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# Requirements on rolling stock in Norway and Sweden regarding EMC with the electrical infrastructure and coordination with the power supply and other vehicles

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# 1 EXECUTIVE SUMMARY

The international standards EN 50 121, EN 50 163, EN 50 238, EN 50 388, and others, define the framework for the electrical compatibility between the rolling stock and the infrastructure systems on electrified railways. However, since the infrastructure systems for historical reasons are not equal in all countries, each national rail administration must define the detailed application of the standards in that country, and specify additional requirements in fields that are not covered by the standards. The present document defines the details of the electrical railway infrastructure in Norway and Sweden, and specifies the electrical compatibility requirements for the rolling stock. In general, these requirements are in accordance with the relevant standards, but certain technical differences exist, also compared to the systems in the other 16.7 Hz countries Germany, Austria, and Switzerland.

## 1.1 General Characteristics

The following is a prioritized list of the problems and general system characteristics that have typically caused train suppliers the greatest difficulties when introducing a new vehicle in the Norwegian and/or Swedish railway network:

1. Low frequency power oscillations, when supplied from rotating converters
2. High levels of line voltage distortion, in particular the 3$^{rd}$ and 5$^{th}$ voltage harmonics, and high crest voltages
3. Regenerative braking and line voltage limitation
4. Power factor control for improvement of the power capacity of weak supply lines
5. The weak power supply in general, characterized by long feeding distances, single-track lines, small rotating as well as static 50 Hz to 16 2/3 Hz converter stations, and a high number of phase-angle controlled vehicles

## 1.2 Technical Requirements

### 1.2.1 Signal interference and telecommunication

| Ref. | System | Requirement / interference limit | Details |
|---|---|---|---|
| S1 | DC (S only) | 25 A, and limits for the DC component at transformer inrush. | *3.2.1* |
| S2 | 95 Hz and 105 Hz (N only) | 1.00 A. Monitoring required. | *3.2.2* |
| S3 | TI21 track circuits (N only)<br>16 bands 1532 Hz to 2610 Hz | <br>TBD A | *3.2.3* |
| S4 | FTGS track circuits (N only)<br>4 bands 4.75 kHz to 6.25 kHz<br>8 bands 9.5 kHz to 16.5 kHz | <br>1.00 A<br>0.50 A | *3.2.4* |
| S5 | Psophometric currents | 1.50 A | *3.2.5* |
| S6 | Broad-band (N only)<br>TBD-7 kHz<br>7-9 kHz<br>> 9 kHz | <br>1.00 A<br>0.50 A<br>0.33 A | *3.2.6* |
| S7 | Radiated interference | According to EN 50 121-3-1 | *3.2.7* |
| S8 | Outside antennas | According to EN and BVS standards. | *3.2.8* |
| S9 | Resistance between wheelsets | < 0.1 Ω. | *3.2.9* |

### 1.2.2 Power supply compatibility

| Ref. | System | Characteristics / requirements | Details |
|---|---|---|---|
| P1 | Line voltage levels | $U_{min2}$ = 10 kV (N only). Voltage jumps may occur at any level between $U_{min2}$ and $U_{max2}$. | *4.3.1* |
| P2 | Line voltage frequency | The line frequency is 16 2/3 Hz. The railway power supply is synchronized to the 50 Hz mains. | *4.3.2* |
| P3 | Line voltage distortion | The line voltage may be heavily distorted, with up to 5 kV 3$^{rd}$ and 5$^{th}$ harmonic. The crest voltage may exceed 30 kV. | *4.3.3* |
| P4 | Neutral sections | Procedural requirements for the loco driver. | *4.3.4* |
| P5 | Power factor (cos(φ)) | The limits for cos(φ) are more strict, compared to EN 50 388. It is generally only possible to regenerate any significant power back into the weak supply system, if a power factor (cos(φ)) control is applied. | *4.3.5* |
| P6 | Maximum line current limitation | Procedural requirements for the loco driver. | *4.3.6* |
| P7 | Current or power control at low line voltage | The power control specified by EN 50 388 is of particular importance due to the weak supply. | *4.3.7* |
| P8 | Low frequency power oscillations | The rotating converters have a poorly damped eigen-frequency at approximately 1.6 Hz. The vehicles must not cause the system to become unstable at any condition. | *4.3.8* |
| P9 | Electrical resonance stability | The input admittance of the vehicles must be passive at all frequencies > 90 Hz. | *4.3.9* |
| P10 | Current harmonics | The limits for the 3$^{rd}$, 5$^{th}$, 7$^{th}$, and 9$^{th}$ current harmonic are 5.0%, 3.0%, 3.0%, and 3.0%, respectively, of the rated current of the vehicle. | *4.3.10* |
| P11 | Relay coordination | In accordance with EN 50 388. | *4.3.11* |
| P12 | Transformer inrush (AC) | The peak inrush current must be < 2.00 kA. | *4.3.12* |
| P13 | Regenerative braking | The vehicle must not cause the line voltage to increase above 17.5 kV (S) or 18.0 kV (N), in regenerative braking. The vehicle must not cause the voltage locally at other types of vehicles to exceed 17.5 kV to any greater extent than what is seen in the existing system (S only). | *4.3.13* |
| P14 | Train heating | In accordance with UIC standards. Inrush tests required. | *4.3.14* |
| P15 | Energy measurement | The ERESS (European Railway Energy Settlement System) system is used. | *4.3.15* |
| P16 | Other electrical equipment | Certain requirements regarding equipment in the driver's cab. | *4.3.16* |
| P17 | Ice on the overhead line | Significant DC levels have been measured in the primary currents of existing vehicles at OHL ice conditions. | *4.3.17* |

## 1.3 Approval Procedures and Tests

The table below outlines the tests that are required for approval. The time needed for the tests depend on a) the number of different operation modes for the vehicle, and b) the free time on the closed track the actual time periods for testing. Most tests must be performed night-time. Experience shows that the categories T1 and T2 require at least two nights each plus transport time, and category T3 1-2 days. In Sweden, category T4+T5 is generally also one day due to the transport. It is expected that category T6 is performed at the suppliers workshop or similar facilities.

It should be noted that these approximate time indications are valid only for a vehicle that is *in its final and approvable state, with all software functions and all parameters frozen*. Any tests required for the supplier's own purposes (i.e., to make the vehicle approvable, or for fine-tuning of software) come in additional and up front.

The test categories T1, T2, and T4 may be performed in either country. The mixed traffic tests T3 must be performed in the country/countries where the vehicle will operate. Test T5 must be performed in Sweden. The tests T6 may be performed anywhere with 16 2/3 Hz or 16.7 Hz supply. For an approval in Norway, parallel measurements in the substation must be made during test T1.

Three different acceleration-brake operation sequences are defined: LOOP, ABAB, and ARO (please refer to section 3.3.4 and 4.4.4).

| **Cat.** | **Condition** | **Suitable test sites** | **Scope and train operation** | **Max. line speed** |
|---|---|---|---|---|
| T1 | Closed track, rotating converters | Alvesta-Emmaboda (S)<br>Hønefoss-Nesbyen (N) | S1-S6 (LOOP)<br>P1, P2, P5-P10, P13 (ABAB, ARO) | < 130 km/h |
| T2 | Closed track, static converters | Eskilstuna-Södertälje (S)<br>Gardermoen line (N) | S1-S6 (LOOP)<br>P1, P2, P5-P10, P13 (ABAB, ARO, voltage jump) | 200 km/h |
| T3 | Mixed traffic | Borlänge area (S)<br>Oslo area (N) | S1-S6, P1-P3, P5-P10, P13 (Normal operation) | |
| T4 | Transformer inrush (peak AC) | Ockelbo (S)<br>Oslo S (N) | P12 | |
| T5 | Transformer inrush (DC, S only) | Ockelbo (S) | S1 | |
| T6 | Other tests | Any possible | S7, P14 | |
| T7 | Non-test approval | N/A | S8, S9, P4, P11, P15-P17 | |

All vehicles must perform tests up to their speed limit during test category T2. Locomotives must be loaded by a reasonably heavy train (≈ 1-2 t per kN max. tractive effort, or ≈ 50-100 t per MW max. power, whichever is the greater) during all tests T1 and T3, in order to create realistic acceleration times. During tests T2, a somewhat lighter load may be used (some 25% of the values above).

## 1.4 Deliverables

The supplier must deliver the following documents and other information regarding electrical compatibility.

**Before testing:**

- Clause-by-clause comments to the present specification section 3 and 4, explaining how the technical requirements are met
- Calculated, previously measured, or otherwise estimated signaling interference and psophometric current levels
- The input admittance versus frequency characteristics
- A simulation study regarding low frequency power oscillations
- Descriptions and characteristics of key functions, such as the current or power control at low line voltages, voltage limitation at regenerative braking, cos(φ)-control, etc.
- Calculations regarding the voltages locally at other types of vehicles (S only)
- Design descriptions, main circuit diagrams, data sheets, and other relevant general information
- Test reports and other documentation showing that the vehicle meets the radiated interference requirements of EN 50 121-3
- Documentation that the vehicle is compatible with relevant requirements outside the field of EMC (such as running dynamics, kinematic envelope, braking performance, etc.), to obtain track access for the EMC tests
- A test plan, including descriptions of the instrumentation and data analysis

**After testing:**

- The test report, including individual conformity statements for each requirement S1-S9 and P1-P16, and including explanations, references to the detailed test results and printouts, and so on.

**Before operation:**

- Vehicle data for power system studies

# 2 INTRODUCTION

## 2.1 Abstract

The international standards (EN, IEC, UIC, etc.) that deal with electromagnetic and functional compatibility between railway vehicles and infrastructure, are kept on a quite general level and do not cover all aspects of relevance for each individual country and national rail administration. Typically, different signalling systems are used in different countries, meaning that specific national requirements apply in addition to the common standards.

In Norway and Sweden, not only the signalling systems, but also the power supply differs significantly in comparison with other 16.7 Hz countries.

It is the objective of the present document to compile all relevant information and all requirements that apply to rolling stock used in Norway and Sweden, with respect to compatibility with the electrical infrastructure and other vehicles; i.e. the power supply, existing rolling stock, and infrastructure systems such as track signalling circuits, telecommunication lines, etc.

Jernbaneverket and Banverket are committed to harmonize, as far as possible, not only their technical requirements, but also their requirements regarding approval procedures and tests. It must be noted, however, that due to a number of technical differences between the two countries, this objective cannot be fulfilled for all requirements.

The document is first and foremost based on the standards EN 50 121 part 1 to 5, EN 50 163, EN 50 238 and EN 50 388. This however does not imply that other standards are not valid.

The document concentrates on the special national conditions that are valid for Norway or Sweden, and on topics that are not completely covered by international standards.

The tests described in the document are considered being type tests. This means that if tests are performed in one country, and the test procedures and conditions are representative also for the other country, then the tests, the recorded data, and the results may also be used for the performance evaluation and approval in the other country, even if the limits are different (i.e., tests in one country can provide data also for the other country).

Requirements regarding the mechanical interaction between the pantograph and the contact line are presented in other documents. Furthermore, the requirements on train control systems, such as ATC (= Automatic Train Control) or ERTMS, and interference with train radio and digital systems such as PCM, ISDN, etc., are not included in this document.

## 2.2 About this document

### 2.2.1 Structure

This document exists in three versions:

- One full version with all sections 1-4. This version is an appendix to Banverkets document BVS 543:19300.
- One version with the sections 1-3 only, and section 4 left unused. This version is an appendix to chapter 5 in Jernbaneverkets document JD 590.
- One version with the sections 1, 2, and 4 only, and section 3 left unused. This version is an appendix to chapter 4 in Jernbaneverkets document JD 590.

### 2.2.2 Validity

Section 1 and 2 of this document are for information only. The formal and valid requirements are given in section 3 and 4. In case of any conflicts, section 3 and 4 take precedence over section 1 and 2.

### 2.2.3 Responsibility

Section 3 of this document is under the responsibility of the signalling departments at Jernbaneverket and Banverket, while the power supply departments are responsible for section 4.

### 2.2.4 Coordination between sections and document versions

Certain parts of section 3 and 4 are harmonised and to some extent equal, in particular the requirements regarding testing. These sections are marked with a vertical line in the left margin, as shown here. Any changes to these sections should be coordinated between the signalling and the power supply departments.

### 2.2.5 National differences

Most requirements apply equally in the two countries. If a requirement is valid solely in one country, this is highlighted with a (Norway only) or (Sweden only) in the level three header for that requirement. Sometimes (e.g., in tables), the shorter (N only) or (S only) is used.

If a requirement is different in the two countries, the following identification is made:

NORWAY AND SWEDEN:

Here the parts of the requirement that are common to the two countries are listed. If there are no common requirements, this heading is not used.

NORWAY:

Here the requirements that are specific to Norway are listed.

SWEDEN:
Here the requirements that are specific to Sweden are listed. The "Sweden only"-section goes on until the next level two, level three, or level four heading, whichever is first.

### 2.2.6 Accuracy

If a requirement is quantitative, i.e. there is a numerical limit; the accuracy of the limit is given by the number of digits used for the requirement.

## 2.3 Abbreviations and Definitions

### 2.3.1 Abbreviations

| | |
|---|---|
| ABAB | Operation sequence (see 4.4.4) |
| ABS | Absolute value |
| AC | Alternating current |
| A/D | Analog to digital conversion |
| ARO | Operation sequence (see 4.4.4) |
| AT | Autotransformer |
| ATC | Automatic train control (called ATP in most countries) |
| ATP | Automatic train protection (called ATC in the Nordic countries) |
| BP | Band-pass |
| BT | Booster transformer |
| BW | Butterworth |
| bw | Bandwidth |
| DAT | Digital audio tape |
| DC | Direct current |
| EMC | Electromagnetic compatibility |
| EMI | Electromagnetic interference |
| $f_C$ | Centre frequency |
| FFT | Fast fourier transform |
| FTGS | Type of track circuit |
| GPS | Global positioning system |
| ID | (Data recording) idendity |
| IIR | Infinite impulse response |
| $I_N$ | Rated current |
| LOOP | Operation sequence (see 3.3.4) |
| N | Norway |
| N/A | Not applicable |
| OHL | Overhead (contact) line |
| P1-P17 | Compatibility requirements, power supply systems |

| | |
|---|---|
| PWM | Pulse width modulation |
| RMS | Root-mean-square |
| RSS | Root-sum-square |
| S | Sweden |
| S1-S9 | Compatibility requirements, signalling and telecommunication systems |
| T1-T7 | Test categories |
| TBD | To be defined |
| THD | Total harmonic distortion |
| TI 21 | Type of track circuit |

### 2.3.2 Definitions

| | |
|---|---|
| Bandwidth | In accordance with EN 50 238 |
| Bin | Output from a FFT. For example, a FFT with a 1 s window length produces bins at the frequencies 0 Hz (DC), 1 Hz, 2 Hz, . . . |
| Closed track | A line section that is single-end fed, and where no other rail vehicles are activated or in operation |
| Crest voltage | The highest value within one period of the rectified AC voltage. For an ideal sinusoidal voltage, the crest value equals √2 times the RMS value. |
| Fault mode | Degraded vehicle operation mode with one or more subsystems (converter, filter, or similar) cut-out |
| Hanning | Weight function used in combination with the FFT, in order to reduce the effect of transients |
| Normal operation | Vehicle operation mode with all subsystems in intended operation |
| Quasi-stationary | An operation condition where the variables (e.g., RMS voltage or current) vary so slowly that no oscillations or other dynamic effects are triggered |
| Rated current | The line current drawn by the vehicle when operating at full power at the nominal voltage of 15.0 kV |
| RMS | Root-Mean-Square. Please notice that different window lengths are used for different purposes. Generally, the window length is defined as a part of each specific requirement |
| Spectral leakage | The phenomenon that a FFT bin at a certain frequency is “contaminated” with energy originating from signal components at the frequencies of the neighbouring bins. This is an effect of the Hanning window |
| Window | Time duration over which data is analysed, e.g., 60 ms or 1 s |

## 2.4 Scope

NORWAY AND SWEDEN:

This document is foremost intended for manufacturers or operators who plan:

A) to specify and design new vehicles for operation in Norway and/or Sweden,
B) to modify or rebuild already existing vehicles, or
C) to introduce already existing vehicles that have not previously been operating in Norway or Sweden.

For this purpose, the document provides detailed information about the infrastructure in the two countries. Some of this information is found in connection with the various requirements, but most is given in the attached appendices.

NORWAY:

The validity and the application of the requirements in this document are defined in the JD 590 "Characteristics of the infrastructure" chapter 1 section 1.4.2. The document JD 590 is an overall document that describes the infrastructure and the compatibility requirements in Norway for all relevant fields. This present document concerning electric compatibility is hence a part of JD 590 as:

- Signal interference is treated in JD 590 chapter 5 "Signalling and train control systems"
- Telecommunication is treated in JD 590 chapter 6 "Telematic applications"
- Power supply is treated in JD 590 chapter 4 "Energy"

SWEDEN:

The requirements in this document are valid for:

- First time use of rolling stock or reintroduction of rolling stock that have been considered out of use permanently.
- Rolling stock that is going to be introduced on sections of track not included in current acceptance.
- Changes, both in hardware and software, in rolling stock usage not in compliance with current acceptance.
- Modifications of rolling stock in a way that may affect the compliance with the current acceptance.

This means that the requirements in this document are valid for new electrical traction vehicle and old used vehicles that have not been used in normal operation in Norway or Sweden before. An old vehicle used in Norway is not automatically accepted in Sweden.

The requirements in this document can however be discussed when applied on imported old vehicles, except for the Electrical Safety and requirements regarding signalling circuits and psophometric currents. Requirements regarding signalling circuits are always valid due to safety aspects. Requirements regarding psophometric currents are valid due to effects for third party.

A summary of how and for which rolling stock the requirements are valid is given in the table below:

| **Category of rolling stock** | **Age of the rolling stock** | |
|---|---|---|
| | **Vehicle design started after 2007-01-01** | **Vehicles designed before 2007-01-01** |
| **Vehicles specifically designed for use in Sweden only** | All requirements are mandatory. | Already accepted, but any rebuilds or modifications should aim for improving compatibility, and must not reduce compatibility.<br><br>For already accepted vehicles, which are to be put in operation on new lines for which the acceptance is not valid, relevant requirements are valid in order to maintain traffic and not to disturb the electrical infrastructure. Relevant requirement are decided on a case-to-case basis. |
| **Vehicles designed for cross border operation, or for use also in other countries** | Safety requirements and requirements regarding signalling systems and telecommunications are mandatory.<br>Non-compatibilities with other requirements might be accepted on a case-to-case basis, but only if it can be demonstrated that the requirements are in fundamental conflict with technical requirements from other countries of operation. | Safety requirements and requirements regarding signalling systems and telecommunications are mandatory.<br>Non-compatibilities with other requirements might be accepted on a case-to-case basis, but only if it can be demonstrated that a rebuild would be in fundamental conflict with technical requirements from other countries of operation, or if it can be demonstrated that the cost of a rebuild is out of proportion. |
| **Vehicles originally designed for use in other countries, but imported for future use solely in Sweden** | Safety requirements and requirements regarding signalling systems and telecommunications are mandatory.<br>Non-compatibilities with other requirements might be accepted on a case-to-case basis, but only if it can be demonstrated that the cost of a rebuild is out of proportion. | Safety requirements and requirements regarding signalling systems and telecommunications are mandatory.<br>Non-compatibilities with other requirements might be accepted on a case-to-case basis, but only if it can be demonstrated that the cost of a rebuild is out of proportion. |

Table 1. Use of the requirements (Sweden only).

## 2.5 General information about the infrastructure

This chapter gives a short introduction to traction power supply systems and track signalling circuits in Norway and Sweden. More specific data about the infrastructure is given as information in APPENDIX 1: Infrastructure data and related information.

### 2.5.1 General

In Norway and Sweden the earth resistivity is high in comparison to most of the rest of Europe. This has direct an effect on traction power supply design to avoid disturbing other electrical systems.

### 2.5.2 Norway

In Norway there are 2500 km of electrified railway (2004). The network around the capital Oslo is meshed with both double and single-track lines. Around this centre there are long (> 500 km) single-track lines to other parts of the country. The Norwegian single-phase network is much weaker than in rest of Europe. In some areas the overhead contact line impedance is so large that changes in the power demand from one train may cause voltage variations up to some kilovolts. Both tap changer vehicles, phase controlled vehicles and inverter vehicles with and without filters operate in the network.

The power supply system is of the type 15 kV, 16.7 Hz. It is synchronized with the 50 Hz national grid, i.e. a decentralized system. There is however a small centralized system in the Oslo area consisting of a 55 kV, 16 2/3 Hz single-phase high voltage transmission line fed by one small hydro power station. This system is connected to the contact lines system via 5 substations (which can be located together with rotary converters).

Apart from the small centralized system the power is fed into the traction power supply system by rotary and static (power electronic) converter stations, which convert the energy from 50 Hz, three-phase, to 16 2/3 Hz, single-phase. The number of active converter units in each converter station is adapted to the hourly variation in load demand to allow maintenance and reduce the losses. There is one small hydro power station feeding directly to the overhead contact line system. In normal operation there is often a one-to-one relation between one converter station capacity and load demand form one train. Due to this, low frequency oscillations have often caused severe problems when new vehicles have been introduced.

In normal operation the system is interconnected between the feeding points, but in order to maintain both rail tracks and contact line, sectioning of the system is a common operation mode.

At present, the booster transformer (BT) system, with or without return conductors, is the main feeding system for contact lines in Norway. However, Jernbaneverket plans to build autotransformer (AT) systems for main long distances lines. There are also some series capacitances and one shunt capacitor in the single-phase network in order to reduce inductive contact line impedance, strengthening the voltage and feeding reactive power. The return path for the traction current, regardless of system and apart from return conductors or any extra earth conductors, always comprise both rails, with exception of stations where single rail track signalling circuits occurs.

On electrified lines AC track signalling circuits are used, either double rail or jointless. Most common are 95 and 105 Hz uncoded track signalling circuits.

ATC equipment type EBICAB 700 is used on most lines.

### 2.5.3 Sweden

In Sweden there are 9 543 km of electrified railway (2004). The railway network is meshed except for the northern part of Sweden. Most of the lines are single track lines except for lines close to Stockholm and the lines between the cities Stockholm, Gothenburg and Malmö.

The power supply system is of the type 15 kV, 16.7 Hz. The system is decentralized and synchronized with the 50 Hz national grid. The power is fed into the traction power supply system by converter stations, which convert the energy from 50 Hz, three-phase, to 16 2/3 Hz, single-phase. The converters are of both rotary and static (power electronic) type. The number of active converter units in each converter station is adapted to the load.

In order to reduce the number of converter stations, the contact overhead line system is also fed by a 132 kV system (a two-phase 2 x 66 kV system with directly earthed midpoint) with transformer substations. This system is used from the middle to the northern parts of Sweden. There is no power generation connected directly to the 132 kV system. The system is fed from transformers connected to the 15 kV 16,7 Hz busbars at the converter stations.

The two feeding systems for contact lines in Sweden are; BT-system (booster-transformer system) with one or two return conductors and AT-system (auto-transformer system). Sometimes also a strengthening wire (reinforcement wire, booster wire) occurs. This is more common in the northern part of Sweden, and this type of reinforcement wire is always used on AT-systems. Its objective is to lower the impedance. Sometimes an additional earth wire is used. This type of earth wire is planned to become standard on AT-system lines. A combined AT/BT-system is currently under investigation for introduction (a first small installation is made).

Most of the railway lines are fed from both ends (double sided feeding). Due to the high earth resistivity booster transformer systems with return conductors are mainly used, when not autotransformer systems are implemented, due to EMC requirements. This causes normally higher line impedance than in the central and south of Europe, where the return current can use the rails and earth all the way to the feeding point. The system is relatively weak with rather high voltage drops.
Only DC track signalling circuits exist on electrified lines in Sweden. At some non-electrified low traffic lines, radio block systems are used.

Only one of the rails, the S-rail, is used for the return path of the traction current. This is regardless of what type of feeding system that is being used (BT- or AT-system). The other rail is always isolated, I-rail, and is used for the DC track signalling circuits.

ATC equipment type EBICAB 700 is used on most lines.

## 2.6 Revision history

| | |
|---|---|
| 05-01-2007: | First version, based on the NIM NES-R10 report with the same title as this document, from 27.11.2006. |
| 07-01-2009: | Second version |

# 3 SIGNALLING SYSTEMS AND TELECOMMUNICATION

## 3.1 References

### 3.1.1 Normative references

| No. | Standard | Applicable to<br>Signalling | <br>Power |
|---|---|---|---|
| 1.1 | EN 50 110-1: Operation of electrical installations. CENELEC, European Standard. | | X |
| 1.2 | EN 50 121: Railway applications – Electromagnetic compatibility (relevant parts in this context).<br>Part 1: General<br>Part 2: Emission of the whole system to the outside world<br>Part 3-1: Rolling stock – Train and complete vehicle<br>Part 3-2: Rolling stock – Apparatus<br>Part 4: Emission and immunity of the signalling and telecommunication apparatus<br>Part 5: Emission and immunity of fixed power supply installations and apparatus<br>CENELEC, European Standard. | X | X |
| 1.3 | EN 50 122-1 Railway applications- Fixed installations Part 1: Protective provisions relating to electrical safety and earthing. CENELEC, European Standard. | | X |
| 1.4 | EN 50 128: Railway applications – Communications, signalling and processing systems – Sofware for control and protection systems. CENELEC, European Standard. | X | |
| 1.5 | EN 50 153: Railway applications – Protective provisions relating to electrical harzards. CENELEC, European Standard. | | X |
| 1.6 | EN 50 155: Railway applications Electronic equipment used on rolling stock. CENELEC, European Standard. | X | |
| 1.7 | EN 50 163: Railway applications – Supply voltages of traction systems. CENELEC, European Standard. | | X |
| 1.8 | EN 50 207: Railway applications – Electronic power converters for rolling stock. CENELEC, European Standard. | | X |
| 1.9 | EN 50 215: Railway applications – Test of rolling stock after completion of construction and before entry into service. CENELEC, European Standard. | X | X |
| 1.10 | EN 50 238: Railway applications – Compatibility between rolling stock and train detection systems. CENELEC, European Standard. | X | |
| 1.11 | EN 50 388: Railway applications – Power supply and rolling stock – Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability. CENELEC, European Standard. | | X |

| | | | |
|---|---|---|---|
| 1.12 | UIC 550, 550-1, 550-2, 550-3: Power supply installations for passenger stock. | | X |
| 1.13 | UIC 552: Electrical power supply for trains – Standard technical characteristics of the train line. | | X |
| 1.14 | UIC 554-1: Power supply to electrical equipment on stationary vehicles from local mains system or another source of energy at 220 V or 380 V, 50 Hz. | X | |
| 1.15 | UIC 512: Conditions to be fulfilled in order to avoid difficulties in the operation of track circuits and treadles. | X | |
| 1.16 | BVS 545.43501: Requirements on external antennas for railway vehicles (only published in Swedish: ”Krav på yttre antenner för järnvägsfordon”) . Banverket. Only normative for Sweden. | X | |
| 1.17 | ITU-T Recommendation O.41: Psophometer for use on telephone-type circuits. | X | |

### 3.1.2 Other references

| No. | Standard | Applicable to | |
|---|---|---|---|
| | | Signalling | Power |
| 2.1 | HS TSI: Directive 96/48/EC – Interoperability of the trans-European high speed rail system, 96/48 ST14EN03 ENE part 2, Draft from 22.06.2006. | X | X |
| 2.2 | Characteristics of infrastructure. Document JD 590. Jernbaneverket, 01.02.2005. | X | X |
| 2.3 | Electro-technical requirements on new electrical vehicles regarding compatibility with the power supply system and other electrical vehicles, BKE 00/14, rev. H. Banverket, July 2004. | X | X |
| 2.4 | Rotating converters BV/JBV: Description of simulation model. emkamatik document 06-0132, ver. 1. Stefan Menth, emkamatik, 18.9.2006. | | X |
| 2.5 | EN 61000-4-7, March 1993. Electromagnetic compatibility (EMC). Part 4: Testing and measurement techniques. Section 7: General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto. IEC, CENELEC. | | X |

## 3.2 Compatibility Requirements

***NOTE:***

*The limits and requirements in this chapter are under investigation and shall be treated accordingly.* Please notice that operating experience indicates that lower limits may be required in some frequency ranges on certain line sections in Norway. These requirements are under consideration. Jernbaneverket may on some route sections permit slightly excessive interference currents for some frequencies. Based on documentation for the noise current spectrum of the vehicle, Jernbaneverket will decide whether or not it is compatible with the route sections in question.

### 3.2.1 S1: DC track circuits

#### 3.2.1.1 Information

NORWAY:

DC track signalling circuits are used only at non-electrified railway stations, plus one single electrified railway station.

SWEDEN:

DC track circuits are the only train detection system in use on electrified lines in Sweden.

Only two credible mechanisms have been identified by which an electric vehicle is capable of generating excessive DC interference currents:

1. Transformer inrush. Low levels can be achieved by a proper design of the main transformer.

2. Ice on the overhead contact wire. It is recognised that it may not be feasible to design a rail vehicle in such a way that compliance can be guaranteed at all ice conditions.

A third cause can be faults in the vehicle.

#### 3.2.1.2 Requirements

General requirements for the vehicle and the signalling equipment are in accordance with EN 50 121-3-1 and EN 50 121-4.

NORWAY:

No requirements.

SWEDEN:

***Interference limits, normal operation.***

The following interference limits apply, with the exception of the inrush current of the main transformer:

| **Frequency band** | **Bandwidth (low-pass)** | **RMS time** | **Limit value** |
|---|---|---|---|
| 0.0 - 2.0 Hz | -3.0 dB: 2.0 Hz | N/A | 25.0 A |

These limits are applicable for one vehicle, and for the maximum configuration of vehicles (i.e. multiple units) for which the approval must be valid.

***Interference limits, transformer inrush.***

The DC-component of the inrush current of the main transformer/s, must not exceed 45.0 A for more than 1.50 seconds, and also not exceed 25.0 A for more than 2.50 seconds. The DC-component is here defined as the mean value over one period of the fundamental, moving average calculation.

This is applicable for one vehicle, and for the maximum configuration of vehicles (i.e. multiple units) for which the approval must be valid. In a multiple formation, it is suggested that the cut-in of the main circuit breakers is staggered, e.g., with a 5 s delay between each cut-in event.

#### 3.2.1.3 Verification

NORWAY:

N/A.

SWEDEN:

***Normal operation test***

Verification shall be done by test runs with measurement and data recording equipment being installed in the vehicle, at normal weather conditions (no frosty lines), and in accordance with the test specification section 3.3. The current transducer must handle the frequencies from DC and upwards.

The following signal processing of the recorded line current signal is suggested:

| **Signal processing** | **Limit value** |
|---|---|
| (Downsampling to 1 kHz, followed by)<br>2.0 Hz $4^{th}$ order Butterworth low-pass filter, followed by an ideal rectifier to give the absolute value. | 25.0 A |

***Inrush current test***
The tests shall be performed at a location where the short circuit current is greater than or equal to 20 kA, i.e. Ik ≥ 20 kA on a single-track line. The train shall be placed beyond the first booster transformer, counting from a converter station, as described in section 3.3.4. (NOTE: this is not the same situation as for the AC inrush current tests, see chapter 4.4.4. The test specified here implies the test location to be at Ockelbo converter station with all converters in operation and all other converter stations connected to the 132 kV system. Other tests sites with scaling of the limit are under investigation.)

The following signal processing of the recorded line current signal is suggested:

| **Signal processing** | **Limit value** |
|---|---|
| (Downsampling to 1 kHz, followed by)<br>60 ms moving average, followed by an ideal rectifier to give the absolute value, followed by an assessment of the time duration for the level exceeding the following values: | |
| 45.0 A: | 1.50 s |
| 25.0 A: | 2.50 s |

#### 3.2.1.4 Documentation

NORWAY:
N/A

SWEDEN:
Documentation shall be a conformity statement and documentation of performed tests.

### 3.2.2 S2: 95 Hz and 105 Hz track circuits (Norway only)

#### 3.2.2.1 Information

Track circuits operating at 95 Hz and 105 Hz are the most commonly used in Norway. Impedance bonds for 95/105 Hz may be used to allow return current to pass by insulated joints used for separating track circuits.

#### 3.2.2.2 Requirements

General requirements for the vehicle and the signalling equipment are in accordance with EN 50 121-3-1 and EN 50 121-4.

***Interference limits.***
The following interference limits apply:

| Centre frequencies $f_C$ | Bandwidth | Time limit | Limit value |
|---|---|---|---|
| 95.0 Hz | - 3.0 dB: $f_C \pm 3.0$ Hz | 1.00 s | 1.00 A |
| 105.0 Hz | | | |

The 1.00 A current limit may be exceeded for shorter time periods than 1.00 s. These limits are applicable for one vehicle, and for the maximum configuration of vehicles (i.e. multiple units) for which the approval must be valid.

***Requirements for monitoring.***
The vehicles must be equipped with interference monitoring systems for the 95 Hz and 105 Hz line current components. The monitoring system must automatically open the main circuit breaker within 2.0 s if the 2.00 A trip level is exceeded.
The suggested signal processing for the monitor is FFT with 1.00 Hz resolution (1.00 s window length).The trip level is 2.00 A RMS for any bin in the bands 92-98 Hz and 102-108 Hz.

#### 3.2.2.3 Verification

Verification shall be done by test runs with measurement and data recording equipment being installed in the vehicle, in accordance with the test specification section 3.3.
The following signal processing of the recorded data is suggested:

| Centre frequencies $f_C$ | Signal processing | Limit value |
|---|---|---|
| 95 Hz and 105 Hz | (Downsampling to 1 kHz, followed by) $2 \cdot 3^{rd}$ order Butterworth band-pass filters with –3.0 dB points at each $f_C \pm 3.0$ Hz, followed by moving RMS, time window < 1.00 s | 1.00 A |

#### 3.2.2.4 Documentation

Documentation shall be a conformity statement and documentation of performed tests.

### 3.2.3 S3: TI 21 track circuits (Norway only)

#### 3.2.3.1 Information

TI 21 track circuits are used on some new lines in Norway, e.g., the Vestfold line.

TI 21 track circuits are designed with 8 channels A-H. The frequency of the carrier signal for the track circuit shifts between two values in each channel. The modulation rate of the frequency shift must lie within certain limits for a correct operation of the track circuit.

#### 3.2.3.2 Requirements

General requirements for the vehicle and the signalling equipment are in accordance with EN 50 121-3-1 and EN 50 121-4.

The following interference limits apply:

| **Centre frequencies $f_C$** | **Bandwidth** *See note 1* | **Time limit** | **Limit value** |
|---|---|---|---|
| Channel A: 1682 Hz and 1716 Hz | -3.0 dB: $f_C \pm 6.0$ Hz<br>-20 dB: $f_C \pm 30$ Hz | 1.50 s | *TBD* |
| Channel B: 2279 Hz and 2313 Hz | | | |
| Channel C: 1979 Hz and 2013 Hz | | | |
| Channel D: 2576 Hz and 2610 Hz | | | |
| Channel E: 1532 Hz and 1566 Hz | | | |
| Channel F: 2129 Hz and 2163 Hz | | | |
| Channel G: 1831 Hz and 1865 Hz | | | |
| Channel H: 2428 Hz and 2462 Hz | | | |

*Note 1: The bandwidth definitions are from the former British Rail Group Standard GS/ES 1914. This standard specifies a limit value of 100 mA, but this is probably not true for TI21s installed in a 16 2/3 Hz environment. The limit value is still under investigation.*

The current limit may be exceeded for shorter time periods than 1.50 s. These limits are applicable for one vehicle, and for the maximum configuration of vehicles (i.e. multiple units) for which the approval must be valid.

#### 3.2.3.3 Verification

Verification shall be done by test runs with measurement and data recording equipment being installed in the vehicle, in accordance with the test specification section 3.3.

The following signal processing of the recorded data is suggested:

| Centre frequencies $f_C$ | Signal processing | Limit value |
|---|---|---|
| 1682 Hz and 1716 Hz<br>2279 Hz and 2313 Hz<br>1979 Hz and 2013 Hz<br>2576 Hz and 2610 Hz<br>1532 Hz and 1566 Hz<br>2129 Hz and 2163 Hz<br>1831 Hz and 1865 Hz<br>2428 Hz and 2462 Hz | Band pass filters with a rejection of ≤ 3.0 dB at ± 6.0 Hz from each $f_C$, and ≤ 20 dB at ± 30 Hz from each $f_C$, followed by moving RMS, time window < 1.50 s.<br>*See note 2.* | *TBD* |

*Note 2: Much work has been spent in the UK in order to design digital filters with the best possible match to these limits, and many proposals exist. It is suggested that the design of filters is left to the applicants. It is likely however that the –20 dB figure could actually be somewhat more – final value is under investigation. (TDB = To Be Determined).*

#### 3.2.3.4 Documentation

Documentation shall be a conformity statement and documentation of performed tests.

### 3.2.4 S4: FTGS track circuits (Norway only)

#### 3.2.4.1 Information

The jointless FTGS track circuits operate at 4 frequencies in the 4.5 to 6.5 kHz frequency band (FTGS46), and at 8 frequencies in the 9 to 17 kHz band (FTGS917). They are used on some newer lines in Norway, e.g., the Gardermoen line.

#### 3.2.4.2 Requirements

General requirements for the vehicle and the signalling equipment are in accordance with EN 50 121-3-1 and EN 50 121-4.

The following interference limits apply:

***FTGS46***

| Centre frequencies $f_C$ | Bandwidth *(see note 3)* | Time limit | Limit value |
|---|---|---|---|
| 4.75 kHz | -3.0 dB: $f_C$ ± 200/2 Hz | 40 ms | 1.00 A |
| 5.25 kHz | -3.0 dB: $f_C$ ± 206/2 Hz | | |
| 5.75 kHz | -3.0 dB: $f_C$ ± 214/2 Hz | | |
| 6.25 kHz | -3.0 dB: $f_C$ ± 220/2 Hz | | |

*Note 3: Attenuation at adjacent channels: max. 30 dB.*

***FTGS917***

| **Centre frequencies $f_C$** | **Bandwidth** *(see note 4)* | **Time limit** | **Limit value** |
|---|---|---|---|
| 9.5 kHz | -3.0 dB: $f_C \pm 360/2$ Hz | 40 ms | 0.50 A |
| 10.5 kHz | -3.0 dB: $f_C \pm 380/2$ Hz | | |
| 11.5 kHz | -3.0 dB: $f_C \pm 400/2$ Hz | | |
| 12.5 kHz | -3.0 dB: $f_C \pm 425/2$ Hz | | |
| 13.5 kHz | -3.0 dB: $f_C \pm 445/2$ Hz | | |
| 14.5 kHz | -3.0 dB: $f_C \pm 470/2$ Hz | | |
| 15.5 kHz | -3.0 dB: $f_C \pm 490/2$ Hz | | |
| 16.5 kHz | -3.0 dB: $f_C \pm 510/2$ Hz | | |

*Note 4: Attenuation at adjacent channels: max. 30 dB.*

The current limits may be exceeded for shorter time periods than 40 ms.

#### 3.2.4.3 Verification

Verification shall be done by test runs with measurement and data recording equipment being installed in the vehicle, in accordance with the test specification section 3.3.

The following signal processing of the recorded data is suggested:

***FTGS46***

| **Centre frequencies $f_C$** | **Bandwidth bw** | **Signal processing** | **Limit value** |
|---|---|---|---|
| 4.75 kHz | 200 Hz | $2 \cdot 2^{nd}$ order Butterworth band pass filters, -3 dB at each $f_C \pm bw/2$ Hz, followed by moving RMS, time window < 40 ms | 1.00 A |
| 5.25 kHz | 206 Hz | | |
| 5.75 kHz | 214 Hz | | |
| 6.25 kHz | 220 Hz | | |

***FTGS917***

| **Centre frequencies $f_C$** | **Bandwidth bw** | **Signal processing** | **Limit value** |
|---|---|---|---|
| 9.5 kHz | 360 Hz | $2 \cdot 2^{nd}$ order Butterworth band pass filters, -3 dB at each $f_C \pm bw/2$ Hz, followed by moving RMS, time window < 40 ms | 0.50 A |
| 10.5 kHz | 380 Hz | | |
| 11.5 kHz | 400 Hz | | |
| 12.5 kHz | 425 Hz | | |
| 13.5 kHz | 445 Hz | | |
| 14.5 kHz | 470 Hz | | |
| 15.5 kHz | 490 Hz | | |
| 16.5 kHz | 510 Hz | | |

#### 3.2.4.4 Documentation

Documentation shall be a conformity statement and documentation of performed tests.

### 3.2.5 S5: Telecommunication disturbances and psophometric currents

#### 3.2.5.1 Information

Interference with digital systems such as PCM, ISDN, etc is not yet covered in this document. This is a field for which more work will be done. Information regarding GSM-R can be found in EIRENE standards from UIC.

The harmonics in the traction current of a railway system may induce noise in conventional analogue telecommunication system. The acceptable level of noise on conventional analogue telephone lines is specified by ITU-T. The limits in this document refer to the psophometric weighted traction current defined as:

$$I_{pe} = \frac{1}{P_{800}} \sqrt{\sum_{n=1}^{\infty} \left(h_f \times P_{fn} \times I_n\right)^2}$$

where $h_f$ =1, which is the equivalent psophometric current measured or calculated for interaction with a telephone line as a cable. $P_{fn}$ is in accordance with ITU-T. For values of $P_{fn}$ see Appendix 9.

#### 3.2.5.2 Requirements

The psophometric weighted traction current must not exceed 1.50 A. The value refers to the 99%- percentile of the measured psophometric current, i.e., the level must be below 1.50 A for 99% of the operation time.

The requirement is applicable for one vehicle and for the maximum configuration of vehicles (i.e. multiple units) for which the approval must be valid.

In case of a fault on the vehicle, for instance when one or more of the traction modules or filters is/are disconnected and the increase of the psophometric current is less than 6.0 dB, the vehicle is allowed to be in working condition until it reaches a workshop, for up to 24 hours. For such a case the limit is doubled. If this demand can not be fulfilled, the vehicle shall be transported in a non-working condition.

#### 3.2.5.3 Verification

Verification shall be done by test runs with measurement and data recording equipment being installed in the vehicle, in accordance with the test specification section 3.3.

For each LOOP operation cycle, the 99%-percentile of the psophometric current level shall be determined. See also EN 50 121-3-1, Annex A (informative). The tolerance of the psophometric weight characteristics, as well as the dynamic characteristics, shall comply with ITU-T O.41.

The following signal processing of the recorded data is suggested:

| Signal processing | Limit value |
|---|---|
| IIR band-pass filter with a characteristic as defined in Appendix 9, followed by a moving RMS with a time window of 140 ms, followed by an analysis of the levels over time (e.g., by determining the percentage cumulative distribution), followed by an assessment of the 99%-percentile level. | 1.50 A |

#### 3.2.5.4 Documentation

Documentation shall be a conformity statement and documentation of performed tests in a technical report. The report shall for each test lap state the 99%-percentile, and the summary shall state the variation of the 99%-percentiles (minimum, typical, and maximum values) for each operation mode (normal operation, and all relevant fault modes).

If the psophometric current varies significantly with speed (e.g., in the case of a rectifier vehicle), the report must additionally present a plot of the psophometric current versus speed.

### 3.2.6 S6: Broad-band interference (Norway only)

#### 3.2.6.1 Information

Historically, the Norwegian State Railways applied broad-band interference limits rather than limits specifically at the signalling frequencies. Jernbaneverket has now initiated an investigation whether or not these broad-band limits are still technically justified; however, until this investigation is finalized, the limits remain valid.

#### 3.2.6.2 Requirements

The following interference limits apply:

| Frequency band | Time limit | Limit value |
|---|---|---|
| TBD – 7 kHz *See note 5* | 1.00 s | 1.00 A RMS |
| 7 – 9 kHz | | 0.50 A RMS |
| > 9 kHz | | 0.33 A RMS |

*Note 5: The lower frequency limit is currently under investigation and is to be decided (=TBD).*

The current limits may be exceeded for shorter time periods than 1.00 s.

#### 3.2.6.3 Verification

Verification shall be done by test runs with measurement and data recording equipment being installed in the vehicle, in accordance with the test specification section 3.3.

The following signal processing of the recorded data is suggested:

| Frequency band | Signal processing | Time limit | Limit value |
|---|---|---|---|
| TDB – 7 kHz *See note 6* | FFT with 8 1/3 Hz resolution (120 ms time window) followed by < 1.00 s moving RMS along the time axis of each FFT bin. The limit value applies per FFT bin. | 1.00 s | 1.00 A RMS |
| 7 – 9 kHz | | | 0.50 A RMS |
| > 9 kHz | | | 0.33 A RMS |

*Note6: The lower frequency limit is currently under investigation and is to be decided (=TBD).*

#### 3.2.6.4 Documentation

Documentation shall be a conformity statement and documentation of performed tests.

### 3.2.7 S7: Radiated interference

#### 3.2.7.1 Information

Conformance with EN 50 121 is the basis for new constructions and upgrading of infrastructure systems.

#### 3.2.7.2 Requirements

Requirements are in accordance with EN 50 121-2 and EN 50 121-3-1. Deviations, based on further evaluation, may be acceptable on a case-to-case basis.

#### 3.2.7.3 Verification

Verification shall be performed by tests in accordance with EN 50 121-2 and EN 50 121-3-1.

#### 3.2.7.4 Documentation

Documentation shall be a conformity statement and documentation of performed tests.

### 3.2.8 S8: Outside antennas on vehicles

#### 3.2.8.1 Information

NORWAY AND SWEDEN:

Requirements in this document consider outside antennas for railway vehicles.

#### 3.2.8.2 Requirements

NORWAY AND SWEDEN:

Antennas for railway vehicles shall satisfy the requirements on touch voltage in accordance with EN 50 122-1 *Railway applications- Fixed installations Part 1: Protective provisions relating to electrical safety and earthing*, and EN 50 155 *Railway applications Electronic equipment used on rolling stock*.

SWEDEN:

Antennas for railway vehicles shall satisfy the requirements in Banverket’s document BVS 545.43501 *Krav på yttre antenner för järnvägsfordon*. (Requirements on external antennas for railway vehicles).

#### 3.2.8.3 Verification

NORWAY:

According to relevant standards, EN 50 122-1 and EN 50 155.

SWEDEN:

According to BVS 545.43501 *Requirements on external antennas for railway vehicles*. Clause 4.1- 4.6. The tests should be performed as a factory type test.

#### 3.2.8.4 Documentation

NORWAY AND SWEDEN:

A conformity statement.

### 3.2.9 S9: Resistance between wheelsets

#### 3.2.9.1 Information

N/A.

#### 3.2.9.2 Requirements

The resistance between wheels of a wheel set must be according to UIC512:1979 (< 0.1 Ω).

#### 3.2.9.3 Verification

According to UIC512:1979.

#### 3.2.9.4 Documentation

A conformity statement.

## 3.3 Validation and tests

### 3.3.1 Requirements prior to tests

NORWAY AND SWEDEN:
Before test runs and/or demonstrations are allowed on the railway lines in Norway or Sweden, certain documentation is required. In addition to the documentation mentioned later in this chapter, which refers to electrical requirements and how to perform tests, there are some other pre-requirements to be met. These pre-requirements and documentation concern topics like:

- train control (ATC)
- profile
- running dynamics
- axle loads
- current collector
- etc.

These pre-requirements are not covered in this document and it is the responsibility of the applicant for the acceptance to contact Jernbaneverket and/or Banverket to get the complete information regarding these requirements.

(Note: it is possible to test or demonstrate a vehicle without ATC by connecting the vehicle under test to an already accepted vehicle. Special provisions must however be made so that correct test conditions are met, i.e. the accepted extra vehicle must not influence the test results.)

NORWAY:
The requirements regarding other topics than electric compatibility captured in this document is to be clarified as a part of the overall compatibility process which is described in JD 590 chapter 1.

#### 3.3.1.1 Interference currents

Documentation which contains estimations, calculations, or previous measurements of interference currents according to the requirements S1-S6 is required. If such documentation cannot be made available, a preliminary test must be performed on a closed track before any other tests are performed. See also the requirements in section 3.2.1 to 3.2.6.

#### 3.3.1.2 Radiated EMI (S7, part of T6)

EMC test regarding radiated emission shall be performed by the manufacturer (or applicant) at the factory before any tests on railway lines in Norway or Sweden. See section 3.2.7.

#### 3.3.1.3 Simulations of dynamic vehicle behaviour

Testing of new vehicles on the railway infrastructure is very costly and shall be kept to a minimum for the benefit of all involved parties in long term. In order to reduce the risk of a failure of some tests as well as to document vehicle characteristics which can not be tested directly, simulations shall be performed by the vehicle manufacturer.

It is recommended that the simulation results are presented to and discussed with Jernbaneverket and/or Banverket prior to the first tests with the new vehicle.

This concerns low frequency power oscillations (see 4.3.8) and electrical resonance stability (see 4.3.9) and is based on EN 50388:2005, clause 10, steps 1 to 11 of the compatibility study.

#### 3.3.1.4 Current or power control at low voltage

Documentation of current limitation as function of voltage is required.

#### 3.3.1.5 Regenerative braking

Documentation of the voltage limitation functions when using regenerative brake is required.

#### 3.3.1.6 Test plan

A test plan shall be presented to Jernbaneverket and/or Banverket before any measurements or tests are carried out. The test plan shall contain a description on how the tests are performed (i.e. what lines shall be used, closed track or mixed traffic and so on) and on the vehicle constellation (load, weight and so on). Furthermore, the test plan shall include a description of the instrumentation and measurement methods that will be used, and how the instrumentation is calibrated. This information shall also be included in the test reports.

### 3.3.2 Coordination with tests regarding compatibility with the power supply

The tests specified in the following sections can to a wide extent be coordinated with the tests regarding compatibility with the power supply.

### 3.3.3 General test program

Table 2 below defines the test categories T1-T7, and outlines the minimum number of tests specifically addressing the requirements S1-S6.

| Cat. | Condition | Scope and train operation |
|---|---|---|
| T1 | Closed track, rotating converters | 2 LOOP sequences in normal operation, and 1 LOOP sequence in each fault mode.<br>(Plus additional tests for P-requirements; the data from these tests must be analyzed also for the S-requirements S1-S6). |
| T2 | Closed track, static converters | 2 LOOP sequences in normal operation, and 1 LOOP sequence in each fault mode, altogether in each end of the line (close to and far away from the substation. I.e., a total of 4 LOOP sequences in normal operation, and 2 LOOP sequence in each fault mode.<br>(Plus additional tests for P-requirements; the data from these tests must be analyzed also for the S-requirements S1-S6). |
| T3 | Mixed traffic | Mainly tests for P-requirements, but the data from these tests must be analyzed also for the S-requirements S1-S6 |
| T4 | Transformer inrush (peak AC) | N/A (P-requirement only) |
| T5 | Transformer inrush (DC, S only) | Minimum 25 successful inrush events |
| T6 | Other tests | According to EN 50 121-3 |
| T7 | Non-test approval | N/A |

**Table 2. General test requirements, S-requirements.**

The tests of category T1 and T2 can be performed in either country. The tests T3 must be performed in the country/countries where the vehicle is going to operate. Test T5 must be performed in Sweden. Test T6 can be performed anywhere with 15 kV 16.7 Hz supply.

### 3.3.4 Test details

#### 3.3.4.1 Test sites

The following test sites are suggested:

| Cat. | Norway | Sweden |
|---|---|---|
| T1 | Hønefoss-Nesbyen on the Bergen line. | Gemla-Lessebo, Alvesta-Kalmar line. |
| T2 | Lillestrøm-Gardermoen, Gardermoen Airport line. | Eskilstuna-Nykvarn, Eskilstuna-Södertälje line. |
| T3 | Oslo area. | Borlänge area (Borlänge-Krylbo, Borlänge-Ludvika). |
| T4 | N/A (P-requirement only). | |
| T5 | N/A | Ockelbo. |
| T6 | Vehicle suppliers own test tracks. | |
| T7 | N/A | |

**Table 3. Test sites, S-requirements.**

#### 3.3.4.2 Power supply configurations

CATEGORY T1: CLOSED TRACK, ROTATING CONVERTERS

The test line must be single-end supplied from one or two rotating converters in island operation. There must be no other trains activated or in operation on the test line. It is recommended that the test permissions allow for operation without ATC.

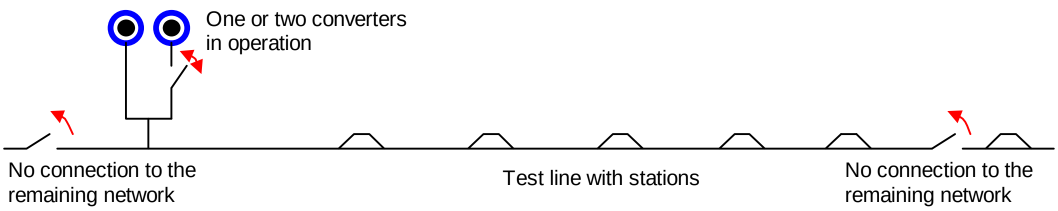



**Figure 1. Supply conditions for T1 tests, S-requirements.**

CATEGORY T2: CLOSED TRACK, STATIC CONVERTERS

The test line must be single-end supplied from one or two static converters. Since these converters are not designed for island operation, the remaining network must be connected in the supply end. There must be no other trains activated or in operation on the test line. It is recommended that the test permissions allow for operation without ATC.

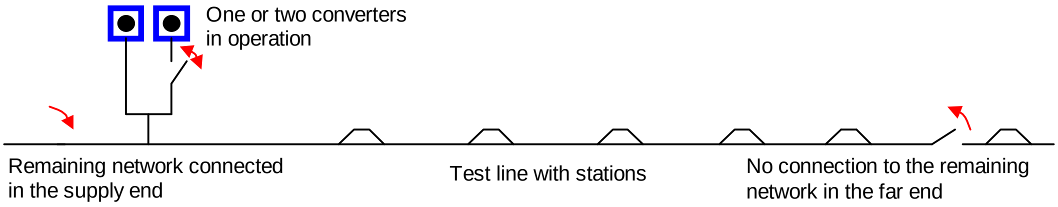



**Figure 2. Supply conditions for T2 tests, S-requirements.**

CATEGORY T3: MIXED TRAFFIC

No specific requirements.

CATEGORY T5: TRANSFORMER INRUSH

Please refer to the detailed description of these tests in chapter 3.3.4.6 below.

#### 3.3.4.3 Train configuration

All tests shall be performed with one vehicle alone and with all configurations of vehicles (i.e. multiple units) for which the approval must be valid. The tests must cover both normal fault-free operation, i.e., with all converters running and all filters etc. in normal mode, as well as all degraded operation modes, i.e., with one or more converter(s) and other subsystems cut-out.

#### 3.3.4.4 Train load

Locomotives must be loaded by a reasonably heavy train (≈ 1-2 t per kN max. tractive effort, or ≈ 50-100 t per MW max. power, whichever is the greater) during all tests T1 and T3. During tests T2, a somewhat lighter load may be used (some 25% of the values above).

#### 3.3.4.5 Train operation – LOOP sequence

The train must be operated according to the "LOOP" speed profile shown in figure 3 below, during all tests specifically addressing the S-requirements.

All vehicles must perform tests up to their speed limit during test category T2. During the test categories T1 and T3, the maximum speed is typically given by the speed limit of the line (or, in the case of locomotives, by the load wagons), meaning that the LOOP sequence must be terminated at a lower speed.

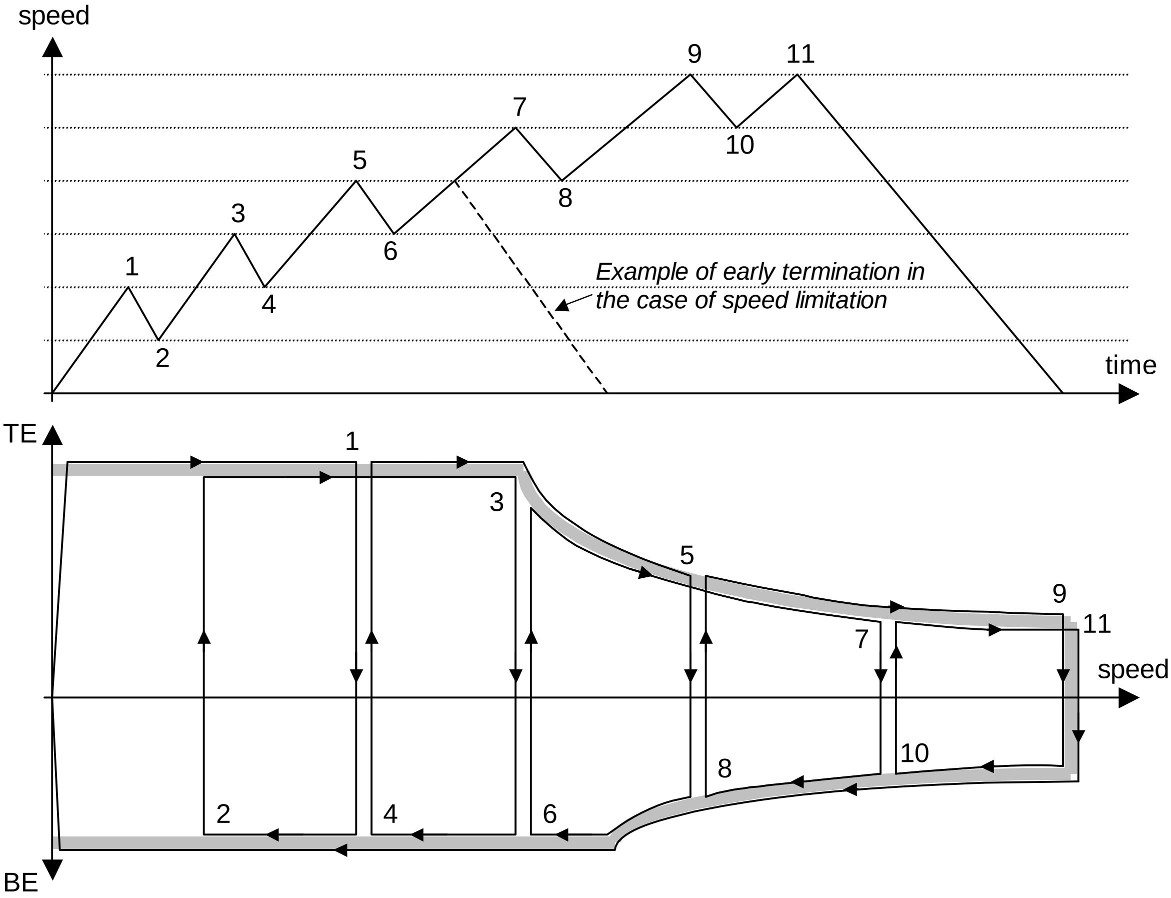



**Figure 3. LOOP operation sequence.**

### 3.3.4.6 Transformer inrush (DC) test (T5, Sweden only)

NOTE: This is not the same test that is specified for AC inrush currents in section 4.4.

The train must be located just beyond the first booster transformer, seen from the converter station, as seen in figure 4 below.

The tests shall be performed with the maximum configuration of the vehicle (i.e. maximal number of units in multiple operation for which the approval must be valid). At least 25 trials of breaker closures shall be performed, preferably more. All trials must be within limits for acceptance.

The DC-component shall be calculated as the mean value over one period of the fundamental, moving average calculation. The transducer must handle the frequencies from DC and upwards. The whole course of the inrush current shall be recorded.

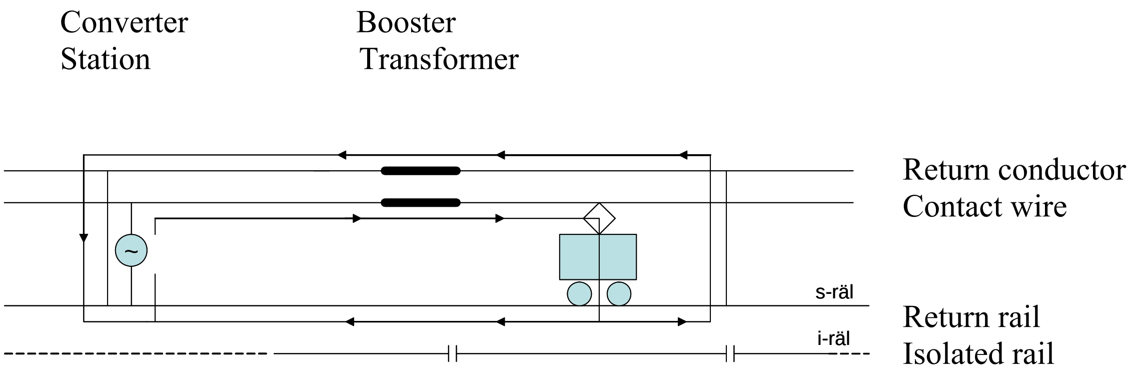



**Figure 4. Train position at the inrush current test. For booster transformer data, please refer to Appendix 1, section A1.2.3, A1.2.4 and A1.5.6.**

### 3.3.5 Measurement instrumentation and methods

#### 3.3.5.1 Measurement instrumentation – requirements S1-S6

All measurements shall be performed with adequate voltage and current transducers (transformers and/or active transducers such as Rogowski coils and Hall transducers. Hall transducers are particularly required for DC measurements).

Sampling instruments as shown in figure 5 below are recommended. For measurements of high frequency phenomena, such as the Norwegian signalling circuit interference, a sampling frequency of approximately 50 kHz is recommended together with an anti-aliasing filter with a cut of frequency of approximately 20 kHz.

It is required that adequate anti-aliasing filters are used. The cut-off frequency of the anti-alias filter for the current measurement must be higher than the highest frequency of interest, i.e., higher than 17 kHz for Norway (FTGS track circuits) and higher than 6 kHz for Sweden (psophometric currents). The sampling frequency must be well above two times these values.

It is recommended that all raw data be streamed directly to a storage device (DAT recorder, hard-disk, or similar) for later post-processing and analysis, in addition to the on-line supervision. For the signal processing see chapter 3.3.5.2 below.

The figure below shows an example of the recommended principle of data recording and analysis, and how to install Hall transducers to measure the DC-current. It is recommended that the speed signal be taken from the vehicle control rather than via GPS, since the test lines comprise numerous tunnels without GPS coverage.

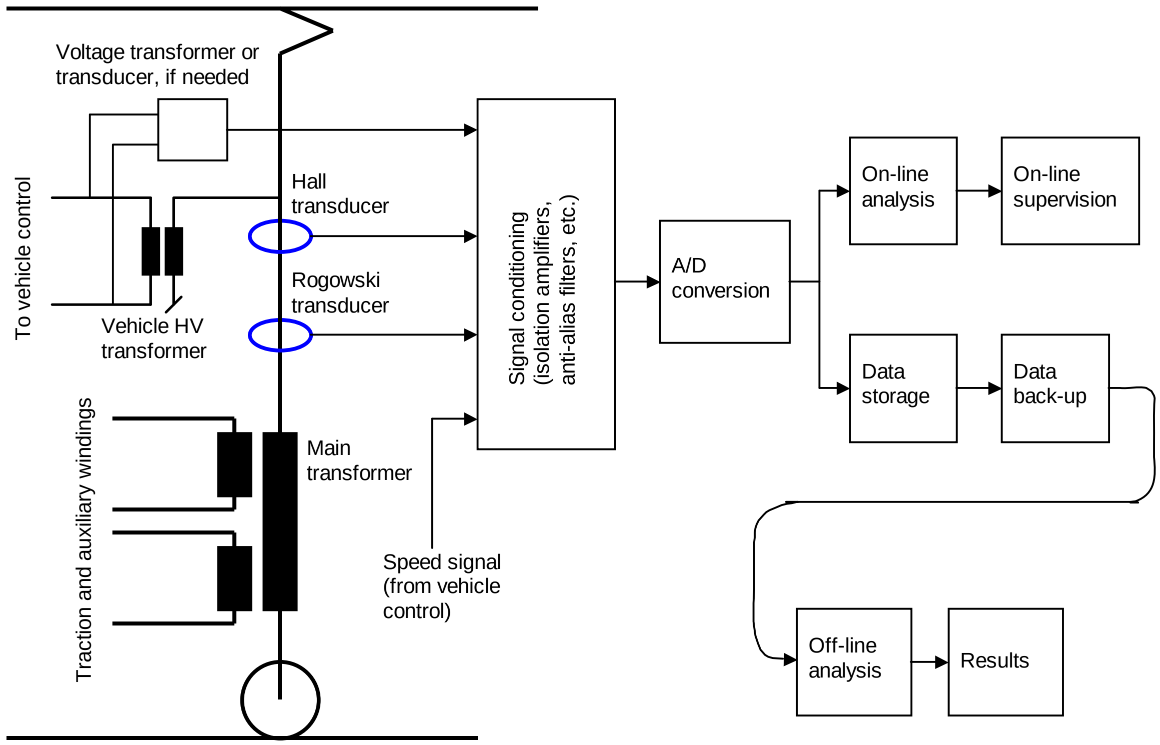



**Figure 5. Transducer position and recommended measuring equipment.**

The tolerance of the overall signal chain including transducers, signal conditioners, A/D converters, and data analysis, must be determined before the tests. A measurement error of less than ± 1% at the fundamental, and less than ± 5% of any of the stated interference requirements, is expected.

The principles of the data analysis, as well as the tolerances, must be described and presented before the tests, as a part of the test plan for the accepting authority.

### 3.3.5.2 Data analysis – requirements S1-S6

The recorded data must be processed and analysed in accordance with the interference requirements S1-S6. The result plots from the analysis (one or more plots per individual LOOP, ABAB, or ARO sequence) must present the following quantities, all versus time:

- RMS line current
- RMS line voltage
- Train speed
- DC current (Sweden only)
- 95 Hz and 105 Hz RMS current (Norway only)
- RMS currents in each of the 16 TI 21 channels (Norway only)

- RMS current in each of the 4 FTGS46 channels, and each of the 8 FTGS 917 channels (Norway only)
- RMS current in the broad-band interference channels. The lower channel should be split in three bands, such that the levels in the following frequency bands are presented separately: 33 Hz – 150 Hz, > 150 Hz – 300 Hz, > 300 Hz – 7 kHz, > 7 kHz – 9 kHz, > 9 kHz (Norway only)

In addition, the following information must be given in each plot:

- Test date
- Line section
- Test ID (reference to the test log)
- Status of the vehicle (number of converters in operation, software revision etc.)
- Distance covered during the test sequence
- 99%-percentile of the psophometric current

If the psophometric current varies significantly with speed (e.g., in the case of a rectifier vehicle), the test report must additionally present a plot of the psophometric current versus speed.

Figure 6 below shows the suggested analysis method, based on a sampling frequency of the raw data of 50 kHz.

For FFT analysis, Hanning windows are recommended.

It is suggested that the psophometric currents are determined by means of a digital IIR filter with a characteristic equal to that specified by Appendix 9. It must be documented that the gain of the filter complies with the tolerance specified in ITU-T O.41 throughout the frequency band 50 Hz – 6 kHz. The recommended RMS integration time is 140 ms.

If FFT methods are used, the psophometric weighting function according to ITU-T (see Appendix 9) shall be applied on the FFT bins according to the formula in section 3.2.5. For FFT bins between the frequencies for which the weighting factors are specified, linearly interpolated values shall be used. The recommended FFT window length is 120 ms. At least 50% overlapping is required. The applicant shall describe how he deals with spectral leakage and frequency variations.

Other types of measurement and evaluation methods, than the recommendations above, can be discussed, but the applicant must then show how these measurements will be carried out and what accuracy will be achieved.

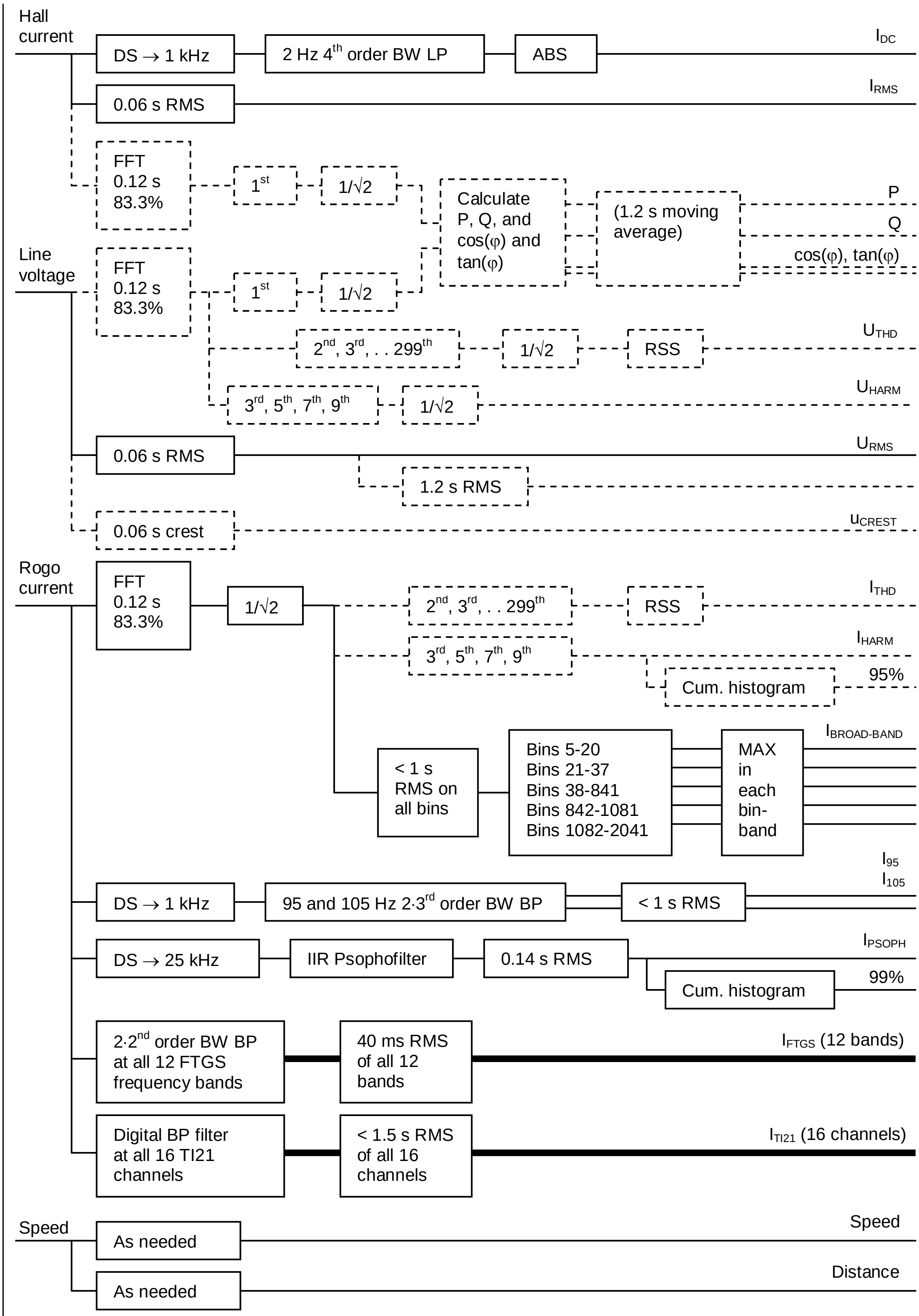



**Figure 6. Suggested post-processing of the recorded data.**

#### 3.3.5.3 Data analysis – S1-requirement (transformer inrush)

The current and voltage waveforms, as well as the 60 ms moving average value of the current, around each inrush event must be plotted, and the time for the 60 ms moving average value of the current exceeding plus or minus 25.0 A must be noted. Each plot must have information about the test date, the exact location of the test, and the data recording ID(s).

#### 3.3.5.4 Measurements and analysis – S7-reqiurement

Measurements procedures and instrumentation are in accordance with EN 50 121, part 2 and 3-1.

## 3.4 Documentation

### 3.4.1 General

All documentation shall be in English. The documentation shall contain:

- Technical functional descriptions, when required
- Measuring equipment
- Accuracy
- Calibration
- Test set up (trains other locos and so on)
- Software version on vehicle
- Time and date for the tests
- Track/line sections and distance from start of line for the presented registrations
- Information about number of repetitions and approximate location for the various tests. Based on this, the applicant must evaluate whether the results can be considered as typical and representative for the later use of the rolling stock, or if special conditions not included in the tests may potentially lead to future problems.
- Discussion of the results and evaluation and a conclusion whether each requirement is fulfilled or not, i.e. a confirmative statement for each requirement.
- A summary report (or a summary as a part of the whole report) where the test results are summarized with remarks and observations, especially incompatibilities and exceedances of limits.

Furthermore, a general technical description containing a principle block diagram of the traction circuits of the vehicle is required.

# 4 POWER SUPPLY

(Applies to “Energy” only. Please see JD590 chapter 4).

| NES | TECHNICAL SPECIFICATION | TS 02 |
|---|---|---|
| NORDIC ELECTRIC POWER CO-OPERATION | FROM THE NES GROUP | APPENDICES<br>PAGES: A41<br>DATE: 01.07.2009 |

# Requirements on rolling stock in Norway and Sweden regarding EMC with the electrical infrastructure and coordination with the power supply and other vehicles

# APPENDICES

# TABLE OF CONTENTS

# A1 APPENDIX 1: INFRASTRUCTURE DATA AND RELATED INFORMATION

This appendix contains more detailed infrastructure data for Norway and Sweden based on requests from the ESC Infobank. The appendices also include a list of existing vehicles.

The data and values shall be regarded as information which can be changed without notice, hence the values shall not be considered as exact stipulated data. More specific information can be given by the authority in each country respectively.

Another source for information about the infrastructure and traffic may be the Network Statements.

## A1.1 Main data

| Data | Norway | Sweden |
|---|---|---|
| Owner | Norwegian National Rail Administration | Swedish National Rail Administration |
| Power supply system | 15 kV, 16 2/3 Hz | 15 kV, 16 2/3 Hz |
| Length of railway network | 4000 km, of which 220 km double track | 9882 km, of which 1734 km are double track or more (11 697 km track length) |
| Length of electrified railway network | 2500 km, of which 220 km double track | 7638 km, of which 1734 km are double track or more (9543 km track length) |
| Map | See appendix 2 | See appendix 3 |
| Modifications planned in future | Rebuilding of weak main lines and construction of some new lines (double track) that will increase capacity and cut travel time between existing railway destinations around Oslo | New single track lines on the east coast in the north of Sweden (Botniabanan and Haparandabanan)<br>New city lines double track in Stockholm and Malmö<br>Strengthening of some weak lines. Further away: High speed lines Stockholm-Mjölby and Gothenburg-Norway. Upgraded lines Stockholm-Sundsvall, Stockholm- Gothenburg, Stockholm-Malmö, Gothenburg-Malmö. |
| Other | The traction power supply is generally weak. | - |

## A1.2 Power generation

| Data | Norway | Sweden |
|---|---|---|
| Direct supply from public network | No | No |
| Supply from public utility via rotary frequency converters | Yes | Yes |
| Supply from public utility via static frequency converters | Yes | Yes |
| Railway owned power stations / generators | Yes, but one hydro power station owned by other company (Statkraft SF) | No |
| Supply network structure | Decentralized, but a small centralized 55 kV network exists in the region south west of Oslo | Decentralized, including a 132 kV-feeding system which connects 8 converter stations |
| Frequency and phase stiffness | Synchronous to public utility.<br>See section 6.1.2 in the report.<br><br>Transient deviation in frequency may occur due to changing load.<br>Phase:<br>For both rotary and static converters phase angle depends on load demand.<br>For a load at cos(φ) = 1.0 the phase normally lags 36º at converters at rated load. | Synchronous to public utility.<br>See section 6.1.2 in the report.<br><br>Transient deviation in frequency may occur due to changing load.<br>Phase:<br>For both rotary and static converters phase angle depends on load demand.<br>For a load at cos(φ) = 1.0 the phase normally lags 36º at converters at rated load. |

### A1.2.1 Connection to public utility

| Data | Norway | Sweden |
|---|---|---|
| Voltage level at connection point (PCC= point of common coupling) | min: 11 kV<br>typ: 66 kV<br>max: 130 kV | min: 70 kV<br>typ: 130 kV<br>max: 220 kV |
| Short circuit power at connection point (PCC= point of common coupling) | min: 70 MVA<br>typ: 250 MVA<br>max: 2500 MVA | min: 594 MVA<br>typ: 2-3000 MVA<br>max: 9260 MVA |
| Short circuit power at substation input | Not calculated | Without any contribution from rotary converters:<br>min: 45 MVA |

| | | |
|---|---|---|
| | | typ: 150-200 MVA<br>max: 480 MVA |
| Modifications planned in future | No information available. | Increased feeding capacity when new converters are commissioned. |

### A1.2.2 Power stations

| Data | Norway | Sweden |
|---|---|---|
| Number of power stations | 1 | None |
| Number of generators per station | min: 2<br>typ: 2<br>max: 2 | N.A.<br>(= not applicable) |
| Rate generator power | min: 600 kW<br>typ: 600 kW<br>max: 600 kW | N.A. |
| Typical short circuit impedance of generator [%] | Unknown | N.A. |
| Typical short circuit impedance of transformator [%] | 3.09+j0.978 | N.A. |
| Modifications planned in future | Increasing generator capacity to 2500 kW | N.A. |

### A1.2.3 Rotary frequency converters

| Data | Norway | Sweden |
|---|---|---|
| Converter name | ASEA Q24, Q38, Q48 and NEBB 7 MVA and 10 MVA | ASEA Q24/Q25<br>ASEA Q38/Q39<br>ASEA Q48/Q49 |
| Number of converter stations | 29 | 25 and 3 which have both rotary and static converters |
| Number of converters units per station | min: 1<br>typ: 2<br>max: 3 | min: 2<br>typ: 3<br>max: 5 |
| Type of converter | Synchronous to synchronous | Synchronous to synchronous |
| Type of excitation and control | Electro-mechanical | Electro-mechanical |
| Damping | Damping windings in generator-machine, none in motor-machine | Damping windings in generator-machine, none in motor-machine |
| Railway side connected to | Contact line for all, but also to 55 kV distribution network in two stations | Contact line |
| Regeneration capability | Yes | Yes |

| | | |
|---|---|---|
| Rated converter power per unit [MVA] | min (Q24): 2.4<br>typ (Q38): 4<br>max (Q48): 10 | min (Q24): 2.4<br>typ (Q38): 4<br>max (Q48): 10 |
| Continuous power per unit (respectively) [MVA] | min (Q24): 3.1<br>typ (Q38): 5.8<br>max (Q48): 10 | min (Q24): 3.1<br>typ (Q38): 5.8<br>max (Q48): 10 |
| Typical short circuit impedance of generator+ Transformer [Ohm] | min (Q48): j7.0<br>typ (Q38): j14.35<br>max (Q24): j33.1 | min (Q48): j7.0<br>typ (Q38): j14.35<br>max (Q24): j33.1 |
| Voltage regulation | Stiff or slightly declining with increasing reactive power demand. | Stiff or slightly declining with increasing reactive power demand. |
| Capacity | The number of active units in each station is adapted to hourly variation in power demand | The number of active units in each station is depending on the actual load and adaptive load statistics. |
| Overloading capacity | Up to +40 % of continuous power for 6 minutes and +100 % of rated power for 2 seconds | Up to +40 % of continuous power for 6 minutes and +100 % of rated power for 2 seconds |
| If overloaded | Converter is instantaneously disconnected | Converter is instantaneously disconnected |
| Modifications planned in future | Static and brushless excitation may be implemented. Maybe increasing the number of converters in each station. | Brushless exciters may be introduced in the future. |

### A1.2.4Static frequency converters

| Data | Norway | Sweden |
|---|---|---|
| Converter name | ABB PWM converter<br>ABB/Adtranz PWM converter: MegaMacs<br>Siemens | ASEA Cyclo-converter: YOQC<br>ASEA/ABB PWM-converter: TGTO<br>ABB/ADtranz PWM-converter: MegaMacs<br>ALSTOM PWM-converter |
| Number of converter stations | 6 | 18 |
| Number of converters units per station | min: 2<br>typ: 2<br>max: 3 | min: 2<br>typ: 3<br>max: 4<br>6 in future |
| Type of converter | PWM converter: Line voltage converter (rectifier) and pulse width modulated | 15 cyclo converters and 37 PWM conveters |

| | | |
|---|---|---|
| | inverter connected together with DC-link | |
| Filters on railway side | Yes, broad band and psofometric filter | Normal filter configuration for cylco converters and MEGAMACS is a wideband filter. Normal filter configuration for other PWM converters is 6th and 8th and wideband |
| Other filters | DC-link: 2nd, 4th, 6th and 8th/9th.<br>Utility grid: Yes | DC-link: 2nd, 4th, 6th and 8th and wideband in MEGAMACS converters<br>Utility grid: Yes |
| Regeneration capability | Only one station, in others the phase angle is shifted to push regenerated energy forward to other trains or stations. Some stations have a resistor for taking care of short term feedback power. | All cyclo converters can regenerate to the 50 Hz-grid. 2 converter stations with PWM-converters can regenerate to the 50 Hz grid. (Alingsås and Järna). All other PWM converters have resistors to take care of short term feedback power. |
| Rated converter power per unit [MVA] | min: 6<br>typ:<br>max: 15 | min: 6<br>typ: 15<br>max: 15 |
| Typical short circuit impedance of output transformer [%] | 0.013+j0.0677 pu | 0.83+j13.0 but can vary a lot:<br>0.83% > ur >1.49%<br>7.94% > ur >13.0% |
| Voltage regulation | Stiff or slightly declining with increasing reactive power demand. Static converters imitate the dynamical response of a rotary converter (ASEA Q48) due to software parameterisation. The 1~ phase voltage angle depends therefore of the 3~ phase angle. | Stiff or slightly declining with increasing reactive power demand. Static converters imitate the dynamical response of a rotary converter (ASEA Q48) due to software parameterisation. The 1~ phase voltage angle depends therefore of the 3~ phase angle. |
| Frequency regulation | Synchronization with the 50 Hz grid is kept by means for phase-locked loops | Synchronization with the 50 Hz grid is kept by means for phase-locked loops |
| Capacity | The number of active units in each station are automatically adapted to | The number of active units in each station is depending on the actual load and |

| | | |
|---|---|---|
| | variation in power demand | adaptive load statistics. |
| Overloading capacity | No short time exceeding of rated power | Normally no overload capacity but MEGAMACS have a short time capacity of 17 MVA |
| If overloaded | If current limit is reached, voltage will be reduced. The voltage will then not be sine adapted. | If current limit is reached, voltage will be reduced. The voltage will then not be sine adapted. |
| Extensions planned in future | | 7 new static converters are under commissioning, in operation 2007-2008 |

## A1.3 Power distribution

### A1.3.1 General data

| **Data** | **Norway** | **Sweden** |
|---|---|---|
| Railway owned power distribution network exists | Yes at 16.7 Hz, in one limited area | Yes at 16.7 Hz |
| Nominal voltage [kV] | 55 (2 x 27.5 kV) | 132 kV (2x66 kV) |
| Number of phases | 2 | 2 |
| Purpose | Connecting one hydro power station, 2 rotary converters and 3 substations | To reduce number of converter stations and have a more even usage of the remaining converter stations |
| Network length [km] | Approx. 157 | 1925 |
| Total cable length | No information available. | Cables north of Uppsala of length 6 km and south of Uppsala 3 km. (these are the longest existing cable sections) |
| Lowest network resonance frequency [Hz] | No information available. | Normally 100 -130 Hz. Resonance frequencies lower resonance frequencies can occur (combinations of lines and connected installed power). |
| Modifications planned in future | No significant modifications | No significant modifications planned |

### A1.3.2 Transformer stations

| Data | Norway | Sweden |
|---|---|---|
| Number of transformer stations | 3 plain transformers, 2 located together with converter stations | 31 plain transformers substations,<br>8 transformer substations located together with converter stations |
| Nominal power rating [MVA] | min: 2x2.5<br>typ:<br>max: 1x8 | All plan transformer substations have one 16 MVA transformer Most transformer substations at converter stations have two 25 MVA transformers but normally only one operating. |
| Short circuit impedance [%] | min:<br>typ: 6.3-6.5<br>max: | min:<br>typ: 5<br>max: |
| Efficiency in nominal point [%] | typ: 98-99 | > 99 at cos(φ) =1.0 |
| Voltage regulation | Typically none, but one station has automatic tap changer | Only tap changers, no on load tap changers. |
| Modifications planned in future | None | No |

### A1.3.3 Transmission lines

| Data | Norway | Sweden |
|---|---|---|
| Typical transversal section (cross section) | 55 kV (2x27.5 kV) normally made up with concrete poles and with the phase height of 9.2 m and phase spacing of 3.5 m. | 132 kV lines (2x66 kV) are normally built with wooden poles with a phase height of 10.8 m (sags included) and a phase spacing of 4m.<br>Earthed top wires only close to substations and on some lines where old 3-pase 220 kV lines have been reused. |
| Conductor material(s) | Cu and FeAl | DOVE: 329 $mm^2$ FeAl |
| Conductor cross section (s) [mm2] | 4x35, 4x50, 2x50 and 2x70 | See above. |
| Specific impedance [Ohm/km] | 0.34+j0.24 or 0.73+j0.28 | Positive sequence:<br>0.1025+j0.126 Ω/km<br>Zero sequence:<br>0.1349+j0.456 Ω/km |

| | | |
|---|---|---|
| | | Pos.seq. capacitance: 9.5862 nF/km<br>Zero seq. capacitance: 6.4444 nF/km |
| Modifications planned in future | No significant modifications | No significant modifications planned. |

### A1.3.4 Cables

| Data | Norway | Sweden |
|---|---|---|
| Specific impedance [Ohm/km] | 0.1+j0.03 or 0.12+j0.28 | Per phase:<br>0.1009 + j 0.026 |
| Specific capacitance [nF/km] | Per phase:<br>0.16 µF/km | Per phase:<br>0.16 µF/km |
| Modifications planned in future | No significant modifications | None known. |

## A1.4 Substations

### A1.4.1 General data

| Data | Norway | Sweden |
|---|---|---|
| Map | Se appendix 2 | Se appendix 3 |
| Number of substations | 38 | See section A1.2.4 and A1.3.2. |
| Type of substations | Transformers only: 3<br>Converters feeding contact line: 35<br>Hydro power station: 1 | See references above |
| Nominal power rating of complete substation [MVA] | min: 2x0.625<br>typ: 2x5.8<br>max: 3x15 | See references above |
| Feeding of railway lines | Single side<br>Double side<br>Multiple side (2 T-connections) | Single and double sided feeding. |
| Distance between substations [km] | min: 12<br>typ: 80<br>max: 92 | See section A1.5.1. |
| Distance of single fed line [km] | min:<br>typ:<br>max: 63 | See section A1.5.1. |
| Normal operation of network | Interconnected | Interconnected |
| Separation of feeding areas (neutral sections) | Seldom sectioned, but depending on operation of utility grid | Normally no separation of feeding areas. |

| | | |
|---|---|---|
| Voltage at railway side | Controlled during operation | 16.5 kV controlled during operation, stiff or slightly declining, proportional to the inductive load (slightly increasing at capacitive load |
| Modifications planned in future | No information available. | More stations will have slightly declining voltage, proportional to the inductive load (slightly increasing at capacitive load |

### A1.4.2 Autotransformers

| Data | Norway | Sweden |
|---|---|---|
| Autotransformers exist | No, but planned in future | Yes, but only on single track lines |
| Voltages [kV] | 2x15 | 2x15 |
| Transformer rating [MVA] | min:<br>typ: 5<br>max: 2x5 | 5<br>Normally two AT's in parallel are used as feeding transformer feeding an AT-line. |
| Short circuit impedance [%] | min:<br>typ: 0.4<br>max: | uk = 0,4 %, 57.53° (or 0.184+j0.117 Ω) |
| Distance between trafos [km] | min: 8<br>typ: 10<br>max: 12 | min: 8<br>typ: 10<br>max: 12 |
| Present on … fed lines | …both single and double side… | …both single and double … |
| Connection of AT to lines | Negative feeder (-15 kV), rail (0 kV) and positive feeder (+15 kV). Positive feeder interconnected to contact line (sectioned) typical each 5 km. | Normal connection, i.e. negative feeder (-15 kV), rail (0 kV) and contact line as positive feeder (+15 kV). |
| Combination with other systems | Not planned | At some lines with booster transformers, i.e. some lines may in the future be converted into ATBT-system. |
| Modifications planned in future | Planned to be used for today's weak lines | More AT-system lines are planned. AT-system may occur on double track lines in the future. |

### A1.4.3 Passive filters and compensators

| Data | Norway | Sweden |
|---|---|---|
| Passive filters exist | Yes | No, only at converter stations with static converters, see A1.2.4 |
| Type of filter | Series capacitor and shunt capacitor | N.A. |
| Schematics etc. | No information available. | N.A. |
| Resonance frequencies | Series: No significant effects on resonance frequencies.<br>Shunt: No information available. | N.A. |
| Where in service | Series capacitor between converter stations on weak lines, shunt capacitor in heavy load area (Oslo S) | N.A. |
| Purpose | Series capacitor for voltage increase and shunt capacitor for reactive power feeding | N.A. |
| Rating | Series cap -j7.35 [Ohm]<br>Shunt cap 4 [MVAr] | N.A. |
| Modifications planned in future | Series capacitors will probably be removed when line is reinforced/rebuilt with AT-system | More filters built when new converters are built |

### A1.4.4 Controlled filters, compensators and balancers

| Data | Norway | Sweden |
|---|---|---|
| Controlled filters/ comp. exist | No | No |
| Type of installation | N.A. | N.A. |
| Schematics | N.A. | N.A. |
| Where in service | N.A. | N.A. |
| Purpose | N.A. | N.A. |
| Modifications planned in future | N.A. | N.A. |

### A1.4.5 Auxiliaries

| Data | Norway | Sweden |
|---|---|---|
| Substation and station supply | Yes | Yes |
| Switch heating | Yes | Yes |
| Train heating | Yes | Yes |

| | | |
|---|---|---|
| Any other equipment | No | See section 6.9.4 in the report. |
| Modifications planned in future | No information available. | None |

### A1.4.6 Other equipment

| Data | Norway | Sweden |
|---|---|---|
| Other equipment exist | No | No |
| Description | N.A. | N.A. |
| Modifications planned in future | No information available. | None |

## A1.5 Railway lines

### A1.5.1 Longitudinal characteristics

| Data | Norway | Sweden |
|---|---|---|
| Map | See appendix 2 | See appendix 3 |
| Max length between feeding points [km] | 92 | 156 (one weak line), normally 60-120 km but shorter in areas with heavy traffic, the longer distance reflects that 132 kV lines are present |
| Max length between feeding points and open line end [km] | 63 | 63 |
| Modifications planned in future | Introducing AT-systems, the max length between feeding points probably will be increased to 120 km | No specific modifications planned. |

### A1.5.2 Cross connections on double-track lines

| Data | Norway | Sweden |
|---|---|---|
| Cross connection is done | Never in normal operation but one shorter line where the two tracks are operated n parallel (connected in the ends) | Exists on some lines (Tranås-Malmö) as normal operation. On other lines only during fault conditions or maintenance. |
| Cross-connections (if existing) are | Switchable, but just in use in fault situations | Switchable. |
| Distance between connections (if existing) | min:<br>typ: very variable<br>max: | Normally 7-10 km. |

| | | |
|---|---|---|
| Modifications planned in future | No information available. | More lines using cross connections are under investigations |

### A1.5.3Cross sections of lines

| **Data** | **Norway** | **Sweden** |
|---|---|---|
| Number of tracks on open line (i.e. outside stations/yards) | Mostly single track, but double and multiple track exist | Normally single track but double track between the cities Stockholm, Gothenburg and Malmö and north and west of Stockhom, see Appendix 3, Network map of Sweden. In the Stockholm area 4 track lines exists. |
| Earth wire | On some lines, both sectioned and interconnected exist | Exits on some lines. |
| Feeder (electrically parallel to contact line) | Normally not, but exist on some lines | Only on a few lines. |
| Feeder (connection in switch posts only) | On some lines | Only at a few locations, e.g . in the Stockholm area. |
| Return conductor | On some lines, normally two 240 $mm^2$ Al | Yes, normally two 212 $mm^2$ Al |
| Auto-/booster wires | No information available. | BT-systems: Booster wire is normally (212 $mm^2$ Al) used in the north of Sweden and some lines in the south, see Appendix 3, Network map of Sweden.<br>AT-systems: Booster wire is normally used. |
| Public utility (no direct connection to railway system) | Not at all | None |
| Auxiliary supply (no direct to railway system) | Not at all | Auxiliary power of 3-phase 22 kV or 11 kV (also 2-phase exists) are normally placed on top of the contact line poles. This auxiliary power is normally fed from converter stations. Loads along the lines can also be fed from the public network. Transformers at loads along |

| | | |
|---|---|---|
| | | the line. The voltage is very weak |
| Open communication lines | On some lines | On most of the lines, placed in the embankment. |
| Typical cross section(s) layout(s) | No information available. | See appendix 6 for a typical BT-line and appendix 7 and 8 for AT-lines. |
| Any other important info | Isolation standard (target/planing level) for the contact overhead line system is 170/70 kV. | Isolation standard (target/planning level) for the contact overhead line system is 170/70 kV. There exists lines with isolation levels between 150/55 kV and 225/75 kV. |
| Modifications planned in future | No information available. | Earth wire are planned to be standard on all future AT-lines, probably also on BT-lines. Exits already on some lines. |

### A1.5.4 Cable sections

| Data | Norway | Sweden |
|---|---|---|
| Length of cable connection substation to contact line [km] | typ: 0.1<br>max: 5 | 0.1 – 4 km, typical value 300 m. |
| Length of feeder cable parallel to railway line (e.g. tunnels, urban areas) [km] | typ:<br>max: short | Exist only in the Stockholm area (4 cable feedings). Typical length : 13 km. |
| Specific impedance [Ohm/km] | min: 0.10+j0.03<br>typ: 0.12+j0.06<br>max: | For cables in the Stockholm area:<br>0.12 + j 0.054 and<br>0.15 + j 0.036 |
| Specific capacitance [µF/km] | min:<br>typ: 0.26<br>max: | For cables in the Stockholm area:<br>0.16 and 0.26 µF/km. |
| Modifications planned in future | Introducing AT-system may cables for negative and positive feeder in tunnels may be necessary | Under investigation (Citybanan in Stockholm). |

### A1.5.5 Return current arrangement

| Data | Norway | Sweden |
|---|---|---|
| Rail types | S49: 2700 km<br>S54: 750 km | Normally UIC 50 and UIC 60 or corresponding. |

| | | |
|---|---|---|
| | UIC60: ca. 200 km | |
| Rail info | Normally welded, isolated gaps/joints exists | One rail welded (S-rail) and one rail with isolated joints (I-rail) which is used by the DC-track signalling circuit. |
| Isolated rails | No isolation at all | Yes, see item above. |
| Return conductor | See section A1.5.3. | See section A1.5.3. |
| Earth wire | On some lines, both sectioned and interconnected (typical distance between connections to rail is 3 km) exist | See section A1.5.3. |
| Track transformers | No | No |
| Other characteristics | No | No |
| Earth resistivity [Ωm]<br><br>Wet soil: 20-200<br>Humus/clay: 50-200<br>Wet sand: 100-300<br>Dry sand: 1000-50000<br>Mountains: 1000-10000 | Railway lines are very often build on bedrock ground or rocky ground. A usable value is 2500 Ωm. | Earth resistivity is high. A usable value is 2500 Ωm. |
| Future modifications plans | No information available. | None |

### A1.5.6 Booster transformers

| **Data** | **Norway** | **Sweden** |
|---|---|---|
| Booster transformers exist | Yes | Yes, on all lines except AT-system lines. |
| Transformer power rating [kVA] | min: 33 (380 A, 87 V)<br>typ: 55 (680 A, 92 V)<br>max: 95 (800 A, 118 V) | 500 A Booster transformer: 158 kVA (500 A, 316 V, 800 A for 1 hour).<br>Older booster transformers of 300 A exists. |
| Short circuit impedance [%] | min: 2.7 + j 2.5<br>typ: 8.4 + j 22.3 | 500 A Booster transformer:<br>typ: 3.86 + j 10.3<br>typ: 11 (absolute value) |
| Distance between booster transformers [km] | min: 2<br>typ: 3<br>max: 20 | typ: 5.6 |
| Specific contact line system impedance [Ohm/km] | typ: 0.013 | See section A1.5.9. |
| Modifications planned in future | No information available. | 3-windings boosters may be introduced if ATBT-systems are introduced. |

### A1.5.7 Neutral sections/Phase gaps

| Data | Norway | Sweden |
|---|---|---|
| Neutral sections exist | Yes | Yes |
| Neutral part is | See clause 6.2 in the report. | Normally floating |
| Location | See clause 6.2 in the report. | At substations and switching posts. |
| May be shunted | See clause 6.2 in the report. | Yes, normally to earth, but to contact line voltage exists. |
| Length [m] | min: 40<br>typ: 90<br>max: 350 | min: 2 at stations<br>min: 60<br>typ: 180<br>max: 180 |
| Concept for emergency supply (e.g. one substation out of order) | No information available. | Converter stations are design for outage of one converter unit with out influencing the traffic. |
| Modifications planned in future | Neutral sections of 402 m are planned for future. | None |

### A1.5.8 Interaction AC/DC railways

| Data | Norway | Sweden |
|---|---|---|
| Infrastructure segment lies adjacent to DC-railways/tramways | Yes | Yes |
| Special arrangements (such as DC train supply with current return through rails on AC lines) | No, not as we know | No |
| Description | Grefsen station (750 V DC parallel and 600 V DC crossing)<br>Bryn station (750 V DC crossing)<br>Trondheim station (600 V DC crossing) | Trams lines (750 V DC) parallel to railway lines in Gothenburg.<br>Underground/subway lines (750 V DC) parallel to railway lines in Stockholm. |
| Modifications planned in future | Lysaker station – tramway face to face planned | No |

### A1.5.9 Numerical values BT system

| Data | Norway | Sweden |
|---|---|---|
| Line impedance , single track lines [Ohm/km] including BT | min: 0.092+j0.106<br>typ: 0.190+j0.210<br>max: 0.233+j0.228 | min: 0.13+j0.16<br>typ: 0.21+j0.20<br>max: 0.30+j0.23 |
| Line impedance , double track lines [Ohm/km] including BT | min: 0.160+j0.180<br>typ:<br>max: 0.218+j0.188 | Not calculated. |
| Specific capacitance, single track [nF/km] (caternary–earth) | min: 9<br>typ:<br>max: 17 | typical for booster transformer lines:<br>8.8 – 11.1 |
| Lowest resonance frequency (contact line network) double side feeding [Hz] | typ: 800 Hz global<br>typ: 450 Hz local | typ: 800 Hz global<br>typ: 450 Hz local |
| Lowest resonance frequency (contact line network) single side feeding [Hz] | typ: 450 Hz local | typ: 450 Hz local |
| Other interesting values | Earth resistivity is high. | Earth resistivity is high. A usable value is 2500 Ωm. |
| Modifications planned in future | No information available. | No |

### A1.5.10 Numerical values AT system

| Data | Norway | Sweden |
|---|---|---|
| Fixed impedance at feeding or starting points [Ohm] | Not yet decided or calculated. | min: 0.189+j0.343<br>typ:<br>max: 0.468+j0.755<br>(see note below the table) |
| Line impedance on single line track [Ohm/km] | Not yet decided or calculated. | min: 0.0335+j0.031<br>typ:<br>max: 0.0715+j0.066<br>(linear approximations including AT's) |
| Line impedance on double line track [Ohm/km] | Not yet decided or calculated. | Not calculated. |
| Specific capacitance, single track [nF/km] (caternary–earth) | Not yet decided or calculated. | typ: 11.9 – 13.5 |
| Specific capacitance, double track [nF/km] (caternary–earth) | Not yet decided or calculated. | Not calculated. |
| Lowest resonance frequency (contact line network) double | typ: 450 Hz global<br>typ: 350 Hz local | typ: 400 Hz global<br>typ: 250 Hz local |

| | | |
|---|---|---|
| side feeding [Hz] | | |
| Lowest resonance frequency (contact line network) single side feeding [Hz] | typ: 200 Hz local | typ: <200 Hz local |
| Modifications planned in future | Exact system design not decided yet | No |

**NOTE** that the values for AT-systems in Sweden regards single track systems. Furthermore note that the AT-system impedances are linear approximations of the AT-system impedances with the intension to get values which can easily be used in simulation programs and for calculations of settings of relay protections. The fixed impedance corresponds approximately to the level of the zero sequence impedance of the system. This impedance shall be placed as a fixed impedance at both ends of the system in case of a AT-system fed from both ends and at the feeding end in case of a single end fed system. The impedance per km corresponds approximately to the positive sequence impedance.

## A1.6 Signalling equipment

### A1.6.1Track circuits

| Data | Norway | Sweden |
|---|---|---|
| DC track circuits | Only on non-electrified lines and at one electrified railway station (Filipstad) | DC track signalling circuits exists on nearly the whole network. None existing only on none electrified lines. |
| High voltage impulse | Do not exist | Do not exist |
| Low frequency (25-275 Hz) | Exist on most of the electrified lines. 95 and 105 Hz only, uncoded. | Do not exist |
| Reed frequency (275-1000Hz) | Do not exist | Do not exist |
| Lower audio frequency (1-4 kHz) | Exist on a small part of the network. Bombardier TI 21 (1.5 - 2.6 kHz), digital processor based and not transmitter signal coded. | Do not exist |
| Upper audio frequency (4-20 kHz) | Exist on a part (110 km) of network. Siemens FTGS (4.7-16.5 kHz), digital and transmitter signal coded. | Do not exist |
| Other | Do not exist | Train radio or radio blocking of trains on some none electrified low traffic lines |
| Modifications planned in future | No information available. | More radio block systems are planned for low traffic |

| | | |
|---|---|---|
| | | lines. |

### A1.6.2 Axle counters

| Data | Norway | Sweden |
|---|---|---|
| Mechanical | Do not exist | No |
| Electro-magnetic | Do not exist | Yes, but not used as signalling equipment They are placed together with axle box heating locked braking detectors |
| Electronic | Do not exist, but are being tested | No |
| Others | Do not exist | No |
| Modifications planned in future | Are planned for future use | None |

### A1.6.3 Automatic train protection (ATP) and automatic train control (ATC)

| Data | Norway | Sweden |
|---|---|---|
| ETCS/ERTMS level 1 | Does not exist | Does not exist. |
| ETCS/ERTMS level 2 | Does not exist | Introduced on the Botniabanan |
| ETCS/ERTMS level 3 | Does not exist | Does not exist. |
| National system(s) | "ATC" used in nearly the whole network. EBICAB700 manufactured by ATSS and Bombardier | "ATC" used in nearly the whole network, manufactured by ATSS and Bombardier.<br>Radio blocking of trains or manual train blocking used on some none electrified low traffic lines. |
| Modifications planned in future | Long term strategy is ERTMS level 2 | Ongoing project for introducing ERTMS level 2 (the lines Malmö-Stockholm-Sundsvall are planed for 2010-2015) |

### A1.6.4 Interference monitors

| Data | Norway | Sweden |
|---|---|---|
| Philosophy of application | Monitors recommended. Monitors needed if safety case can not be fulfilled otherwise | DC-current monitor on new electrical traction vehicles is required. |

| | | |
|---|---|---|
| Purpose | Monitored frequencies: 95 and 105 Hz.<br>Trip level 2 A rms.<br>Filter characteristics ±3 Hz.<br>Response time 1 sec. | To monitor the DC-component, a component which can have an influence on the track signalling circuits. |
| Type(s) in service | 95 and 105 Hz monitor for warning and disconnection of main circuit breaker. | DC-monitors are in operation on some new vehicles. |
| Modifications planned in future | No information available. | None |

### A1.6.5 Interference limits

| **Data** | **Norway** | **Sweden** |
|---|---|---|
| Frequency band (name) | See section 5.2 and 5.4 in the report. | Limits on DC-components and psophometric currents, see section 5.2 and 5.4 in the report. |

### A1.6.6 Data transmission and remote control systems

| **Data** | **Norway** | **Sweden** |
|---|---|---|
| System(s) | Various communication systems exists, such as PCM (puls code modulation, BF (frequency carrier), etc, on Cu-cable. Also ordinary telephone lines on Cu-cables excists. Opto-communication is the dominating transmission for long distances communication.<br>GSM-R is being introduced in the whole country. | Various communication systems exists, such as PCM (puls code modulation, BF (frequency carrier), ADSL, etc, on Cu-cable. Also ordinary telephone lines on Cu-cables exists. Opto-communication is the dominating transmission for long distances communication.<br>Transmission used for SCADA-systems are ELCOM, X25, RP570 and more. At the moment IEC 870-5-104 (on TCP/IP) is introduced.<br>GSM-R is being introduced in the whole country. |

## A1.7 Operational conditions

### A1.7.1 Line frequency

See section 6.1.2.1 in the report.

### A1.7.2 Line voltage RMS value

See section 6.1.1.1 in the report.

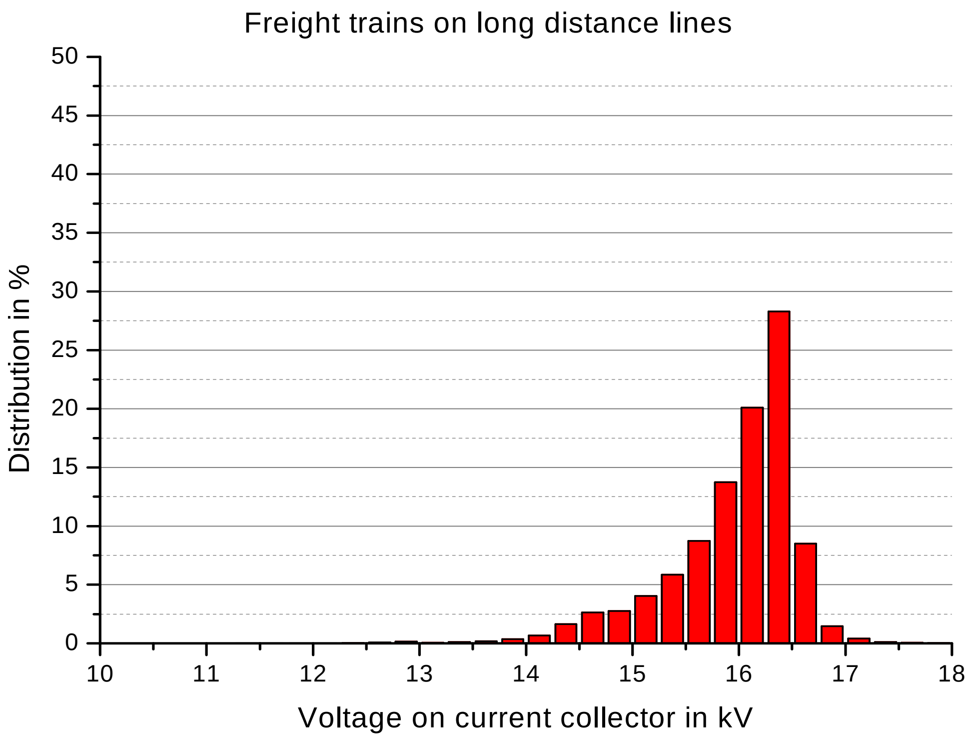
Based on simulation in SIMPOW® TRACFEED® the figures below show a typical statistical distribution of the fundamental voltage at the pantograph of a vehicle in Norway. The values can be used as a fairly good approximation also for Sweden.

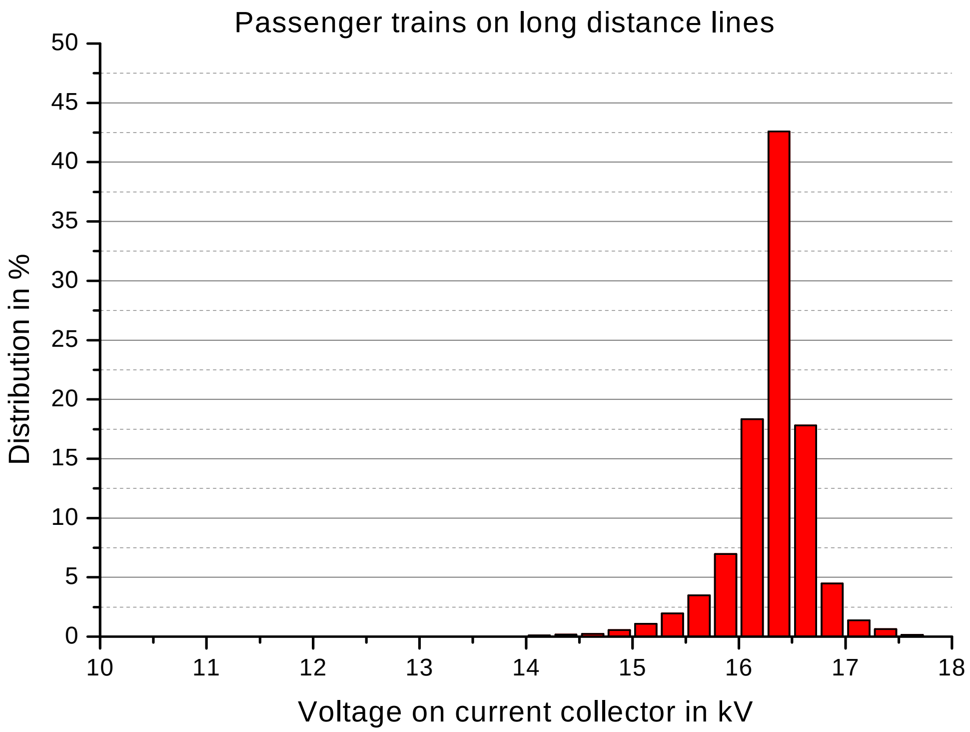
The information is based on 1-second values (mean values during one second) for a 35 different trains considered as representative of the operation to day. Vehicle and line vary and the trains are divided and aggregated into the following groups:

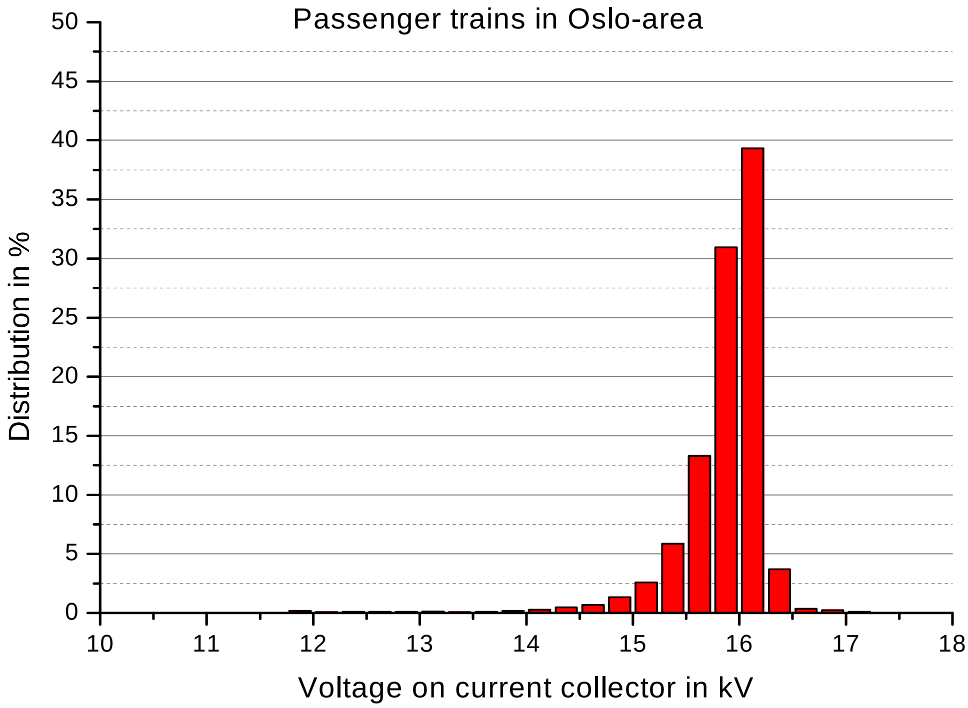
- Freight trains on long distance lines, normally considered as weak lines (Bergen line, Dovre line, Sørland line and Ofoten line).
- Passenger trains on long distance lines, normally considered as weak lines (Bergen line, Dovre line, Sørland line and Ofoten line).
- Passenger trains in Oslo area, also including the Gjøvik line, Østfold line and the Vestfold line. The Olso area is normally considered as relatively stiff compared to long distance lines.

The voltages shown below are simulated for traction, coasting and braking mode, and includes stops at stations between start and stop.

Note that this figures show an overall distribution. For shorter time intervals the voltage distribution for a single train deviates from the figures shown due to sections of lines with lower voltage quality.


Freight trains on long distance lines
Distribution in %
50
45
40
35
30
25
20
15
10
5
0
10
11
12
13
14
15
16
17
18
Voltage on current collector in kV


Passenger trains on long distance lines
Distribution in %
50
45
40
35
30
25
20
15
10
5
0
10
11
12
13
14
15
16
17
18
Voltage on current collector in kV



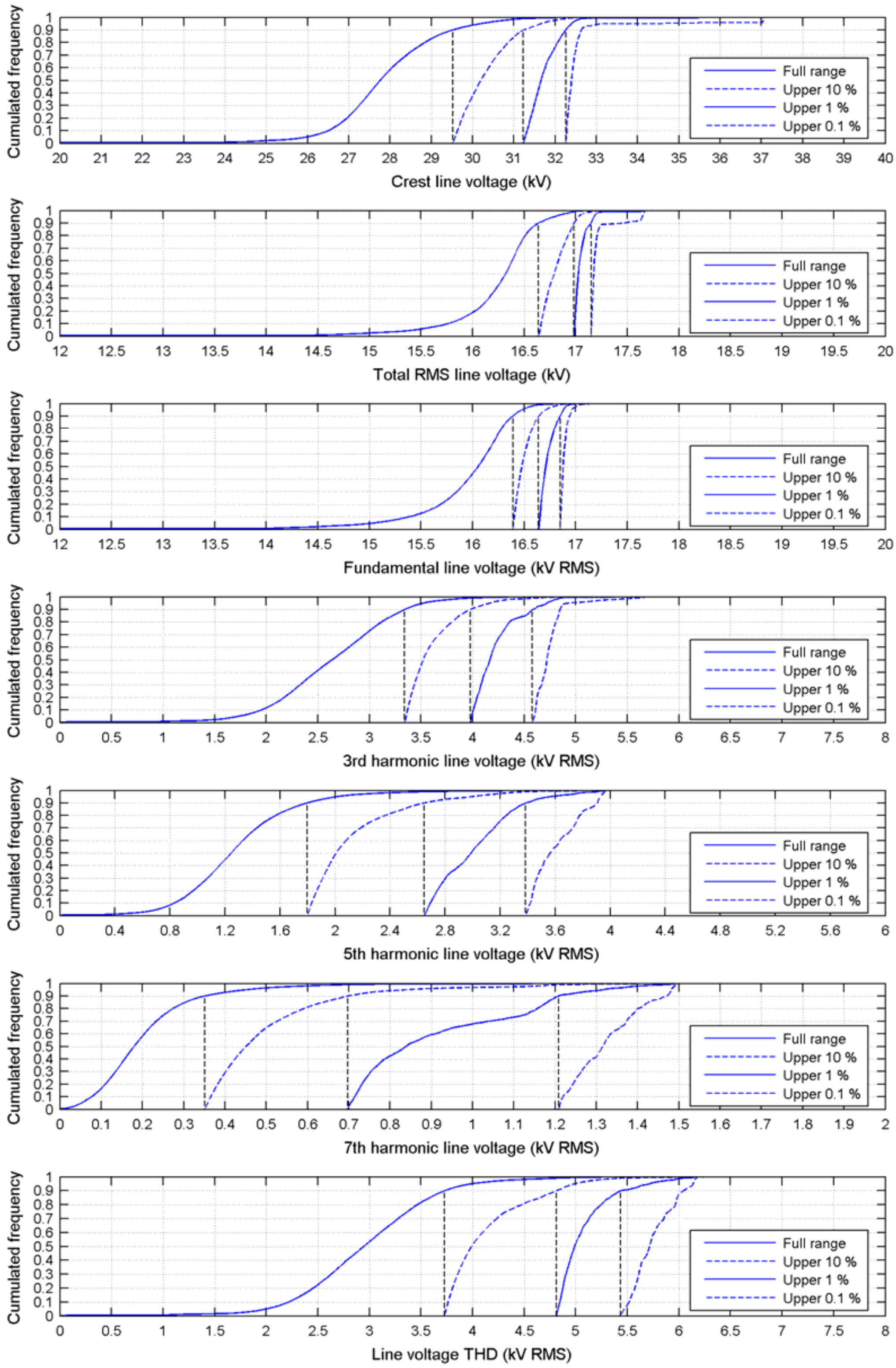

### A1.7.3 Line voltage spectrum

| Data | Norway | Sweden |
|---|---|---|
| Sub-harmonics or regular frequency variations occur | Yes, see clause 6.5.1 in the report. | Yes, see clause 6.5.1 in the report. |
| Line voltage content with harmonics up to 1000 Hz | Significant to very large, higher harmonic orders do occur but are not significant, see section 6.1.3.1 in the report. | Significant to very large, higher harmonic orders do occur but are not significant, see section 6.1.3.1 in the report. |
| Line voltage content with harmonics 1000-3000 Hz | Very low, no influence on vehicle known from earlier tests | Very low, no influence on vehicle known from earlier tests, so far. |
| Typical spectra | See section 6.1.3.1 in the report. | See section 6.1.3.1 in the report. |

The figure below can be regarded as a typical statistical distribution of the line voltage harmonics for Norway and Sweden. (The values of the figure below are based on recordings made during tests with a locomotive on the Borlänge-Ludvika/Krylbo-Frövi-Eskilstuna line sections in Central Sweden, October 2005. Recordings and analysis by L. Buhrkall.)

## Typical distribution of line voltage interference components, measured in Central Sweden.

PLEASE NOTICE: The curves showing the distribution of the fundamental 16 2/3 Hz voltage components are not typical for low voltages at weak supply.



### A1.7.4 Regenerative brake

See clause 6.8 in the report.

### A1.7.5 Power factor

See clause 6.3 in the report.

### A1.7.6 Earthing

| Data | Norway | Sweden |
|---|---|---|
| Earthing principles | The midpoint of the 2x27.5 kV high transmission line is directly earthed. | The 132 kV system has directly earthed midpoints in the 2-phase system (2x66 kV). AT-systems (2x15 kV) have directly earthed midpoints. |

### A1.7.7 Traffic information/characterisation

| Data | Norway | Sweden |
|---|---|---|
| City area | Train density equal to line capacity | Train density equal to line capacity |
| Suburban area | Train density equal to line capacity | Train density equal to line capacity |
| Long distance lines | 0-6 trains per feeding distance depending on traffic. In high load periods up to or even higher than line capacity. | Some lines (south from Storvik and south from Hallsberg to Mjölby has train density equal to line capacity. Otherwise 0-6 trains per feeding distance. |

See respective Network Statement.

### A1.7.8 Network operation

| Data | Norway | Sweden |
|---|---|---|
| Case | The network is normally interconnected with adapted feeding capacity. Sectioning of contact line due to maintenance or failure often occur. Maintenance of converter stations may result in reduced feeding capacity. Sectioning and reduced feeding capacity results in lower resonance frequencies | Single feeding of lines during maintenance or fault conditions may occur resulting in very high impedances at the far end from feeding point and lower resonance frequencies. Other cases not applicable for vehicle compatibility |

### A1.7.9 Infrastructure classes

Expressions used in table below correspond to the definitions in EN50 163 and EN 50388. For more details see corresponding chapters in the report. Classification of infrastructure is to be given in respective Network Statement, but classes written in *italic* are most used.

| **Data** | **Norway** | **Sweden** |
|---|---|---|
| Line voltage levels | *V1: according to EN 50163:2004*<br><br>V2: $U_{min2}$=10000 V and $U_{min1}$=11000 V | *V1: $U_{max2}$ = 17500 V* |
| Maximum current limitation | C1: $I_{max}$ = 900 A<br><br>C2: $I_{max}$ = 700 A<br><br>C3: $I_{max}$ = 450 A | Max current per train is 900 A in tractive mode. Higher values in braking mode can be accepted. |
| Regenerative braking | B1: $I_{max}$<br><br>B2: 10 MW / 600 A<br><br>B3: 8 MW / 500 A<br><br>*B4: 5 MW / 300 A* | No classes defined. |
| Low frequency power oscillations | Under investigation. | Under investigation. |

## A1.8 Existing electrical vehicles

Passive filters refers to HV-filters or filters on a separate winding of the transformer, not filters on the DC-link in case of an inverter vehicle.

Active behaviour refers to if the control system compensate for harmonics in the traction current in order to draw a sinusoidal current

### A1.8.1 Electrical locomotives in Norway and Sweden

| Operator | Vehicle (no of vehicles in op. in brackets.) | Type | Passive filter | Active behaviour |
|---|---|---|---|---|
| Hector Rail AB (pre-liminary accepted) | BR 441 (2) (DB BR 189) | Inverter | Yes | up to 83 1/3 Hz |
| Hector Rail AB | BR141 (3) (ÖBB Class 1012) | Inverter | No | up to 250 Hz |
| Hector Rail AB | BR142 (6) (ÖBB Class 1142) | Tap changer | No | No |
| CargoNet AS, Hector Rail AB, GreenCargoAB | CE119/BR241/BR 185.2 (20-30) (DB BR185.2) | Inverter | Yes | up to 83 1/3 Hz |
| MTAB | Dm 3 (19) | Tap changer | No | No |
| MTAB, TKAB | Da (5) | Tap changer | No | No |
| Raillion AS | EG 3100 (13) | Inverter | Yes | Yes, up to unknown freq. |
| NSB AS, Ofotbanen AS | El 13 (5) | Tap changer | No | No |
| CargoNet AS | El 14 (31) | Tap changer | No | No |
| Hector Rail AB | El 15 / BR 161 (6) | Tap changer, diode rectifier | No | No |
| CargoNet AS, TKAB, TGOJ | El 16 (17) | Phase angle control | Yes | No |
| NSB AS | El 17 (10) | Inverter | Yes | Unknown |
| NSB AS | El 18 (22) | Inverter | No | up to 83 1/3 Hz |
| MTAB | IORE (2x9=18) | Inverter | Yes | up to 83 1/3 Hz |
| TGOJ | MA (32) | Tap changer | No | No |
| SJ AB, Green Cargo AB, TÅGAB, TGOJ | Rc 1 to Rc 7 (356) | Phase angle control | Yes | No |
| Green Cargo AB | Rm (6) | Phase angle control | Yes | No |

### A1.8.2 Electrical multiple units in Norway and Sweden

| | | | | |
|---|---|---|---|---|
| Ofotbanen AS | Class 68 (3) | Tap changer | No | No |
| NSB AS | Class 69 a-g (77) | Phase angle control | a-c: yes<br>d-g: no | No |
| NSB AS | Class 70 (16)<br>("IC 70") | Inverter | No | up to about 300 Hz |
| Flytoget AS | Class 71 (16)<br>("FPT") | Inverter | No | up to about 850 Hz |
| NSB AS | Class 72 (36) | Inverter | No | Unknown |
| NSB AS | Class 73 (22)<br>Identical to class 71 | Inverter | No | up to about 850 Hz |
| SL | X1 (94) | Phase angle control | Yes | No |
| SJ | X2 (43)<br>("X 2000") | Inverter | Yes | up to<br>216 2/3 Hz |
| Arlanda Banan AB | X3 (7)<br>("Arlanda Express") | Inverter | No | unknown |
| SJ and SL and other regional operators | X10 to X14 (137) | Phase angle control | yes | No |
| SJ, TKAB | X20 to X23 (3) | Tap changer, diode rectifier | unknown | No |
| SJ / DSB | X31-32 (3x53)<br>("Öresund train") | Inverter | yes | unknown |
| SJ | X40 (2x16 and 3x27 ordered) | Inverter | no | up to 150 Hz |
| SJ and regional operators | X50-54 (50)<br>("Regina") | Inverter | yes | up to 83 1/3 Hz |
| SL | X60 (71 ordered) | Inverter | no | up to 150 Hz |

(for a good general overview of vehicles in NO and SE see also www.jarnvag.net)

# A2 APPENDIX 2: NETWORK MAP NORWAY

(Applies to “Energy” only)

Substation transformer
Converter station
55 kV High Voltage Transm. line
Electrified railway

# A3 APPENDIX 3: NETWORK MAP SWEDEN

(Applies to Sweden only)

Substation transformer
Converter station
55 kV High Voltage Transm. line
Electrified railway

# A4 APPENDIX 4: ADDITIONAL INFORMATION FOR STABILITY STUDIES

(Applies to “Energy” only)

Substation transformer
Converter station
55 kV High Voltage Transm. line
Electrified railway

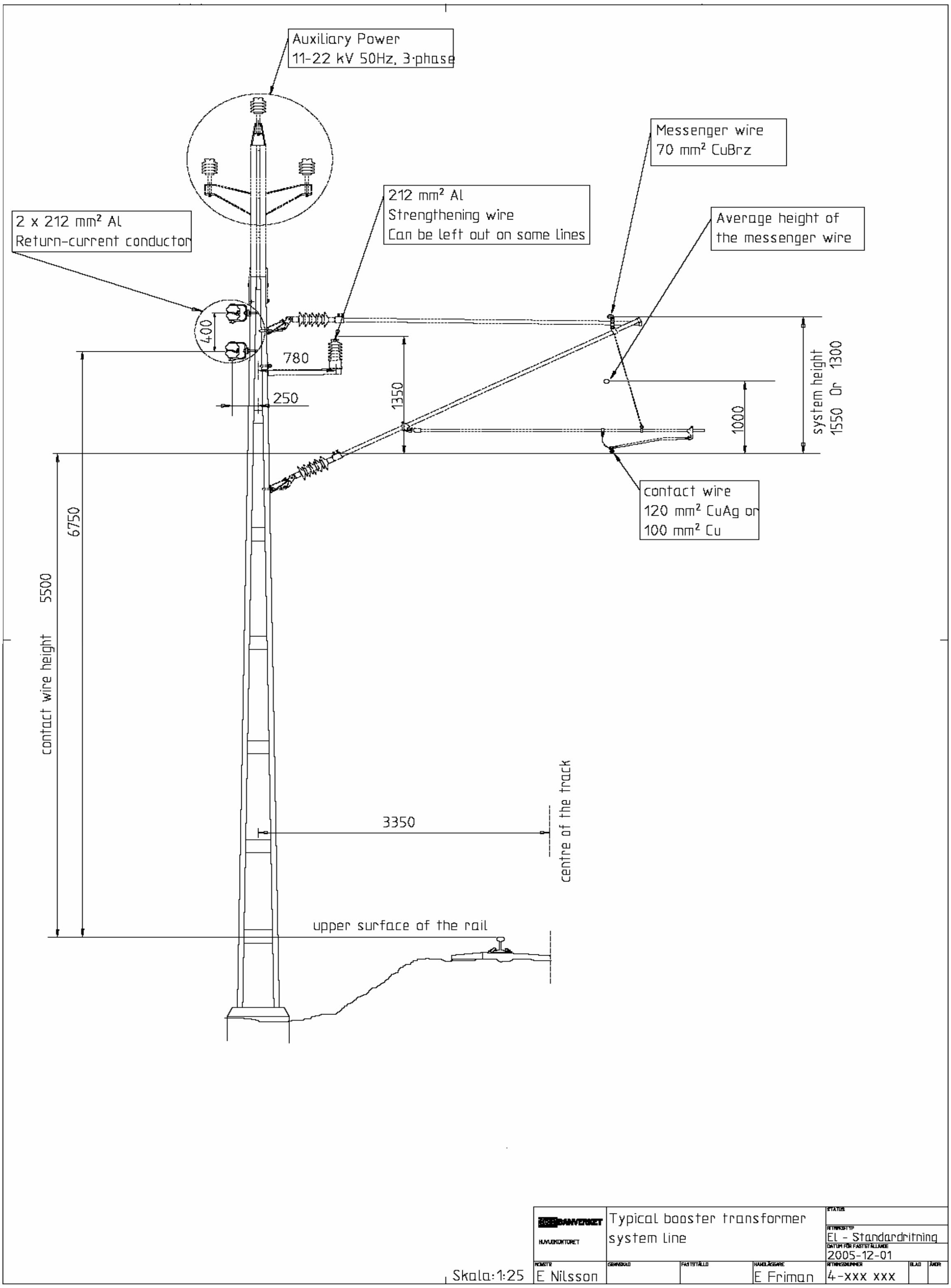
# A5 APPENDIX 5: DYNAMIC BEHAVIOUR OF ROTARY CONVERTERS

(Applies to "Energy" only)

Substation transformer
Converter station
55 kV High Voltage Transm. line
Electrified railway

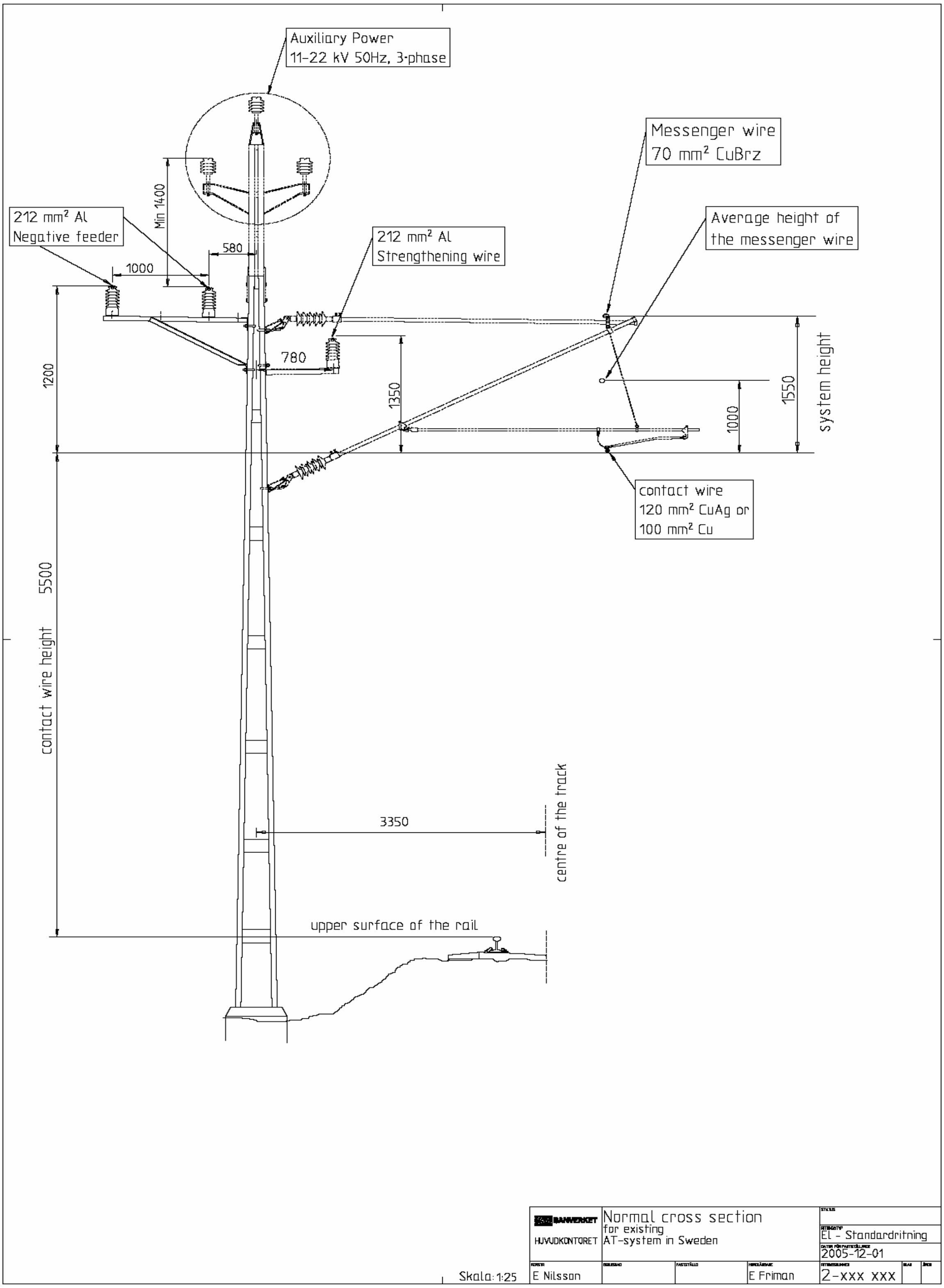
# A6 APPENDIX 6: TYPICAL CROSS SECTION OF A BOOSTER TRANSFORMER LINE IN SWEDEN

(Applies to Sweden only)


Auxiliary Power
11-22 kV 50Hz, 3-phase
Messenger wire
70 mm² CuBrz
212 mm² Al
Strengthening wire
Can be left out on some lines
Average height of
the messenger wire
2 x 212 mm² Al
Return-current conductor
400
780
250
1350
1000
system height
1550 Or 1300
contact wire
120 mm² CuAg or
100 mm² Cu
6750
contact wire height 5500
3350
centre of the track
upper surface of the rail
Typical booster transformer
system line
EL - Standardritning
2005-12-01
Skala:1:25
E Nilsson
E Friman
4-xxx xxx

# A7 APPENDIX 7: CROSS SECTION OF EXISTING AT-SYSTEM LINES IN SWEDEN

(Applies to Sweden only)


Auxiliary Power
11-22 kV 50Hz, 3-phase
Messenger wire
70 mm² CuBrz
Average height of
the messenger wire
212 mm² Al
Negative feeder
Min 1400
580
1000
212 mm² Al
Strengthening wire
780
1200
1350
1000
1550
system height
contact wire
120 mm² CuAg or
100 mm² Cu
5500
contact wire height
3350
centre of the track
upper surface of the rail
Skala: 1:25
BANVERKET
HUVUDKONTORET
Normal cross section
for existing
AT-system in Sweden
EL - Standardritning
2005-12-01
E Nilsson
E Friman
2-xxx xxx

# A8 APPENDIX 8: CROSS SECTION OF NEW STANDARD FOR AT-SYSTEMS LINES IN SWEDEN

(Applies to Sweden only)

# A9 APPENDIX 9 : PSOPHOMETRIC WEIGHTING FACTORS ACCORDING TO ITU-T

| **Frequency** [Hz] | **Weighting factor, $P_{fn}$** |
|---|---|
| 16,66 | 0,056 |
| 50 | 0,71 |
| 100 | 6,91 |
| 150 | 35,5 |
| 200 | 89,1 |
| 250 | 178 |
| 300 | 295 |
| 350 | 376 |
| 400 | 484 |
| 450 | 582 |
| 500 | 661 |
| 550 | 733 |
| 600 | 794 |
| 650 | 851 |
| 700 | 902 |
| 750 | 955 |
| 800 | 1 000 |
| 850 | 1 035 |
| 900 | 1 072 |
| 950 | 1109 |
| 1 000 | 1 122 |
| 1 050 | 1 109 |
| 1 100 | 1 072 |
| 1 150 | 1 035 |
| 1 200 | 1 000 |
| 1 250 | 977 |
| 1 300 | 955 |
| 1 350 | 928 |
| 1 400 | 905 |
| 1 450 | 881 |
| 1 500 | 861 |
| 1 550 | 842 |
| 1 600 | 824 |
| 1 650 | 807 |
| 1 700 | 791 |
| 1 750 | 775 |
| 1 800 | 760 |
| 1 850 | 745 |
| 1 900 | 732 |
| 1 950 | 720 |
| 2 000 | 708 |
| 2 050 | 698 |

| **Frequency** [Hz] | **Weighting factor, $P_{fn}$** |
|---|---|
| 2 100 | 689 |
| 2 150 | 679 |
| 2 200 | 670 |
| 2 250 | 661 |
| 2 300 | 652 |
| 2 350 | 643 |
| 2 400 | 634 |
| 2 450 | 626 |
| 2 500 | 617 |
| 2 550 | 607 |
| 2 600 | 598 |
| 2 650 | 590 |
| 2 700 | 580 |
| 2 750 | 571 |
| 2 800 | 562 |
| 2 850 | 553 |
| 2 900 | 543 |
| 2 950 | 534 |
| 3 000 | 525 |
| 3 100 | 501 |
| 3 200 | 473 |
| 3 300 | 444 |
| 3 400 | 412 |
| 3 500 | 376 |
| 3 600 | 335 |
| 3 700 | 292 |
| 3 800 | 251 |
| 3 900 | 214 |
| 4 000 | 178 |
| 4 100 | 144,5 |
| 4 200 | 116 |
| 4 300 | 92,3 |
| 4 400 | 72,4 |
| 4 500 | 56,2 |
| 4 600 | 43,7 |
| 4 700 | 33,9 |
| 4 800 | 26,3 |
| 5 000 | 20,4 |
| > 5 000 | 15,9 |
| > 6 000 | 7,1 |