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Measures for limiting the disturbance of light current installations by electric traction (in particular thyristor apparatus)

Dispositions pour limiter les perturbations des installations à courants faibles par la traction électrique (en particulier organes à thyristors)
Maßnahmen zur Beschränkung der durch elektrische Traktion hervorgerufenen Störungen in Schwachstromanlagen (besonders bei Verwendung von Thyristoren)

UNION INTERNATIONALE DES CHEMINS DE FER
INTERNATIONALER EISENBAHNVERBAND
INTERNATIONAL UNION OF RAILWAYS

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The person responsible for this leaflet is named in the UIC Code

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Summary

Thyristors are used in converters or rectifiers, which are used in traction vehicles and sub-stations. These converters and rectifiers form important sources of harmonics, which may cause disturbances in light current installations.

From A.C. traction vehicles, the disturbance is reduced if the number of sequentially controlled thyristor bridges is increased. Also, filters on the traction vehicle reduce the harmonic content of the traction current.

In D.C. or A.C. sub-stations, filters may be used to reduce the disturbing current.

In the A.C. contact line, booster-transformers or auto-transformers may be used to limit the disturbances.

Light current cables along the railway line should have a metallic sheath. Steel tape armouring around the sheath reduces the disturbances further. Also, the circuits in the cable should be well balanced to earth.

In the second half of the leaflet, studies to be conducted during an electrification project are dealt with.

1 - General

Field of application

This leaflet is intended to describe the remedies and formulate the recommendations which will limit the problems, and avoid consequent malfunction due to these disturbances.

In light current installations, disturbances are caused by electric traction equipment, especially where thyristors are used.

Thyristors are used in the construction of converters which are used:

- on traction vehicles,

- on coaches, to supply electrical apparatus,

- in electric traction sub-stations for frequency conversion.

These converters, in which thyristors are controlled by phase-angle switching, by pulsed operation or used in half-controlled circuits, form important sources of harmonics which are capable of disturbing light current installations.

2 - Systems aimed at improving electromagnetic compatibility

2.1 - General

In the absence of special precautions, the permitted levels of disturbance are not generally respected for lines installed near to the track, even when only one traction vehicle is in use. This statement has been verified by many tests with different traction systems.

To comply with the limits, action must be taken which is appropriate for the conditions.

The electromagnetic induction can be reduced in several ways. Action can be taken on the vehicles, on the traction supply system and on the telecommunications installation. In particular cases, several measures can be combined to produce a sufficient reduction of disturbance.

2.2 - Suppression at source

The following is a summary of the actions which can be taken on the high power side.

2.2.1 - On the traction vehicles

The disturbance is reduced in A.C. traction systems if the number of sequentially controlled thyristor bridges is increased.

The following table gives the relevant experimental results.

Traction systems with thyristors	Number of bridges on the thyristor vehicle			Diode vehicle
	2	4	8	
Catenary current measured at the sub-station	260	255	260	270 A
Disturbing current measured at the sub-station	4,7	2,4	2,0	1,9 A

Filters on the traction vehicle will reduce the harmonic content of the traction current.

Tests by SJ showed that the ratio of the disturbance currents for a locomotive without a filter and with a filter was about 4 or 5.

Measurements made by DB with a locomotive having three phase traction, gave a ratio of 3 for the psophometric voltage induced in a telephone cable.

Filters on the traction vehicle reduce the higher harmonics which essentially determine the disturbing current but they increase the lower frequencies, below 200 Hz.

Asymmetry between the firing angles of thyristors in the arms of a bridge, cause the appearance of even harmonics. To avoid the influence of these harmonics, it is advisable to select a thyristor control scheme which limits the angle of asymmetry.

2.2.2 - In the sub-station

When thyristors are used for rectification, conversion or inversion, alternating currents developed in the D.C. traction current, often at 300 Hz and its multiples, can be reduced by filters or damping circuits. In this case, care must be taken that these filters do not cause additional resonances in the traction circuit.

In the case of D.C. traction, the sub-stations are the most important source of disturbance. This is why, to reduce disturbance, one should adopt (with others) the following measures:

- use of rectifiers in the sub-station with, if possible, a high number of phases (6, or better still 12). In the case of 12-phase rectifier circuits, the disturbance can be, depending on the circuit, half that which occurs in 6-phase circuits,

- maximum symmetry in the rectifier group,

- maximum reduction of compensating currents between adjacent sub-stations at elevated frequencies (300, 600, 900 Hz, etc.). The circuits of the sub-stations must be as identical as possible.

2.2.3 - Arrangement of the traction supply

Related to the influence on light current circuits, the catenary and rail return current, and the current induced in the rails by the catenary current, exercise opposite effects since the two magnetic fields are in essentially opposing directions (at least at the fundamental frequency and low harmonics).

Compensation is however always incomplete since the return current divides between the rails and earth, and this division is dependent on frequency.

The situation can be improved by placing a special return conductor (compensating conductor) beside the catenary. In addition, the use of suction transformers in A.C. traction systems produces a current in the return conductor which is essentially equal to the catenary current, but of opposite phase.

Tests on Swedish State Railways showed that the use of suction transformers reduced the longitudinal e.m.f. in a track-side cable by between 5 or 6 times. For aerial circuits, the ratio was more than 10. These values were obtained with an average spacing between suction transformers of 5 km.

NB : an effect, similar to that obtained with suction transformers, is available if the A.C. supply is connected not as usual between catenary and rail, but at double voltage between catenary and return conductor. Auto-transformers (1:1) are then connected across this double voltage source at intervals, with the mid-point bonded to rail. ("AT" system or 2 x 25 kV).

Due to a resonance phenomenon, forced oscillations are found in traction circuits near the resonant frequency. These oscillations are the dominant cause of disturbance on light current circuits. It may therefore be necessary to reduce these by the use of resistor/capacitor circuits.

2.2.4 - Systems other than traction

If thyristors are used in heating and air conditioning installations on trains, the harmonic currents can be reduced by a filter or damping circuits.

2.3 - Protection at the low power circuit

The arrangements mentioned below must particularly be used with traction systems which use thyristor control.

The metallic sheath of a cable serves as a screen for the light current circuits. This sheath is connected to earth at various places and, at least, near the two ends of the cable (with D.C. traction, as necessary, via capacitors or diodes to avoid electrolytic corrosion), in order to establish a circuit for the compensating current in the sheath and earth. The current in the sheath produces a magnetic field which is effectively in opposition to the disturbing field and hence reduces the longitudinal e.m.f.

Steel tape armouring, placed around the sheath, acts as the magnetic core of a transformer. This armouring increases the coupling between the sheath-earth loop and the light current circuit-earth loop, hence (as in a transformer) reducing the magnetising current which is necessary, and hence reinforcing the effect of the metallic sheath.

Additionally, a further low resistance armouring can be added over the steel tapes, to further reinforce the effect of the main sheath and tapes. This extra armouring must, as the cable sheath, be connected to earth at various points and at least near the two ends. The restrictions mentioned above for D.C. traction apply.

Light current circuits must, as far as possible, be well balanced, implying:

- an attenuation factor between the sheath of the cable and the internal conductor-pair of between 60 and 66 dB at 800 Hz. These values are based on experience since the difference in capacitance of the two conductors with respect to the sheath is less than or equal to 250 pF within each manufactured cable length (500 to 1 000 m). If this capacitance difference is greater, it can be compensated by transposing the conductors (also in the case of existing or older cables). If this arrangement gives unacceptable results on certain circuits, capacitors can be placed between the conductor and the sheath;

- that all the circuits in the same cable are terminated at their ends in equipment which is as symmetrical as possible. Each circuit which introduces a voltage to earth into the cable, degrades the characteristics of the other circuits. It is for this reason that telecommunication circuits are terminated at repeaters. This termination is not possible on local personal circuits or subscriber telephones linked to a central or automatic exchange, due to the signalling and microphone supply. Recommendation Q.45 of CCITT (see Bibliography - page 12) stipulates that for voice communication, the attenuation of asymmetry in the terminating equipment must be greater than or equal to 40 dB in the frequency range 300 to 600 Hz, and greater than or equal to 46 dB in the frequency range 600 to 3 400 Hz.

If the attenuation of asymmetry is insufficient, it is possible to improve it by using longitudinal chokes. These act as small repeaters connected along the circuit to establish a forced symmetry of termination. These chokes increase slightly the attenuation of the circuit, for example by 1 dB.

One of the most important measures to reduce disturbance is correct earthing.

With old cables which are already installed, disturbance can be dealt with at the ends of the cable. For this purpose, active reduction transformers (ARS) can be used. However, in all cases, this measure is only effective when it is used with a galvanic connection to earth (earth return). One conductor in a cable is used to sense the asymmetry, being used to measure the disturbance which exists on that conductor, as on all the others. To this end, the earthing of the sensing conductor is direct at one end and via a high resistance at the other. It is across the terminals of this resistor that the disturbance is detected, then amplified, and injected with reverse polarity into the other circuits via a transformer.

A difficulty is that different circuits in the same cable are affected differently, depending on their method of connection to other parts of the line and the symmetry of their termination. Amplification of the monitored voltage can only be a compromise.

NB : in addition, protection against danger (shock) is incomplete (in particular, the sensing conductor is totally unprotected).

One can envisage, for installations using old cables:

- either a reduction of the amplified sections to provide an increased signal to noise ratio,
- or changing from the use of audio frequencies for telephone transmission, over long distances, to the use of multiplex or PCM transmission,
- or the use of isolation techniques to avoid long D.C. connections.

3 - Studies to be conducted during an electrification project or a modification scheme

Information related to electric traction and necessary for the study

Those responsible for an electrification project, concerning the compatibility of that project with neighbouring installations, must first obtain, from the different services concerned:

- the definition of the type of electric traction system which will be used:
  - the number and characteristics of the overhead and rails,
  - the leakage reactance of the transformers which are initially proposed,
  - the current waveforms for normal and short-circuit conditions, and the duration of short circuits before clearance,
  - the values of the loadings foreseen for the traffic, the time variation of traffic (peak hours), etc.
- the type of locomotives to be used:
  - current consumption,
  - frequency spectrum of the current absorbed by the locomotive,
  - equivalent disturbing loadings:
    - for an aerial circuit,
    - for a cable circuit,
  - for the different types of traction equipment which are foreseen:
    - the expected future traffic.
- the average conductivity of the earth in the areas where the line is to be built or electrified.

3.1 - Studies related to the trackside residents

3.1.1 - Enquiries among the trackside residents

It is necessary in the first place to inform all the residents near to the track through the proper administrative channels. Among those affected, the national telecommunication authority is the system which has the most extensive and vulnerable network.

It appears desirable to place at the disposition of the telecommunication authority, the documents necessary for the calculation of the disturbing voltages, sufficiently before service operation, or to allow the necessary measures to be put into effect immediately after service begins.

The telecommunication organisation must then, on receipt of this information, supply to the railway, the facts necessary for prediction purposes, including in particular the general plans of their system as it will be at the date of service of the project. Also required are definitions of the affected equipment and their sensitivity to disturbance.

3.1.2 - Choice of supply system

From these factors, after predictive calculations and an overall financial assessment of the system, the railway authority can adopt the most advantageous supply system, including in their review:

- the foreseeable costs of protecting the circuits of the telecommunication authority,

- the costs or savings which follow from the choice of the supply technique, i.e.:

  - the supply of the sub-stations,
  - the number of sub-stations,
  - the compensating conductor,
  - the cables to be used,
  - etc.

The objective of this phase of the study is to establish whether it is more advantageous (and this must be decided very quickly) to suppress the disturbances at source on the railway, or to install protective devices on the telephone installations, having understood that in the case of a balance between these options, the choice should always provide suppression at source. This is the more logical treatment and is the best provision for the future. Appendix A - page 10 gives an example of the financial comparison between a 1 x 25 kV and a 2 x 25 kV system (auto-transformers).

The protective methods at source include:

- balancing the supply system:

  - auto-transformers,
  - suction transformers,
  - compensating conductors,
  - coaxial,

- the provision of harmonic filters on the traction vehicle or on the catenary system.

3.1.3 - Determination of the disturbances and the choice of protection

The railway organisation then carries out in detail the theoretical calculations of danger and noise voltages, using the methods defined by CCITT (see Bibliography - page 12) for each zone of disturbance and seeks, with the Telecommunication Organisation, the most suitable protection (technically and financially). If, at this stage of the project, it is apparent that the cost of the protection is much higher than first estimated, it is still possible to reconsider the initial choice of supply system.

Among the means of protecting the public telephone network, the principal ones are:

- diversion of routes,

- the use of cables having a good screening factor (except for short distances),

- the use of digital transmission systems for data,

- the creation of centres linked by immunised systems (radio links, HF analogue or digital systems),

- the use of active reduction transformers,

- the use of balancing chokes.

To take maximum benefit from these studies and activities, a close collaboration between the railway and telecommunication organisations is essential.

3.2 - Studies related to railway installations

The same studies of disturbances must be made for railway installations and the financial information must be integrated with that obtained from the studies described above.

Where the disturbances have already had to be reduced at source to provide protection for the public network, it is advisable to consider the use of more economic cables than those foreseen for high levels of induction.

Other economies are equally possible since, for example, the supply to sub-stations must sometimes be provided by special high voltage feeders. The 2 x 25 kV method of connection, which reduces disturbance, also allows the use of longer track sections, avoiding the need to provide so many sub-stations and the high voltage lines which feed them.

On the other hand, the cost of the project is increased by the need to install the 25 kV feeder and the auto-transformers, but it is reduced by the reduction of the protection required for the telephone system.

NB : Appendix A illustrates the relative cost elements, based on an actual example.

Finally, the whole of the traction system return circuits must be re-examined if new methods of feeding (such as 2 x 25 kV) are used. For example, with the installation of auto-transformers spaced a short distance apart, significant rail to earth voltages can appear at certain locations.

The general re-examination of the traction return circuit is also necessary due to the general trend towards higher powers in new projects and the higher currents which this implies.

Appendix A - Example of the cost comparison between 1 x 25 kV and 2 x 25 kV traction systems

A.1 - Study by SNCF (values in MF - 1986)

Type of installation	1 x 25 kV 1	2 x 25 kV 2	Difference in cost 2 - 1
High voltage	16	10	- 6
Sub-stations	29	19	- 10
Auto-transformers[a]	-	33	+ 33
Overhead	191	220	+ 29
Telecommunications:			
- Railway	68	61	- 7
- National PTT	68	0,5	- 67,5
Signalling	27	28	+ 1
Miscellaneous	4	4	0
Total	403	375,5	- 27,5

a. The evaluation of the effects, case by case, along a line equipped with auto-transformers, requires a very detailed knowledge of the light current cables which are influenced, noting that the particular features of the system do not allow the use of an overall screening factor.

As a result of a cost comparison for a specified line, carried out by SNCF, an auto-transformer scheme was chosen with a cost reduction of 7%.

NB : Studies by DSB have shown that the use of the "AT" system can reduce costs by 13%.

A.2 - Study by DSB (values in MDK - 1986)

Type of installation	1 x 25 kV With suction transformers	1 x 25 kV WIthout suction transformers	Difference in cost
Traction circuit	0	48,5	+ 48,5
Telecommunications:			
- National network	67,5	9,7	- 57,8
Total	67,5	58,2	- 9,3

A.3 - Study by VR (values in 1000 FIM per km of line - 1986)

Type of installation	1 x 25 kV With suction transformers	1 x 25 kV Without suction transformers	Difference in cost
Suction transformers	0	38,00	+ 38,00
Telecommunications:			
- Railway	130,00	100,00	- 30,00
- National network	150,00	2,00	- 148,00
Total	280,00	140,00	- 140,00

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