection transformer) and direct-grounded for extra high voltage network (modified Woodbridge connection transformer)			
2.2.1.2	unknown			
2.2.1.3	see 2.1.2			
2.2.1.4	yes, but series reactor usually connected to the negative side of the recti-fier and thereby suppressing the harmonics, in case of a 6-pulse rectifier the shunts are provided for the 6th, 12th and 18th harmonics			
2.2.1.5	yes, but series elements with static capacity C, resistance R may be provided between trolley and rail			
2.2.1.6	no ; no			
2.2.1.7	parallel condensers are disconnected in case of no load (night)			
2.2.1.8	-/-			
2.2.1.9	no			
2.2.2.1	disconnected at limit voltage of arrester and below			
2.2.2.2	interrupted at limit voltage of arrester and below			
2.2.2.3	-/-			
2.2.2.4	yes, but practically no influence, because of small capacitance			
2.2.2.5	-/-			
2.2.2.6	unknown			
2.2.2.7	unknown			
2.2.2.8	no			
2.2.3.1	gapped and gapless ligthning arresters with protection level narrow-gauge 105 kV , Skinhansen 140 kV booster transformer auto-transformer series condenser			
	in substation lightning arrester 28 kV, surge at 90 kV and below	in substation lightning arrester 56 kV, surge at 179 kV and below	in substation lightning arrester 42 kV, surge at 135 kV and below	in substation lightning arrester 84 kV, surge at 267 kV and below
2.2.3.2	standard insulating strength 150 kV		standard insulating strength 200 kV	
3.1	arrester 80 kV, surge 84 kV and below		arrester 120 kV, surge 120 kV and below	
3.2	surge tests for main transformers (full wave and chopped wave test and commercial frequency test voltage)			
3.3	commercial frequency test 50 kV full wave 120 kV chopper wave 140 kV		commercial frequency test 70 kV full wave 175 kV chopper wave 200 kV	
3.4 - 3.6	-/-			

Annex E

Table E4: Legend and Annotations to Tables E1 to E3

legend

-/-	question was not answered
unknown	answer cannot be given exactly , because of data-lecking or other reasons
P	rated power
U	rated voltage
Imax, in	maximum input or traction current
Imax, br	maximum braking current

annotations

1) given values for r and l depend on return current path and type of track, see Table E5

2) -transformers for on-board voltage step-type control
-transformers with auxiliary winding for voltage chopper control
-controlled voltage adding units for d.c substations
-controlled thyristor converters
-devices for longitudinal capacity compensation of a.c. systems
-controlled devices for transverse capacity compensation
-compensated converting sets

3) hvn : high/very high voltage network
mvn : medium voltage network
lvn : low voltage network

Table E5: Loop Impedance Values (Question 1.1.6) / UNITED KINGDOM (25 kV/50 Hz)

return current path	loop impedance for parallel energized tracks (Ω/km), 50 Hz		
	single track	two track	four track
rail return	0.185 + j 0.479	0.100 + j 0.293	0.054 + j 0 166
return conductor only	0.178 + j 0.423	0.094 + j 0.242	0.051 + j 0.137
booster transformers with return conductor (excluding booster transformer impedance)	0.266 + j 0.712	0.133 + j 0.366	0.088 + j 0.242

Annex E

Table E6: Electrical characteristics of some traction vehicle types / CHINA (25 kV / 50 Hz) Reference: Question 1.1.13

type of electric locomotive	rated power kW	maximum input current by traction/braking A	auxiliary converter type Arno A	quantity of electric locomotives in a train composition
SS 1 Type	3780	231 / <20	11	1 to 3
SS 2 Type	4350	277 / <20	12.8	1 to 2
SS 3 Type	6400	2x190 / < 2x15	10	1

Table E7: Electrical characteristics of some traction vehicle types / FRANCE (25 kV / 50 Hz) Reference: Question 1.1.13

type of engin	year	rated power kW	maximum input current A	maximum braking current A	traction equipment
BB 15001-67	1971	4400	300	100	thyristor bridge and mixed bridge in serie + dc current motor
BB 22201-405	1976	4400	300	without	transformer + mixed bridge + dc current motor
TGV-PSE 2 motor-carriages per train	1981	6450 per train	370	without	on ac lines different from L.G.V. power is limited to 2650 kW
TGV-A 2 motor-carriages per train 73 train in service	1988	8800 per train	490 per train	without	2 mixed bridges in series + ondulator + synchron motors - power limitation on classical ac lines

Annex E

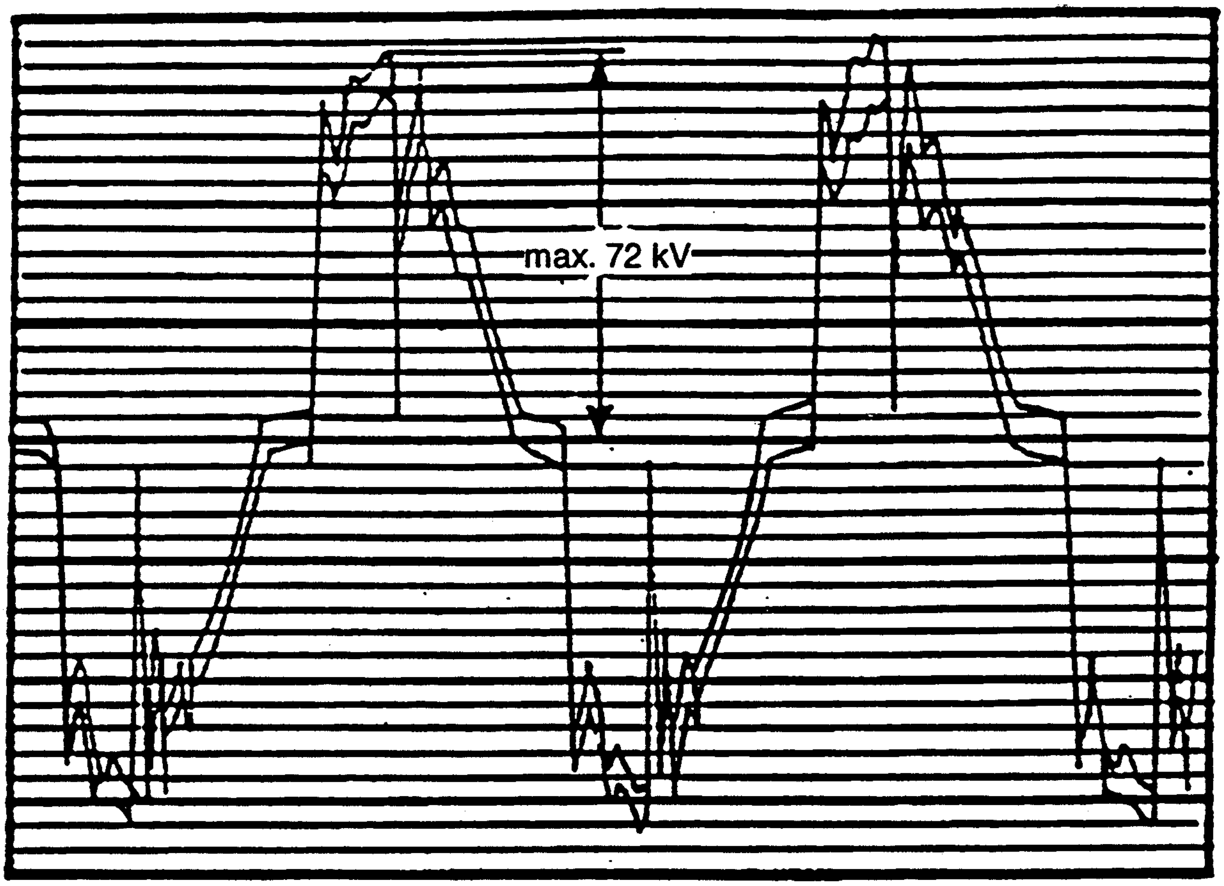

Figure E1: Overvoltages in 25 kV / 50 Hz traction power supply

Source: FRANCE / SNCF

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Annex E

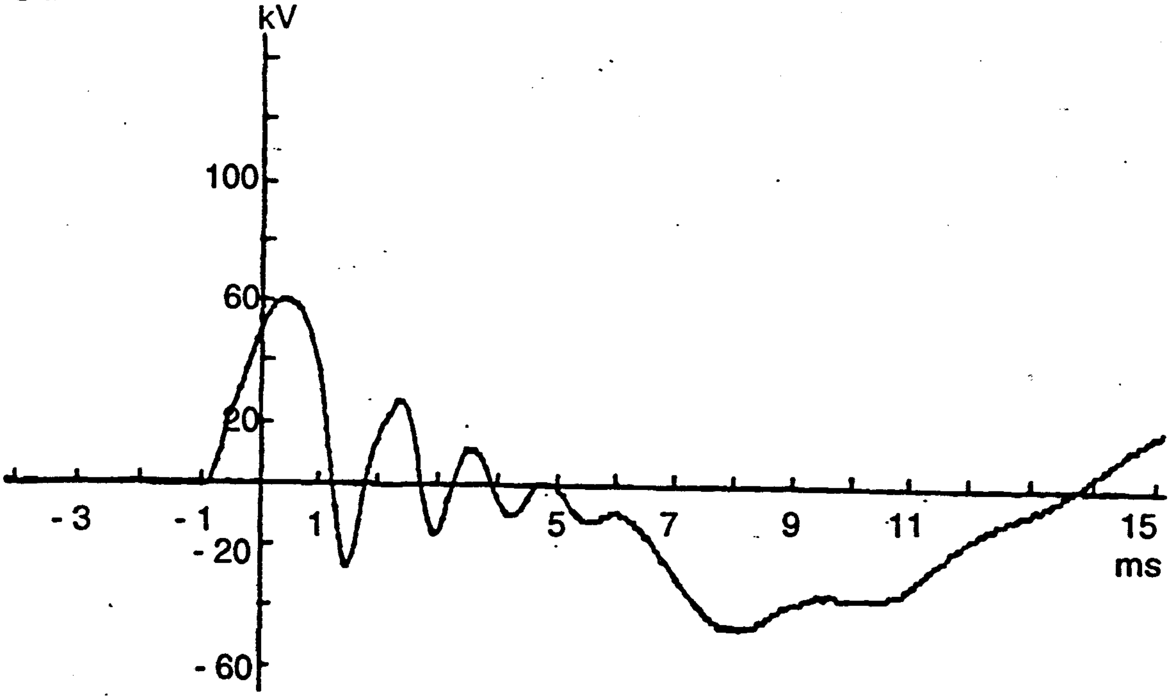

Figure E2: Overvoltages in 25 kV / 50 Hz traction power supply

Source: UNITED KINGDOM / BR
Switching surge

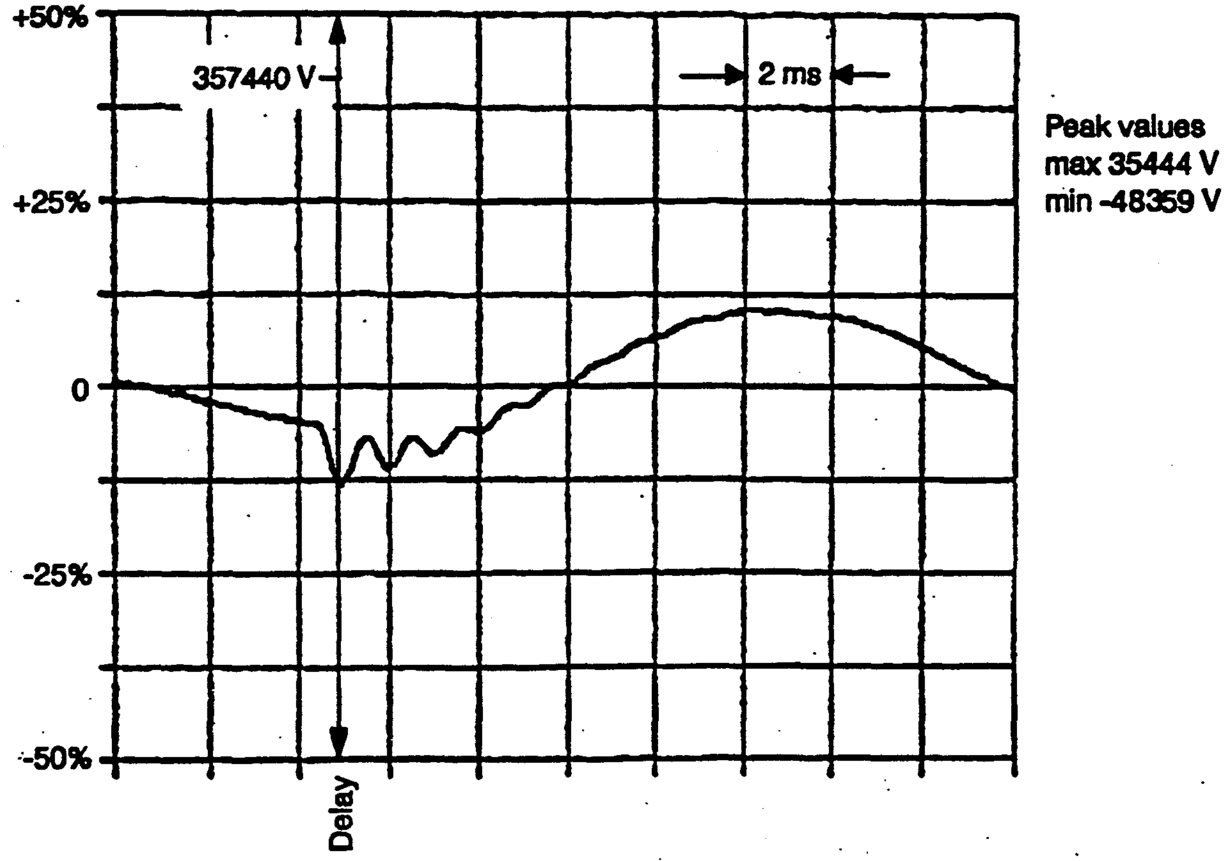

Figure E3: Overvoltages in 25 kV / 50 Hz traction power supply

Source: UNITED KINGDOM / BR
Surge superimposed 50 Hz voltage

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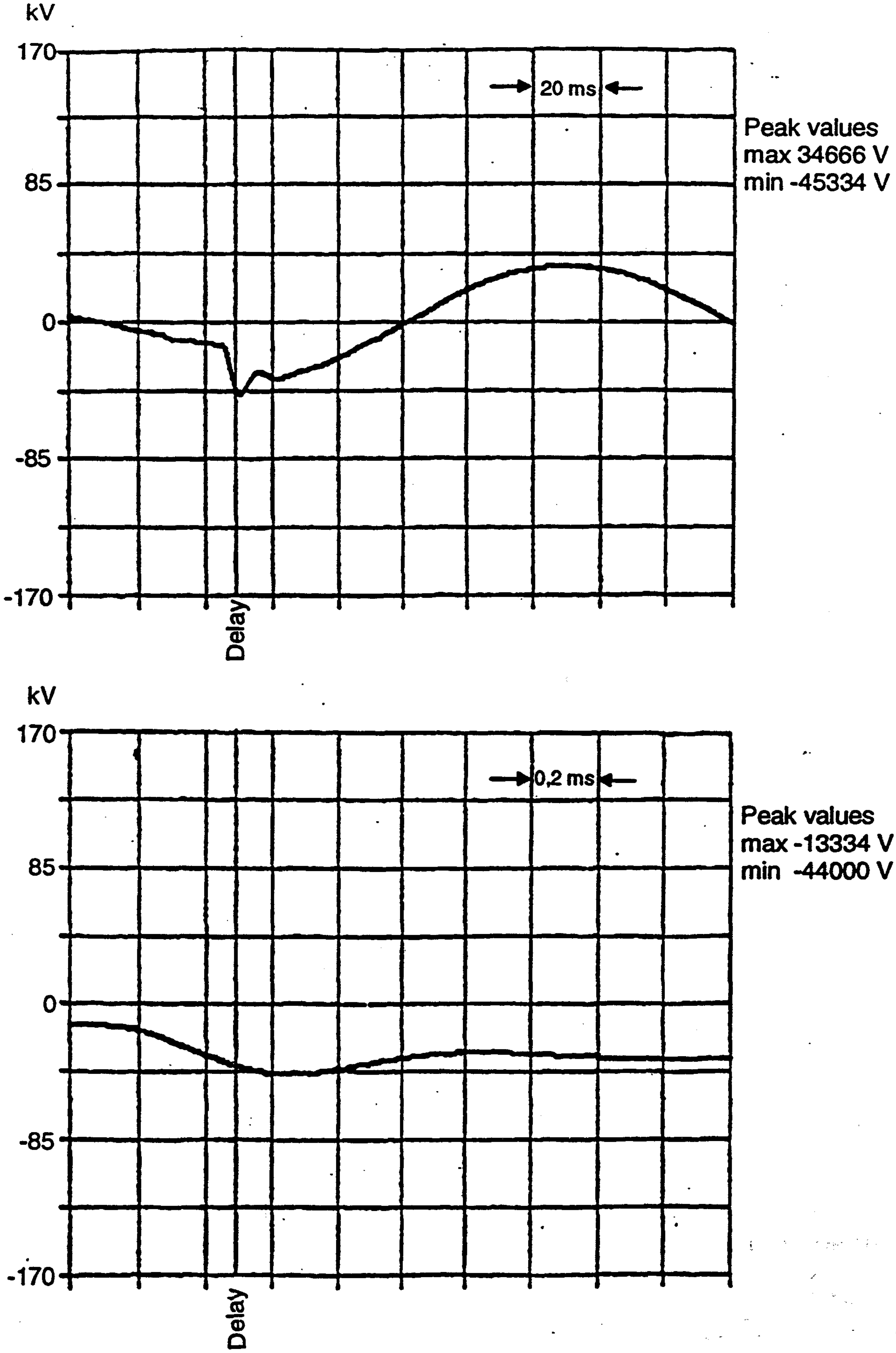

Figure E4: Overvoltages in 25 kV / 50 Hz traction power supply

Source: UNITED KINGDOM / BR

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