Analysis tool adapted for the different electromagnetic compatibility issues in the railway domain

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Abstract

In this paper, a study methodology available for different types of electromagnetic interferences in railways domain is described. An analyzing tool has been developed, initially dedicated to the detection and the analysis of the transient signals in the railway power supply system [1]. The aim of this work is to enlarge the usefulness of this tool and to adapt it to the most important railways EMC problems.

1. Introduction

The railways domain is characterized by various types of electromagnetic interferences (EMI). This variety is mainly due to the large number of EMIs sources, and also to the growing number of vulnerable systems embedded or in the vicinity of the trains, especially signalling systems. The variety of the sources and of the victim systems requires the use of various technics and competences to study and diagnose the EMC issues. Then, it could be useful to develop an EMC analysis tool which would be adapted to the analysis of different interference signals characteristic to the railway domain, whereas these signals being significantly different in terms of frequency, power and time characteristics.

An inventory of the most important interferences, signals, sources and potential victims related to railways domain has been carried out to reach this goal. Then, a classification under different characteristics as frequency, time domain variation and power of the signals has been done. In EMC, the frequency band to consider in railways, goes from DC components, as those added by the pantograph arcing on the supply current [2], to approximately the GHz to protect the GSM-R communication, through low frequency used by the track circuit systems. The interference signals to study can be permanent as the EM field radiated by the catenary, periodic as the supply current harmonics or transient like the disturbances phenomena produced by railways sub-stations and conducted on the power supply lines [1]. This classification constitutes a rich database and a detailed description of each interference signal, with its frequency and time shape, power range, main sources, propagation path and potential victims. In the first part of this paper, two potential victim systems extracted from this inventory are presented in details: the UM series joint less track circuits (UM71) which is based on some kHz conducted signals in rails, and the GSM-R communication system, which is a radio frequency system operating at about 1 GHz. Both systems are vulnerable to different types of interferences and the post processing has to be adapted in order to extract the most significant noise factors for each system. In the second part of the paper, a time-frequency analyzing tool is described. Taking into account the requirements that the analysis tools has to verified to answer to railway EMC issues, a specific process is presented.

2. Signalization systems: Track circuit and GSM-R

Communication and signalization systems in the railway domain have evolved through time and are divided into wired and wireless systems. Each country has its own signalization and traffic regulation system, which complicates travelling through different countries. While track circuit features are not the same in every country, in Europe, the European Railway Traffic Management System (ERTMS) is deployed to unify the communication and signalization protocols using the GSM-R system for communication between trains and control centers and the Eurobalise system for localization and spot communication.

2.1 Track circuit

Track circuits permits the regulation of railway traffic by the detection of the presence of any vehicle on a given stretch of track. Using this information, signalling then ensures a safety distance between trains. The track circuit working principle is based on a transmitter and a receiver placed at each extremity of the track section and the transmission of a signal through the transmission line composed of the two rails. If the transmitted signal is shunted by a train axle and thus is no more received at the track extremity by the receiver, then the track section is declared occupied by a vehicle. There are two main types of track circuits, in the first one, track sections are electrically separated by joints on the rails, and the transmitted signal is generally an electrical pulse. The second type makes use of jointless tracks and the sections separation is ensured by using different frequencies on consecutive track circuits.

The UM71 is a jointless track circuit and among the most used ones in France, it alternates four different carrier frequencies (f_0) to avoid crosstalk between adjacent tracks, 1,700 Hz and 2,300 Hz track circuits on one track, and 2,000 Hz and 2,600 Hz track circuits on the parallel track [3]. Transmitted signals are FSK modulated with a maximum frequency deviation $f_0 \pm 11$ Hz. In the reception side, the filter bandwidth is $f_0 \pm 40$ Hz and the minimum reliable working current is 175mA [4].

Due to track circuit signals being transmitted through the running rails also used as a return current conductor, two main perturbations can disturb the track circuit operation. The first one is current harmonics. Track circuits receivers have 80Hz-width pass band filters centered on the carrier frequency and some current harmonics can be within this band. Therefore, they could interfere with track circuit signal or damage the receiver circuit if they carry enough power. These harmonics can result from a low quality of the supply current (as the distortion caused by pantograph arcing [2] or generated by sub-stations), or from the onboard power systems (as the PWM induction motor drive or the uninterruptible power supply). The second perturbations are transient disturbances due to electrical transient phenomena produced by power supply systems as sub-stations [5] or the sliding contact between pantograph and catenary. These disturbances cover wide frequency bands and can reach high power peak level. They may be conducted through the supply current and interfere with the track circuit signals. The impact of interferences due either to the supply current or to the traction unit is greater when the return current is unbalanced distributed on both rails, the difference may reach above 100 A [6].

2.2 GSM-R

GSM-R is a wireless communication system based on the GSM communication standard allowing data transmission (voice and signalization information) between trains and railway control centers. GSM-R uses the same architecture network used for the public GSM, which consists of Base Transceiver Stations (BTS) along the railways lines connected to the control and regulation centers via the Base Station Controllers (BSC). GSM-R antennas are fixed on the roof of trains and connected to the onboard mobile station through a shielded cable.

In Europe, frequency bands allocated to GSM-R are close to those of public GSM: 876-880 MHz for the uplink and 921-925 MHz for the downlink. Each band is divided into 20 channels of 200 kHz. Only 18 of them are used to prevent overlapping by public GSM frequencies. GSM-R also uses a Time Division Multiple Access (TDMA) system, thus every channel can be shared simultaneously by 8 users, and each one of them occupies a 577 µs “Time slot” interval of a 4.615 ms periodic TDMA frame [7].

GSM-R uses the specific Euroradio protocol allowing some erroneous frames correction or retransmission of information until a correct reception. This feature makes the GSM-R robust to some of the electromagnetic interferences. Nevertheless, the continuity of the GSM-R system is fundamental for the safety of the railway network, therefore, the study of the disturbances that might affect the robustness of GSM-R is very important.

Regarding the frequency band used by GSM-R, public GSM can be a source of interference, indeed, only 400 kHz separate the last frequency used by GSM-R from the first one used by the public GSM and an overlapping can easily happen if public GSM BTS are located in the vicinity of the railway lines. In [8], measurements performed on the Belgium railway network, showed that the power level of the GSM overlapping signal can reach -75 dBm in the GSM-R band. This overlapping level is comparable to the average GSM-R signal power (between -25 dBm and -95 dBm). Thus, public GSM signals are able to disturb GSM-R; and more recently problems occurred on the GSM-R with the newly deployment of the 4G public network.

Transient interferences can also disturb the GSM-R. GSM-R antennas are located on train roofs, thus, are close to the sliding contact between pantograph and catenary which is a source of recurrent transient disturbances. In [9], these transient disturbances were measured in the time domain and a post processing of the recorded signals in the downlink GSM-R band (921 – 925 MHz) showed that transient power level varies mainly between -40 and -70 dBm over the GSM-R channels, which is comparable to the power level range of the GSM-R reception signals. The average time duration of the recorded transient disturbances does not exceed 20 ns, which is much shorter than one data bit duration (3.7 µs). This highlights the need to analyze the recurrence of these disturbances. Indeed, the more recurrent the transient disturbances are, the more data in a TDMA frame will be affected. Thus, when such interferences are studied, it is necessary to assess the percentage of the GSM-R channels time occupancy by the disturbances, and regarding the GSM-R communication protocol, the recurrence could be defined, from which the transient appearance can threat seriously the GSM-R communications.

3. Time-frequency analyzing tool dedicated to railway issues

The current tool is based on a previous work which was performed in order to examine the supply current and the disturbances created by a sub-station [1]. The analyzing method is based on measurements in the time domain, to be able to detect transient signals, and a time-frequency analysis of the measured signals. Time-frequency data allows seeing the frequency variations of a signal along time, to observe if any transient phenomenon occurs and to determine the bandwidth, the duration and the power range of these phenomena. Nevertheless, in some cases, the visual detection of transient disturbances is very difficult on the time-frequency representation, especially when their power level is in the same range of the measured stationary noise. So, the tool, in its final version, has to include an automatic analysis of the time-frequency data.

The analysis tool is based on the wavelet transform principle by adapting the time window duration during the time-frequency analysis in order to adapt the frequency resolution to each frequency band of the signal. Thus, time-frequency space is divided into frequency bands with a fixed step and time windows which durations are inversely proportional to the studied frequency range. The width of the calculation time window is then defined by taking into account the resolution frequency required and, eventually the time characteristics of potential victim systems.

In the case of track circuits, supply current harmonics have to be detected. The tool has to permit us to analyze the return current on the running rails and measure the power of the current harmonics especially those corresponding to track circuit carrier frequencies. The frequency resolution obtained with the tool analysis has to be similar to input filter of the receiver. Regarding the track circuit system described in this paper, the frequency resolution has to be set to 80 Hz. Then, harmonic and transient disturbances power can be estimated and compared to the critical power level of the track circuits. In the case of GSM-R, the resolution bandwidth offered by the tool has to be similar to the input filter of the GSM-R receiver. The GSM-R channels are spaced of 200 kHz and the width of input filter is 120 kHz. But, in parallel, concerning the GSM-R is also necessary to take into account the data rate. Indeed, knowing that a bit transmission time is 3.7 µs with the GSM-R, it is necessary to analyze the data with a time resolution comparable to be able to confront the recurrence of the transient noise with the binary flow.

The tool should then offer a perfect flexibility to define the time and frequency resolutions and to respect the Heisenberg inequality, stipulating that the product of Δt and Δf is constant. Frequency resolution Δf is defined regarding the frequency band studied, and time resolution Δt depends on the sampling rate and the width of the calculation window. Consequently, we did not apply an FFT algorithm to avoid to be limited by power of 2 to define the width of the calculation time window. In order to get a powerful analysis for a very large frequency band based on adaptive window, we designed a tool whose relative bandwidth is easily adjustable, and whose computation time is faster as possible. For Hanning, Hamming, or Gaussian windows, the weight associated to a sample within a window is not the same as that associated to it within the next window. This makes the relationship between two neighboring windows more complex and increases the computation time. For the rectangular window, the relationship between two windows shifted by one sample is very simple. This shifting means adding a new sample, and deleting the latest one. This property optimizes significantly the computation time. However, the rectangular window also has disadvantages, notably, the side lobes at -13 dB lower than the main lobe. A way to correct this disadvantage is to apply the convolution with the rectangular window several times: the convolution of two rectangular windows is a triangle window, and the convolution of three corresponds to x2. And thus, by applying successive convolutions of the measured signal with a rectangular window, we can reduce the side lobes, as showed in Fig.1.

Fig. 2 shows the result for a signal composed of 4 different frequencies (4 kHz, 23 kHz, 130 kHz and 850 kHz) along the time. The sampling frequency is 20 MHz. The time-frequency analysis was performed with a logarithmic step for 300 frequencies between 100 Hz and 2.5 MHz and the convolution by the rectangular window was applied 4 times. This result for 100000 points and a very thin resolution frequency (80 Hz at 2600Hz) was obtained in 5 s, and with this process the calculation time does not depend on the number or width of the time windows. Now, the next objective is to introduce new parameters in the tool in order to adapt and vary the frequency and time resolutions according to the frequencies of interest of the railway systems.

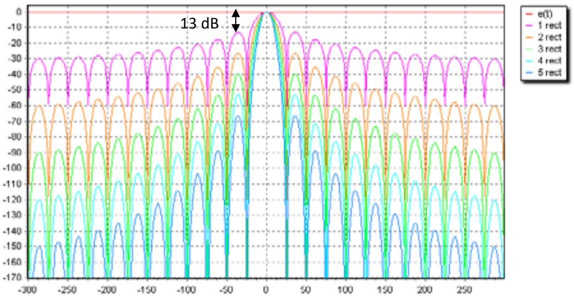

Fig. 1 Spectral representation of the convolution of e(t) by many rectangular windows

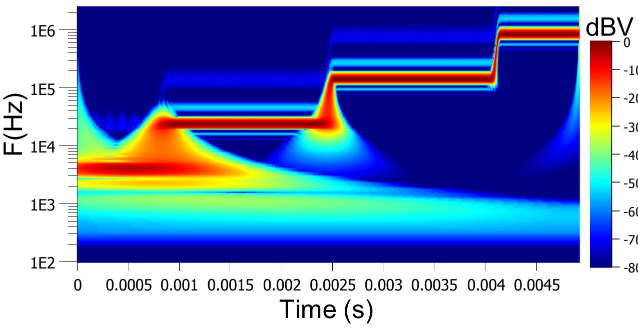

Fig. 2 Time-frequency representation of 4 frequencies signal with a 4 time convolution by rectangular window

4. Conclusion

Variety of issues related to EMC in railways requires the involvement of several experts and specific measurement and analysis methodologies. To illustrate this situation, we described the issues related to signaling and communication systems as track circuits and GSM-R In order to design an analysis tool that fits with all of the railway issues, we proposed an appropriate processing method for time-frequency analysis. We showed that we could achieve sufficiently flexible and fine resolutions in order that the calculated time-frequency data being comparable with the victim systems bandwidths and in very reasonable computation time.

5. Acknowledgements

This work has been funded by the Railway Institute of Technological Research “Railenium”.

6. References

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