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TECHNICAL
REPORT**

**CEI
IEC
61374**

Première édition
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1997-04

**Surintensités dans les systèmes
d'alimentation de la traction**

**Overvoltages in traction
supply systems**



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- **Bulletin de la CEI**
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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*.

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and for medical electrical equipment,

- IEC 60878: *Graphical symbols for electro-medical equipment in medical practice*.

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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**

**TECHNICAL
REPORT – TYPE 3**

**CEI
IEC**

61374

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Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

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- A Answers to d.c. systems with nominal voltage 600 V, 630 V, 660 V, 750 V, 800 V
- B Answers to d.c. systems with nominal voltage 1,5 kV
- C Answers to d.c. systems with nominal voltages 3 kV, 3,3 kV
- D Answers to a.c. systems with nominal voltages 15 kV/16^{2/3} Hz, 12 kV/25 Hz
- E Answers to a.c. systems with nominal voltage 25 kV, 50 Hz

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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.
- 2) Les décisions ou accords officiels de la CEI concernant les questions techniques représentent, dans la mesure du possible un accord international sur les sujets étudiés, étant donné que les Comités nationaux intéressés sont représentés dans chaque comité d'études.
- 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.
- 4) Dans le but d'encourager l'unification internationale, les Comités nationaux de la CEI s'engagent à appliquer de façon transparente, dans toute la mesure possible, les Normes internationales de la CEI dans leurs normes nationales et régionales. Toute divergence entre la norme de la CEI et la norme nationale ou régionale correspondante doit être indiquée en termes clairs dans cette dernière.
- 5) La CEI n'a fixé aucune procédure concernant le marquage comme indication d'approbation et sa responsabilité n'est pas engagée quand un matériel est déclaré conforme à l'une de ses normes.
- 6) L'attention est attirée sur le fait que certains des éléments de la présente Norme internationale peuvent faire l'objet de droits de propriété intellectuelle ou de droits analogues. La CEI ne saurait être tenue pour responsable de ne pas avoir identifié de tels droits de propriété et de ne pas avoir signalé leur existence.

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.

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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.

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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.

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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.

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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 compiled 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*

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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;
- capacité 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 through 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 μ s, 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 μ s.

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 μ s, 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 μ s 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.

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

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

[illegible]

:- question was not answered
:- answer cannot be given exactly , because of data-lecting or other reasons
:- unknown
:- U
:- P
:- I_{max} , in
:- I_{max} , br
:- maximum input or traction current
:- maximum braking current
:- rated voltage
:- rated power
:- because of data-lecting or other reasons
:- question was not answered

1) classical equipment without regenerative braking and with rheostatic controlled starting
 $P = 1100 \text{ kW/train}$
 $I_{\max} = 1450 \text{ A/train}$
 auxiliary converter 40 A/train
 equipment with regenerative braking and with rheostatic controlled starting
 $P = 1590 \text{ kW/train}$
 $I_{\max} = 3000 \text{ A/train}$
 auxiliary converter 60 A/train

2) per vehicle unit

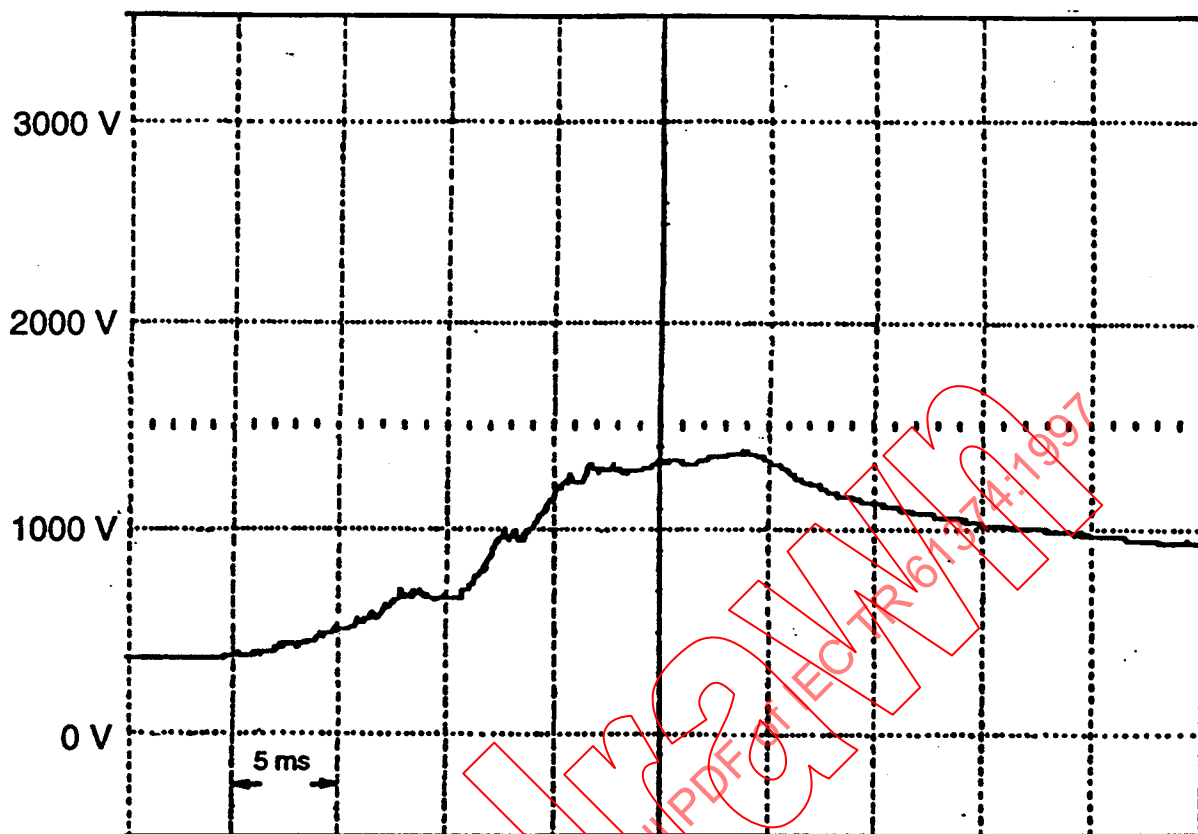


Figure A1: Overvoltage in 630 V traction power supply

Source: London Underground / UNITED KINGDOM

Switching overvoltage created by an eight-car train of A60/62 stock,
shutting off at maximum traction current

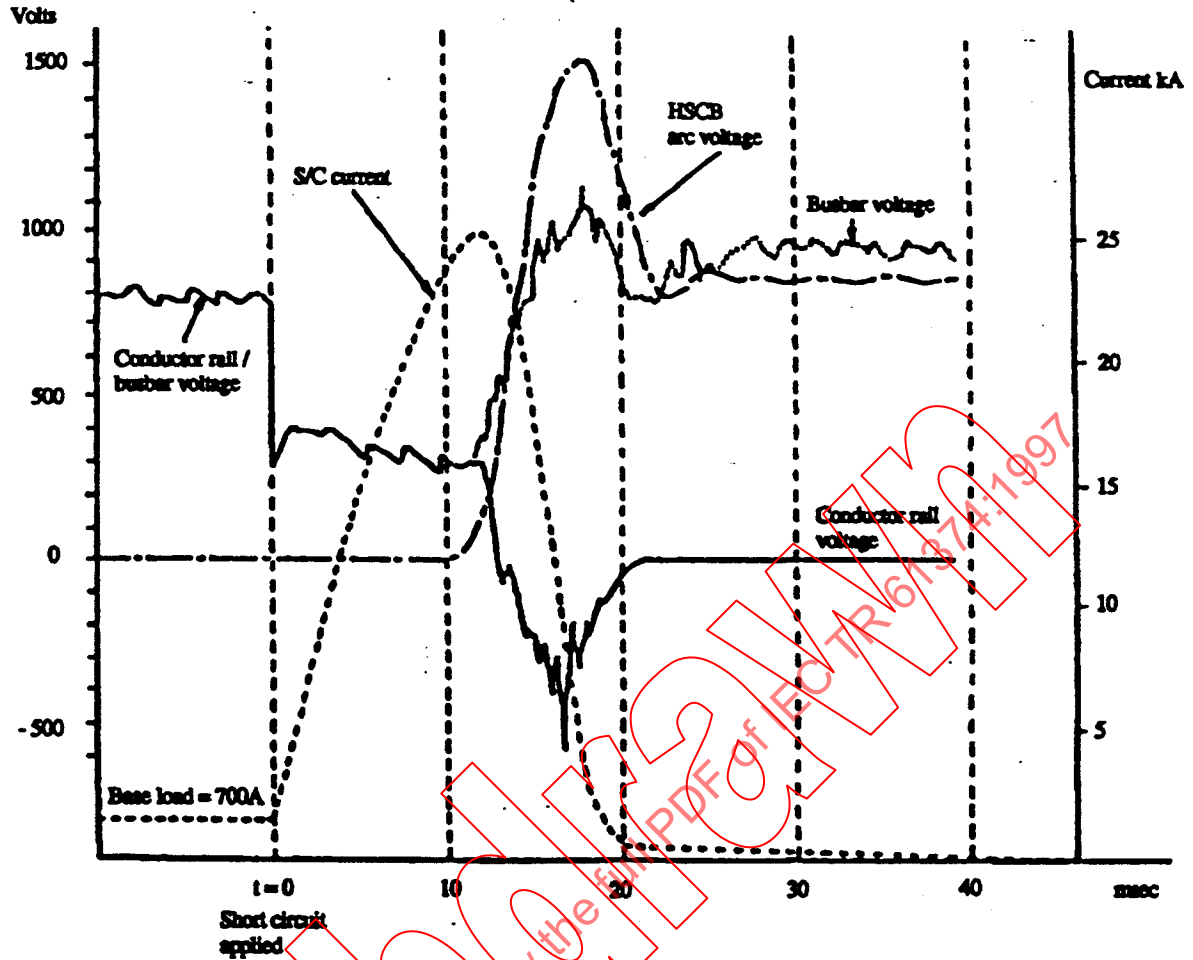


Figure A2: Current / Voltage Profiles of a 750 V Traction Power Supply

Source: British Railways / UNITED KINGDOM

H.S.C.B. Clearance of short circuit applied adjacent to
750 V, 2.5 MW rectifier substation

Prospective current ≈ 45 kA

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)						
1.1.2	1.5 kV dc	SNCF/RATP	SNCF/RR	A.T.M.	JRG (former JNR)	NS	Tyne and Wear Metro
1.1.3	1000 V - 1800 V	1.5 kV dc	1.5 kV dc	1.5 kV dc	1.5 kV dc	1.5 kV dc	1.5 kV dc
1.1.4	1500 V - 1740 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
1.1.5	1500 V - 1740 V	1500 V - 1740 V	1510 V - 1600 V	-/-	1220 V - 1700 V	-/- - 1875 V	-/- - 1900 V
1.1.6	15 - 45 mΩ	15 - 45 mΩ	0.03 Ω	-/-	-/-	20 - 150 mΩ	25 mΩ - 113 mΩ,
1.1.7	$r = 65 \text{ m}\Omega/\text{km}$	$r = 23 - 28 \text{ m}\Omega/\text{km}$	$r = 23 - 28 \text{ m}\Omega/\text{km}$	$r = 70 \text{ m}\Omega/\text{km}$	$r = 33.3 \text{ m}\Omega/\text{km}$	$r = 35 - 50 \text{ m}\Omega/\text{km}$	$r = 104 - 122 \text{ m}\Omega/\text{km}$
1.1.8	$l = 1.5 \text{ mH}/\text{km}$	$l = 1.2 \text{ mH}/\text{km}$	$l = 1.2 \text{ mH}/\text{km}$	$l = 2 \text{ mH}/\text{km}$	$l = 0.9 - 1.1 \text{ mH}/\text{km}$	$l = 0.65 - 1 \text{ mH}/\text{km}$	$l = 0.2 + j 0.5 \Omega''$
1.1.9	$c = 18 \text{ nF}/\text{km}$	$c = 18 \text{ nF}/\text{km}$	$c = 18 \text{ nF}/\text{km}$	$c = 18 \text{ nF}/\text{km}$	$c = 18 \text{ nF}/\text{km}$	$c = 15 \text{ nF}/\text{km}$	$c = 15 \text{ nF}/\text{km}$
1.1.10	8 km - 30 km	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
1.1.11	-/-	-/-	transformer taps	-/-	-/-	-/-	not applicable
1.1.12	transformer taps	transformer taps	transformer taps	-/-	thyristor rectifier, transformer	thyristor rectifier, transformer	on-load tap changers,
1.1.13	inverter	inverter	no	no	inverters	not applicable	manual tap changing
1.1.14	overhead	overhead	overhead	overhead/third rail	overhead	overhead	no
1.1.15	equipment with and without regenerative braking, see Table B4	equipment with and without regenerative braking, see Table B4	equipment with and without regenerative braking, see Table B4	rheostatic controlled starting	no	no regenerative braking, electrical locomotives do not	in substations 1, 2 or 3
1.1.16	braking, see Table B4	braking, see Table B4	braking, see Table B4	rheostatic controlled starting	no	ride multiple, maximum of	rectifiers 90.9 A or
1.1.17				converter 28 A, train composition: 4 motor carriages + 2 trailers	no	coupled railcars 7 for 2-articulated train sections and	126.4 A, ratings 1000 W
1.1.18				$I_{\text{max, in}} = 600 \text{ A}/\text{motorcar}$	no	5 for 3-articulated train sections, $I_{\text{max, in}} = 4000 \text{ A}$,	or 1500 W operating singly or in pairs, outer bogies
1.1.19				$I_{\text{max, br}} = 350 \text{ A}$	no	auxiliary rotating converter 13.3 A and electronic converter 26.6 A	motored, $P = 187 \text{ kW}$, 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	-/-	-/-	-/-	overvoltage 2000 V with a duration about 20 - 30 ms	overvoltage 2430 V at mid-point 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

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

2.1.3	-/-		damages on transformers in fixed installations by lightnings yes	cable damage caused by a category overvoltage, in fixed installations damages by lightnings yes	-/-	failures when one silicon-rectifier had been working and another was started to work -/- see Figure B1 detection: 40 - 200 ms clear: 30 - 100 ms	this seldom appears yes -/- -/-	-/- yes, particularly during abnormal feeding see Figures D3 / D4 close-up faults 20 ms distant faults up to 75 ms	UNITED KINGDOM
2.1.4	-/-				-/-				
2.1.5	-/-		see Figure B2	exponential form with rising time 50 µs for overvoltage 9 kV, duration 3 ms clear : 5 s	-/-				
2.1.6	-/-				-/-				
2.2.1.1	-/-		-/-	-/-	-/- ; -/-	-/- ; primary side neutral and not grounded -/- -/- -/- yes -/- no ; no parallel condensers are disconnected in case of no load (night) -/- no	-/- ; phase to phase -/- -/- -/- max 900 Vrms at 300 Hz yes ; 1875 V for 5 min -/- -/- switching or control faults of the distribution board in the supply networks	yes ; 1500 V negative not deliberately earthed -/- not applicable -/- not applicable no ; not applicable not applicable not applicable no	
2.2.1.2	-/-		-/-	-/-	-/- ; -/-				
2.2.1.3	-/-		-/-	-/-	-/-				
2.2.1.4	-/-		yes, 300 Hz or 600 Hz	yes, 300 Hz , 600 Hz, 900 Hz depending on feeding rectifier	-/-				
2.2.1.5	-/-		-/-	-/-	-/-				
2.2.1.6	-/-		-/- ; -/-	no ; no	-/- ; -/-				
2.2.1.7	-/-		-/-	-/-	-/-				
2.2.1.8	-/-		-/-	-/-	-/-				
2.2.1.9	-/-		-/-	-/-	-/-				
2.2.2.1	-/-		-/-	-/-	-/-	yes, at limit voltage of arrester and below yes, at limit voltage of arrester and below	-/-	not applicable	
2.2.2.2	-/-		yes	yes, see 2.1.1.2	-/-		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 not applicable not applicable	
2.2.2.4	-/-		-/-	-/-	-/-	no influence (small capacity)	yes yes		
2.2.2.5	-/-		-/-	yes, with 2 trains on distinct rails when one of them was urgently braking	-/-	-/-	yes -/-	no yes, but only during abnormal feeding no	
2.2.2.6	-/-		-/-	-/-	-/-				
2.2.2.7	-/-		-/-	-/-	-/-				
2.2.2.8	-/-		line defects (picking-up)	-/-	-/-	no			
number		CHINA	FRANCE	FRANCE	ITALY	JAPAN	NETHERLANDS		UNITED KINGDOM

Annex B

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

2.2.3.1	-/-	lightning arresters type GADRAT-SOULE 6 kV, set up in series with a capacitance 40 μ F and a fuse type EMPIRE BAGS, spacing 700 -1500 m 40 kV	-/-	lightning arrester, every 500 m from feeder : types gapped and gapless 28 kV 100 kV	spark-gap with SiC - resis- tance (SOULE cZ) 2 kV, spacing 1500 m 35 KV at 1/50 μ s	surge diverter EMP type MHBM15DC 1.8 kV, spacing 7 km insulator : 60 kV, substa- tion and cable test : 6 kV	
2.2.3.2	-/-		-/-				
3.1	-/-	lightning arresters type SOULE 6 kV for global protection, static con- verters	arresters (one per pantograph) 8.5 kV 1/50 μ s with a dischar- ging current of 10 A	arresters 3 kV 91AM-6Ab-28 with capacitance 4 μ F	capacitor 4 μ F between pantograph and vehicle, ex- cept of "Elok 1600" ha- ving an arrester type SOULE 8500	capacitor ASEA-BICC ty- pe EHJ to BS 1650, 4 μ F working at 3 kV and innu- lated to 22 kV	
3.2	-/-	-/-	dielectric test at 5750 V and test of devices at 4900 V for 1 min	Insulation resistance mea- surement at 2.5 kV: ≥ 1 M Ω IEC 9-10(IV-1967)	hand-cranked generator over- voltage test ("Megger")	flash test for resistance banks at 5 kV, Megger tests for cables and other components	
3.3	-/-	-/-	-/-	-/-	-/-	yes, but only during ab- normal feeding	
3.4	-/-	-/-	-/-	-/-	no, at voltage 1875 V the rolling stock shall work normally	no	
3.5	-/-	-/-	-/-	-/-	-/-	no	
3.6	-/-	-/-	-/-	-/-	-/-	no	
number	CHINA	FRANCE	FRANCE	ITALY	JAPAN	NETHERLANDS	UNITED KINGDOM

legend

-/- : question was not answered
unknown : answer cannot be given exactly, because of data-lacking 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 BB 22201 - 405	1969 1976	5500 4400	4000 4200	without without	rheostatic controlled locomotive transformer + mixed bridge + rectifier + dc current motors
BB 7201 - 410 BB 7411 - 440	1976 1986	4400 4400	4200 4200	without 1400	rectifier + dc current motors 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

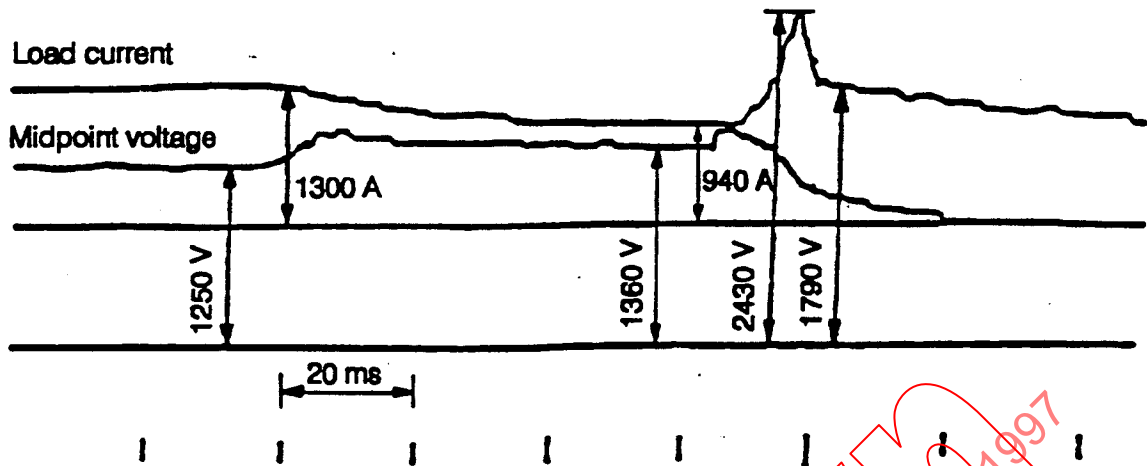


Figure B1: Overvoltage in 1,5 kV DC traction power supply

Source: JAPAN

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

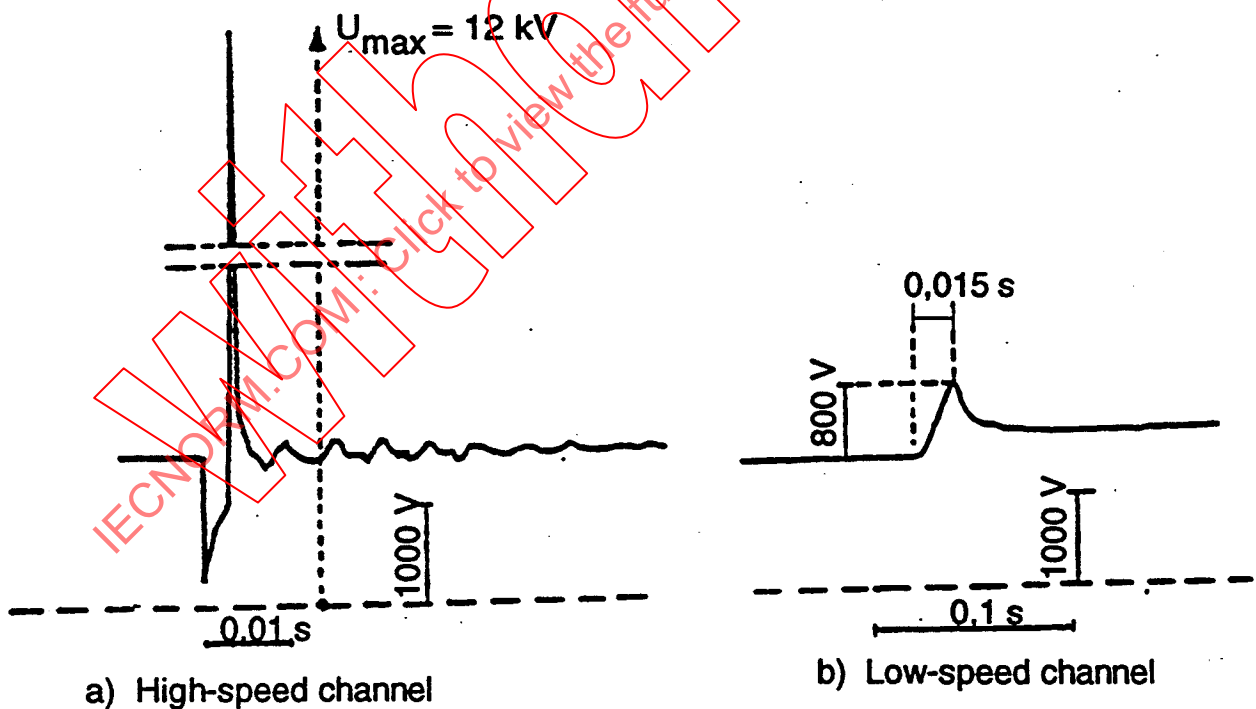


Figure B2: Overvoltages on a 1,5 kV DC power supply line

Source: RATP / SNCF / FRANCE

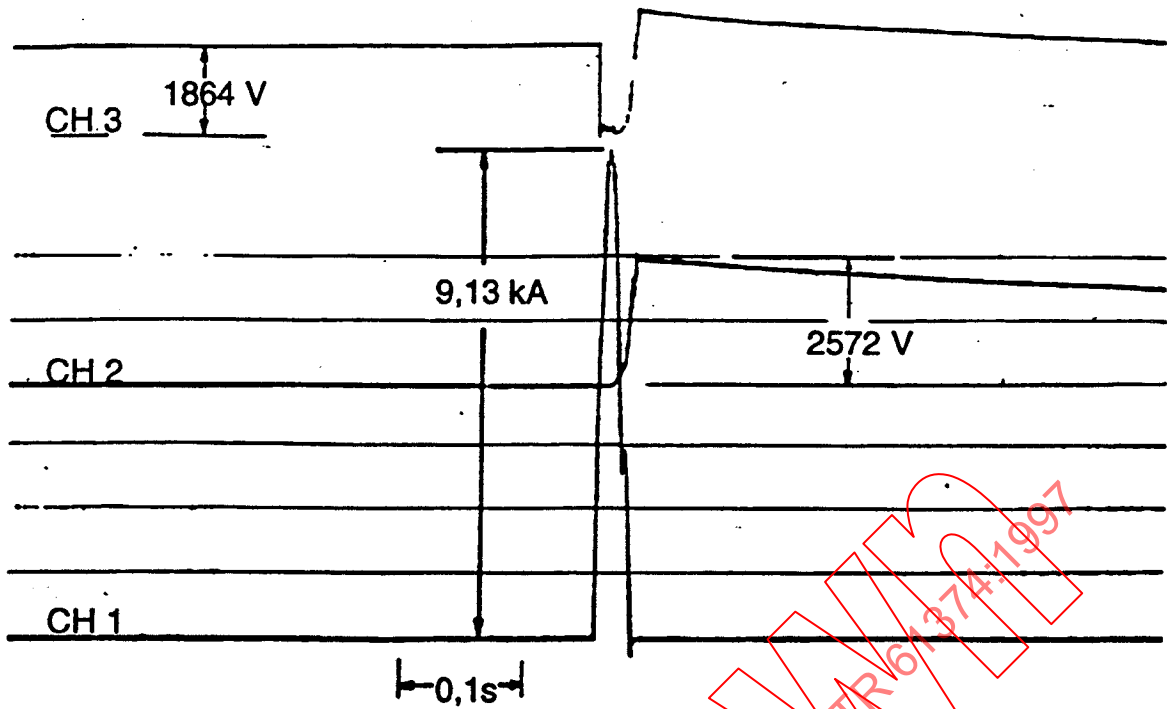


Figure B3: Overvoltage in 1,5 kV DC traction power supply

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

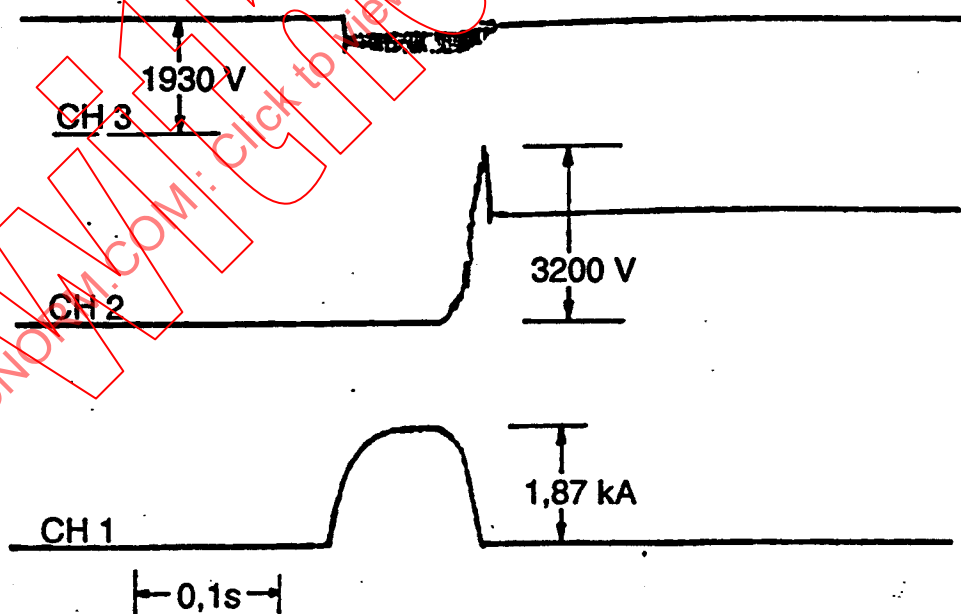


Figure B4: Overvoltage in 1,5 kV DC traction power supply

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

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 de	3 kV de	3.3 kV de	3 kV de	3 kV de
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	2.0 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	$r = 0.05 \Omega/\text{km}$	$r = 0.048 - 0.06 \Omega/\text{km}$	$r = 0.043 \Omega/\text{km}$	$r = 0.062 - 0.112 \Omega/\text{km}$	$r = 0.034 - 0.067 \Omega/\text{km}$	-/-
1.1.7	$l = 1.5 \text{ mH/km}$	$l = 0.73 - 1.94 \text{ mH/km}$	$l = 1.3 - 1.4 \text{ mH/km}$	$l = 1.5 \text{ mH/km}$, 1.8 mH/km	$l = 1.0 - 1.3 \text{ mH/km}$	-/-
1.1.8	c unknown	c = 15 - 24 nF/km	c = 11 - 12 nF/km	c unknown, but surely small	c unknown	-/-
1.1.9	5 - 41 km	15 - 30 km	15 - 40 km	18 - 22 km average maximum 30 km	4.5 - 6 km	-/-
1.1.10	(0.05 + 0.01(rail)) Ω/km	-/-	-/-	-/-	1.17 Ω/km - 1.75 Ω/km	-/-
1.1.11	automatic voltage adjustment under load	transformer taps, ± 10 % and ± 20 %	transformer taps	no	transformers, converters, see annotation	-/-
1.1.12	no	no	no	no	inverters	-/-
1.1.13	overhead	overhead	overhead	overhead	yes	-/-
	-/-	P = 5000 kW per rectifier group, up to 5 groups in a substation, no regenerative braking	rheostatic and regenerative braking, for more information see annotation	P = 1830 - 4480 kW pneumatic and rheostatic, but no regenerative braking	overhead 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	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 mainly isosceles triangle, 5-20 ms duration, 2 - 5 ms	-/-
2.1.5	no	-/-	-/-	unknown	-/-	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	-/-	-/-
2.2.1.1	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

2.2.1.4	no	yes, due to a distortion of feeding voltage of 22 kHz	-/-	yes; the permitted value is 5% for constant and 10% for periodical distortions	-/-	-/-
2.2.1.5	yes	no ; not used	-/-	no	-/-	-/-
2.2.1.6	no ; no	no filters 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 filters used	-/-	no	-/-	-/-
2.2.2.1	no	yes; filter protection at 4.4 kV	-/-	no	no	yes, hurrfullest overvoltages, maximum level 11.4 kV
2.2.2.2	yes	no	yes	yes	-/-	-/-
2.2.2.3	no	no filters used	yes	no	-/-	-/-
2.2.2.4	no	no (on vehicles with pulse converters use of L-C filter)	-/-	no	-/-	-/-
2.2.2.5	yes, but not especially loading of input filters	yes, but very seldom	-/-	yes	yes, but only with transformer in idling conditions	-/-
2.2.2.6	no	no	-/-	yes	-/-	-/-
2.2.2.7	no	yes, during a function of fuses	-/-	yes	-/-	-/-
2.2.2.8	no	no	-/-	no	-/-	-/-
2.2.3.1	arresters, sparkgap 12 kV at spacing 1400 m	surge arrester type QZM or VDM 3.6 with starting voltage in the range 6.4 - 7 kV	insulator flashover "dry wires" surge arresters only in correspondence to substations	lightning arresters level of polish standard BN-75/9317-87 for feeding lines (14 kV), and type QZM-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 nonlinear resistors 4.3 - 6 kV	magnetic-valve type lightning arresters type QZM-4/10 7.5 kV and condenser type lightning arresters 4 µF type KOT, in locomotives EU07 add. tionally double air sparkgap JRG-3 (16 ±0.5) kV according to Polish standard	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 wave-shapes, simulation with inductive circuits	yes	-/-	minimum 20 pulses of both polarities in 1 s intervals
3.3	yes	unknown	no	no, but directives for coordination of insulation design shall be drawn	-/-	-/-
3.4	no	cannot be answered	test at 12 kV for 60 s	no ; no	-/-	-/-
3.5	no ; -/-	cannot be answered	no ; energy level 10 - 35 kJ	no ; no	-/-	-/- ; 0.5CU ¹ (C: capacitance of the object), for maintenance more important near energy level ; total duration and repetition frequency of overvoltage
3.6	no	unknown	no	no	-/-	-/-
number	BELGIUM 3 kV	CZECHOSLOVAKIA 3kV	ITALY 3kV	POLAND 3.3kV	USSR 3kV	YUGOSLAVIA 3kV

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
I _{max} , in	maximum input or traction current
I _{max} , 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 engines -- I _{max,in} = 2000 A -- I _{max,br} = 700 A

Annex C

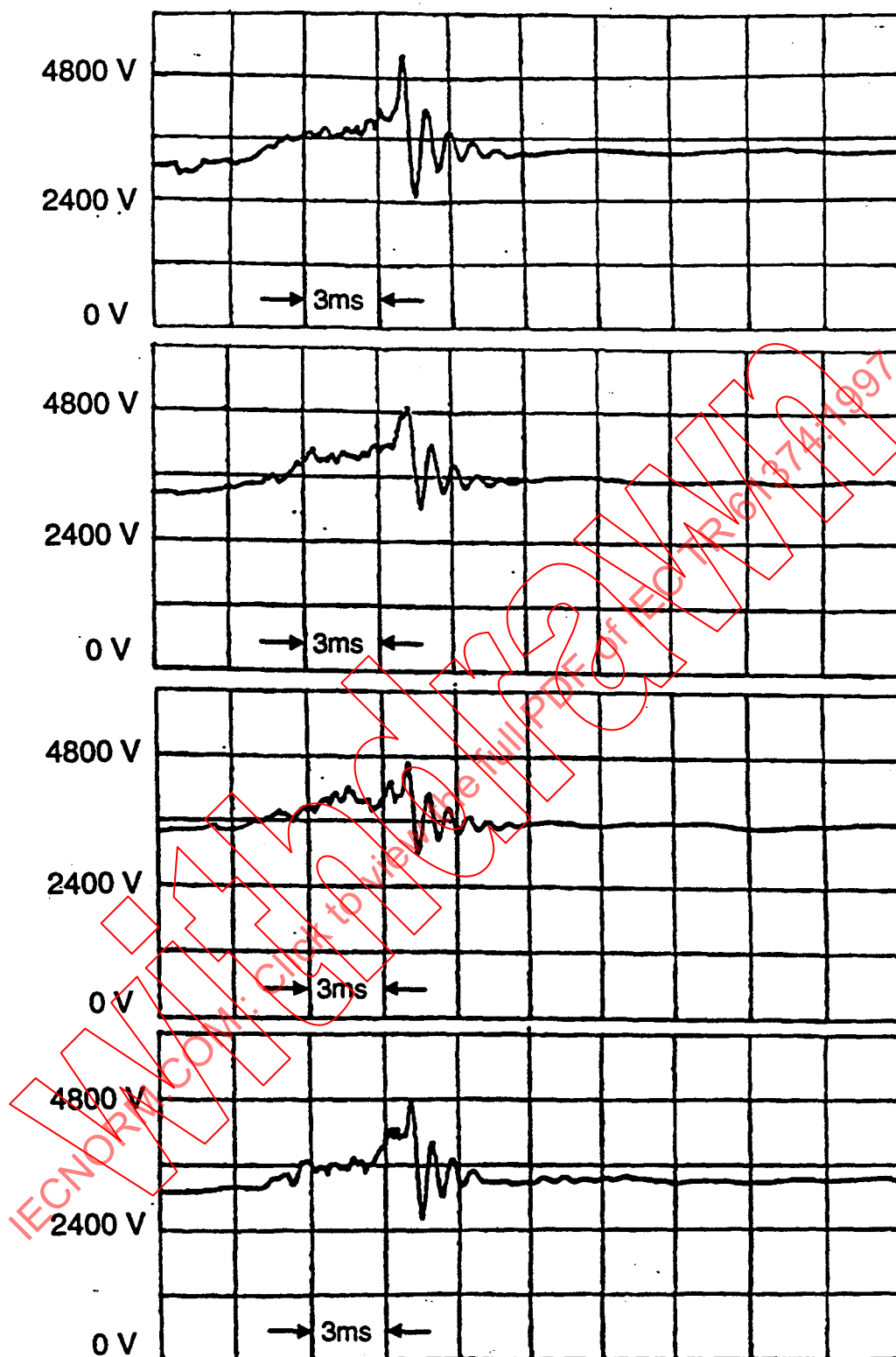


Figure C1: Overvoltages in 3 kV DC traction power supply

Source: YUGOSLAVIA

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	asynchronous 1.0 - 15 Ω	0.7 Ω - 1.4 Ω	from 0.16 Ω + j0.38 Ω	0.33 Ω - 0.8 Ω
1.1.6	r = 86.9 mH/km l = 0.92 mH/km c = 11 nF/km / 20 nF/km ² < 110 km unknown	r = 210 mH/km l = 2 mH/km c = -/- 12 km - 114 km Bergen 4.5 + j4.5 Ω Stavanger 3.54 + j3.54 Ω Gjovik 13.3 + j13.3 Ω Trondheim 7.95 + j7.95 Ω transformer taps and automatic adjustment inverters yes, by phase compensation at Oslo central station	r = 140 - 300 mH/km l = 1.52 - 2.2 mH/km c = -/- 40 km - 160 km open line constant voltage control	r = 110 mH/km double track l = 1 mH/km c = 20 nF/km 20 km - 40 km unknown transformer taps no yes, in great converter-plants possibility of phase-shifting with synchron-generators	r = 140 mH/km l = 1.2 mH/km c = -/- 14 km - 55 km 8 Ω transformer tabs -/- 1 compensation station used, 15 kV - 4 Mvar	r = 173.1 mH/km l = 2.5 mH/km c = unknown 3.58 km - 18.6 km no transformer taps, no load (manual) tap changer no
1.1.7						
1.1.8						
1.1.9	voltage of generator					overhead no regenerative braking, P = 5600 kW, I _{max} = 577 A, I _{max} br = 50 A, composition of 1 or 2 locomotives with 6 or 14 coaches, static, single wave, single thyristor converter, bridge, full wave rectifier 185 A
1.1.10	no	overhead	overhead	overhead	overhead	overhead
1.1.11	local capacitors	for types and characteristics see table 1, distinguishing in locomotives and motor coaches	yes, in connections with static converter stations (integrated with harmonic filter)	yes, in great converter-plants possibility of phase-shifting with synchron-generators	yes, in great converter-plants possibility of phase-shifting with synchron-generators	yes, in great converter-plants possibility of phase-shifting with synchron-generators
1.1.12	overhead	for types and characteristics see table 1, distinguishing in locomotives and motor coaches	no regenerative braking, P = 3600 kW thyristor controlled, I _{max} = 500 A, static auxiliary converter 750 V, 160 V	no regenerative braking in locomotives P = 4650 kW, I _{max} = 530 A, I _{max} br = 220 A, in locomotives with asynchronous motors and converters P = 3200 kW, I _{max} = 290 A, I _{max} br = 200 A and in motor-cars with DC-controlled rectifiers P = 1750 kW, I _{max} = 290 A, I _{max} br = 200 A	no regenerative braking, P = 5600 kW, I _{max} = 577 A, I _{max} br = 50 A, composition of 1 or 2 locomotives with 6 or 14 coaches, static, single wave, single thyristor converter, bridge, full wave rectifier 185 A	no regenerative braking, P = 5600 kW, I _{max} = 577 A, I _{max} br = 50 A, composition of 1 or 2 locomotives with 6 or 14 coaches, static, single wave, single thyristor converter, bridge, full wave rectifier 185 A
1.1.13	rheostatic controlled braking, see table 2					
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	no measurements available	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, 2 periods	-/-
2.1.3	yes, 31 failures by 1000 lightning per year	yes, transformer due to lightning impulses	yes, transformer due to lightning impulses	50 short-circuits per year due to lightning	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 D12	-/-	-/-
2.1.6	total average time for eliminating failures 175 min	output lines from substations have auto-reclosing after 3 s	no measurements available	60 ms - 300 ms depending on overcurrent amplitude	-/-	-/-
2.2.1.1	-/-	not relevant	not applicable	-/-	-/-	phase to neutral, solidly grounded neutral
2.2.1.2	no ; tap changers of transformers are disconnected only under no-load conditions	line is done through rotating conv. principally yes, but the voltage regulator of the converter gives a corresponding limitation	yes, but not 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	-/-	-/-	-/-

Table D2: Answers to AC systems: nominal voltage 15 kV / 16²/₃ Hz | 12 kV / 25 Hz

1017 kV	yes, 5 % rise in voltage not applicable	-/-	-/-
no	-/-	-/-	-/-
no, because frequency is kept constant	-/-	-/-	-/-
no	-/-	-/-	-/-
no filters used	unknown	-/-	-/-
no	unknown	-/-	-/-
no	unknown	-/-	-/-
no	unknown	-/-	-/-
no	unknown	-/-	-/-
no	unknown	-/-	-/-
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 spacing normally > 250 mm, but > 175 mm is permitted	no lightning arresters	-/-	power-frequency withstand voltage 70 kV, impulse withstand voltage 170 kV
arresters XBD 26 or XAD 230 S/XAD 243 24 kV, 55 kV maximum flashover voltage	lightning arrester ASEA type XAD 20S, 60 kV	-/-	new locomotives mostly equipped with metal-oxide arresters type MWA 4 kV, older machines have surge arresters with resistor discs and spark gaps
on traction vehicles no tests performed, high voltage equipment tested by the manufacturer	-/-	-/-	-/-
yes	-/-	-/-	-/-
damage by overvoltage should be limited to break down the arrester itself	-/-	-/-	-/-

Annex D

Table D3: Legend and Annotations to Tables D1 and D2

legend

question was not answered
answer cannot be given exactly, because of data-lacking or other reasons
rated power
rated voltage
maximum input or traction current
maximum braking current

annotations

1)
2)

for single line
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
EI 11	40	1676	140	no	passenger train :	
EI 12	7	2400	200	no	1 locomotive and 3 to 14 coaches	3 locomotives per train (Ore-train locomotive)
EI 13	37	2650	220	no		
EI 14	31	5082	450	no		
EI 15	6	5406	500	no	freight train :	2 locomotives per train (Ore-train locomotive)
EI 16	17	4400	550	no	1 to 2 locomotives	
EI 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	-/-	conventional locomotives with rheostatic controlled starting, with rheostatic braking
110/111/112	3620	480	-/-	
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

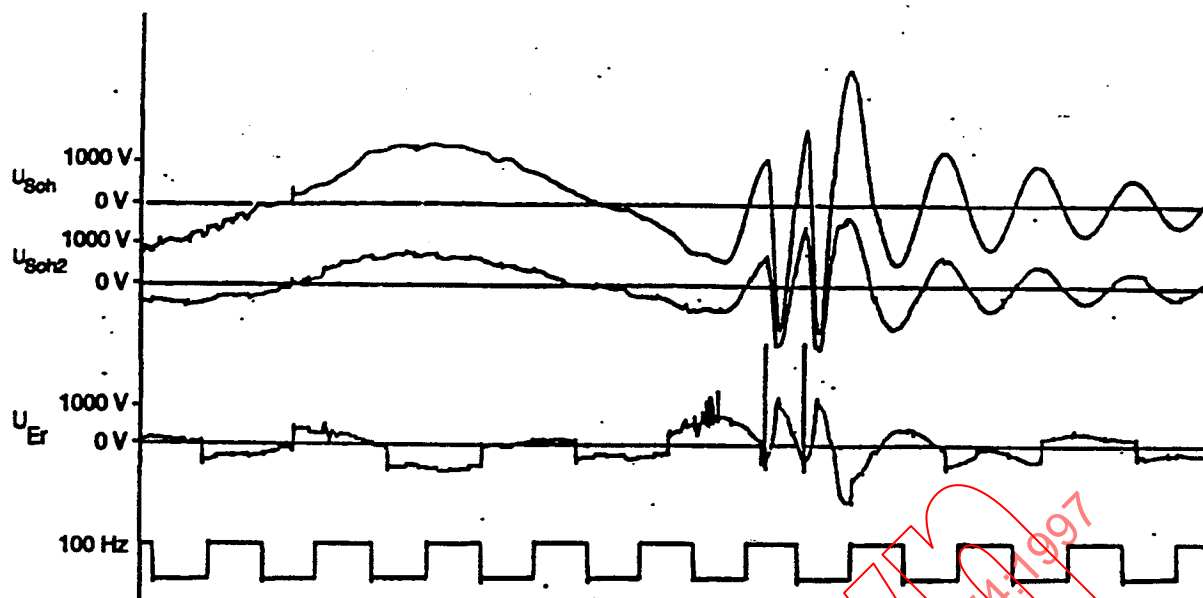


Figure D1: Overvoltages at the terminals of a load

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

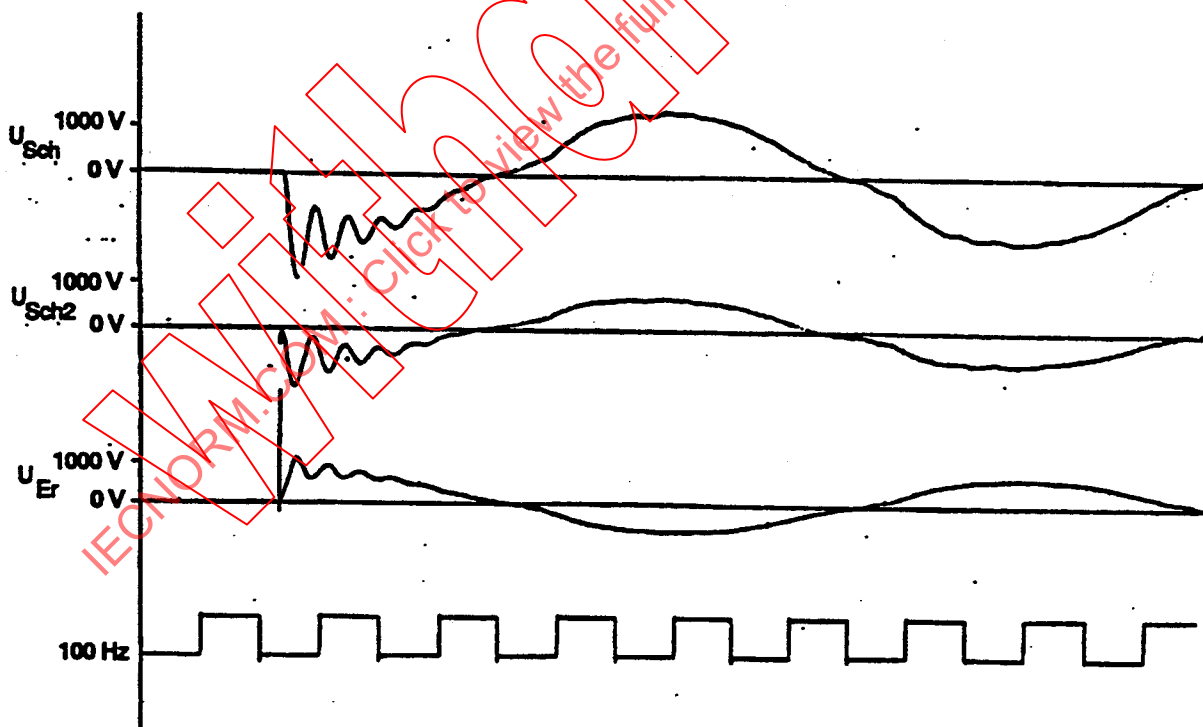


Figure D2: Overvoltages at the terminals of a load

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

Annex D

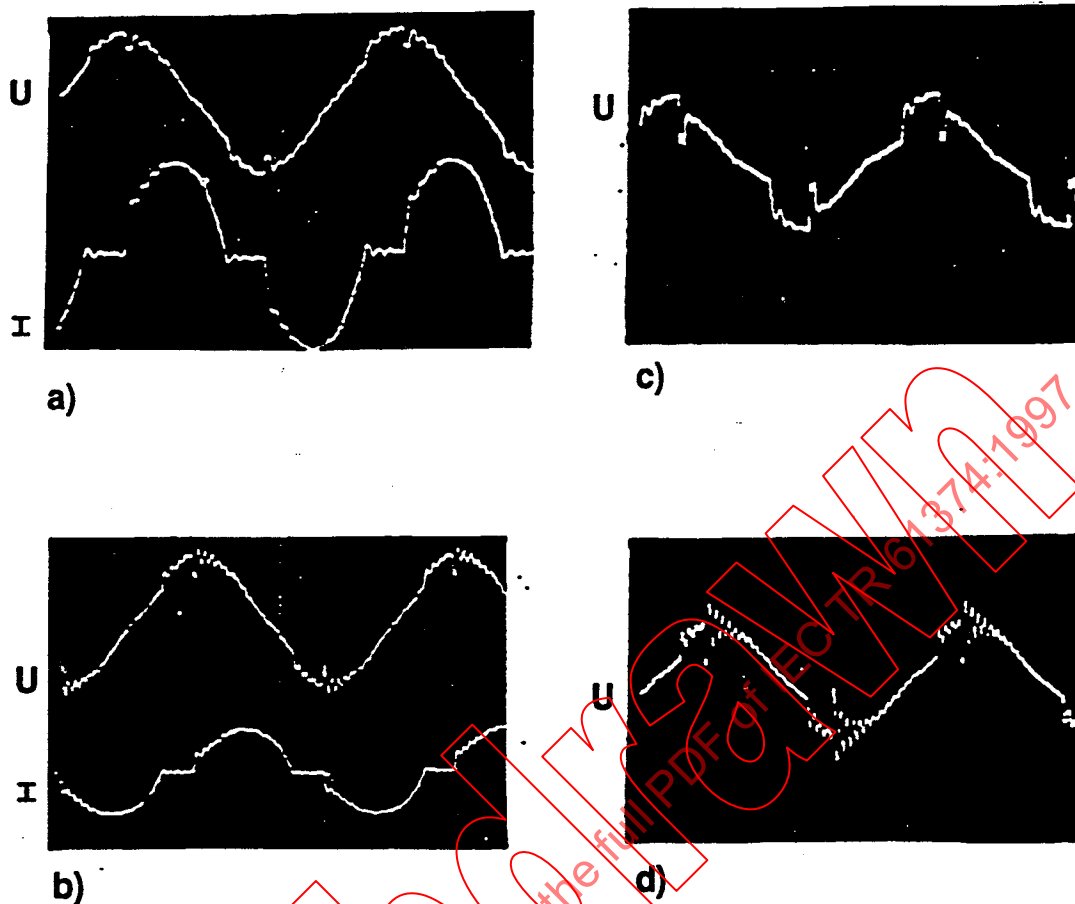


Figure D3: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB

a) measured at transformer-substation

$U = 15 \text{ kV}$ $I = 400 \text{ A}$

b) measured at transformer-substation

$U = 15 \text{ kV}$ $I = 800 \text{ A}$

c) + d) measured at end of line

$U = 16,1 \text{ kV}$

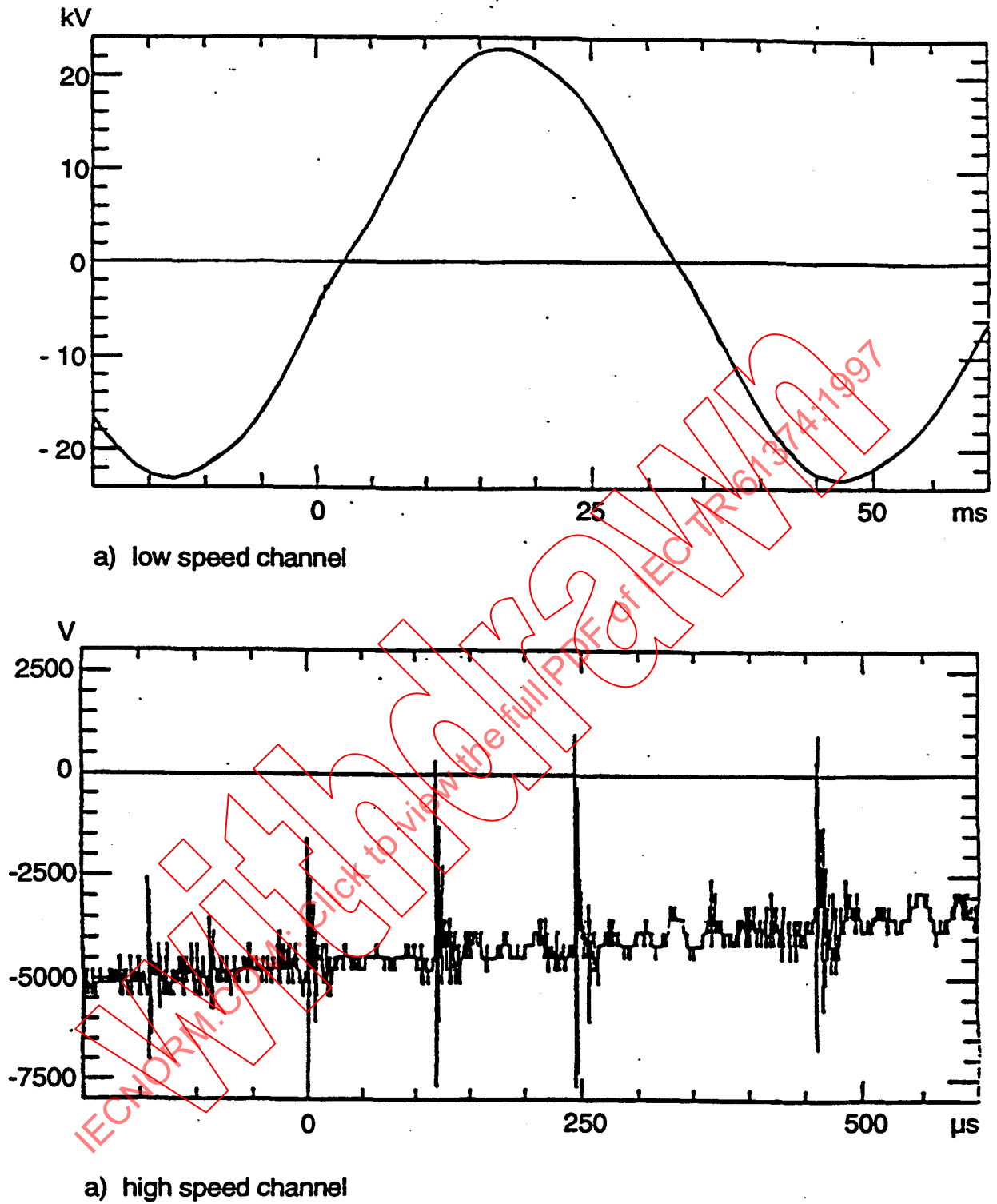
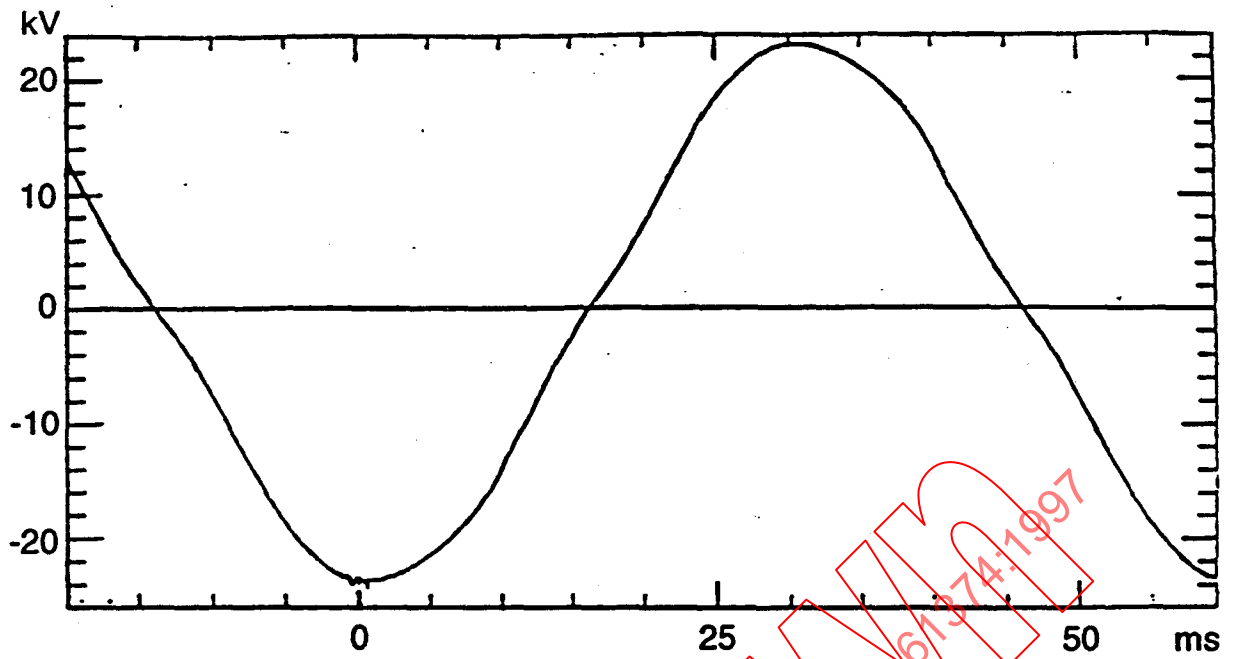
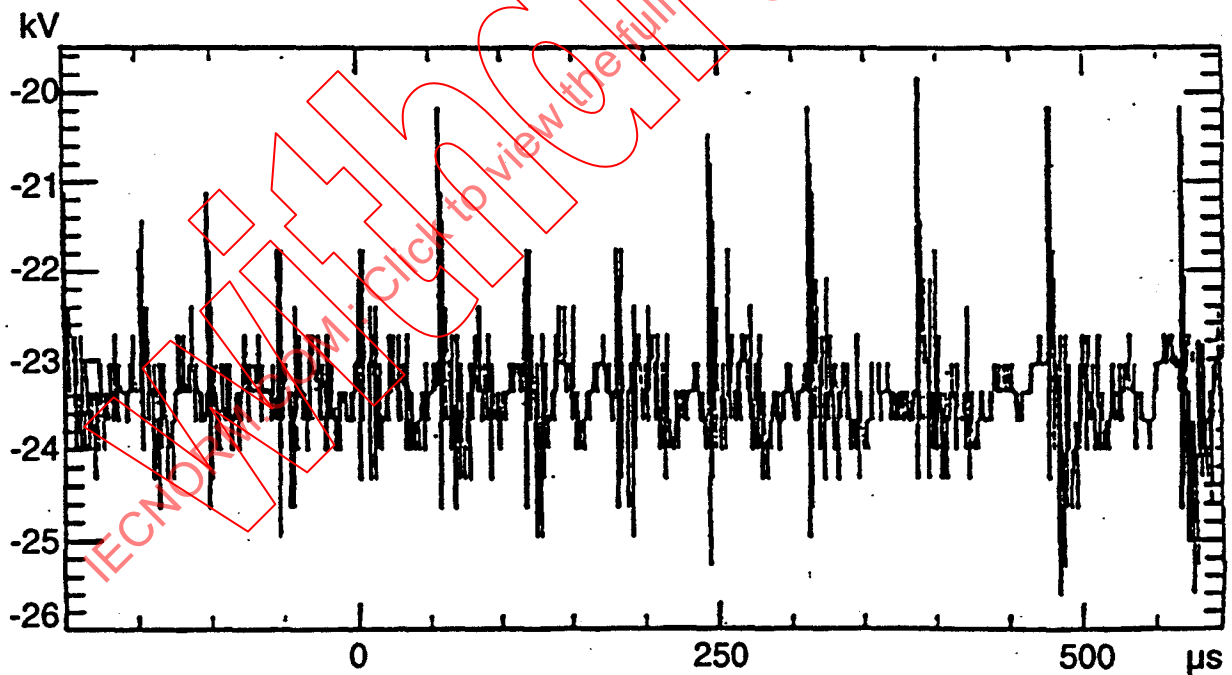


Figure D4: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB



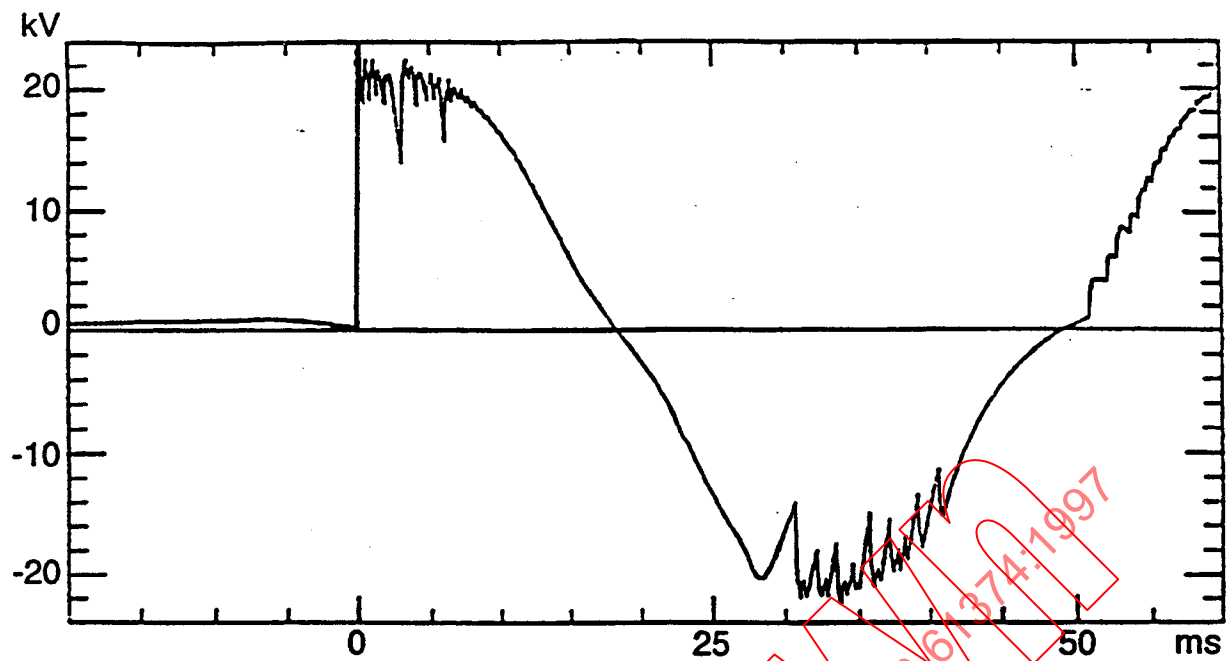
a) low speed channel



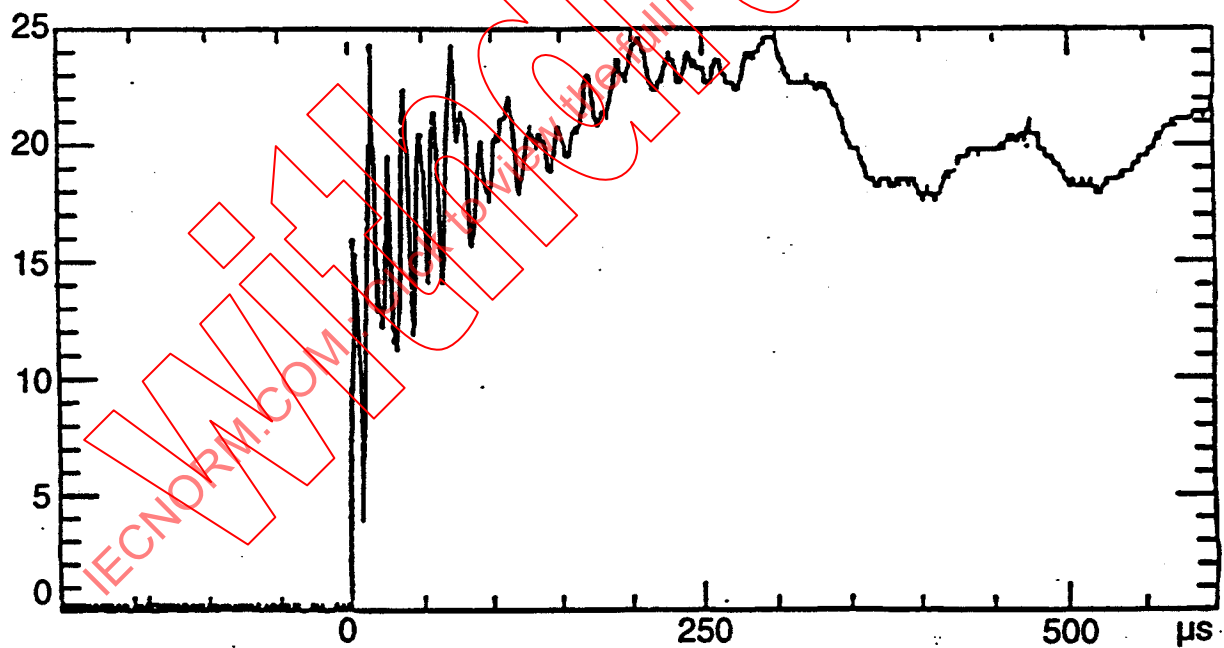
b) high speed channel

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

Source: SWITZERLAND / SBB



a) low speed channel

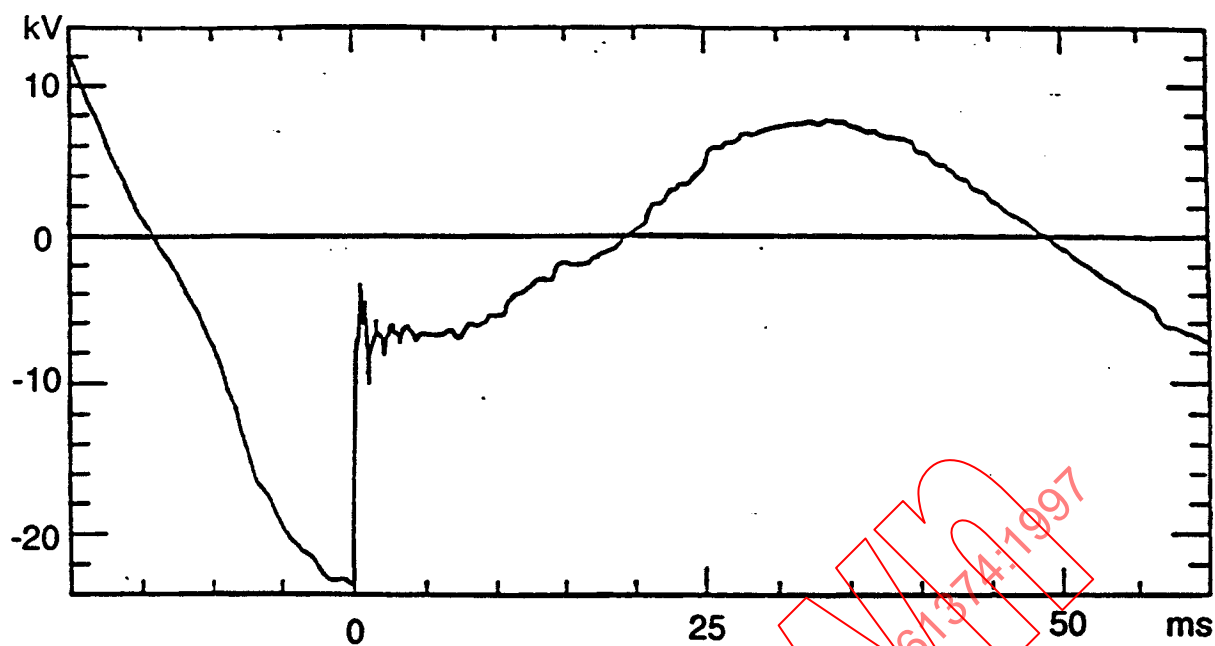


b) high speed channel

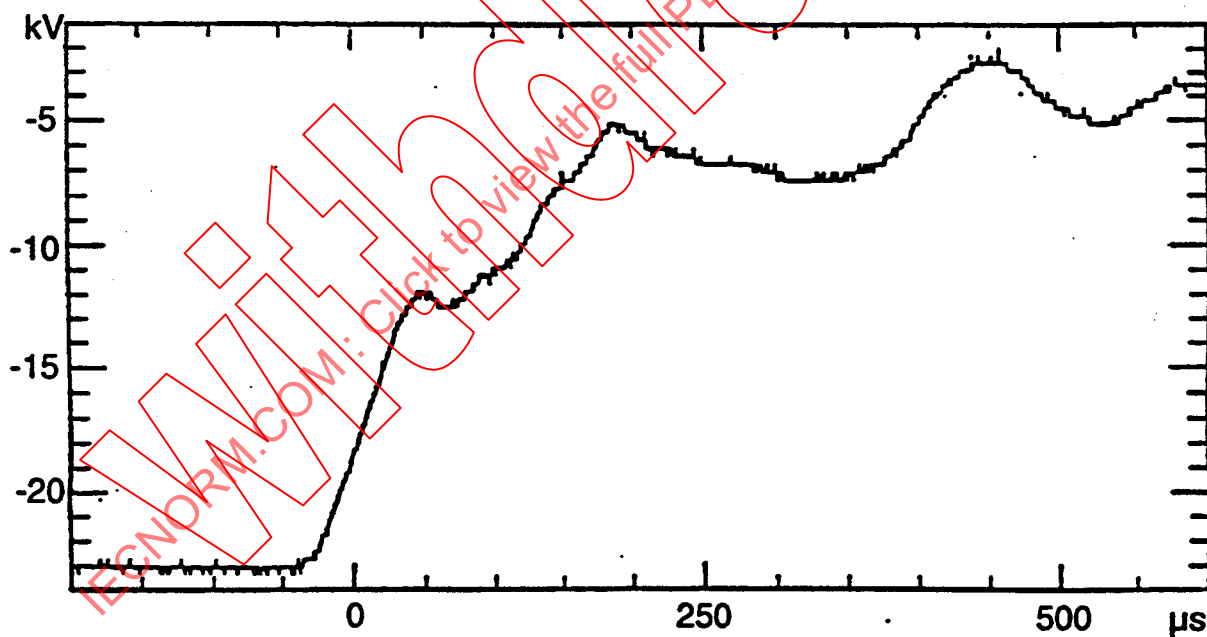
Figure D6: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB
Background unknown

Annex D



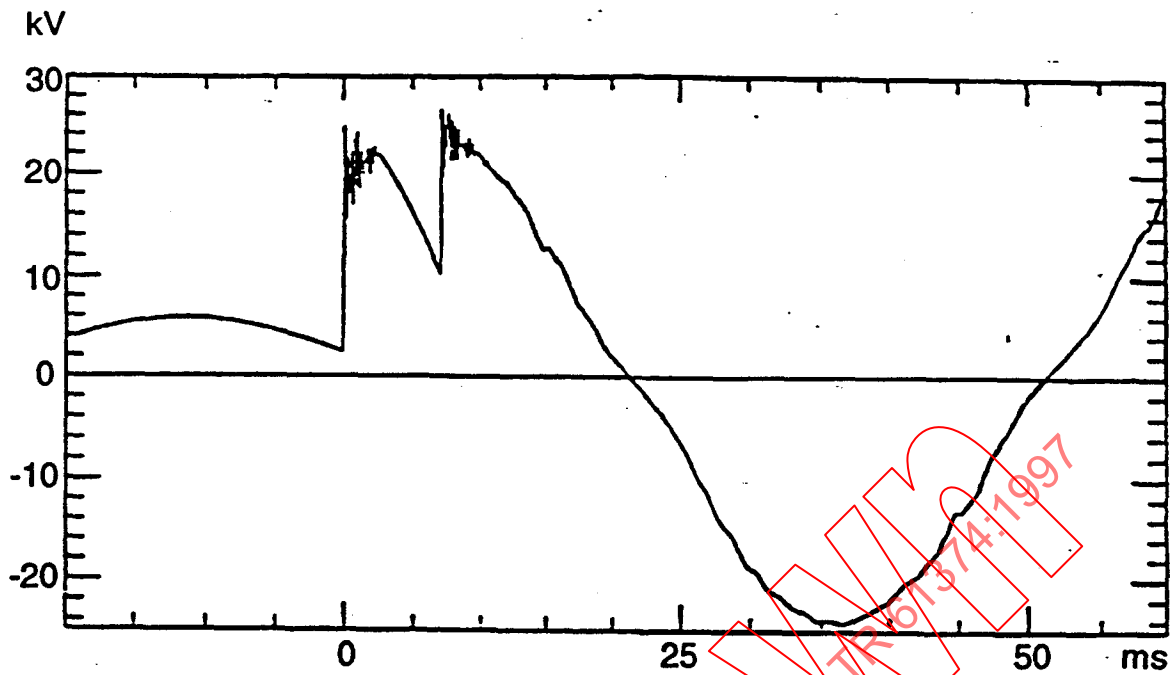
a) low speed channel



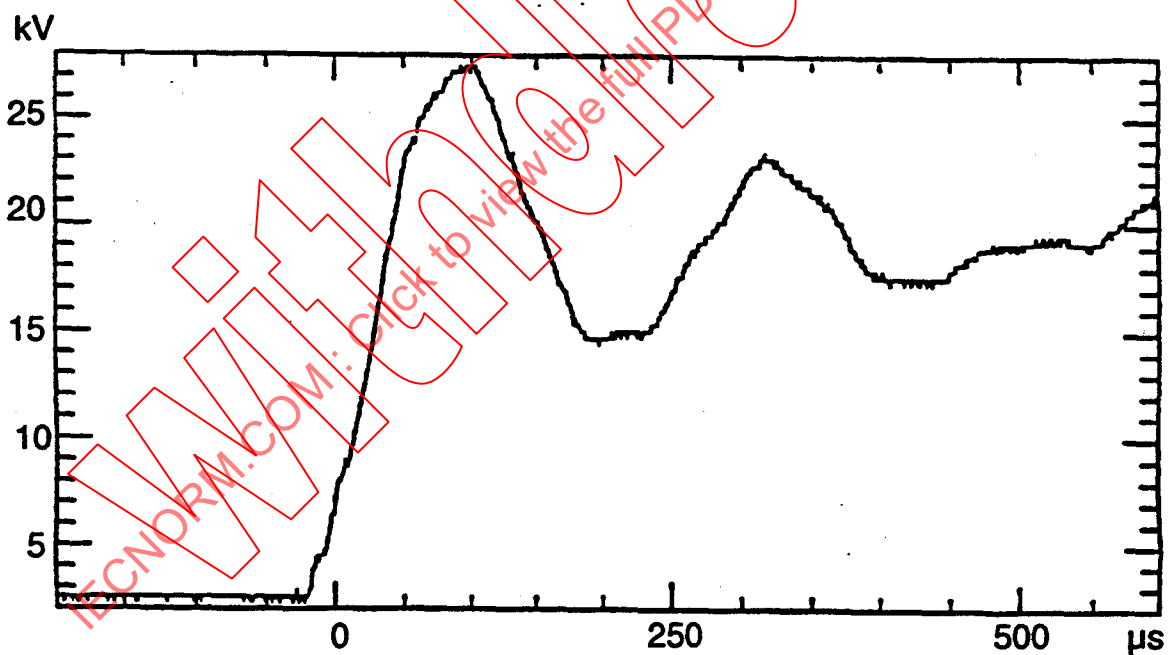
b) high speed channel

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

Source: SWITZERLAND / SBB
Background unknown



a) low speed channel

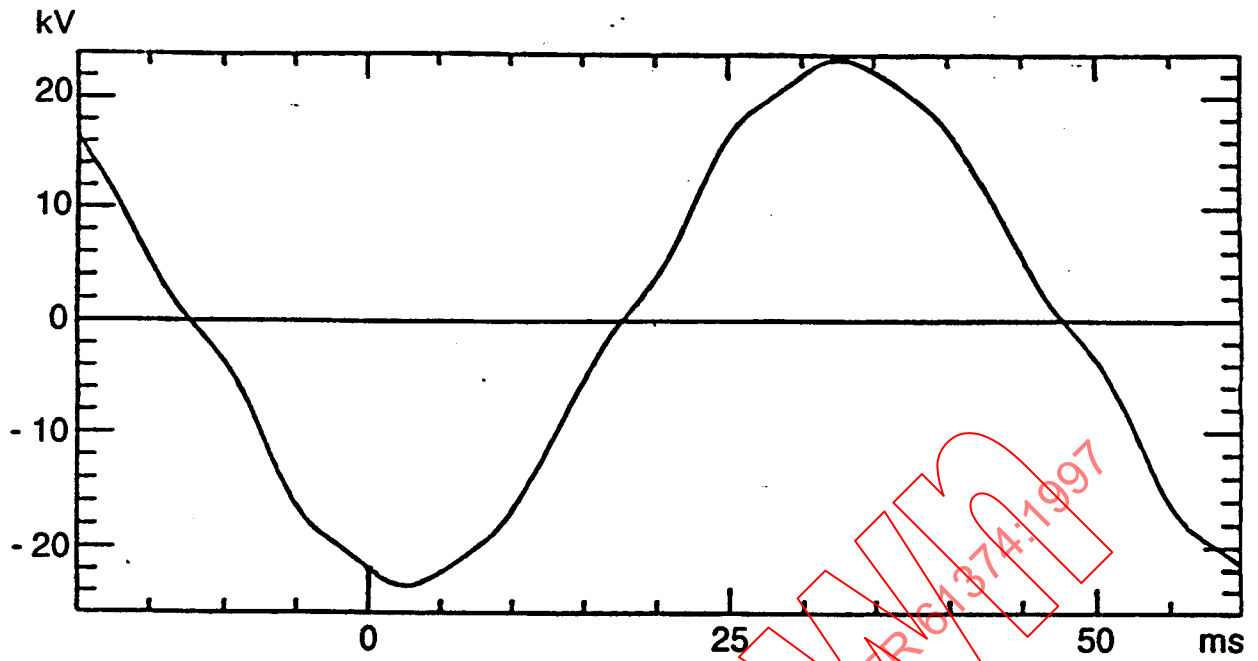


b) high speed channel

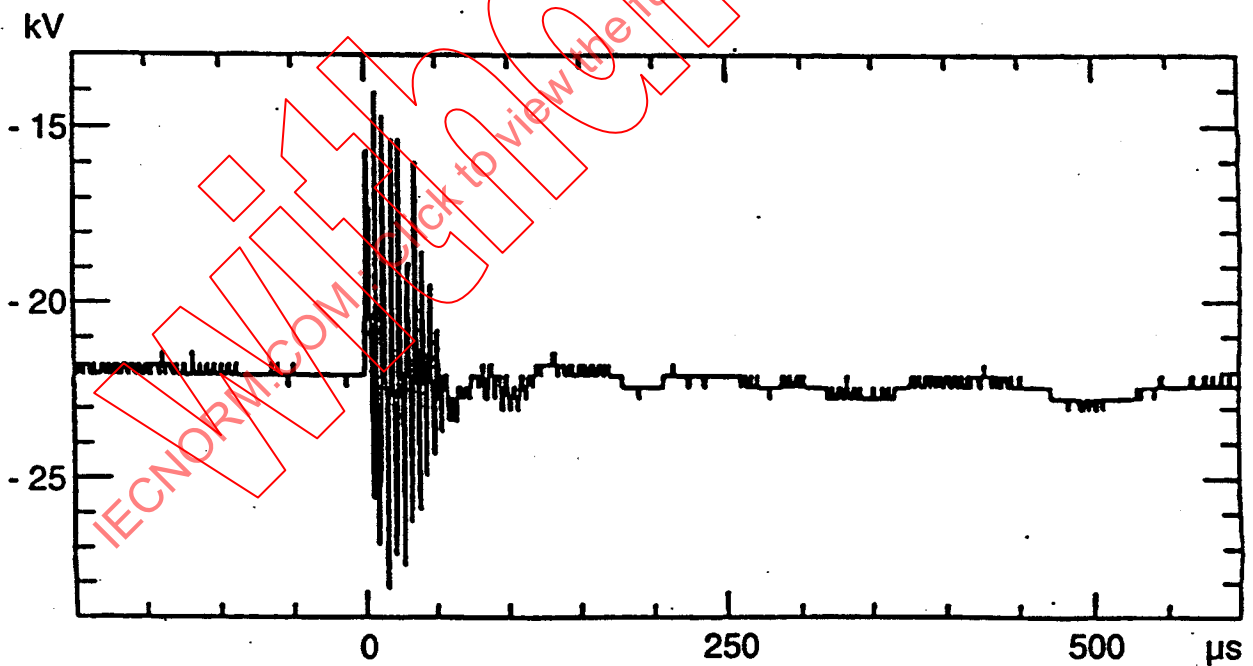
Figure D8: Overvoltages in 15 kV / 16 2/3 Hz traction power supply

Source: SWITZERLAND / SBB

Background unknown, refeeding of line after short-circuit



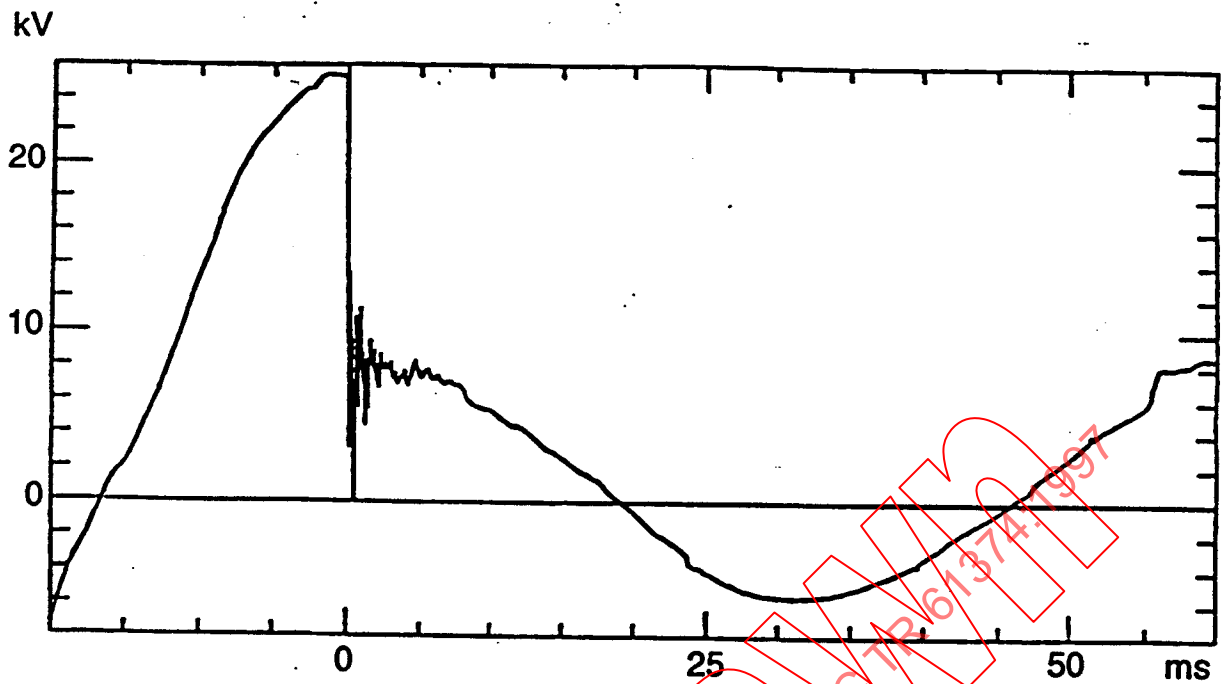
a) low speed channel



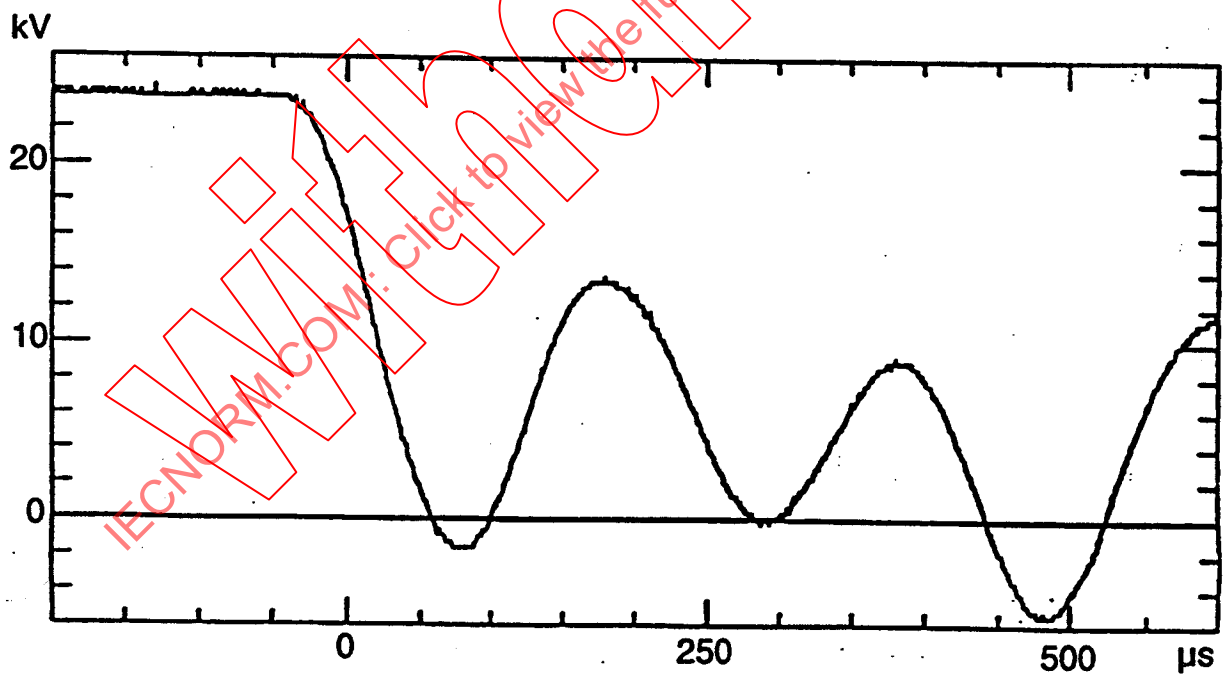
b) high speed channel

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

Source: SWITZERLAND / SBB
Background unknown



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