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Electromagnetic compatibility between 25 kV-50 Hz rail system and parallel 3 kV d.c. lines: influence on d.c. electronic traction converters

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Abstract

This paper reports on the investigation performed by field tests and simulation about the behaviour of an electronic rail vehicle supplied by a d.c. voltage with a 50 Hz ripple induced by a parallel high-speed line. Measurements recorded in the Italian Railways (FS – Trenitalia) 25 kV-50 Hz test site are used to elaborate the input data and to choose significant conditions for the simulations. Simulation results, as well as measurement results are presented.

1 Introduction

In the next few years the Italian railway system will go through a phase of major changes that will transform it deeply. New high speed lines, now under construction, will be opened to increase the commercial speed of people and goods transport and to relief the existing conventional lines from part of the traffic that nowadays over saturates their capacity. Due also to the orographic configuration and to the high urbanisation of the territory, in many cases the new lines will run quite close to the existing ones and sometimes they will be parallel at a distance of few meters. On one hand this is very convenient from many points of view, e.g. construction and impact on the environment, but on the other hand this may cause some compatibility problems. In fact the new high-speed lines will be sup-plied with a 25kV, 50 Hz alternating voltage (2x25kV system), whereas the existing lines are fed with a 3kV d.c. voltage. To study possible electromagnetic interference problems and to eventually propose suitable solutions and counter-measures, FS has launched a working group formed by specialists of rolling stock engineering (Rolling Stock Technology Unit - Treinitalia S.p.A.), infra-structure owner (RFI), Italferr (railway infrastructure engineering company) and university. The chosen approach was:

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- set up a physical test site reproducing a configuration of parallelism between a 25kV-50Hz line and a 3kV line;
- build a simulation model of the whole electrical system (formed by the various conductors and discrete components of the high speed line and the conventional line in their interference area);
- validate the model trough a series of field test campaigns;
- perform simulations in order to predict interference levels;
- study countermeasures;
- test their effectiveness.

The infrastructure works for first segment of the future high-speed network are almost finished and the first 25 kV train running for tests on the high-speed line is scheduled for the end of year 2002.

2 Problem description

Simulations and preliminary field tests have shown that, as expected, the a.c. system influences the d.c. system trough radiated and conducted interference. In particular it was found that an alternating 50 Hz current component circulates in the d.c. system conductors and a 50 Hz voltage ripple is present in the d.c. catenary voltage. Figure 1 shows the schematic representation of the a.c. and d.c. parallel lines present in the test site. The figure highlights also the two major mechanisms of disturbance propagation.
The main foreseen problem is the disturbance towards the signalling system of the d.c. network. In fact the signalling system adopted on the traditional Italian network is based on codified currents circulating in rail circuits and the carrier is at a frequency of 50 Hz. Other possible compatibility problems are:

- disturbance to the regular operation on the 50 Hz harmonic current detector installed on all Italian electronic traction rolling stock;
- influence of the d.c. system on the a.c. systems by means of direct continuous return currents flowing in a.c. system conductors and possibly causing saturation problems on the main transformer of a.c. rail vehicles;
- higher frequency (around some kilohertz) disturbance on the d.c. system caused by the traction current harmonics produced by a.c. traction converters;
- high 50 Hz ripple on the line voltage and high 50 Hz component in the line current.

The focus of this paper is on the investigation performed to find out if and how this last phenomenon affects the vehicles circulating in the DC system. While significant influence is not expected on traditional rheostatic rolling stock, effects may be negative on modern electronic converter fed rolling stock, which is becoming predominant in the Italian railway network. Electronic power converters for traction and auxiliary systems are in fact very complex, deeply non-linear and time varying systems. This implies that, in theory, the 50 Hz excitation can produce different and complex effects on the converter behavior,

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depending for example on the level of the interference, the operating conditions, the value of d.c. voltage and so on. One possible effect could be the alteration of the reference electrical operating conditions causing unpredicted behavior of the control algorithm with affection on the performance of the converter. Even if such a large alteration is not present, smaller instability areas of functioning could be exalted by the considerable 50 Hz disturbance ripple which, of course, was not took into account in the design phase and this could lead to an abnormal emission of harmonic components in the input current. Due to the non-linearity of the system the frequency of such harmonics may in principle not be the same of the input excitation and this may interfere with the signalling systems that are adopted in the disturbed areas of the existing d.c. network.
Preliminary field tests have shown that also the high frequency disturbance on the on the d.c. system caused by the traction current harmonics produced by a.c. traction converters is relevant. These currents are relatively small on the a.c. conductors but are highly coupled due to the high frequency: the variation of the flux of the B field over any loop in the d.c. system conductors is very high in the unity of time and therefore high is the voltage induced in such loops.
Presumably this type of disturbance will not affect the operation of the traction converter because its spectral distribution is typically out of its band of regulation, but careful investigation is needed to exclude other problems.

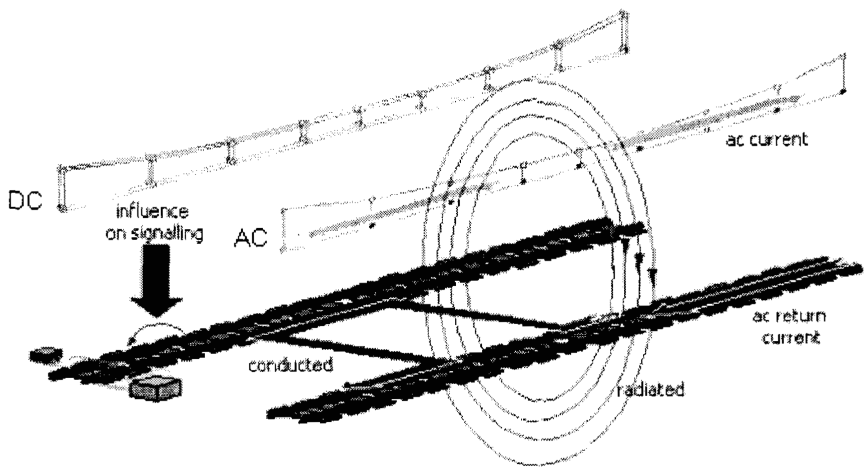

Figure1: Parallel d.c. and a.c lines, main coupling phenomena.

3 Experimental results

Hereafter are presented some experimental measurements recorded in June 2001 in the FS test site. On the 25 kV track was circulating a train composed by 2 multi-voltage locomotives class E402B and some coaches. On the d.c. system

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track was circulating a train powered by a locomotive of class E412 (incidentally, also the locomotives class E412 are multi-voltage) fully equipped with measuring instruments suitable for the harmonic current emission tests.
On the a.c. track during the test runs one locomotive ran at full power while the other kept braking electrically with pantographs down, dissipating power on the braking resistor. This configuration allowed absorbing continuously a net traction power of about 6 MW and the current circulating on the a.c. system conductors produced disturbance on the nearby d.c. track. In figure 2 is reported in the time domain the amplitude of the 50 Hz voltage ripple induced on the d.c. line.

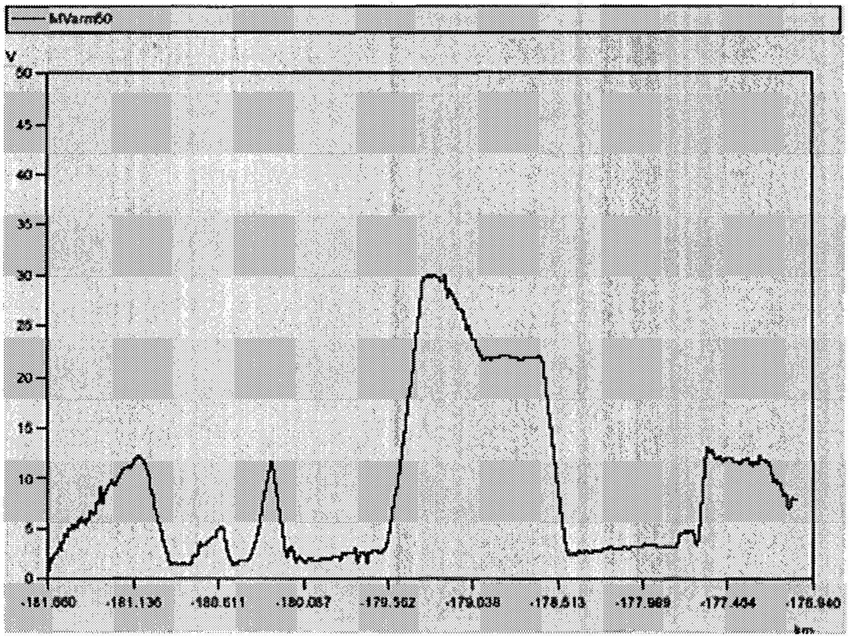

Figure2: Amplitude of the 50 Hz voltage ripple on the d.c. line.

The first effect that was experienced was the intervention of the harmonic current detector on the E412 loco. As expected the electromagnetic field flow through the loop formed by the line-locomotive-rails-substation on the d.c. track induced a 50 Hz voltage source and the corresponding harmonic current. This current almost immediately raised over 1 A that is the threshold for the intervention of the device. After the exclusion of the harmonic current detector it was possible to restart the locomotive without and during the test runs no other problems were experienced for what concerns the scope of this paper. As expected, a large 50 Hz harmonic current was present but this seemed no to affect the operation of the locomotive. Figure 3 presents the harmonic current spectrum of the E402B locomotive and the correspondent relative induced

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voltage measured on the d.c. line. It is evident the relationship between the two plots.

After the first analysis no sort of malfunctioning or abnormal operation of the electronic converters was found. Apart from the obvious 50 Hz and high frequency disturbance, the harmonic current spectrum absorbed by the disturbed E412 locomotive is comparable to the one measured under undisturbed conditions. This is presented in figure 4.

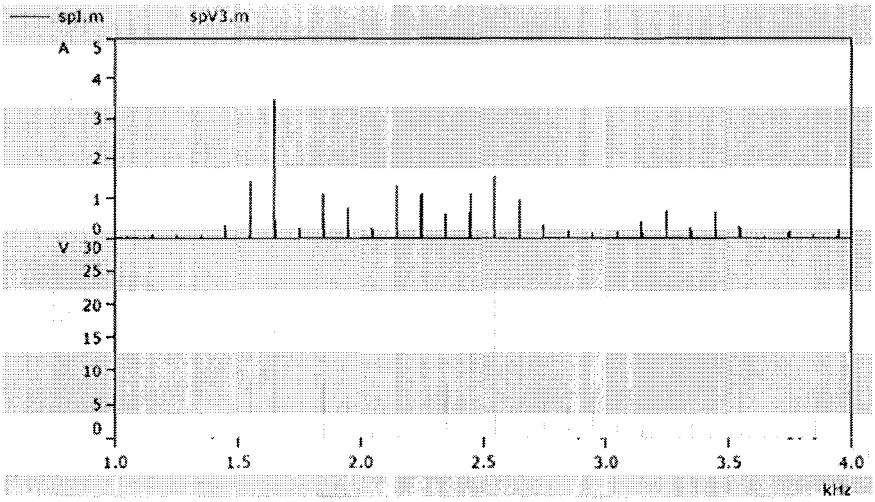

Figure3: Harmonic current spectrum and induced line voltage disturbance.

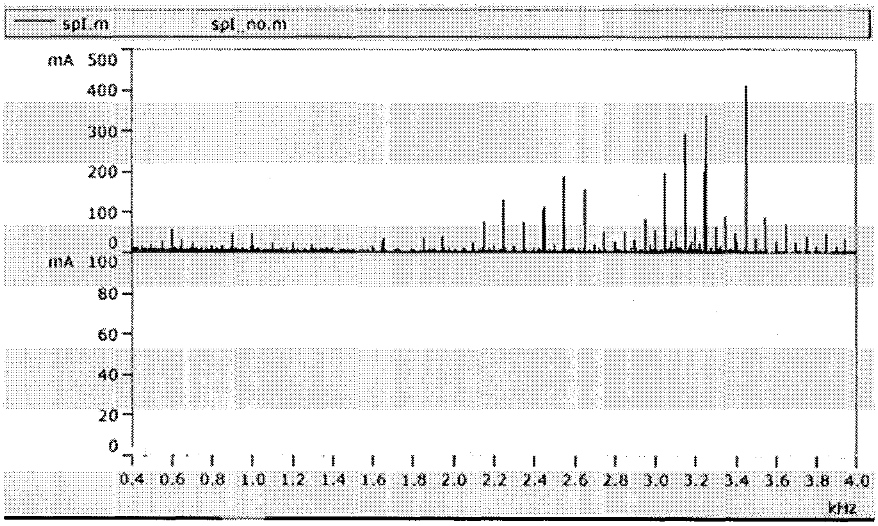

Figure 4: E412 harmonic current in disturbed and undisturbed conditions.

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4 Model description

A good prediction of the amplitude of the harmonic currents generated by the train can be done via a modelling of the electronic power converters and the associated electrical equipment. With such a tool, the investigation can be performed both in normal and degraded condition. In the application described in this paper the model was used predict the behaviour of the converter under disturbed electrical conditions. The investigation has been performed resorting to an integrated time domain model of the new Trenitalia double deck commuter train TAF. The TAF integrated model was developed within the European research project ESCARV (BRITE EURAM III - Industrial and Materials Technology RTD3/Technologies for Surface Transport Means Program, Reference No. BE 97-4097, see [1] and [2]).
The TAF train global model was produced as a single executable software program in the C++ language. The train is built by a consortium formed by different train manufacturers: ANSALDOBREDA, FIREMA and Bombardier. The integrated model is constituted by the TAF traction model from FIREMA (very detailed, including control algorithm) and the auxiliary converter model from ANSALDO (complete information on the hardware and software of the converter). The validation shown that such an integrated model is able to better represent the real system rather than two non-interacting models. Further details are given in [3] and [4].

5 Simulations

The TAF global model was used to simulate the behaviour of the train in a disturbed environment like the one present in the experimental test site and probably similar to those present in segments of parallelism between the new high speed lines and the traditional ones.
Several simulations have been performed to find out if the complex non-linear system of the train converters reacted in some unpredictable way to the high disturb present in its input voltage. As mentioned it is not theoretically possible to exclude the onset of unstable or abnormal behaviour of the converters present on board. However this may happen in any operating condition and so it could be extremely difficult to reproduce such behaviour even if it is present.
To take into account the presence of the disturbance produced by the nearby a.c. line the d.c. substation model has been modified and the harmonic spectrum of the voltage at its output has been made compatible with the one measured during previous campaigns of field tests. Basically speaking, as a first step, it was chosen to add a great number of further voltage sources of appropriate frequency and amplitude to reproduce qualitatively the power spectrum of the measured signals. At the present moment no evidence of any particularly critical "strange"

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behaviour has been found. However, simulations have shown that conditions may exist where non-linearity and time variance of the converter system play an important role.

A first condition that has been identified is related to an inter-modulation phenomenon between an existing low frequency harmonic component and the large 50 Hz component induced by the parallel a.c. line. Figure 5 compares the line current in disturbed and undisturbed conditions. Examining the spectrum of the current in the two different conditions (figure 6) it is evident that apart from the 50 Hz one, additional harmonic components are present in the disturbed line current. These components, resulting from the inter-modulation between the 50 Hz component - due to the disturbance - and an existing 10 Hz component, are located, as expected, at 40Hz and 60 Hz.

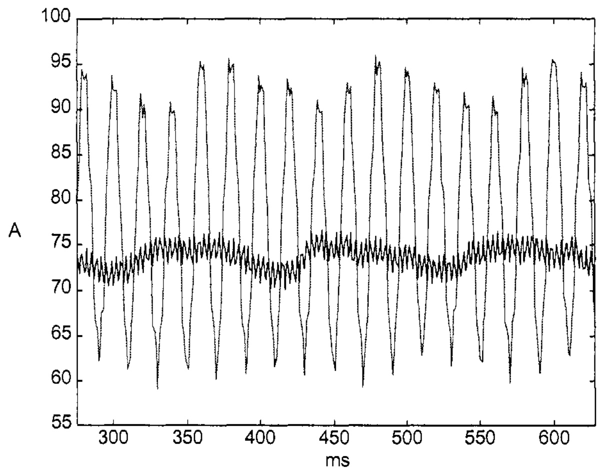

Figure5: Line current, disturbed and undisturbed conditions, case 1.

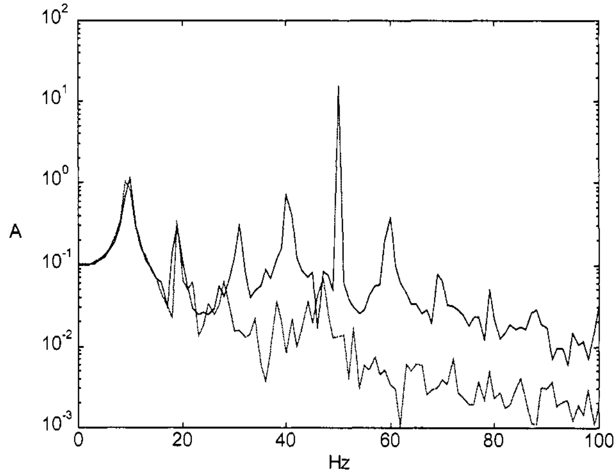

Figure 6: Current spectrum, disturbed and undisturbed conditions, case 1.

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A second case is described by figures 7 and 8. In this case the simulation is relative to a phase of electric braking and the difference between the two curves in the time domain is very evident. It seems that 50 Hz disturbance causes a sort of low frequency oscillation, possibly related to the regulation strategy of the control software. Figure 8 shows that in this case the difference between the two spectrums is more complex and can not be justified just by inter-modulation effects.

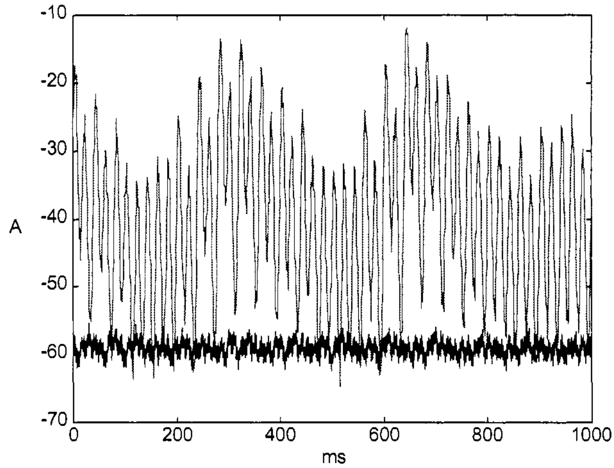

Figure 7: line current, disturbed and undisturbed conditions, case2.

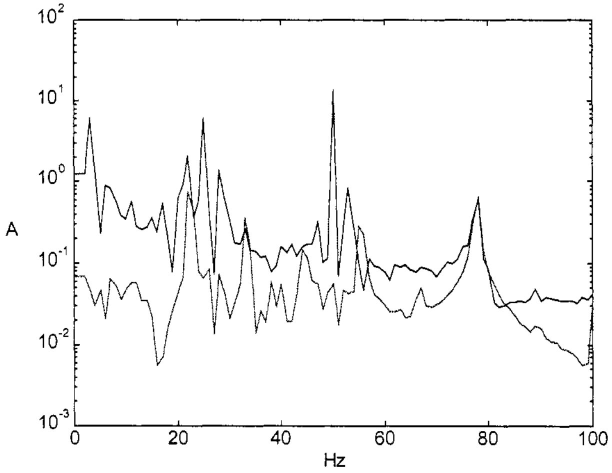

Figure 8: Current spectrum, disturbed and undisturbed conditions, case 2.

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Conclusions

The preliminary results of the field tests are favourable and no particular effect seems to be notable affecting the normal operation of the traction converters. Using simulation tools, some conditions have been found in which the non-linearity and the time variance of the converter play a significant role. However, such conditions are rare and they have been obtained assuming a very high 50 Hz disturbance. In these cases the behaviour of the converter never appeared critical. Nevertheless further investigations are required and extensive simulations will be performed. Additional specific field test campaigns are also foreseen in order to cover a larger amount of cases, considering other locomotives and different operating conditions.

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