Measurement of A.C. current propagation on a D.C. powered railway track

Citation for published version (APA):
Hesen, P. L. J., Deursen, van, A. P. J., Zanden, van der, H. M., & Waes, van, J. B. M. (2004). Measurement of A.C. current propagation on a D.C. powered railway track. In P. A. A. F. Wouters, S. Kapora, & A. P. J. Deursen, van (Eds.), *Proceedings of the International Symposium on Electromagnetic Compatibility (EMC Europe 2004) Eindhoven, The Netherlands* (Vol. 2, pp. 514-517). Technische Universiteit Eindhoven.

Document status and date:
Published: 01/01/2004

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 18. Mar. 2025

MEASUREMENT OF A.C. CURRENT PROPAGATION ON A D.C. POWERED RAILWAY TRACK

P.L.J. Hesen(1), A.P.J. van Deursen(1), H.M. van der Zanden(1) and J.B.M. van Waes(2)
(1) Department of Electrical Engineering, Eindhoven University of Technology
P. O. Box 513, 5600 MB Eindhoven, The Netherlands
(2) Holland Railconsult, P.O. Box 2855, 3500 GW Utrecht, The Netherlands
E-mail: p.l.j.hesen@tue.nl

Abstract: An experimental method is described to investigate the undesired penetration of power frequency current in a d.c. railway track. The method is versatile, and can be applied without changes in the railway systems. The immediate goal was the verification of models for the electromagnetic compatibility between the train detection system in a d.c. track and a nearby a.c. railway power system. At the end other applications by the same method are briefly mentioned.

I. INTRODUCTION

The high-speed tracks and heavy-freight tracks under construction in the Netherlands demand a more powerful traction supply than the existing 1500 Volts d.c.-system. In order to harmonize with other European countries, a 25 kV/50 Hz supply is introduced, first on “Betuweroute”, the dedicated heavy freight line connecting Rotterdam Harbour with Germany. Another example is the High Speed Line South (“HSL-Zuid”) connecting Amsterdam to Brussels and Paris. In the densely populated country the railway systems preferably share corridors with other infrastructure. However, the coupling between the 25 kV supply and neighbouring systems should then be carefully considered, and indeed a large number of model studies have been carried out, which resulted in EMC measures already implemented in the design. To validate the models and to prove the effect of the measures, extended full-scale measurements with typical load currents are preferred. However, a more flexible and less expensive method is sought to start with.

In this contribution we present the first results of a test method, which has not often been used in large extended networks such as the rail environment: injection of a current at a single but very stable frequency, and synchronous detection by a lock-in detector of the resulting current and voltage distribution in the railway network or other systems in its environment. The advantages of the method are many. The sensitivity is high, since the detection bandwidth of the lock-in can be reduced to the order of or even smaller than 0.1 Hz. The frequency can be selected close to the power frequency, but slightly different to fall in a region where little interference occurs from other circuits. The injection current amplitude may be small, such that the measurements do not interfere with the normal operation of the equipment. Finally, if appropriate sensors are chosen, the experiments can be performed online without interruption of normal train traffic.

We present measurements of propagation of an alternating current in a d.c. powered railway track. The immediate motive for this experiment came from other investigations. One of the train detection systems operates at 75 Hz, and has proved to be sensitive to a certain extent to 50 Hz interference. In the actual situation, the a.c. source may be the a.c. powered railway system, such as the high-speed or heavy-freight track mentioned before. The coupling occurs directly via the rails at a junction, or by means of induction or through a common ground connection.

II. MEASUREMENT SETUP

To test the method in a railway environment, we arranged for measurements at an isolated railway track near Leusden. A single non-electrified freight track ran from a shunting yard to a local industry park; see Fig. 1. After the park the rails continued for several hundred meters. No train detection systems were installed to the right of the industry park. Consequently a low-resistance connection between the rails and the ground was allowed there.

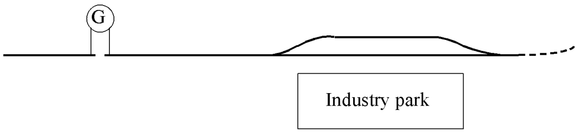

Fig. 1 – Schematic representation of the Leusden track. The dashed part leads to the shunting yard.

A 60 Hz sinewave oscillator with frequency accuracy and stability of the order of 10^{-7} and a power amplifier (G in Fig. 1) delivered a current of up to 2 A. The current was injected into both rails in parallel at an rail insulation point between two sections. The dead-end extension of the track (to the left of G in Fig. 1) served as ground electrode. The current through the rails to the right of G was determined at various positions up to 1200 meter in the direction of the industry park. We employed two nearly identical, commercially available Rogowski coils, one around each rail. The mutual inductance M of the coils with respect to the rail is 0.33 μH. Both coils were connected in series; the thus summed output was proportional to the algebraic sum of the current through both rails. A low-pass filter mounted in the wall of the EMC cabinet containing the lock-in amplifier, limited the signal bandwidth to about 5 kHz. An identical second sinewave oscillator provided the reference frequency for the lock-in. This allowed sufficiently accurate current amplitude measurements, because the possible difference in frequency fell well within the lock-in bandwidth. However, the relative phase of both oscillators might vary by up to several tens of degrees during the time of the measurements. So we refrained from absolute phase determination in these experiments.

The measurements in Leusden proved the setup had the required sensitivity and selectivity with respect to omnipresent power frequency interference. The second experiment was carried out at a track where train detection systems were installed, the location O10 near the city of Elst. There the Betuweroute will cross a d.c. powered North-South track. The situation of the site for the O10-measurement is depicted in Fig. 2. The power amplifier was connected between one rail of the d.c. system and a steel sheet piling belonging to a bridge for a road crossing the d.c. track. The closed loop for the injected current of 1 up to 4 A was formed by the rail, and continued into both tracks A, B via the interconnection at L2. At L0 a rail insulation prevented current to the North. As in Leusden, the current left the rails by its distributed contact with the soil.

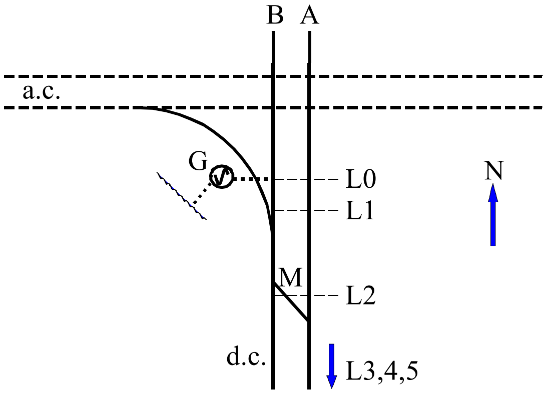

Fig. 2 – Sketch of setup of the North-South d.c.-tracks crossing the a.c.-track.

Since the Rogowski coils were connected in series, the signal due to the opposite phase current for the train detection systems cancelled to a large extent. Nevertheless, the frequency for the injection current was selected to minimize the interference by the two different train detection systems at the O10 site. One system operated with a nearly sinusoidal 75 Hz current, the other employed a pulsed voltage of about 1 μs rise time and a repetition frequency of 10 ± 0.2 Hz. We found a minimum residual current and noise level through the rails at 64 Hz. During the measurements all train detection systems remained in function, except the pulsed system for the section of the track where the current was injected. This minimized the time needed to convert from and to normal train traffic. The measurements were carried out between 3.00 and 6.00 o'clock during an interdiction. Although the phase of the current over the 4 km distance could not be determined, the relative phase of the track currents at each location could be established quite well, which allowed vectorial addition of the track currents.

III. RESULTS

The upper curve in Fig. 3 shows the current amplitude as function of the position for the first Leusden measurement. The injected 60 Hz current was 2 A. A least-square fit to the data [1] resulted in a 1/e distance of 0.48 ± 0.1 km. The uncertainty mentioned here and the error bars shown in the Figure will be discussed in Sect. IV. Note that the simple fit with a single exponential assumes that the series impedance and the parallel conductance to ground are constant over the considered length of the track. The faster than average decay found in the experimental data at distances below 30 m indicated that this was only approximately true. A search for parallel conductors in the soil over this part of the track was inconclusive.

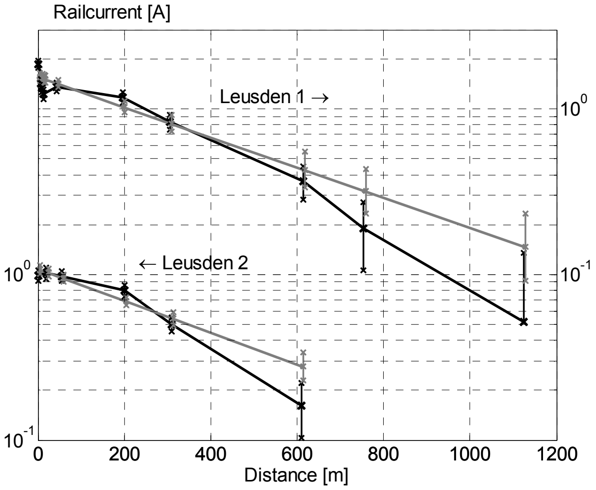

Fig. 3 – Current summed for both rails measured in Leusden.

The measurements were repeated two months later with an injected current of 1 A. The data in the fit are given by the lower curve in Fig. 3. The 1/e distance derived from the fit was 0.45 ± 0.08 km, which agrees well with the previous result. The initial faster decay was not reproduced in these measurements.

At O10 we injected 4 A at 64 Hz, and measured the currents through the parallel tracks at six positions L0 up to L5 (see Fig. 2) distributed over 4 km of the track, where it was accessible with our measuring equipment in the three hours available for taking data. The data are summarized in Table I.

Table I – Current distribution at O10

Location	*Distance (m)*	*Current amplitude (A)*		
		Track "A"	*Track "B"*	*Link "M"*
L0	0	0.0	4.09	--
L1	100	0.0	2.08	--
L2	437	0.0	1.45	0.22
L3	2320	0.34	1.21	--
L4	3130	0.42	0.40	--
L5	4260	0.38	0.38	--

In view of the frequency stability of the sinewave oscillators, the relative phase shift over the half hour measuring time at each location can be neglected. Figure 4 shown the total current at each location, obtained by vectorially adding the currents through the tracks.

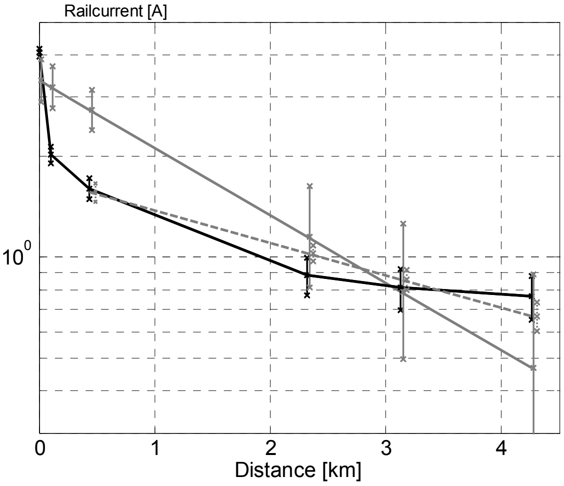

Fig. 4 – Sum of the currents through the tracks as a function of distance in the O10 experiment.

A fit to all data (solid line) results in a 1/e distance of 2.2 ± 0.7 km. Here again, the experimental data show a faster than average decay over the first 0.5 km from the current source G. But, contrary to the Leusden case, a large number of parallel current paths was present here, such as the bend, the steel sheet piling and the bridge itself, as well as other constructions. The 'less perturbed' track starts then at 0.5 km. A fit to these data only (dashed line) corresponds to a 1/e distance twice as large: 4.4 ± 0.7 km. Over the last 2 kilometers of the investigated track the current decay is small, if any occurs at all within the given accuracy. As a tentative explanation, in addition to a possible lower admittance of the rails towards ground, we mention that the track over the last 2 km runs over a dike towards an elevated bridge crossing the river de Waal near the city Nijmegen. The dike may also increase the resistance of the current path through ground.

The inverse of the 1/e distance α can be expressed in the series impedance Z'_s and the admittance Y'_p to the ground:

$$\alpha = \mathrm{Re}\sqrt{Z'_s\, Y'_p} \qquad (1)$$

The primes indicated that the quantities are assumed per meter. We approximate Y'_p by the measured d.c. conductance to ground corresponding to 0.2 S/km. Using the value for Z'_s given in [4], we obtain an 1/e distance of 3.9 km for the O10 measurement. This is in good agreement with the value actually observed averaging over the data of the last 2 km. No reliable value of Y'_p was available for Leusden.

IV. ACCURACY CONSIDERATIONS

The unshielded Rogowski coils used for the measurements were selected because the coils could be mounted around the rails and dismounted in a short time, and because of the stability of the sensitivity M. The coils had a rather high resistance. Any voltage between the coil and the rail causes a current I_c through the capacitance C_p between the coil windings and rail. If C_p is evenly distributed over the length of the coil, the current I_c effectively flows through half of the coil impedance $Z = R + j\omega L$ towards the cable shield; here R is the resistance of the coil and L its self-inductance. As a result a disturbing voltage $V_d = ½ZI_c$ appears at the input of the signal cable, which cannot be discriminated anymore from the actual signal corresponding to the current I_p to be measured. In dry conditions, the capacitance between the coil and the rail is 30 pF, and the influence of the possible parallel leakage resistance can be neglected. The coil has an internal resistance $R \approx 65\ \Omega$. The voltages between rail and coil have been measured separately. From these data we derived worst-case values for V_d of 10 μV for Leusden and 15 μV for the O10-measurement. These margins should be compared to the signal voltage of 120 μV corresponding to a 60 Hz current of 1 A through a single coil. The error margins shown in Fig. 3 and 4 correspond to the worst case values mentioned. The stated errors in the decay lengths have been calculated from the errors in the experimental current data by standard error propagation theory.

V. DISCUSSION

The measurements indicate that once a power frequency current enters the d.c. track, its influence may extend over considerable distances, in particular for tracks as O10 with small conductance to ground. This necessitates careful consideration of the influence of that current on the train detection system. It is difficult to rely on a transmission line model only. Such an analysis would require input data as the local conductivity to ground, which may vary rapidly over the track, and which will depend on weather conditions. The measurements proposed and demonstrated in this contribution are quickly performed, and require only limited personnel. Further advantages of the method are:

- the control and 1500 V power supply systems can remain operational, which saves time,
- the injected currents are relatively small; the experiments do not present additional safety issues with respect to personnel,
- calculations of interference can be validated before the completion of the 25 kV system.

For rail-current measurement a different types of sensors have been developed in the past [5], which allowed the train wheels to pass. The sensors have been mounted and used over a prolonged period in another measurement campaign. The proper resistance of these sensors is two orders of magnitude smaller than the Rogowski coils used in this investigation, which would have improved the accuracy of the current measurement. However, the accuracy attained here sufficed to answer the questions that lead to these measurements. In addition, a longer preparation time than available here would have been needed.

In other experiments we used a similar current injection system, and applied it to a 10 kV medium voltage power distribution grid in a city. These measurements were carried out in cooperation with the power distribution company NUON. The oscillators were frequency controlled such that the frequency stability increased to one part to 10^9. The phase difference between the injected current and local current/voltage could be reliably measured over an extended period, up to the order of a day. This phase determination is a welcome additional test on models, which is usually limited to relative amplitudes.

VI. CONCLUSIONS

Current injection at about 60 Hz proved to be a reliable method to study the propagation of 50 Hz power frequency current in d.c. railway tracks. The measurements provide a necessary, although not complete basis for decisions on whether the train detection system present needs to be adapted or not. Other information needed is for instance the sensitivity of the equipment concerned, or the actual a.c. amplitude. The interpretation of the 1/e distance and the application of the results to other locations requires utmost care, in view of the number of assumptions made. We earlier mentioned the constant series impedance and parallel conductance. The amplitude of the current injected here, is of the order of what could be expected. But additional d.c. through the rails, or different a.c. amplitude may change the 1/e distance as well.

ACKNOWLEDGEMENT

This investigation has been carried out by order of Holland Railconsult. The authors thank dr. ir. B. Gravendeel, ir. J.A. Minkman, ing. J.H.N. Barelds of Project Organisation Betuweroute , ir. E.J. van Rees and ing. H. Velgersdijk of Holland Railconsult, ir. R. Koopal of Arcadis. The technical assistance of ing. T. Ras and P. Hamelink, both at AEA Technology, during the measurements is greatly appreciated.

REFERENCES

[1] Bevington, P.R. and D.K. Robinson, *"Data reduction and error analysis for the physical sciences"*, 2nd ed., McGraw-Hill, London, 1992.

[2] W. Koch, *"Erdungen in wechselstromanlagen ueber 1 kV"*, zweite Auflage, Springer-Verlag, Berlin, 1955.

[3] J.B.M. van Waes, *"Safety and EMC-aspects of grounding: experimental studies in high-power systems"*, PhD Thesis, Eindhoven, 2003.

[4] R.J. Hill, D.C. Carpenter, "Rail Track Distributed Transmission Line Impedance and Admittance: Theoretical Modeling and Experimental Results", *IEEE Tr. Vehicular Technology*, Vol. 42, pp. 225 – 241, 1993.

[5] Van Deursen, A.P.J., H.W.M. Smulders, R.A.A. de Graaff, and J.B.M. van Waes, "Characterization of AT railway traction power supply, measurement system and results", *Proc. Internat. Symposium on Electromagnetic Compatibility EMC'04*, June 1 - 4, 2004, Sendai, Japan, pp. 469 - 472.