OVERVIEW OF THE INTRODUCTION OF A NEW TRACTION POWER SUPPLY SYSTEM IN THE NETHERLANDS

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Abstract: In the last decade the Netherlands have been working on the introduction of a new traction power supply system. In this paper an overview is given of the activities which have been undertaken to study the behaviour of this "new" system and draw up the requirements for a generic system design.

Key words: traction power supply, simulation, measurements, emc, signalling

1. Introduction

During the last decade the railway community in the Netherlands has been working on the introduction of the 25 kV/50 Hz traction power supply system. Planning for high-speed lines and heavy freight lines, the demand for a more powerful traction power supply system, in comparison to the existing 1500 Volt DC traction power supply system, arose. As a railway system is a rather complex composition of a large number of sub-systems, each performing its specific function in the total of the infrastructure, a special development programme was started. Final goal was to create a “library of specifications” describing a generic system design combined with design rules on implementing these specifications. The “complete” system had to be covered. Electro Magnetic Compatibility between all sub-systems should be reached, as well as with respect to third parties. European tendering of infrastructure projects is facilitated by the use of this “design library”, minimising possible interface problems.

To provide a solid scientific basis for the specifications several theoretical studies have been performed on for instance load-flow and asymmetrical load of the 3-phase grid, touch- and step-voltages, disturbance of cable-communications, possible influence to third parties, etc. Contributions to these studies have been made by Holland Railconsult as well as by several other engineering companies through-out the whole of Europe.

Multiple papers, on the work done, already have been published in periodicals and on international conferences [1,2,3,4,5]. In this paper an overview of the techniques used during the course of the project is given.

2. Systems engineering

The Netherlands too will be using a traction power supply system based on 25 kV/50 Hz in the future. At least on two new lines, The Havenpoortlijn (“Betuweroute”, Rotterdam harbour to the German border) and the High Speed Line South (Amsterdam-Rotterdam-Belgium). At a later date probably the High Speed Line East (Amsterdam-Utrecht-Arnhem-Germany) as well as the main network will be electrified using 25 kV. This means that at regular intervals European Tenders will be held for the electrification of a railway track, both for modifications as well as for new lines.

2.1 Generic design

Experience from the repeated design and building of traction power supply systems in the past has made it clear that project independent partial designs, standard component specifications, and a standard design process do exist. These are the generic requirements, design rules, and interface descriptions between subsystems or between different disciplines.

This generic design set has the following benefits:

- A design which can be put out to contract per discipline to European Contractors;
- Electromagnetic Compatibility between the design and it’s environment;
- Standardisation of installation parts and components (as much off the shelf as possible);
- A standard lay-out of the buildings belonging to railway system (such as sub-, autotransformer- and switching stations);
- Limited education and training demands for staff and other personnel;
- A system to which a new functionality can be added easily.

Normally the top-level requirements for a new system are well known. More difficult and incomplete it is known how the new system has to function in relation to existing organisations for management and maintenance of the existing railway system. These implicit wishes and demands will become more clear after the realisation of a number of projects. At that moment these implicit wishes and
demands can be transformed into explicit demands, if needed with small changes in the organisation responsible for the system.

2.2 Systems Engineering Approach

The challenge is to describe the complete railway infrastructure in generic requirements, generic design rules and generic solutions. In this process, such a large number of documents are written, that indeed a complete generic library is created. The specifications have been based on general requirements and modes of operation imposed by the outside world –external requirements- as well as on the demands arising out of a specific railway system related field of interest –the internal requirements-.

In general all requirements imposed on a component are related to a higher requirement, until the highest requirements, the Top Level Requirements, have been reached. The Top Level Requirements are independent. A consistent set of requirements, which tends to be complete, has been achieved by the use of Systems Engineering Approach Method.

While tracing backwards from the existing demands to the Top Level Requirements, is becomes clear that the demands from the management, maintenance and control organisation have not been laid down unambiguously. For the correct specification of a technical system, it is necessary that all external demands are clear and transparent. This means that all implicit demands and wishes have to be transformed in explicit requirements.

![Diagram of railway system]

Figure 1 - Overview external system demands

3. Simulation

The nature of the AC system demands a thorough analysis with respect to all aspects being related to reaching EMC. Earth return currents, generation of electromagnetic fields and common mode currents on cable screens determine the electromagnetic compatibility with other railway systems, third parties and human beings.

Caused by the nature of the railway-system a series of equations describing the multiconductor transmission line system has to be solved to obtain these distributions. To solve these equations SimspoG was developed.

Being a system of n inductive coupled conductors, the equations of Carson-Pollaczeek can be used to evaluate the self and mutual impedances of the conductors within the traction power supply system.

Of course these impedance components only give the possibility to evaluate the typical impedance of a given conductor configuration. Therefore, while analysing the system, it is useful to calculate the current distribution within the power supply system as function of, for example,

- Load position;
- Supply system type;
- Rail to earth conductance;
- Local conductor geometry.

The general equation describing the supply system can written as:

$$\begin{bmatrix} U' \\ I' \end{bmatrix} = A \begin{bmatrix} U'' \\ I'' \end{bmatrix} \tag{1}$$

In this equation a relation between voltage and current on both ends of the system is given.

![Diagram of system sectioning]

Figure 2 - System sectioning

Taking as example the simple system shown in figure 2, this system can be written as:

$$A = A_{ct} * A_{trans} * A_{ct} * A_{tt} \tag{2}$$

Multiplying the individual transfer functions gives the overall transfer function of the system under study. Each of the individual transfer functions gives a relationship between the voltages and currents on both sides of the section concerned.

After solving eqn 3, using the applicable boundary conditions, the values of $U'$, $I'$, $U''$ and $I''$ are found and the voltages and currents on each border section can be calculated by multiplying, for example

$$\begin{bmatrix} U'_{tt} \\ I'_{tt} \end{bmatrix} = A_{tt} * \begin{bmatrix} U'' \\ I'' \end{bmatrix} \tag{3}$$

So consequently carrying out this exercise finally $U'$ and $I'$ must be found.

Up till now the SimspoG simulation tool has been used for several types of engineering studies:

- Selecting of power supply system with respect to, for example, common mode currents on cable screens;
- Determining the lay-out of earthing systems with respect to touch- and step-voltages;
- Calculating traction return current distribution in tunnels;
- Applicability and effectiveness of resonance bonds in a system separation section;
- Modelling track-circuits with respect to earthing system design and broken rail detection.

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The simulation tool SimspoG has been extended with several components in order to increase its flexibility and usability. One of the most important items is the capacitive coupling between all conductors. This is required when frequencies above 50 Hz need to be studied.

3.1 Example

SimspoG has been used also to perform simulations on track circuits. The key issue in these simulations was broken rail detection. Because of the cross bonds and other connections in the earthing and traction return system, track circuit current can take an alternative route in case of a broken rail. As a result, broken rail cannot be detected.

A model has been made to perform simulations on these circuits. The model contains the joints, the impedance bonds and the track circuit transmitter and receiver that are present in the track as shown in figure 3.

![Figure 3 - Single-track return-circuit with impedance bonds](image)

A broken rail can be modelled and the influence of parameters like:
- number of track circuits between the connections with the earthing system,
- length of the track circuit (in this example 500m),
- number of parallel tracks,
- location of the broken rail,

can be evaluated. The figure shows the results of a simulation with a broken rail.

![Figure 4 - Current distribution in the return-circuit](image)

4. Measurements

Based on the specifications a 14-km long test line has been built on the “Havenspoorlijn”, the first part of the heavy freight line “Betuweroute”, from Rotterdam to Germany. Under the direction of Holland Railconsult a measurement program has been prepared and carried out to check the behaviour of the 25 kV system as built. Approximately 800 parameters have been measured under several conditions.

A major problem related with measurements in the close vicinity of a railway system is the harsh Electro-magnetic environment. Combined with the need for a large bandwidth (50 Hz – 9 kHz), a good sensitivity, and the need to measure at a 25 kV level, this poses a challenge to the measurement systems to be used. Starting from the differentiating/integrating-measurement principle developed by the Eindhoven University of Technology, the necessary equipment for measurements in a railway-system has been developed in close co-operation between both partners.

Using the already available equipment at the Eindhoven University of Technology, preliminary measurements on the Luxembourg 2x25 kV North Line have been performed in 1998 to prove the usefulness of the D/I-principle in a railway-environment.

Implementing the experience gained during measurements in Luxembourg, a special set of sensors and integrators was developed, custom made for the railway environment. Combined with “conventional” equipment such as E- and H-field antennas and a spectrum analyser, this makes it possible to determine the complete EM behaviour of a railway system, fingerprinting it completely.

4.1 The Differentiating/Integrating-principle

The developed measurement systems rely on the D/I-principle, as mentioned before. The differentiating sensor emphasises the high frequency components of the signal sent into the cable. In the EMC-cabinet the signal is integrated, thus restoring the original signal and reducing the high frequency interference coupled in along the measurement cable. This is of great benefit, especially in the railway-environment where the distance between sensor and EMC-cabinet is usually quite long.

![Figure 5 - D/I-system set-up with EMC Cabinet](image)

The EMC-cabinet, housing the 230 V mains filter, the integrators and filters, is bonded to the local ground, and forms a blockade with respect to
common mode currents and disturbing HF EM-fields for the sensitive measurement equipment. The main advantage of this EMC cabinet is that in harsh EM-environments, such as close to a railway track, reliable measurements are possible, even when using "standard" EM-sensitive measurement equipment, like fast digital oscilloscopes. A further advantage is the large bandwidth of the measurement system. Depending on the type of sensor, a bandwidth of 1 Hz to 100 kHz, 1 MHz can be reached or even up to 100 MHz is possible.

4.2 Measurement Plane

The current distribution in a railway system, combined with step- & touch voltages is an important aspect of EMC studies. Therefore, in many field experiments, a “Measurement Plane” (figure 6) is created.

![Measurement Plane](image)

Figure 6 - Measurement Plane for current distribution studies

This is an imaginary plane, perpendicular to the railway track. All currents passing through this plane in actual conductors are measured. By vectorial adding of these currents the earth return current can be calculated (Kirchhoff's Current Law). By using several measurement planes along a railway system, the complete longitudinal current distribution of a railway system can be studied.

4.2 Field experiments

As already mentioned, experience with both AC-current measurements has been gained on the Luxembourg railway network. An example of the data gathered during these experiments are the traction harmonics of a Z2000 engine, a part of the results obtained in Kautenbach, Luxembourg.

![Z2000 emu line-current](image)

Figure 7 - Z2000 emu line-current

5. Conclusion

For the complete railway system, for all parts, specifications have been drawn up and validated. The interface descriptions have been written for each discipline. Interface descriptions along the contract/tender borders (when these are not identical to the discipline borders, as usually is the case) could also be useful, however due to the larger number of options this is not very practical, unless these options can be limited. Already the generic design library is in use for the design and the tendering of major projects. Thus the usefulness of the Systems Engineering Approach Method in the introduction of new technologies in the railway environment has been proven.

The SimspoG tool has shown it’s reliable application in the design process. After several years of development and testing, it has been used in multiple cases. Extensive measurements have shown the usefulness of the calculation results in practice.

The application of the D/L-measurement system on the first Dutch 25 kV line has shown that it’s design is EMC-sturdy and reliable. The flexibility of the system has been shown in field-measurements outside the Netherlands.

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References