Fault detection of Railway EMC problems using MATLAB models

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Abstract

The complexity of the railway system increases when more electronics are used. When dealing with railway infrastructure that has not been renewed over the last several years like in Sweden and with new trains equipped with significant electronic components, it can find itself in one of the most relevant railway problems: the intensive emergency stop can be brake triggered, causing prolonged delays with cascading effects. The reason is that the train control central (TCC) could find unexpected signals from the track due to transient electromagnetic fields that interfere in the train control system circuits.

In this paper a Matlab model of the power supply system of the Swedish railway infrastructure is proposed in which it is possible to integrate a train as an active load. The source of these transient electromagnetic (EM) fields is the engine which can be integrated in different position of the track to study the behaviour of the low frequency system from an electrical point of view. The output of the model can be used as an input for a design of an electromagnetic model in higher frequencies. After the design of the model, a measurement campaign in the north of Sweden to validate the model was carried out.

1. Introduction

These days more and more electronics is used in the railway system with the ultimate aim of improving the reliability, availability, maintainability and safety of the system. The increased use of electronics enables the system operators including the locomotive driver, control centre operators, maintenance crews, planning division to obtain the required data and information on the state and location of train, state of railway tracks, presence of maintenance activities on the track, and so on. As the safe and smooth operation of rolling stock depends upon various factors including the reliable functioning of electronics components and systems, there are possible adverse effects also. The signalling system may produce erroneous signal prompting the control and

command centre to fail. The electromagnetic emissions may interfere with each other resulting in erroneous outcome.
The rolling stock electromagnetic emissions are a major concern for train manufacturers and railway infrastructure operators [1] in Europe and elsewhere. Available harmonized electromagnetic compatibility (EMC) standards (EN50121-2 [2], EN50121-3-1 [3] and EN50121-3-2 [4]) do not completely address interoperability issues caused by rolling stock interferences with signalling systems (GSM-R, BTM, LTM and STM). Moreover, these standards do not cover representative worst-case conditions derived by transients in the rolling stock behaviour typically generated by feeding and track circuits' discontinuities.

This situation causes waste of time and resources for train manufacturers when integrating rolling stocks and signalling systems. And with tested trains in use, problems may still arise occasionally. Then, the technical solutions are not straight forward. The duration of the field testing employed to solve this kind of problems and to go through the certification process may vary between 3 months and 12 months costing between 25 k€ to 1,5 M€ [1]. Further, the railway infrastructure operators suffer the railway infrastructure availability reduction caused by the rolling stock electromagnetic incompatibility with the safety critical signalling systems and may cause an estimated reduction of 10% of the availability in the most crowded lines.

In this context, TREND (Test of Rolling Stock Electromagnetic Compatibility for cross-Domain Interoperability) project has been initiated with the objective of addressing this situation by means of the design of a test setup to enable the harmonization of freight and passengers rolling stock approval tests for EMC focusing not only on interferences with broadcasting services but also on railway signalling systems. It aims to identify and design the cross acceptance test sites on electrified and non-electrified lines that reproduce representative worst case conditions for steady state and transient behaviours. These worst case conditions will be obtained thanks to the modelling of the rolling stock and the rail and feeding infrastructure. The thorough analysis comprises measurement, modelling and safety and availability analysis of the effect of rolling stock's electromagnetic interferences (EMIs) on the neighbouring systems. The system potentially affected by these EMIs will be completely covered. These are classified in four research areas: spot signalling system (which includes BTM, LTM and STM), track circuit, GSM-R and broadcasting services (which include TV, radio, Freight RFID, WIFI and GSM). This complete physical environment will permit a precise analysis of the EMI coupling model affecting the whole communication systems. The successful design of a test procedure recreates representative worst-case for the rolling stock electromagnetic emissions that could affect interoperability including transient phenomena.

2. The complexity of EMC model in railway

Directive 2008/57/EC on the interoperability of the railway system within the European Community [5] defines the railway as a series of subsystems:

- Infrastructure
- Control command and signalling
- Power

- Rolling stock
- Operation and traffic management
- Maintenance
- Telematics.

However, the national railway system in every country consists of two physical parts; the mobile part (rolling stock, telematics) and the static part (infrastructure, control command and signalling and power). The mobile part can be further sub-divided into two categories defined by its power source; electric or non-electric. The electrically powered mobile part must comply with all the physical requirements of the non-electric mobile part e.g. gauge, loadings, platform height and so on but must also be compatible with the electrical systems. Unlike the physical aspects, the electrical aspects do not have an easily defined or constrained interface with the rest of the world and hence they are potentially more difficult to assess.

There are three potential modes of interaction between all electrical systems; these are conduction, induction and radiation. Although, in theory, all three modes take some part in every interaction most interactions are dominated by a single mechanism. However it would not be practical to define compatibility in terms of the pure interactions by asking general questions e.g. "How are induced effects considered in your safety management system?". Rather the compatibility demonstration is specified between defined parts of the system e.g. between train return current and corrosion of bridge supports. This reduction to specific systems, subsystems and interactions makes a generic definition for cross acceptance extremely problematic even if limited, as in this case, to compatibility between rolling stock and infrastructure (or neighbouring systems).

The international railway community always aspires to explore any possible common consensus between the requirements of individual country and the wider generic phenomena capable of causing similar interactions in all the member countries. Existing assessments may be narrowly defined or even be specific to a single train or infrastructure component.

2.1 Infrastructure

The power supply system is a subsystem of the overall railway system and cannot be designed in vacuum. Therefore, to specify the requirements of the power supply, the starting point is the physical layout of the route, the location of the passenger stations, the topography of the track route including the curves to be encountered and their physical characteristics. This information together with the required acceleration and speed of the train as a function of position along the track can be used, to determine the tractive effort requirement of the train as a function of position.

Different operating scenarios are assumed starting with the number of trains per hour to run, in what station a train should stop, what are the speed limits at various lengths of the route, the required acceleration and deceleration, and so on. All these acts are to determine location of the trains at any instant of time. Having those snapshots, the concerned engineer determines the power requirements at the different points on the tracks (where the trains are). This information provides the interface between the overall system and the power supply system energizing the trains. The specifications of the electrification system constitute a subset of the overall specifications, for example, voltage specifications are specified by international standards such as BS EN 50163 [6] and IEC 60850 [7].

There are two basic components that influence the performance of the railway power supply system:

- Capacity and number of Auto Transformers (AT) and converters: The power requirement of each train on each track and the location of each train is calculated using the speed and the traction effort and therefore capacity and number of the power supply units is established in order to fulfil the demand of the vehicles.

- Power lines. The power lines (wires) are the messenger, the catenary, the static, and the feeder wires; one for each track. In few literatures, the messenger wire and the catenary wire are called the catenary system or the Overhead Catenary System (OCS). The rails are used as return conductors also. The configuration of the system specifies the coordinates, material and diameter of each conductor (horizontal and vertical distances, usually from the centre of the track) and also what type of conductors are to be used.

2.2 Rolling stock

Various types of rail traction used in Europe use some form of power electronics. Diesel engines are less of an issue in that they do not use electric traction and as such the threat emissions (most of which will arise from an alternator are likely to be relatively low frequency. Rectifiers converting DC to AC may introduce higher harmonics from the alternator but these are only likely to be a problem below a few MHzs.

However, from both the radiated emissions and EMI with broadcasting services perspectives, electric traction is more of an issue. Electric traction units receive power through conductors either above or below the train parallel to the track through either a conducting shoe on a separate power rail; or, more commonly, an overhead catenary/pantograph system. In Sweden the overhead arrangement is run at 15 kV AC at 16.7 Hz.

3. Matlab model for the infrastructure

A typical AC railway power feeding system receives the electricity supply at the substation. For technical reasons, like feeding reliability, protection, rotation of phases, and so on, any feeding section is isolated from the others and supplied with only one power substation/converter. A feeding section is typically about 100 kilometres long. Conventionally, the power substation/converter is connected to the feeder transformers 10 kilometres apart from each other.

The detailed scheme of the power supply system in the Swedish railway infrastructure is shown in figure 1.

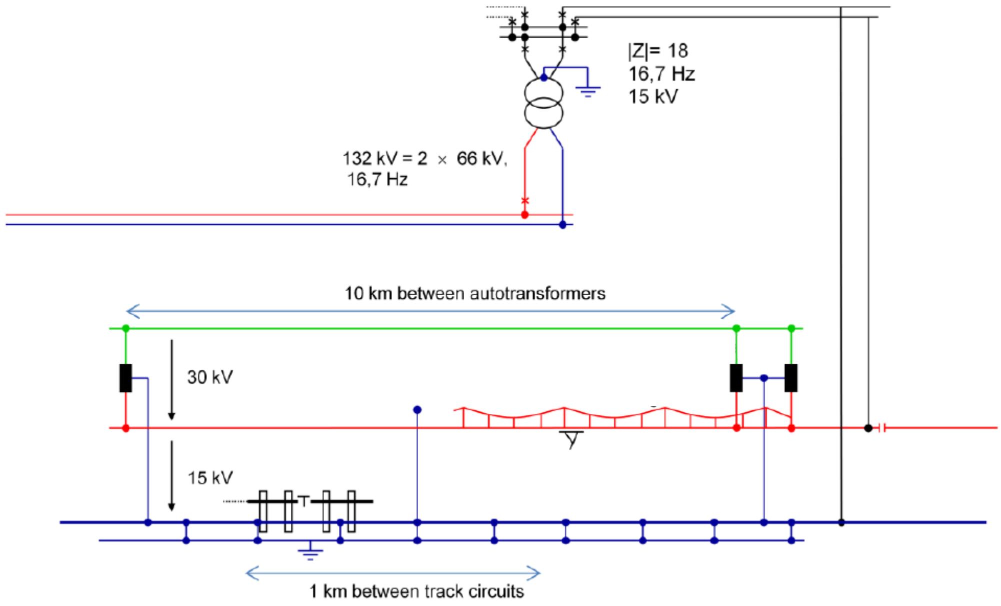

Figure 1. Detailed scheme of the power supply system in the Swedish railway infrastructure after the converter.

There are two major components to be modelled in the infrastructure. The cables feed the system and run along the tracks hanged from the poles. The transformers are located at every certain number of kilometres and assure the power supply to the transmission lines.

3.1 Cable system

The catenary system (C) in the figure below represents the messenger wire and the contact wire. The contact wire (the wire touching the pantograph) should be as horizontal as possible so that the contact pressure between the contact wire and the pantograph is more or less uniform. However, a wire supported at the two ends on poles will assume a catenary shape represented by hyperbolic function. Hence, a wire, called the messenger wire is supported at the two ends at the poles with the help of insulators and the contact wire is attached to the messenger wire by hangers of varying lengths to keep the contact wire as horizontal as possible. Figure 2 shows a schematic diagram of a Swedish pole with ten conductors in a single track configuration. For greater accuracy, each wire is modelled separately and no bundling of conductors was performed. The mutual impedances have been calculated using readily available formula and presented in the tables below. To model the line in SimPower, the mutual inductance element is used. Since there are 10 wires, there are large number of mutual impedances and are connected as shown in figure 3.

This single track has been modelled as a black box that comprises of all conductors between two poles (60 meters distance) and represented as a 10 inputs / 10 outputs system where the lines are interacting according to coupled inductions and mutual capacitances.

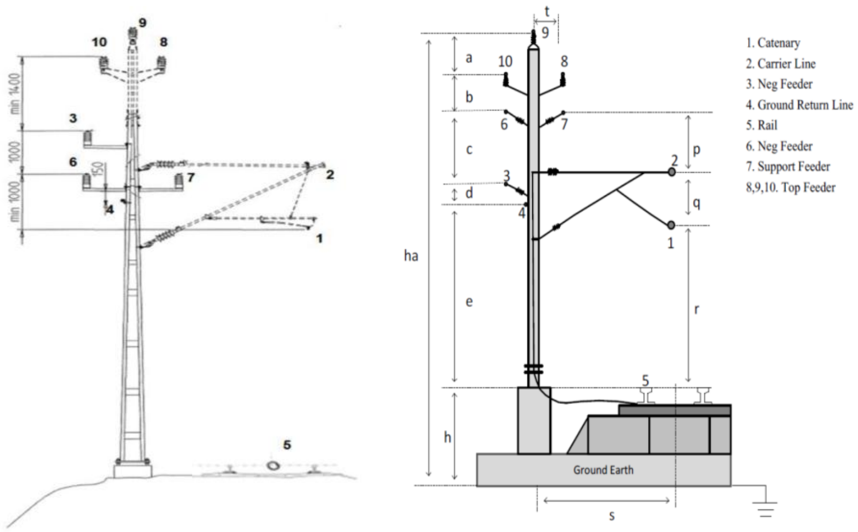

Figure 2. Swedish Power line pole.

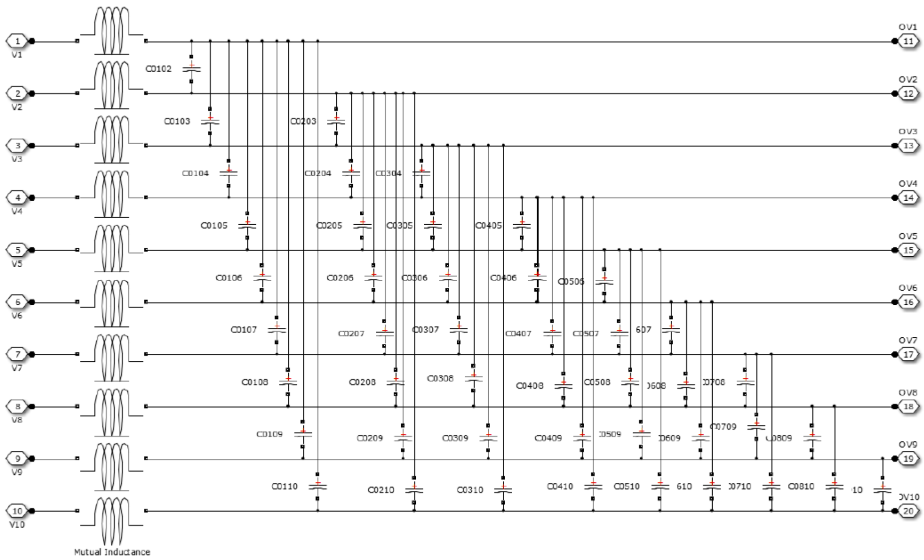

Figure 3. Cable coupling between transformers.

3.2 Transformer

As the autotransformers are used in the Swedish railway infrastructure, it is relevant to present the equivalent electrical circuit used to model the auto transformer as shown in figure 4:

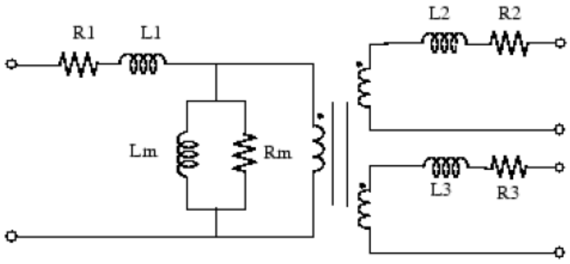

Figure 4. Equivalent circuit diagram of the autotransformer.

The whole infrastructure system can now be represented by a single model taking into consideration that series configuration of the blocks corresponding to the cable will come out as an accurate version of the real catenary system.

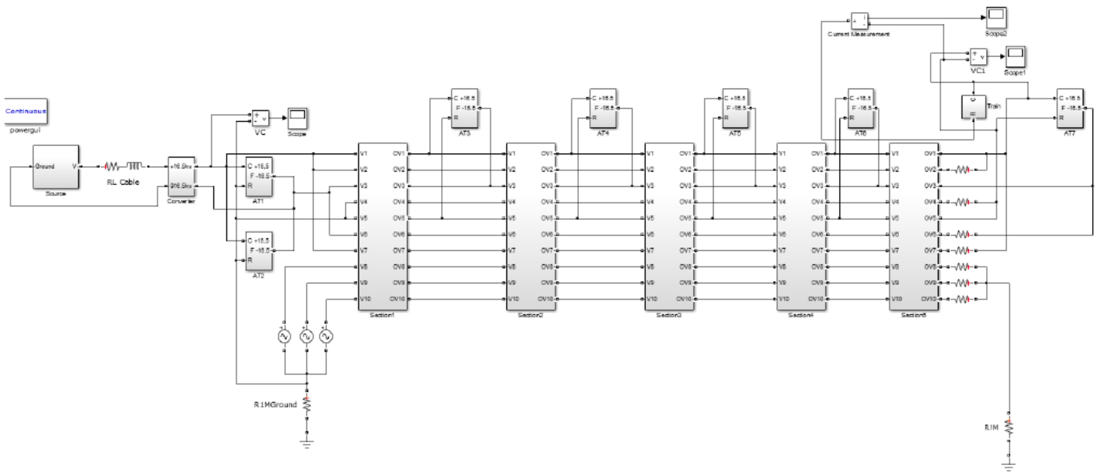

Figure 5. Matlab model of the power supply system in the Swedish railway infrastructure.

Figure 5 shows the model developed to simulate the railway infrastructure in terms of power supply. Distance between the converter and end of the line is 100 kilometres (section isolated). In between, several auto transformers can be found in the interval of ten kilometres to feed the corresponding sections. These track sections have cable sets (10 input/outputs boxes) connected in series configuration (each box corresponds to 60 meters as a distance between poles).

4. Integration with rolling stock: System of systems approach

The proposed railway infrastructure system modelled with Simulink offers the flexibility integration of train anywhere along the track. This enables the system to check different scenarios when the train is close to the transformer or far and the power transferred is minimum. It also allows to simulate the worst scenarios for transmission lines in terms of signal propagation.

The accuracy of the integration is such that the train can be allocated anywhere between two poles, but the train being an active load will unfortunately contaminate the power line with harmonics. One very important verification test was to check the validity of the model for the idle currents in absence of train. See figure 6.

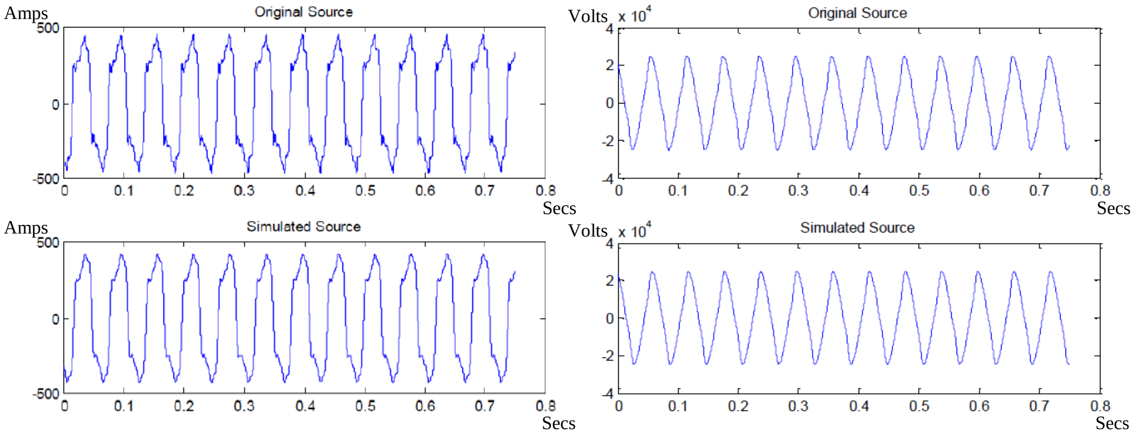

Figure 6. Original and simulated current and voltage between the converter and the AT.

The similarities in both signals partially verifies that the model reproduces real condition in absence of active load what creates optimum initial condition to introduce the rolling stock as a subsystem of the overall railway system.

Once the train load is connected, the signals (power supplied by the converter) are entirely different and there is an obvious phase shift between the voltage and current. Measured and simulated signals don’t differ significantly and, therefore, the model can be assumed as valid under certain boundary conditions.

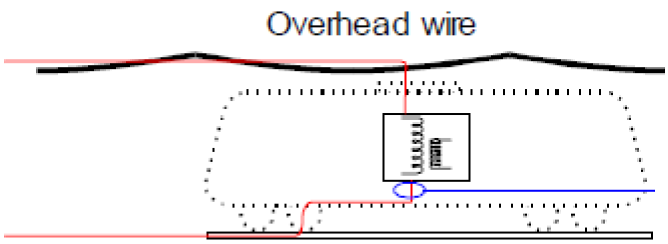

Figure 7. Schematic diagram of the train.

The outcomes of this integration will be the different power signals produced by the presence of the train in different position along the track. This dynamic response containing harmonics and high power consumption will produce some undesired effects in the surrounding areas affecting electronics systems and components and other stuffs as a consequence of radiated emissions produced by these conducted signals.

Therefore, the previously described model exhibits the capability to replicate the conducted emission along the track in the power systems. The conducted emission may be potentially dangerous for the safety of signalling systems and other electromagnetic sensitive stuff.

5. From conduction to radiation model: Fault detection stage

Computed power signals must be converted in radiated signals in order to check their effects on the neighbouring electronic devices and systems. Matlab/Simulink is limited for that purpose and there are several commercial tools and software available which can provide a high frequency view of radiation.

The software chosen was the CST STUDIO SUITE [8], a 3D design software. Our case of study was the Niemisel Station (Northern Sweden), when we performed a measurement campaign to obtain all the required values to reproduce the same scenario in the model.

This software has demonstrated its ability to provide the most accurate and efficient computational solutions for electromagnetic designs as circuit simulation in a wide range of frequencies. It offers a wide range of EM simulation platform to address design challenges across the electromagnetic spectrum, from static and low frequency to microwave and RF, for a range of applications, including EDA & electronics, EMC & EMI and charged particle dynamics. The main piece of this software's product range is CST STUDIO SUITE®, capable of providing a complete set of 3D electromagnetic simulation tools, along with a number of related products dedicated to more specific design areas such as cable harnesses, PCBs and EM/circuit co-simulation.
These functionalities fit perfectly into the requirements of the work being carried out as part of the consortium. For this purpose, CST CABLE STUDIO™ will be used. This simulation software is dedicated to the three-dimensional analysis of signal integrity (SI), conducted emission (CE), radiated emission (RE), and electromagnetic susceptibility (EMS) of complex cable structures in large electrical systems. It provides powerful import filters from popular MCAD and ECAD tools for smooth integration into the industrial workflow.
CST CABLE STUDIO™ (CST CS) is equipped with enhanced visualization capabilities in order to interactively highlight the selected signals or cables in both the 3D graphic view, as it can be shown in the figure 8, and the 2D schematic view.

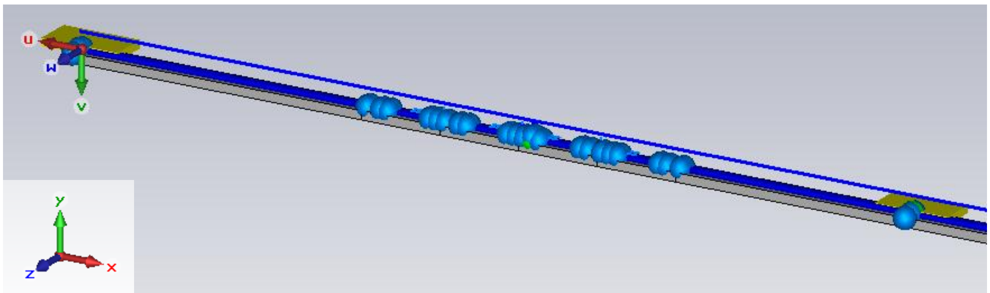

Figure 8. CST CABLE STUDIO 3D model.

The goal of the model is the study of the radiated emissions, mainly produced by the train and in the connections between the cables. See figure 9 in the next page.

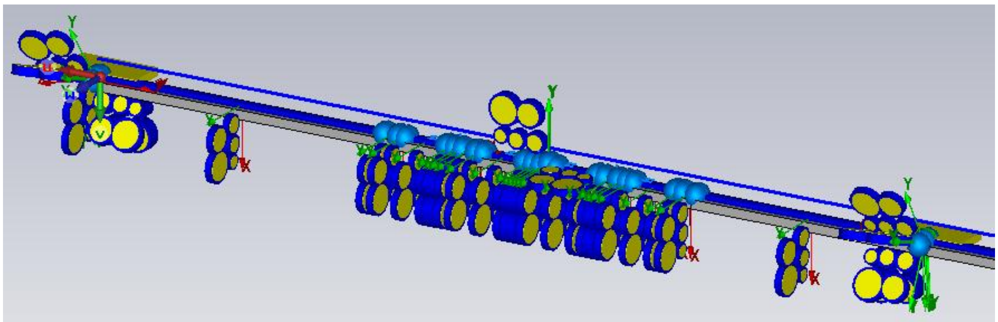

Figure 9. Radiated emissions.

6. Conclusions

The paper discusses about the possible erroneous operation in railway system because of EMI of different electrical and electronics systems and has proposed the model of the power supply system in the Swedish railway infrastructure to integrate a train as an active load to carry out simulations. The goal of this fault detection technique is the simulation of interaction between complex subsystems, which comprise the railway system. These systems of systems approaches aim to reproduce faulty scenarios, which are not dependent on the individual functioning of the subsystems but appear when subsystems interact. EMC issues in railway seem to be a feasible technique for NFF (Non Fault Found) techniques where traditional condition monitoring fails due to the lack of knowledge regarding the multivariable interdependence among the systems.

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