Coexistence between the Metro system and power lines in the urban area of Lisbon

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Abstract

Within an urban environment due to lack of space more often infrastructure systems are bundled. In the case of electrical systems such as a high-voltage line and a Metro system this can lead to compatibility problems; therefore a careful analysis may be necessary. In the case of Metropolitano de Lisboa a 220 kV high-voltage line is running in parallel and crossing over a new extension (on a viaduct) of the Yellow Line of the Lisbon Metro system. Also the station Senhor Roubado and Odivelas are located in the near vicinity. As the possibility exists that the EM-fields generated by the high-voltage line can influence the safety critical signalling and telecommunication installations used by the Metro system, as well as human beings, both measurements in a wide frequency band as well as simulations have been performed. As a precautionary measure, a metal covering primarily intended as a guard against vandalism has been designed to act as a Faraday Cage. The reinforcement present in the civil structure supporting the Metro System has been earthed properly. The measurements and simulations are in good agreement and lead to the conclusion that a sufficient safety margin exists over the complete frequency bandwidth, therefore Electro Magnetic Compatibility can be guaranteed. For human beings a safe situation has been created, EM fields are lower than the limits as imposed by the World Health Organisation (ICNIRP). It can be concluded that bundling of infrastructure systems in an urban area is possible, but the designs have to be adapted meticulously, and care should be given to the analysis of the coexistence of all systems concerned.

Keywords: Metro system, Electro Magnetic Compatibility, power lines, environment.
1 Introduction

The opening to the public of the Yellow Line’s extension between Campo Grande and Odívelas is a landmark of great importance in the history of the Metropolitano de Lisboa. After 44 years of service to the population of Lisbon, the Metropolitano de Lisboa for the first time goes outside Lisbon to suburban cities of Odívelas and Loures, providing to a population of 300,000 inhabitants the possibility of travelling safer, faster and without traffic difficulties every day. The extension with a length of 5 km (1 km viaduct & 4 km tunnel) has five new stations Quinta das Conchas, Lumiar, Senhor Roubado, Ameixeira and Odívelas. The stations Senhor Roubado and Odívelas include in two important Transport Interfaces, making parallel bus lines superfluous, a Park & Ride interface allows a modal shift from individual transport to the Metro, which is of course a main objective of any public transport company. A volume of 145 million passenger minutes per year is expected, travelling times: from Odívelas to Campo Grande 10 min., to Marquês de Pombal 18.5 min., and to Baixa-Chiado 30 min. One of the major benefits of this extension is to avoid the entrance of 900,000 vehicles/year in Lisbon, with consequences on the parking, reduction of traffic, and a significant reduction of the emission of pollutants. The environment benefits a reduction of nitric oxide and carbon monoxide in excess of 380 tonnes/year. The total investment in the extension Campo Grande - Odívelas and the new stations was 360 million Euros, the period of construction was 5 years. An overview can be found in Figure 1.

![Figure 1: Lisbon city including suburban areas.](image-url)
2 Project overview

2.1 General

An overview of the network of Metro Lisbon can be found in Figure 2.

Figure 2: Overview Metro Lisbon.

Figure 3: Overview Senhor Roubado-Odivelas section.
Between the stations Senhor Roubado and Odivelas the metro system passes over a valley on a viaduct. For the construction of the metro extension a 220 kV high-voltage line was relocated. After the relocation the high-voltage line is running in parallel with the metro system over several hundreds of metres at a distance of approximately 40 m and crossing directly over it with only a relative short distance between the lower phase bundles and the top of the metro line. An overview of the local situation can be found in Figure 3 and 4. From left to right in Figure 3: Odivelas Station, the viaduct and Senhor Roubado Station, three lines indicate the old position of the HV-Line, one line indicates the present position.

![Image](image_url)

**Figure 4:** HV line and Metro viaduct in urban area.

### 2.2 Project approach

From the early start of the project a number of actions were taken. Within the procurement specifications of the electro-technical equipment, it was assured that the equipment was in conformity with the European EMC directive, in this case in accordance with [1]. During the construction of the civil structural assets an earthing network was installed, realising a connection towards earth of the reinforcement present in the viaduct [2]. It is normal procedure for Metropolitano de Lisboa to take precautions against vandalism when the system is above the ground. In this case the provision against objects being thrown on the track has been realised as a full metal cage, with a relatively small mesh size. As this metal is coupled galvanically, a Faraday cage is constructed. This Faraday cage is an
effective means of reducing electro magnetic fields coupled into the system from the outside world.

Metropolitano de Lisboa was mainly concerned with the following issues:

- Safety of human beings in stations;
- Safety of human beings in metro cars passing under the high-voltage line;
- Safety of signalling equipment present on the viaduct;
- Possible interference at the train detection layer (track circuits);
- Safety of telecommunication equipment.

In order to address the above mentioned issues, the following project approach was chosen:

- In the period between the finalisation of the construction, but before the start of the test operations a large number of measurements were performed:
  - Low Frequency magnetic fields;
  - High Frequency magnetic fields;
  - Low Frequency electrical fields;
  - High Frequency magnetic fields;
  - Induced currents in the running rails.
- Simulations were performed for the 50 Hz magnetic fields;
- Simulations were performed for the 50 Hz electrical fields;
- An inventory of equipment specifications was made;
- The functioning of safety critical systems was analysed;
- The compatibility margin for telecommunication systems was determined;
- The safety of human beings was studied.

The measurements were performed in a co-operation between Metropolitano de Lisboa, REFER (Portuguese Railway Infrastructure Administration) and Holland Railconsult.

3 Measurements

3.1 General

Measurements were performed in three locations:

- On the viaduct in the middle of the section where the parallelism occurs, approximately 220 m from station Senhor Roubado (site 1);
- On the viaduct, at the location where the high-voltage line crosses the viaduct (site 2);
- In the urban area, directly under the high-voltage line (site 3).

For the locations on the viaduct the low frequency electrical field and the low frequency magnetic field were measured inside the Faraday cage and outside the Faraday cage, thus the effectiveness of the screening of the Faraday cage could be established. Due to the size of the high frequency antennas it was only possible to measure the high frequency electrical and high frequency magnetic field inside the Faraday cage. An impression of a small part of the measurement equipment used can be found in Figure 5.
3.2 Low frequencies

As the major emission of the High-voltage line is expected within the range of 50 Hz commercially available equipment (manufacturer Narda) was used to determine the electrical and magnetic field strength within the frequency range of 10 Hz–32 kHz. The results indicated that the damping of the Faraday cage is approximately a factor 2 for the magnetic field, and approximately a factor 300-1000 (depending on measurement site) for the electrical field. This is in accordance with the expectations found in general EMC literature [3]. During the measurements it was not possible to determine the amount of energy transported over the line, but data were provided by REN based on the data logs of their SCADA system [4]. Using these data it was possible to correlate the measurements and the simulations to the loading of the line. The E-field strength inside the Faraday cage (site 1) is 0.15 V/m, outside 5 V/m, H-field: 0.55 A/m inside and 1.1A/m outside, site 2 values: 2 V/m inside, 2 kV/m outside and 2.2 A/m inside. 2.8 A/m outside (all values at 50 Hz).

3.3 High frequencies

Using the measurement techniques as described in [5], a fingerprint of the high frequency behaviour of the High-voltage Line and the EM environment in which the Metro system has to function was made. The effectiveness of the Faraday cage could not be determined directly, but a comparison between sites 1 and 2 and site 3 shows that the damping is in the range of 3 – 10 dB. The emission of the High-voltage line is mainly in the range 9 – 150 kHz, whereas the EM
environment at higher frequencies is mainly determined by intentional transmitters, such as FM radio communication and GSM.

### 3.4 Induced currents

Using specially developed Rogowski Coils and integrators [6], the induced currents in the rail were measured. An example of one of the results can be found in Figure 6. The influence of the High-voltage line can be seen quite clearly, note the peaks at 50 Hz, 150 Hz, 250 Hz and 350 Hz. At 5 kHz the current from the train detection system itself (including side lobes) can be seen, the peak at 2 kHz is caused by a track circuit in the adjoining track.

![Induced current in the rails](image)

Figure 6: Current in the running rails, location 2.

### 4 Simulations

#### 4.1 Electrical fields

Using in house developed simulation tools the 50 Hz electrical field strength was calculated for all locations, an example for site 1 can be found in Figure 7. Note that the field close to the surface of the Metro system can be disturbed due to local imperfections. The metal of the Faraday cage was modelled as a perfect metal plane, as modelling the individual bars of the cage would result in a large amount of work and would increase simulation running time to unrealistic levels. The results of the simulations matched well with the measurements.

#### 4.2 Magnetic fields

The 50 Hz magnetic field strength was calculated for all locations, an example for site 1 can be found in Figure 8. Note that the current induced in the
reinforcement of the civil structure has been included in the simulation. The results of the simulations matched well with the measurements.

![Simulated electrical field strength site 1.](image1)

![Simulated magnetic field strength location 1.](image2)

**Figure 7:** Simulated electrical field strength site 1.

**Figure 8:** Simulated magnetic field strength location 1.

### 5 Analysis

When comparing the measured emission levels [7] with the known immunity levels a sufficient compatibility margin was found for systems, see Figure 9. For
the signalling system the difference between 50 Hz and the working frequency is sufficient to ensure a safe functioning. A similar conclusion can be drawn for human beings based on [8]. An example for H-field can be found in Figure 10.

Figure 9: Compatibility margin for systems.

Figure 10: Compatibility for human beings.
6 Conclusions

A successful combination of infra structural elements such as a Metro system and a high-voltage line in a densely populated area is possible, but actions have to be taken to ensure compatibility, in this case a careful selection of equipment, and a thorough design of the earthing system. The decision to combine the functions of anti-vandalism precautions and Faraday Cage proved to be very useful. A detailed analysis of the as built situation is needed, as a basis of the safety case for the mass transport system. The combination of simulations and measurements on a number of locations over a large frequency bandwidth were a very powerful tool in proving the possibility of a peaceful coexistence between the metro System and a major power line in the urban area of Lisbon.

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References