Experimental variability of track to ground conductance measurements

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Abstract. To fulfil IEC 62128-2 (EN 50122-2) standard stray current requirements, the new or revamped DC electrified transportation systems shall achieve very good levels of track to ground insulation. This insulation shall be witnessed, usually in construction phases, by means of accurate measurement. Some measurement techniques are suggested by IEC 62128-2 standard but literature leaks about considerations about their measurement uncertainty. The paper purpose is to fill this gap and analyse the variability of track to ground conductance measurements.

1. Introduction
DC electrified transportation systems are a very common way of urban transportation [1]. The current absorbed by the vehicles for traction usually uses running rails as return path towards the traction substation. A good track to ground insulation is a very important parameter to limit the current exchange between rails and soil [2]. This current is known as stray current from DC transportation system.

Stray current might be described by leakage current density against a certain position [3]. Stray current may cause corrosion to the buried metallic structures in the nearby of DC railway [4]-[6]. International standard IEC 62128-2 (EN 50122-2) [7], imposes an average stray current per length of a single track line of 2.5mA/m; to guarantee that no damage in the tracks occurs over a period of 25 years. Such limit is function of the positive average rail potential shift during the 24 hours and the rail to ground insulation level.

Nowadays, the increased demand of public transport, bring to vehicles running 24 hours a day; so the average rail potential increases and thus, to fulfill the standard prescriptions, a better track to ground insulation is needed. Track to ground insulation shall be proved during construction phases and some measurement methods are proposed by IEC 62128-2 [9]. The better the insulation to be measured, the lower should be the variability of the measurement; in order to allow the comparison with limits imposed by the standard.

Literature about track to ground conductance measurement is not very well populated and few papers deals about the variability reached by such kind of measurements. ASTM G165 standard proposes a method to consider the measurement results reliable but does not deal about the measurement variability [10]. IEC 62128-2 never spoke about measurement variability. Some interesting papers identified variabilities due to test set up both experimentally and by simulations [11][12]. Those variabilities may be considered as due to systematic errors that can be corrected fixing appropriately the test set up. Variability due to random errors which affect track to ground conductance measurement, have never been evaluated in literature although IEC 62128-2 standard suggests to perform many measurements with the same test set-up to evaluate the consistency of the results. The present paper would fill out this
gap, analyzing the repeatability of track to ground conductance measurement using the two methods suggested by IEC 62128-2 standard.

2. Track to ground conductance measurement

There are two measurement methods suggested by IEC 62128-2 standard [7] to perform track to ground conductance measurements: Method described in Annex A.2. allows measurements in case of very long longitudinal track section (over 2km) and in presence of continuous metallic structures. It is used typically in tunnel or viaduct sections; Method described in Annex A.3. needs a track section defined between two insulating rail joints or two rail cuts, shorter than 2km.

Method (A.2) defines the length of measurement section by two voltage readings A and B, taken between track and metallic continuous structure. The track is supplied by a DC power supply (PS) in the middle of the defined A-B section; with positive pole connected on the track and negative pole connected on metallic structure. The current and voltage of the power supply are measured. The current which flows in the running rails over the section is measured using the voltage drop on the rails and the rail resistance value. The track conductance per unit length is calculated by the ratio of the current leaked out from the measurement section and the mean of the three voltage readings. The data collected could be affected by systematic errors. Such errors could be: the effect of rail welding and variations due to temperature that changes the rail resistance measurement; contemporary measurements in the 3 locations (A, B and PS); the presence of works (working boogies) that may produce DC noise [13].

Using method (A.3) the measured track section is defined by rail cuts or insulating rail joints. The section is supplied at one side by a power supply (PS) with the positive terminal connected to the measured track section and the negative pole connected to the tracks behind. Track voltage is measured at least 50 m away from the power supply injection point, using a remote electrode as reference. The track conductance is calculated as current voltage ratio. A systematic error could be the location of voltage measurement that should be closer to the end of the track (opposite from PS injection point) the shorter is the track section measured. Some correction factors are under development in order to fix this error [12]. The resistance to earth of the negative of PS shall be in the order or less than 1/100 of the track to earth resistance to be tested [10].

3. Analysis of measurement variability

The variability of various track to ground conductance measurements has been evaluated as follows. All methods require the measurement of two or more electrical sizes that may be sampled far away one to each other and the different traces synchronism has been not easily guaranteed. The measurements have been recorded using three pc oscilloscopes (Picoscope 4424, 12 bit configurable with a full-scale of 50mV leading a resolution better than 25uV and ±1% of accuracy) and an active current probe (LEM HAT 800-S, with 5mVA sensitivity and ±0.5% of accuracy). The power supply has been switched on for at least 10s (in order to have a great portion of record not affected by soil polarization) and then switched off for a same time. The use of a low pass filter in input of the readings, filtered high frequency noise components although it was not completely efficient in filtering external noise at low frequencies. In order to taking account of these problems, the recorded signals have been post-processed as briefly described below:

- the data sampled by the different oscilloscopes have been synchronized with the first switch on of the power supply, using thus power supply current and voltage as reference;
- when the distinction of the measurement from DC floor noise was not possible, the relatives signals have been set to 0 (this may be the case of voltage readings to estimate the current flow in one side of the track using A.2. method, very close to the end of the track section);
- data have been filtered in order to obtain DC component (<1Hz);
- during the “on phase” of the power supply some samples resulted affected by the polarization effect. Such samples have been removed for the conductance calculation;
- the “off” samples have been identified as 1 second after switching off the power supply;
eventually the track to ground conductance has been calculated for every on-off interval of the measurement;

• Considering the single measured section with a specific measurement set up and environmental conditions, the identified “on-off” intervals in the measurement were used to evaluate the variability of the measurement, expressed as Type A combined standard uncertainty, according to sec. 5 of GUM [14]. The measurement results are thus expressed with the average value of the n measurements results in the same test conditions (Gmean) and their dispersion about this mean named experimental standard deviation of the mean (Gstd). To give an immediate term of comparison between the variability when the conditions are varied the measurement variability is also expressed as the ratio of the standard deviation and the mean value of the measurement in percent (Gstd %).

The variability of track to ground measurement using the method suggested in A.3 of the IEC 62128-2 standard is shown in Table 1, where eight measurements in different track sections, with different characteristics and conditions have been considered. The measurement variability is better than ±1% of the mean conductance value in dry conditions, and slightly worse in wet conditions. The worse measurement variability in wet conditions was expected as measurements were performed in a sunny day (almost 30°C), wetting the rails in order to see the effects on track insulation, thus eventually the different measurements performed considered slightly different wetting conditions; increasing the measurement variability. In general very low track to ground conductance values, in the order of mS/km, can be measured with a variability of ±1% of the measured value.

Table 1. Track to ground conductance measurement variability using method A.3. of IEC 62128-2.

| Meas ID | Track length (m) | Track conditions | Gmean (S/km) | Gstd (S/km) | Gstd (%) |
|---------|------------------|------------------|--------------|-------------|----------|
| #1      | 237              | Dry              | 0.00636      | 0.00005     | 0.82     |
| #2      | 237              | Wet              | 0.10041      | 0.00070     | 0.69     |
| #3      | 237              | Humid            | 0.03104      | 0.00024     | 0.78     |
| #4      | 113              | Dry              | 0.00643      | 0.00006     | 0.88     |
| #5      | 113              | Wet              | 0.02767      | 0.00090     | 3.2      |
| #6      | 113              | Wet              | 0.02543      | 0.00070     | 2.7      |
| #7      | 79               | Embedded         | 1.02717      | 0.00334     | 0.33     |
| #8      | 79               | Embedded         | 1.02746      | 0.00372     | 0.36     |

¹High variability expected due to hot sun that dried track while measurement was performed.

The variability of track to ground measurement using the method suggested in A.2 of the IEC 62128-2 standard is shown in Table 2, where six measurements in different track sections, with different characteristics and conditions have been considered. The variability in measurement results is higher than using method A.3. Measurement #4 should not be included in the evaluation because very low current flowed during the measurement; hence the voltage readings to estimate the current which leaks from the measured section were not accurate. It is chosen to include it inside the table, to point out the attention about PS current during the measurement, that has to be high enough to allow a reliable and accurate reading of the rail voltage drop. The variability is near ±5% of the measured conductance value when the conductance is in the order of tens of mS/km and increases for lower conductance values. There is not an evident dependency of measurement variability due to track section length.

Table 2. Track to ground conductance measurement variability using method A.2. of IEC 62128-2.

| Meas ID | Track length (m) | Track conditions | Gmean (S/km) | Gstd (S/km) | Gstd (%) |
|---------|------------------|------------------|--------------|-------------|----------|
| #1      | 700              | Humid            | 0.05583      | 0.00292     | 5.2      |
| #2      | 1071             | Dry              | 0.00792      | 0.00062     | 7.8      |
| #3      | 1065             | Dry              | 0.00293      | 0.00033     | 11       |
4. Conclusions

Track to ground conductance measurement variability due to random errors was analyzed. Two measurement methods, suggested by IEC 62128-2 standard, have been taken in consideration: named A.2 and A.3. The measurement variability using method suggested in annex A.2 of the standard is higher than that using the method suggested in annex A.3. Method A.2 for very well insulated short track sections needs high power supply current to be accurate. Method A.2 allows measurement of track conductance in the order of 10mS/km with a measurement variability about ±5% of the measured value, for lower conductance values the measurement uncertainty increases. Method A.3 allows measurement of track conductance in the order of 1mS/km with a variability about ±1. It is thus more indicated for measurement performed on very well insulated track; taking the provision of a very good negative connection of the power supply with a resistance to earth in the order or less than 1/100 of the track to earth resistance. Further investigation may be carried on using a different and more accurate method (Rogowsky coils) than rail voltage drop, to estimate the leaked current used in method A.2.

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|---|---|---|---|---|
| #4 | 245 | Dry | 0.00458 | 0.00233 |
| #5 | 1200 | Humid | 0.48446 | 0.02304 |
| #6 | 339 | Humid | 0.02528 | 0.00151 |