Electromagnetic Compatibility Management in the Design of New Italian High Speed Lines


°Sciro S.r.l.
Via Fieschi, 25/6a - 16121 Genova, Italia
Tel. +39 010 5702652
Fax. +39 010 5702703

*Italferr S.p.A.
Via Marsala, 53 – 00185 Roma, Italia
Tel. +39 06 49752347
Fax. +39 06 49752664

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Summary
This paper describes an innovative approach to the process of electromagnetic compatibility management, as a support to the design of new Italian High Speed Lines fed at 2x25 kV – 50 Hz.

The Italian scenario shows some particularities that make the case study unique, regarding interference problems related to the safety of AC track circuits, installed on the existing railways lines. Mainly due to geographical constraints of the Italian territory, the new lines will be realised really close to the existing ones: inductive and conductive coupling phenomena occurs among the 50 Hz feeding system of the new high speed lines and the track circuits of the existing lines that are operated at 50 Hz too.

The software tool has been implemented, according to CCITT directives, to perform interference study. By means of an ad hoc measurements site, the model and the software tool have been validated.

Parametric analysis have been performed in order to evaluate the influence, on the track circuit (victim), of different features, such as earth resistivity, rail impedance and conductance, distance between the two railway lines, configuration of the high speed line power supply system, train positioning, track circuits length and configuration.

Thanks to the implemented tool, an overall study has been carried out to evaluate innovative mitigation actions which may be adopted to reduce interference problems.

The study has analysed new solutions, operating on both the design of the high speed line power supply system and on the introduction of shields and modifications to track circuits on the DC railways lines.
1 Italian high speed lines scenario

The Italian high speed lines (Figure 1) can be thought of as a big "T". The east-west line runs from the French border through Turin, Milan and Venice to the Slovenian border, with the north-south line connecting Milan, Bologna, Florence, Rome and Naples. The new high speed lines have been built to European standards using the latest medium and long distance passenger and freight technology. They are integrated with the existing railway system by numerous interchange points and future links to the European high speed system. The new lines will almost double the number of trains the system can currently carry in conditions of maximum safety. This will allow existing lines, relieved of much of their current traffic, to be dedicated to local, regional and freight transport, which is an essential part of re-organising...
Italy's mobility system. Major urban junction restructuring is needed for high speed line penetration into cities.

Figure 2 shows the layout of Roma – Napoli new high speed line, which runs very close to the existing lines: Roma – Tivoli, Roma – Cassino – Caserta and Caserta – Aversa. Table 1 summarises data about lines proximity and highlights the importance of interference phenomena problems.

<table>
<thead>
<tr>
<th>Railway Line</th>
<th>DC line length equipped with double-rail track circuits [m] (within 1000 [m] from High Speed line)</th>
<th>Single rail track circuits installed in stations (within 3000 [m] from High Speed Line)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roma – Tivoli</td>
<td>850</td>
<td>8</td>
</tr>
<tr>
<td>Roma – Cassino – Caserta</td>
<td>61125</td>
<td>144</td>
</tr>
<tr>
<td>Caserta – Aversa</td>
<td>2825</td>
<td>Not available</td>
</tr>
<tr>
<td>Total</td>
<td>64800</td>
<td>156</td>
</tr>
</tbody>
</table>

Table 1: Roma-Napoli lines proximity data

1.1 Track circuits (victims)

Figure 3 shows the electrical schema of Italian double-rail and single-rail track circuits operating on the existing lines; double-rail track circuit is terminated by two inductive boxes, which allow to keep signalling code into the block section and to make DC traction current go back to electrical substation; in single-rail track circuit the traction current is carried by a single rail, while the over is insulated.
The transmitter generates a signalling code at the industrial frequency of 50 Hz, which runs to the track circuit end and is picked-up by the receiver. When a train enters the block section, the leading wheelset short circuits the current, no signal arrives at the receiver and the track circuit results occupied.

Two different factor may influence the track circuit operation, due to interference generated by high speed line: induced voltage value across the receiver and train axle current. The induced voltage across the receiver may change the state of an occupied block section, which may result clear; the induced train axle current may change the signalling code detected by the train and passed to the on-board decoding and safety equipment.

1.2 AC high speed line feeding system (source)

Figure 4 shows the basic diagram of the 2x25 kV 50 Hz feeding system with autotransformers.

The autotransformers are fed with a voltage which is double of the normal traction voltage; the difference of potential between contact line system and rail is the normal traction voltage. Purpose of the autotransformers is to compel, as far as possible, the return current to flow along the inverted feeder, except in the section where train is taking current.
Placing the inverted feeder as close to the contact wire as possible reduces the inducing loop size. Due to the leakage impedance of autotransformers windings and their limited power the system is not perfect, so rail current exists all over the power supply section and part of the rail current flows into the ground, causing a further induction problems to the adjacent railway and telecommunications lines.

Figure 5: High speed line overhead contact system

Figure 5 shows the reference configuration of Italian high speed line overhead contact system, composed of the following conductors:

<table>
<thead>
<tr>
<th>No.</th>
<th>Conductor</th>
<th>Material</th>
<th>Resistivity [Ω/km]</th>
<th>Diameter [cm]</th>
<th>Section [mm²]</th>
<th>X [m]</th>
<th>Y [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Catenary</td>
<td>Cu</td>
<td>0.15</td>
<td>1.4</td>
<td>120</td>
<td>-2.50</td>
<td>6.55</td>
</tr>
<tr>
<td>2</td>
<td>Contact line</td>
<td>Cu</td>
<td>0.12</td>
<td>1.45</td>
<td>150</td>
<td>-2.50</td>
<td>5.30</td>
</tr>
<tr>
<td>3</td>
<td>Inner rail</td>
<td>UNI60</td>
<td></td>
<td></td>
<td></td>
<td>-1.74</td>
<td>0.01</td>
</tr>
<tr>
<td>4</td>
<td>Outer rail</td>
<td>UNI60</td>
<td></td>
<td></td>
<td></td>
<td>-3.26</td>
<td>0.01</td>
</tr>
<tr>
<td>5</td>
<td>Ground conductor</td>
<td>Cu</td>
<td>0.19</td>
<td>1.26</td>
<td>95</td>
<td>-4.60</td>
<td>-0.96</td>
</tr>
<tr>
<td>6</td>
<td>Return conductor</td>
<td>Al</td>
<td>0.225</td>
<td>1.575</td>
<td>150</td>
<td>-6.07</td>
<td>5.50</td>
</tr>
<tr>
<td>7</td>
<td>Inverted feeder</td>
<td>Al</td>
<td>0.109</td>
<td>2.28</td>
<td>307</td>
<td>-6.53</td>
<td>8.00</td>
</tr>
<tr>
<td>8</td>
<td>Catenary</td>
<td>Cu</td>
<td>0.15</td>
<td>1.4</td>
<td>120</td>
<td>2.50</td>
<td>6.55</td>
</tr>
<tr>
<td>9</td>
<td>Contact line</td>
<td>Cu</td>
<td>0.12</td>
<td>1.45</td>
<td>150</td>
<td>2.50</td>
<td>5.30</td>
</tr>
<tr>
<td>10</td>
<td>Inner rail</td>
<td>UNI60</td>
<td></td>
<td></td>
<td></td>
<td>1.74</td>
<td>0.01</td>
</tr>
<tr>
<td>11</td>
<td>Outer rail</td>
<td>UNI60</td>
<td></td>
<td></td>
<td></td>
<td>3.26</td>
<td>0.01</td>
</tr>
<tr>
<td>12</td>
<td>Ground conductor</td>
<td>Cu</td>
<td>0.19</td>
<td>1.26</td>
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<td>13</td>
<td>Return conductor</td>
<td>Al</td>
<td>0.225</td>
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<td>150</td>
<td>6.07</td>
<td>5.50</td>
</tr>
<tr>
<td>14</td>
<td>Inverted feeder</td>
<td>Al</td>
<td>0.109</td>
<td>2.28</td>
<td>307</td>
<td>6.53</td>
<td>8.00</td>
</tr>
</tbody>
</table>

Table 2: AC line conductors characteristics

2 Software toll development and validation

Figure 6 shows the design and verification process flow that has been adopted to implement and validate the software tool utilised to carry out the electromagnetic interference study. The process flow follows the well-known V-diagram. In the implementation branch of the V we start with system modelling and terminate with the software design and development; in the verification branch, we follow the branch upward, starting from software unit test and ending with model validation.
The system model has been conceived according to CCITT Directives utilising a multiconductor line circuit representation. Lumped element representation of the system has been adopted and the principle of network theory has been used to numerically describe the system circuit by means of the appropriate voltage and current relations.

The equivalent circuit (Figure 7) is composed by a sequence of multiconductor line elements and discrete intermediate and termination points. The multiconductor elements are composed by an arbitrary number of conductors and characterised by line parameters (self and mutual elements for the series impedance and shunt admittance per unit length). The intermediate and termination points are composed of an arbitrary number of impedances and generators which may connect the incoming conductors and the earth each over.
Involved equipments models have been implemented, such as AC and DC electrical substations, autotransformers, AC and DC trains loads, track circuits, single and double tracks AC and DC line sections and so on.

![Software tool structure diagram](image)

Figure 8: Software tool structure

The software tool (Figure 8) is composed of three different module:
- the simulation core able to solve the network equivalent circuit and calculate current and voltage in each branch and node;
- a database which contains simulation input and output data;
- a graphical user interface (GUI) which helps users in the simulation scenario definition and in the analysis of the results.

The single software module has been tested apart and integration tests have been performed comparing simulation outputs with the results of other commercial tools.

The Chiusi – Terontola double track railway line has been equipped by Italian Railways with an ad hoc measurements site in order to validate the implemented model and software. Measurements results has been useful to validate equipments model in different line configuration and to calibrate simulation parameters.

### 3 Parametrical analysis

A set of parametrical analyses have been carried out in order to evaluate disturbance values on double-rail and single rail track circuits in function of a set of parameters which characterise real railway layouts:
- earth resistivity,
- train load positions on the inducing AC line,
- track to earth conductance of the AC line,
- return conductors to earth conductance of the AC line,
- autotransformers faults,
- track to earth conductance of the DC line,
- track impedance of the DC line,
- return conductors to earth conductance of the DC line,
- train load position on the DC line;
- AC to DC line distance;
The basic case study configuration is constituted by an AC 2x25 kV 50 HZ railway line (24 km long) which runs parallel to a DC 3 kV railway line, equipped with double-rail or single-rail track circuits, characterised by a standard length of 1500 meters.

Parametrical analyses allowed to determine the worst inducing line configuration, in terms of parameters value and loads position, which has been assumed as the default configuration to investigate mitigation actions.

Due to parametrical analyses results and adopting a safe approach, the operation of double rail track circuits, within 1000 [m] from AC high speed line, and single rail track circuits within 3000 [m], are considered hazardous and/or affecting line efficiency and traffic regularity. Further studies have to be performed to improve the safety level of DC line operation.

4 Mitigation actions to reduce interference problems
Thanks to the implemented tools, a study has been carried out to evaluate innovative mitigation actions which may be adopted, to reduce interference problems on double-rail track circuits, avoiding their replacement.
The study has analysed new solutions, operating on both the design of the high speed line power supply system and on the introduction of shields and modifications to track circuits on the DC railways lines.

4.1 Mitigation actions on the high speed line design
Table 3 summarise the analysed hypotheses of inducing AC line design modification (Figure 9), while Table 4 reports simulation results related to the track circuit characterised by the higher induced voltage. Generally train axle current reduction is proportional to voltage reduction across track circuit receiver.

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shield introduction made up of an additional return conductor on the support of the overhead line at 0.0 meters height</td>
<td>9a</td>
</tr>
<tr>
<td>2</td>
<td>Shield introduction made up of an additional return conductor on the support of the overhead line at 3.5 meters height</td>
<td>9a</td>
</tr>
<tr>
<td>3</td>
<td>Shield introduction made up of an additional return conductor on the support of the overhead line at 7.0 meters height</td>
<td>9a</td>
</tr>
<tr>
<td>4</td>
<td>Return conductor installed at 7.5 meters height;</td>
<td>9b</td>
</tr>
<tr>
<td>5</td>
<td>Inverted feeder installed at 7.5 meters height and return conductor at 8.0 meters height</td>
<td>9c</td>
</tr>
<tr>
<td>6</td>
<td>Inverted feeder installed inside of overhead line support</td>
<td>9d</td>
</tr>
</tbody>
</table>

Table 3: Test case list related to AC line design modification
Table 4: AC line mitigation actions - Simulation results

<table>
<thead>
<tr>
<th>Case</th>
<th>Disturbance reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>23</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
</tr>
<tr>
<td>6</td>
<td>11</td>
</tr>
</tbody>
</table>

Disturbance on track circuits decrease increasing the height of the return conductor: the current in the return conductor compensates the effect of ground conductors and rails currents. Cases 1 to 3 involve greater installation costs than case 4 to 6, due to the introduction of an additional conductors; all cases imply a verification of the overhead contact line support design.

4.2 Mitigation actions on victim DC line

Table 5 summarises the analysed test case related to victim DC line design modification, while Table 6 reports simulation results related to the track circuit characterised by the higher induced voltage.
Table 5: Test case list related to DC line design modification

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Additional loop inside track circuit</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>Circuit track length reduction</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>Twisted circuit track</td>
<td>12</td>
</tr>
</tbody>
</table>

Figure 10: Case 7 - Additional loop inside double-rail track circuit

Figure 11: Case 8 - Short length double-rail track circuits
Case Disturbance reduction [%]

<table>
<thead>
<tr>
<th>Case</th>
<th>Disturbance reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>8a</td>
<td>41</td>
</tr>
<tr>
<td>8b</td>
<td>59</td>
</tr>
<tr>
<td>9a</td>
<td>97</td>
</tr>
<tr>
<td>9b</td>
<td>67</td>
</tr>
</tbody>
</table>

Table 6: DC line mitigation actions - Simulation results

Case 7 does not involve a great disturbance reduction, while cases 8 and 9 seem to be a good choice in this way. The circuit track length reduction solution is more expensive then twisting track circuits solution, which implies only additional insulated joints and some electric bounds.

Twisting track circuit in a even number of sections may cause unwanted effects, if the AC load is placed close to the middle insulated joint: theoretically the disturbance reduction is null.

Further analyses have been carried out in order to evaluate disturbance reduction in case of twisted track circuits with odd sections number, in particular three; a first parametrical analysis has been performed taking into account load position on AC line: voltage reduction across circuit track receiver is always about from 65 to 68 percent of voltage value without twisting points.

In this case train axle current reduction is not proportional to voltage reduction, so a second parametric analysis has been carried out, calculating axle current in function of DC train
position and AC load position: current reduction, is not linear with voltage reduction but close
to 35 percent in the worst case.
Voltage reduction equal to 80 percent and minimal axle current reduction equal to 50 percent
are obtained, increasing track circuit sections from 3 to 5.

5 Conclusions
This paper has described the Italian railway approach to the process of electromagnetic
compatibility management as a support to the design of new Italian High Speed Lines fed at
2x25 kV – 50 Hz.
Parametric analysis results help designer to evaluate the safety level of double-rail and single
–rail track circuits installed on 3 kV DC traditional railway lines, which run close to the new
high speed lines.
According to simulation results and adopting a safe approach, the operation of all double rail
track circuits, within 1000 [m] from AC high speed line, and single rail track circuits, within
3000 [m], are considered hazardous and/or affecting line efficiency and traffic regularity.
Further studies may be performed, by means of the implemented tool, to better evaluate
interference phenomena in real operating conditions.

Granted that changing track circuits operating frequency is the most obvious but very
expensive way (track circuits and rolling stocks renewal) to solve interference problems,
modifying the high speed overhead contact line configuration, without additional conductors,
and/or twisting the track circuits seems to be the most effective solutions to reduce
interference disturbance.
Experimental results show how these solutions may be negligible, due to direct interference
phenomena on rolling stocks antennae, if AC and DC lines are very close.
The Chiusi-Terontola measurements site will be utilised to further investigate and validate the
effects of mitigation actions, in particular on rolling stock antennae and on board equipment.

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