

## PEACEFUL COEXISTENCE BETWEEN A.C. AND D.C. SYSTEMS

H.W.M. Smulders<sup>1</sup>, R. Koopal<sup>2</sup>.

<sup>1</sup> Movares. Utrecht. The Netherlands

<sup>2</sup> Prorail. Utrecht . The Netherlands

\*Contact: erwin.smulders@movares.nl\*

### Abstract

In The Netherlands a densely populated country, due to reasons of available space it is necessary to bundle infrastructure as much as possible. Therefore the new High Speed Line (50 Hz a.c. system) runs in parallel with the conventional line (1.5 kV d.c. system) over a length of approximately 20 km with a minimal distance (11 m). This causes an inductive and galvanic coupling between both systems. This lead to limitations in the use of the a.c. system. In order to increase capacity and make the system attractive to customers, the compatibility issue had to be addressed. As a result this can lead to a.c. voltages and currents in the d.c. system, which can have a negative influence on the correct functioning of the railway system. Some aspects:

- Step and touch voltages (safety of human beings!);
- a.c. currents in the d.c. running rails, which can have a negative influence on the correct functioning of track circuits;
- a.c. voltage between catenary an running rails, which can have a negative influence on the correct functioning of d.c. rolling stock;
- a.c. currents through d.c. substations, which can lead to the generation of harmonics (modulation with harmonics produced by rolling stock);
- a.c. currents through d.c. rolling stock, leading to a higher production of interference currents by the d.c. rolling stock;
- d.c. current in a.c. transformers.

In the last years, ProRail, the Dutch Infrastructure Manager has run an extensive program, consisting of studies, simulations and measurements in order to prove that compatibility between both systems is possible. In order to reach this compatibility mitigating measures were implemented in both the a.c. as well as in the d.c. system. Also the majority of rolling stock present in the d.c. system was tested with respect to its behaviour, when an a.c. voltage is added. A safety case has been drawn up, especially to address the compatibility issue. At the moment the safety case has been accepted. New regulations for rolling stock as well as infrastructure must ensure that the compatibility created remains intact in the future. It can thus be proven that using a well organised approach peaceful coexistence is possible, but is not easy to reach.

### 1. Introduction

The High Speed Line South, which connects Amsterdam with Brussels and Paris, consists of two parts which are equipped with a 2 x 25 kV/ 50 Hz traction power supply system. The northern part which runs from Hoofddorp to Rotterdam runs in parallel with the conventional line Schiphol – Leiden for approximately 5 km from Hoofddorp to Nieuw-Vennep. The southern part which runs from Barendrecht to the Belgian border runs in parallel with the conventional line Rotterdam - Breda for approximately 20 km from Lage Zwaluwe to Breda.

Due to the intense parallelism (see Figure 1) a significant EM coupling between the grounded a.c. system and the floating d.c. system exists, which leads to a.c. voltages and currents in the d.c. system. After the initial start of traffic on the line, which consumed a limited amount of energy, mitigating measures had to be taken in order to ensure the correct functioning of the conventional line when the high speed line is operating at full power.



Figure 1 High Speed Line South, construction phase

## 2. Strategy

After taking initial measures in the d.c. system in the period 2005-2006 [1] the high speed line could be used for 2 x 1 kA loads in one AT-section, but due to remaining risks for the d.c. system the load had to be limited to 2 x 0,5 kA. Remaining risks identified were:

- Step & Touch Voltages;
- Track circuits, 75 Hz, mono-rail and bi-rail (common mode voltage and current in rails);
- a.c. voltage imposed on d.c. rolling stock (between catenary and rails);
- a.c. current flowing through d.c. substations;
- EBS (Electronic Control System, interlocking).

The strategy used was to take as much mitigating measures in the a.c. system as possible, as this is useful for a number of victims in the d.c. system. As a secondary step measures were taken in the d.c. system. Finally an attempt was made to minimise the galvanic coupling.

## 3. Mitigating Measures

### 3.1 Traction Power Supply (TPS) system of High-Speed Line

As the influence of a.c. system is less when the load is less severe in an AT-section adjacent to the d.c. system, to reduce the length of the AT-sections where the intense parallelism occurs, this is a powerful tool to control the influence. In the northern section 1 AT-post was added, in the southern section 3 AT-posts were added, see Figures 2 & 3. New AT-posts are indicated in yellow. Red indicates the a.c. system, blue the d.c. system. North is on the right hand side of the graphs.

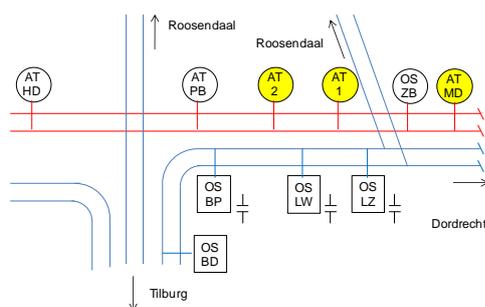


Figure 2 Southern section HSL-South

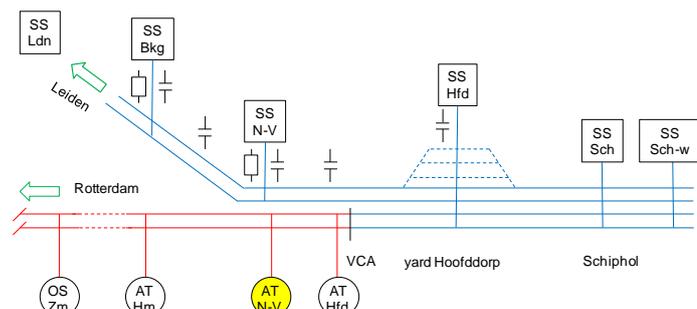


Figure 3 Northern section HSL-South

Due to the adding of AT-posts, the short-circuit current increases, and is no longer in line with TSI requirements. Therefore in substation “Zoetermeer” as well as in substation “Zevenbergschen Hoek” limiting reactors were installed at the 150 kV side of the traction transformer. A further issue is short circuits in the a.c. system. In this case currents are thus high that influence on track circuits in the d.c. system is likely. However due to mechanical inertia, the track relay is not influenced in case the excitation is 100 ms or less. After some modifications in the protection relays of the TPS this could be realised.

### 3.2 Track circuits

In The Netherland 75 Hz GRS track circuits both mono-rail as well as bi-rail are commonly used. These track circuits are integrated with the ATP-system (ATB-EG). The current is LF modulated, 75 to 270 pulses per minute indicating different speeds allowed. Therefore changing track circuits would also mean that the ATP system has to be changed, leading to expensive modifications in rolling stock. This lead to the decision to retain the GRS track circuits. As mono-rail GRS track circuits are much more susceptible to 50 Hz common mode currents and common mode voltages, whereas bi-rail GRS track circuits are only susceptible to 50 Hz common mode currents at a much higher level, it was decided to remove the mono-rail types. Where the conventional line runs in parallel, all mono-rail types where replaced with bi-rail types. This was also done for branch lines, until the first substation on the branch line. For mono-rail track circuits at a larger distance, where the influence of 50 Hz does not lead to safety related issues, but only to more wear, a more restrictive maintenance interval was imposed.

### 3.3 Step & Touch Voltages

In the situation where no mitigating measures were taken the worst-case touch and step voltage which could occur in the d.c system was approximately 70 V per 1 kA consumed in the a.c. system. As the a.c. system is designed for 1 kA per train, it is clear that the limits as imposed by [2] will be surpassed in the system when the a.c. system is at full operational load.

Apart from reducing the length of AT-sections as mentioned before, earthing of the running rails of the d.c. system is an effective way to reduce voltage, however this is in contrast of the requirements imposed by [3]. Therefore it was decided to earth the rails of the d.c. system using capacitor banks [4]. A capacitor bank consists of 2 units each 24 mF connected to a 0,25  $\Omega$  earthing facilities. In total at 5 locations on the Northern section and 6 locations on the Southern sections capacitor banks were placed, also see Figures 2 & 3. The effect of the mitigating measures can be seen in Figures 4 & 5. Combined voltages are given per 200 m section.

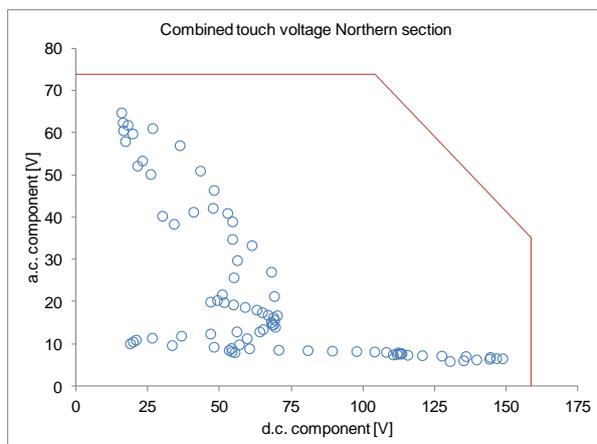


Figure 4 Northern section HSL-South

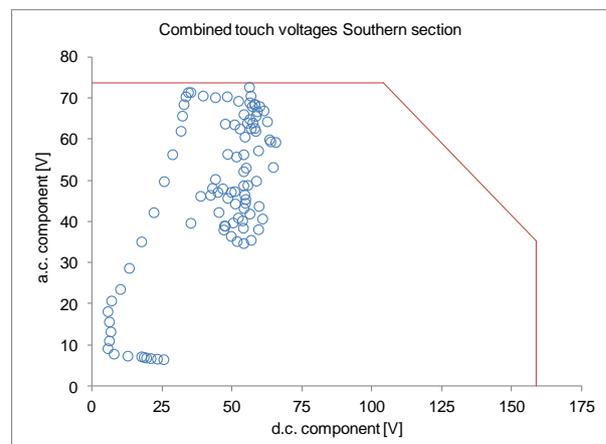


Figure 5 Southern section HSL-South

The voltages in the a.c. and d.c. system have been determined using simulations. As the worst-case, the crossing of two trains in the middle of an AT-section at maximum speed, takes only 22 s, slightly higher values than for the permanent case (120 V d.c. & 60 V a.c. can be used. As it can be seen from Figures 4 & 5 compliance with [5] has been reached.

It should be noted that capacitor banks can only be placed at the location of d.c. substations, otherwise the 50 Hz voltage between catenary and rolling stock ("Thevenin equivalent") would increase. When positioned at a substation location this is not the case as the 50 Hz internal impedance of the substation is then in parallel to the internal impedance of the rolling stock.

### **3.4 EBS**

Analysis showed that EBS (Elektronische Beveiliging SIMIS, an interlocking system) could be influenced (by a short dip of the track circuits) in a negative way by a short-circuit in the a.c. system, leading to possible wrong side failures. By studies it could be proven that a replacement of the TRPR relay by a TPR relay the risk could be mitigated. Hence this measure was taken.

### **3.5 Coupling path**

Galvanic coupling through "Mother Earth" is an important source of influence, which should be avoided. However the a.c. system has to be earthed in accordance with [2]. Thus the only option to minimise this coupling path is to insulate the d.c. system as well as possible from earth. It is customary to use VLD's, type F, to connect the catenary support structures to the running rails in the d.c. system. In case a VLD fails, most commonly due to lightning or a short circuit in the a.c. system, this leads to a partial earthing of the rails. As solution a type of VLD-F was chosen which can withstand the voltages coupled in due to a short circuit in the a.c. system, and a more restrictive maintenance regime has been implemented. Furthermore a special set of design rules has been drawn up to avoid galvanic coupling between the return circuits of the a.c. and the d.c. system [6].

## **4. Rolling Stock**

Initially during the study phase the important issue of the influence of 50 Hz currents induced in rolling stock was underestimated. A 50 Hz current flowing through rolling stock can be modulated with already existing frequencies, which could lead to difficulties within the traction installation or with auxiliary power supply. Thus tests have been performed on the Wildenrath test site, where a 25 V, 50 V or 75 V was superimposed on the 1.5 kV d.c. voltage. The main problems encountered were related to control systems:

- An EMU with a GTO traction installation equipped with an active interference current compensation system caused a 75 Hz interference current. The active impedance tries to compensate both the external 50 Hz current and an internal current;
- An active impedance present in an auxiliary power converter caused several harmonics, among them some which were close to 75 Hz, by the combination of the internal 317 Hz, the 300 Hz d.c. ripple and the superimposed 50 Hz;
- The superimposed 50 Hz was repeatedly able to push the traction installation over the control limits of the automatic regulation curve [7] thereby causing reduction or interruption of traction power. This causes transients and the related interference current similar to an interruption or start-up.

As a result the planned retrofit of the VIRM-1 class train has been advanced, the GTO traction installation has been replaced by an IBGT type. Other possible disturbance mechanisms were within the susceptibility limits of the upgraded train detection layer as long as the superimposed 50 Hz voltage remains smaller than 50 V.

## 5. Substations d.c. system

An problem anticipated was the modulation of a 50 Hz interference current with a 25 Hz or 125 Hz current produced by rolling stock under the right condition in a d.c substation, causing 75 Hz currents. To tackle this problem MeMo (Modulation Monitoring) systems, providing additional protection have been placed in the d.c. substations along the HSL-Zuid.

However measurements quickly showed that the most severe interference currents where not caused by 50 Hz related phenomena. Normally the cause was defects in rolling stock still undetected. The amount of occurrences of this phenomena have led to the decision to implement the MeMo systems at a larger number of locations, not related to the HSL-Zuid parallelism.

## 6. Simulations & Testing

The initial design was checked by simulations (special model in ATP) by Arcadis. The final design was also checked simulation by Movares, using SimspoG. Simulation results were checked by extensive measurements. For the measurements two types of load were used. Either a generator-transformer combination at the a.c. substation, and a short-circuit between catenary and the running rails to simulate a load [1], or rolling stock. An example of the latter can be found in Figure 6. Two trains, each consisting of a pair of Thalys are moving simultaneously in one direction, thus providing a 2 kA load. The measurements corroborated the simulation results.



Figure 6 Pair of double Thalys moving south at 300 km/h

## 7. Safety Case

The Safety Case was drawn up based on the simulations and measurements and consists of four parts, see Figure 7.

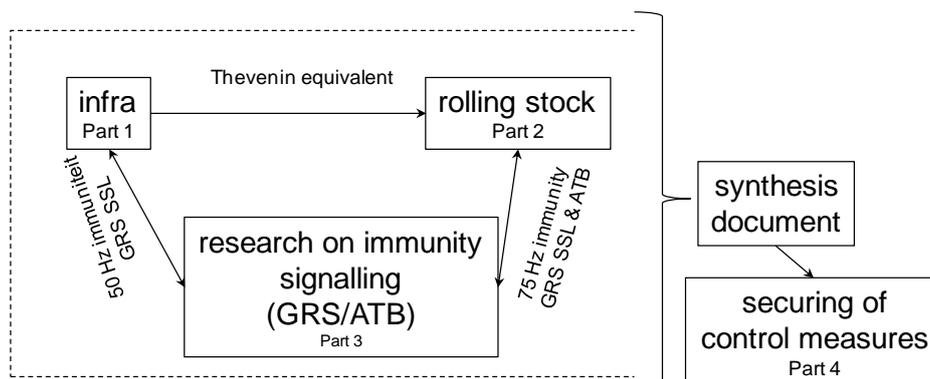


Figure 7 Overview of Safety Case

Part 1 gives an overview of measures taken in the fixed installations to ensure compatibility, and uses the detailed information of part 3 on the immunity of signalling systems. The results on 50 Hz voltage impressed on rolling stock are used in part 2 to prove that the harmonics produced by rolling stock

remains within limits. A synthesis document lists all results and draws the conclusion that all remaining risks were mitigated sufficiently. Finally it was ascertained that the control measures taken are maintained and remain in place in part 4.

After careful reviewing of all documents by several independent ProRail experts in the fields of Traction Power Supply, Signalling and Telecoms, the safety case was submitted for final validation, which was obtained successfully. This marked the start of the full operational use of the line.

## **8. Conclusions**

A well structured approach using simulations, validated by measurements has proven to be successful. Especially the presence of legacy system at the d.c. side, of which the immunity and behaviour under the influence of 50 Hz was not well known provided the taskforce with challenges. It was necessary to add 1 AT-post in the Northern section, and 3 AT-posts in the Southern section. In addition, 5 capacitor banks were placed in d.c. system parallel to the Northern section, and 6 capacitor banks were placed in d.c. system parallel to the Southern section. Mono-rail track circuits were replaced by bi-rail track circuits. Measures were taken with respect to EBS and VLD-F's used in the d.c. system. The VIRM-1 series of rolling stock had to be modified. Thus a safe environment for human beings, fixed installations and rolling stock was created. Main conclusion is that peaceful coexistence between a.c. and d.c. systems is possible, but is not easy to reach in case of the extreme parallelism which is present in the case of the High Speed Line South in The Netherlands.

## **9. References**

- [1] Waes, J.B.M. van, Janssen, M.F.P., Smulders, H.W.M., Oostveen, J.P., "EMC aspects of voltage changeover areas", WCRR 2008, Seoul, Korea.
- [2] 50122-1 "Railway applications – Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock", Cenelec, Brussels, 2011.
- [3] 50122-2 "Railway applications – Fixed installations - Electrical safety, earthing and the return circuit - Part 2: Provisions against the effects of stray currents caused by d.c. traction systems", Cenelec, Brussels, 2010.
- [4] Koopal, R., Evertz, E., "50 Hz track circuits parallel to a 25 kV 50 Hz railway line", WCRR 2008, Seoul, Korea.
- [5] 50122-3 "Railway applications – Fixed installations - Electrical safety, earthing and the return circuit - Part 3: Mutual Interaction of a.c. and d.c. traction systems", Cenelec, Brussels, 2010.
- [6] ProRail, Ontwerpvoorschrift "Maatregelen Parallelloop voor bestaande railinfra met 25 kV railinfra van de HSL-Zuid en de Betuweroute", version 4, d.d. 01-10-2015 (in Dutch).
- [7] 50388, "Railway Applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability" Cenelec, Brussels, 2012.

## **Acknowledgements**

The authors would like to express their gratitude to the members of the BB21 team of ProRail under the leadership of Roelof Pieters, who were responsible for much of the ground laying work for this project. Also they would like to thank all the members of the HSL-Zuid Taskforce for the excellent cooperation, in particular the leaders, Ruud Wieringa, Gerard Willemsen and Mario Piekhaar.