THE BEHAVIOUR OF DIFFERENT EARTHING SYSTEMS FOR ELECTRIFIED RAILWAYS USING AC VOLTAGES UNDER SHORT CIRCUIT CONDITIONS

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ABSTRACT

It is well known that the return circuit for railway lines electrified at 2x25 kV, 50 Hz is an important element to ensure the electrical safety of the line when subject to fault conditions. Therefore, care should be taken when studying and developing the earthing system of this circuit.

Firstly, the efficiency of three possible earthing systems for the return circuit is investigated under the presence of an electrical fault. A second study focuses to the impact of some important environmental parameters on the touch and accessible voltages.

INTRODUCTION

When developing new electrified railway lines, (ERL) energized at 2x25 kV alternating current (50 Hz), it is extremely important to take special care concerning the return circuit (RCC), which is part of the ERL's electrification system. Choosing the most adequate RCC depends on several parameters such as economical aspects, environmental conditions and constructional and technical aspects.

A RCC of an electrified railway system can be constructed using underground earthing cables (CdTE), overhead protection cables (CdPA – earthing wire), additional local earthing rods, the running rails, earthing grids of local substations and several bonds (junctions) between the above components when present along the ERL.

Besides its technical necessity, the RCC interacts also with the train signalling system and takes an important role in the general electrical safety concept of the railway line:

- **Technical:** the RCC ensures a well-defined return circuit for the traction current charged by the trains.
- **Signalling:** the RCC is by way of the running rails part of the signalling circuit controlling the traffic.
- **Safety:** a well-developed RCC eliminates dangerous accessible and touch voltages when having an electrical fault occurring somewhere along the railway line.

This paper deals mainly with the electrical safety aspect of a RCC, taking in to account its technical importance as well as its dependency of environmental parameters: the European Standard Publication EN 50122-2 [1] stipulates maximal values for the touch and accessible (step) voltages as function of time during an electrical fault. Taking a total breaking time for standard switchgear of 100 ms to disconnect a short circuit, the touch voltage is limited to 842 V_{RMS} while the tolerated permanent accessible voltage is 60 V_{RMS}.

The next sections study the behaviour and efficiency of different RCC, saying investigating their earthing system in detail when subject to different electrical faults. For each earthing system, variations of the most important technical and environmental parameters are studied.

REFERENCE MODEL AND SIMULATIONS

Equivalent model current return circuit

As mentioned before, the RCC is part of the overall electrical system of an electrified ERL powered at 2x25 kV, 50 Hz. Such an electrification system uses a typical conductor configuration [2] as schematically shown in Figure 1. Two conductor groups are distinguished: the catenaries group supplying the electrical energy to the loc using a contact wire "cw" and its messenger wire "mw". The energy supply is optimized by using an additional feeder "fd" at the cw-voltage, but with a phase shift of 180° (opposite phase).

The second group is the RCC composed of i.e. CdPA, CdTE and the running rails R1 and R2. The studied earthing system is part of the RCC and contains the CdPA and/or CdTE together with local earthings (masts, traction- and autotrans-former substations) and the equivalent earthing impedance of the concrete foundations of the catenaries masts.

It is important to remark that Figure 1 shows only one track of an ERL, a similar configuration is used for the second track.

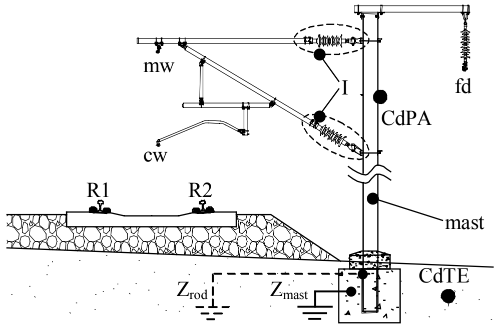

Figure 1 : Reference model 2x25 kV electrification

In order to carry out the study, a reference ERL is defined. The line consists of one traction substation and two autotransformer stations, shown in Figure 2. The distance between the catenaries masts is 50 m and the total length of the ERL is 15.6 km. Every 600 m, there is an equipotential bond between the CdTA and CdPE, a DTX. In total there are also 6 LTI's installed.

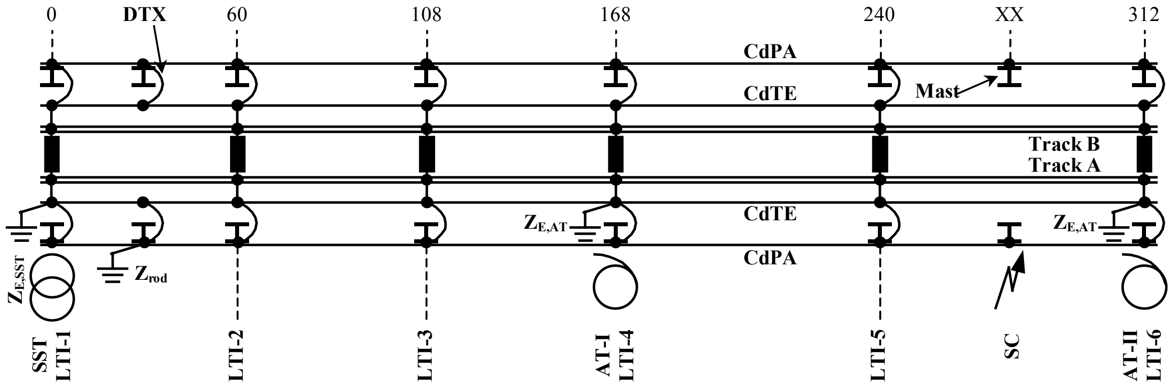

Figure 2 : Current Circuit – Reference model for calculations

Such an LTI is an impedance bond between the rails of each track, cross-bonded to the CdPA and/or CdTE. All conductors are shown at Figure 2.

An electrical equivalent circuit is built using equivalent earthing impedances [3], [4] and a pi- model for the rails and different conductors and. The conductors' series impedances are simulated using Carson's Theory in order to include the mutual coupling between current carrying conductors and the influence of a conductive ground.

Finally, the system and its fault are mathematically simulated using its equivalent admittance matrix model, resulting in the voltages induced in the different nodes, the masts [5].

Different earthing systems, faults and simulations

In total three different earthing systems, being part of the RCC of ERL are studied. Their responses when subject to two different fault conditions are examined in detail: the induced voltages along the tracks and the voltages induced at each of the catenaries masts are calculated.

The three studied earthing systems, are (see Figure 2):

- An overhead protection wire CdPA in parallel with an underground earthing cable CdTE along each track;
- Using only an earthing wire CdPA;
- The combination of a CdPA cable and additional earthing rods Z_{rod} connected to each catenaries mast.

As fault conditions, two frequently occurring faults are modelled: a dielectric breakdown of an insulator and an internal fault in a traction engine. Both fault conditions are discussed in the next section.

For each fault condition and each earthing system, several simulations are executed using different values for common environmental and electrical parameters. The impact of the the short circuit's position; the specific resistivity of the soil (ρ_{earth}); the leakage admittance of the tracks (Y_{track}); the equivalent earthing impedance of the catenaries masts' concrete foundations (Z_{pole}) and when applicable, the equivalent earthing impedance of the masts' additional earthing rods (Z_{rod}) are studied. Their different values are briefly summarized in next section.

SIMULATION RESULTS

Parameter variation

Each different parameter mentioned in the previous section is varied for both failure categories. In order to determine their effect on the pole voltage and track voltage, they are all compared against a reference earthing system: a system built of a CdPA in parallel with a CdTE, subject to a fault at the centre between two general LTI junctions and two equipotential bonds between CdPA and CdTE (DTX). Using the above reference ERL, the fault occurs at mast 282.

The parameter variations can be summarized as:

- **Position of the fault:** reference location at mast 282 and shifted towards a DTX (mast 276) or a LTI (mast 241).
- **Leakage admittance of the tracks Y_{track}:** reference value is 2.5 S/km, variations are 1.0 and 0.1 S/km.
- The **earthing impedance** of the masts' concrete foundations Z_{pole}: reference impedance is set to 50 Ω where 27 Ω and 65 Ω are the variations.
- The **specific resistivity of the soil ρ_{earth}:** reference value is 100 Ω.m and is varies into 75 and 250 Ω.m.
- The **earthing impedance** of the additional earthing rods Z_{rod}: initially there are no additional rods installed. When applicable, values are 3 Ω, 10 Ω and 15 Ω.

Insulator failure

An insulator failure is defined as a dielectric breakdown of an electrical insulator installed between a mast and a cantilever ('I' at Figure 1).

The fault condition is modelled as a direct short circuit between the contact wire (cw) and the mast. This short circuit is modelled as low impedance of $Z_{SC} = 0.01\ \Omega$ and all calculations are executed for a 1x25 kV, 50 Hz electrical supply system. Finally, the short circuit occurs always at track A while track B is not energized.

For every simulation, the voltages induced at each mast (U_{mast}) and along the tracks (U_{track}) are recorded. As example, Figure 3 gives the mast voltage for a short circuit applied to mast 282 of the reference earthing system: *P/CW_TrA* represents the voltage at the masts of track A and *P/CW_TrB* the voltages of the masts belonging to track B. As expected, the mast carrying the short circuit (SC) is subject to the highest voltage (in this case 606.28 V). Only for the readers' information, the position of the traction substation (SST), the autotransformer (AT) and LTI's are indicated on the figure.

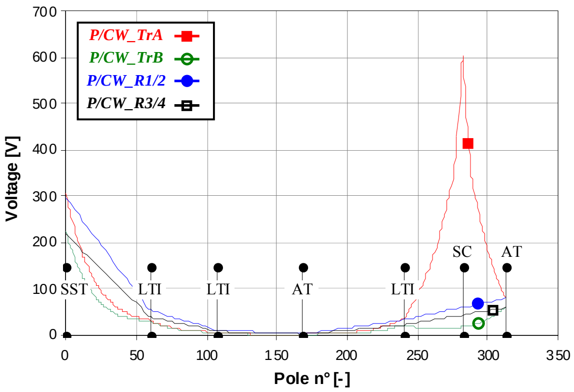

Figure 3 : Voltages – Insulator Failure

Similar, the voltages along both tracks are in Figure 3 pictured as *P/CW_R1/2* representing the voltage of track A and *P/CW_R3/4* for the voltages of track B. Contrary to the mast voltage, minor differences between the induced voltages along the two tracks can be noticed.
Finally, the simulation results are summarized in Table 1, column "*SC–Mast-CW*".

Engine failure

An engine failure is defined as a direct electrical breakdown in the traction engine of a loc. This fault situation is modelled as a short circuit with low impedance between the contact wire and both rails of the track at which the loc is present.
All short circuit calculations are executed for the electrical supply system mentioned for an insulator failure and occur at track A (track B is not energized).

As before, Figure 4 pictures the mast voltages when a short circuit is introduced at the location of mast 282 for the reference railway system: *R/CW_TrA* and *R/CW_TrB* represents the voltages calculated at the masts of track A respectively at the masts belonging to track B. Minor differences between the induced mast voltages at the two tracks are noticed.
At the same picture, the track voltages are represented by *R/CW_R1/2* and *R/CW_R3/4* for the voltage along track A respectively along track B. Contrary to the mast voltages, a major difference is present: as expected, the voltage along the track at which the fault occurs is much higher in the railway section between the last two AT's, covering the SC. At the SC location, a track voltage of 517.12 V is simulated.

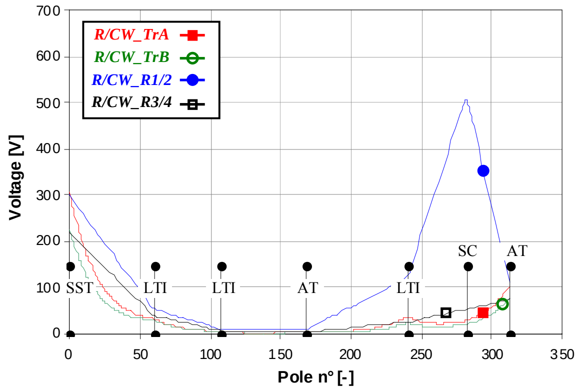

Figure 4 : Voltages – Engine Failure

Finally, the simulation results are also summarized in Table 1, column "*SC–Track-CW*".

CONCLUSION

Three different earthing systems, being part of the RCC of an electrified ERL are studied when subjected to two frequently occurring fault conditions. Several simulations, based on a 1x25 kV, 50 Hz electrification during an engine failure or an insulator failure are executed by modifying the most important parameters for each earthing system.

In general, it can be concluded that the development and practical implementation of an optimal earthing system or in general the RCC for a ERL is key. Their behaviour depends on several environmental and technical parameters, and should be studied in detail for each new situation.

Taking a system built of a CdPA in parallel with a CdTE cable and subject to a fault at the centre between two general LTI junctions and two DTX equipotential bonds as reference, following conclusions can be drawn (Table 1):

- The **position** of the fault plays an important role for both voltages at the masts and along the tracks: an insulator failure close to a DTX lowers the mast voltage and an engine failure close to a LTI has a positive effect on the track voltages (decreasing).
- The **resistivity of the earth** has a direct influence on the mast voltages (and indirectly on the track voltage) when having an insulator failure: increasing ρ_{earth} increases the voltage. In case of an engine failure, the influence is less important for the track voltage, but more important for the mast voltage.
- The **leakage admittance of the tracks** $\mathbf{Y_{track}}$ influences mainly the track voltage in case of an engine failure: The better the tracks are insulated from the soil, the higher the track voltage will be. In case of an insulator failure, obviously only the track voltages increases with increasing Y_{track}.

Table 1 : Calculation results – Summary of different situations

General							SC – Mast-CW		SC – Track-CW	
Mast	**CdTE**	**CdPA**	**.ρ_{earth} [Ω m]**	**Y_{track} [S km]**	**Z_{mast} [Ω]**	**Z_{rod} [Ω]**	**U_{mast} [V]**	**U_{track} [V]**	**U_{mast} [V]**	**U_{track} [V]**
282	**X**	**X**	**100**	**2.5**	**50**		**606.28**	**59.76**	**29.89**	**517.12**
241	X	X	100	2.5	50		325.72	155.72	6.00	35.11
276	X	X	100	2.5	50		473.76	49.834	25.13	543.58
282	X	X	100	0.1	50		604.74	71.08	68.37	956.10
282	X	X	100	1.0	50		605.27	66.59	49.53	751.11
282	X	X	100	2.5	27		578.55	52.83	26.53	517.39
282	X	X	100	2.5	65		614.54	61.89	30.91	517.03
282	X	X	75	2.5	50		557.91	45.96	23.31	520.08
282	X	X	250	2.5	50		767.27	111.86	53.70	506.31
282		X	100	2.5	50		1477.00	225.07	102.57	520.68
282		X	100	2.5	50	3	420.80	9.69	4.88	518.58
282		X	100	2.5	50	10	721.80	50.432	24.24	517.36
282		X	100	2.5	50	15	847.22	73.04	34.73	516.57

- The **earthing impedance of the concrete foundations Z_{mast},** is for both failure types less important regarding the mast voltage while the track voltage remains more or less constant. A low Z_{mast} strengthens the overall earthing grid and reduces the pole voltage.
- The **earthing impedance of additional earthing rods**, **Z_{rod}**, in the absence of a CdTE has only a positive effect on the mast voltage when Z_{rod} is limited in value. In case of an engine failure, the mast voltage increases with increasing Z_{rod} while the track voltage remains constant.

When there's only a CdPA available, the worst-case scenario for insulator failure is reached. In case of an engine failure, only the pole voltage increases extremely compared with the reference model.

The simulations show that the choice of an optimal earthing system for the RCC is function of different parameters and depends also of the failure category to protect:

- In case of an **insulator failure**, the absence of a CdTE can be compensated with additional individual earthing rods for the catenaries masts IF the equivalent earthing impedance Z_{rod}, is restricted. However, the track voltage in case of an engine failure is independent of Z_{rod}.
- In case of an **engine failure**, the track voltage is extremely reduced if the tracks have high leakage admittance, meaning the tracks are less insulated from earth. Care should be taken because Y_{track} has significant importance for signaling reasons. In case of an insulator failure, no significant effect of Y_{track} to the mast voltage is recorded.

The last conclusion confirms the results obtained by changing the location of the short circuit along the track with respect to the LTI bonds. In case of an engine failure, the lowest track AND mast voltages are obtained for short circuits in the direct neighbourhood of an LTI, meaning a low equivalent local earthing impedance for the tracks.

Regarding the studied reference model, it can be concluded that the most optimal earthing system to be installed for a RCC consists of following elements:

- Both a **CdTE** and **CdPA** should be present together with several equipotential bonds.
- When installed in soils having a high specific resistivity ρ_{earth}, it is advisable to install **additional earthing rods** connected to every or to some catenaries masts.
- It is very important to ensure **high track-to-ground leakage admittance Y_{track}**. This means, install the tracks in such way that they have very low track-to-ground impedance.

ACKNOWLEDGEMENTS

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