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A systems approach to solve the locomotive and signalling EMC problem

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Abstract

Much has been published on the locomotive and signalling system electromagnetic compatibility problem over the past decade and many solutions has been proposed. The problem can however only be solved optimally if a systems approach is taken. With this approach the railway system is viewed from a level where the locomotive and the signalling are components. The procedure described here starts by defining an acceptable risk for the railway system and then these requirements are allocated to individual components of the railway system, in a top down fashion. In order to ensure conformance to the allocated risk requirements, tests are performed under normal operating conditions and a failure mode effects and criticality analysis (FMECA) is performed for failure conditions, for each of the subsystems. Apart from the description of the procedure and its correlation with the draft CENELEC standard, practical results on tests and simulation are also presented.

1 Introduction

Problems experienced in Europe on projects such as the Eurostar, and in South Africa with the introduction of the first variable frequency drive locomotives and train sets, have clearly indicated that a new approach to EMC assessment was needed. In the case of the Eurostar the requirements in the specifications of the locomotives was such that it could be met by the installation of a vital ("fail safe") interference monitor. When the locomotives was tested however, it was soon discovered that the availability of the locomotive was seriously effected by regular tripping due to interference being detected by the IMU. The sensitivity of the signalling had to be modified in order to make the availability of the train service more acceptable. If it could be done in the reverse order, maybe a vital interference monitor might not have been required.

In South Africa the specifications for new rolling stock did not include any interference profiles and only called for the locomotives to be compatible with the installed signalling system, implying the inclusion of fault conditions. After initial tests it was soon realised that in order to be able to issue compliance certificates, a means (such as an IMU) was required to ensure compatibility under fault conditions. This requirement was met with a lot of resistance from the rolling stock engineers. From their point of view the sensitive signalling equipment should rather be replaced with modern coded type track circuits.

Apart from the above, Spoornet has recently been commercialised and is thus changing from a technology driven company to a profit driven company. Since the survival of the company relies on business principles, risk assessment has become part of the decision making models, and absolute safety have to make way for cost effective systems which are safe enough, and thus presents an acceptable risk.

These influences, together with experience of compatibility assessment, have led to the development of a new EMC assessment methodology, which will be presented in this paper.

2 A systems approach

Electromagnetic compatibility is the joint responsibility of the signal and rolling stock engineers. Since the signal engineers is being perceived as the custodian of railway safety however, they usually feel more responsible for the EMC. With the introduction of new rolling stock the signal engineer would determine the maximum allowable interference levels which could be tolerated in terms of the susceptibility of installed signalling equipment on the effected routes. If this could not be met with the new locomotive, this would mean that the signalling equipment could fail under certain conditions, thus violating the fail safe principle. Therefore he would require the locomotive to be compatible, even under all possible fault conditions.

By doing this he is essentially imposing the probability requirements of the signal system onto the rolling stock EMC problem. It is this single factor that has caused a lot of conflict between the signal and traction engineer. The probability requirements for failures causing a wrong side failure in the signalling system must surely be different from the probability requirements for failures on the locomotive, which can cause a wrong side failure.

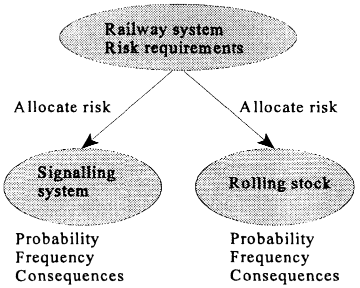

Figure 1 Top down allocation of risk requirements

This can only be understood if a systems approach is used to address the problem. This requires that the railway system which include subsystems such as signalling, rolling stock, personnel, operating methods and procedures should be viewed as a whole and that this integrated system should deliver the required safety, reliability and availability. Acceptable risk should be defined for the railway system first, and then these requirements should be allocated to the subsystems. Each subsystem should then be treated on its own and solutions should be found enabling conformance to the allocated requirements, as shown in Figure 1.

3 Risk assessment

Spoornet Risk Management has developed a risk assessment system consisting of a three dimensional value system. These dimensions are:

- Likelihood (probability) of a hazardous event occurring (P)
- Consequences of an occurring hazardous event (C)
- Frequency of such an event occurring (F)

Each of these dimensions is allocated a range of values as presented in Appendix A. Every hazardous event is then rated in terms of these values and the risk is calculated:

$$\text{Risk} = P.C.F$$

3.1 Allocation of the risk requirements to signalling

Once the risk requirements for the railway system are defined, and allocated to the subsystems such as the signalling system, compliance can be investigated. In the case of the signalling system there are thousands of signals, track circuits, and interlocking installed, which are used to issue millions of authorisations daily. Therefore it can be concluded that the frequency of a hazardous event (WSF) is very high.

If a hazardous event occurs, then it is accepted that the consequences are usually catastrophic in terms of damage to assets and human lives. Therefore it can be further concluded that the consequences are rated very high as well. In order to conform to the allocated risk requirements the signal engineer is left with only one dimension under his control, namely the probability. It is therefore not surprising that wrong side failure figures such as 1 in 10^7 years are used for the signal equipment.

3.2 Allocation of the risk requirements to rolling stock

In the case of rolling stock interfering with the signalling a number of very specific conditions must be present. As an example take the case of locomotive with a variable frequency drive causing a wrong side failure. For interference to occur the locomotive speed has to be correct, it has to be travelling on a fairly long, specific type of single frequency track circuit, drawing a lot of current and simultaneously have some failed input filter capacitors. In terms of this example then it can be concluded that the frequency of such a hazardous event occurring is not very high.

The consequences, when the event occurs, are also considered to be catastrophic and therefore a very high rating is allocated. From this it can easily be concluded that in order to conform to the allocated risk, the probability of failures on the locomotive does not have to be as severe as those of the signalling system. Therefore it is wrong to make the signalling requirement applicable to the rolling stock, and visa versa.

4 Risk assessment procedure during EMC assessment

Because of the technical detail and the complexity of interference mechanisms, risk assessment of a hazardous event must be substantiated with scientific analysis of the electromagnetic compatibility. This analysis can be divided into two phases namely

- assessment during normal operating conditions
- assessment during failure conditions

4.1 Assessment during normal operating conditions

When new locomotives are acquired, it is essential to ensure that the locomotive and the signalling system are compatible under normal working conditions [1], otherwise signal system availability will be seriously affected. Thus compatibility under normal working conditions (see Figure 2) can be achieved by modifications on the locomotive, on the signalling system, or a combination of both. This decision must however be made jointly between the Signals and Rolling Stock departments in order to ensure an optimised solution from a railway system point of view.

At Spoornet an extensive test programme is followed to prove the electromagnetic compatibility under normal working conditions. Information on these tests and the facilities developed by Spoornet has been published elsewhere [2].

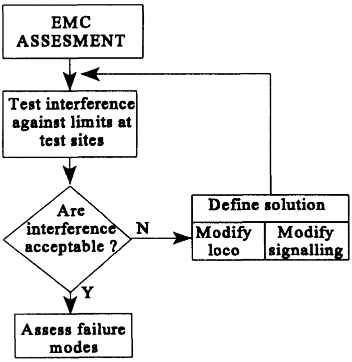

Figure 2 EMC assessment with normal conditions

As an example the assessment of the Class

14E main line locomotive will be used. The results shown in Figure 3 depicts a situation where a consist of three locomotives generates an interference level above the allowable limits for a particular type of track circuit employed on DC traction lines.

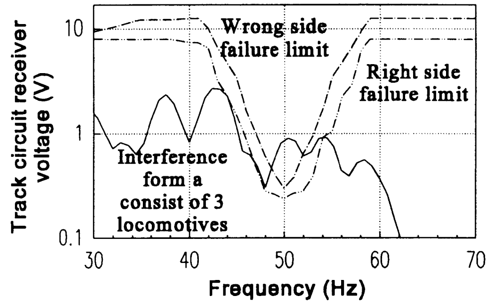

Figure 3 Measured interference voltage

Since this occurs under normal working conditions, this is obviously an unacceptable situation and a modification to either the locomotive or the signalling system is required. Because of the extensive installed base of signalling equipment, it turned out that it is more cost effective to modify the locomotive to reduce the interference. Therefore an active filter was introduced on the locomotive as shown in Figure 4.

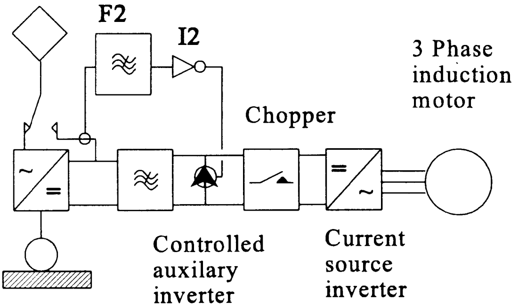

Figure 4 Block diagram showing an active filter

With this modification the current at the input of the locomotive is measured and filtered The output of the filter (F2) is used to control a controlled current source (auxiliary inverter) in such a way that the interference current drawn on the input is effectively cancelled.

Tests performed on the locomotives after the modification is shown in Figure 5.

From the graph in Figure 5 the effectiveness of the active filter can be clearly seen. These results clearly indicate that electromagnetic compatibility can be achieved under normal working conditions.

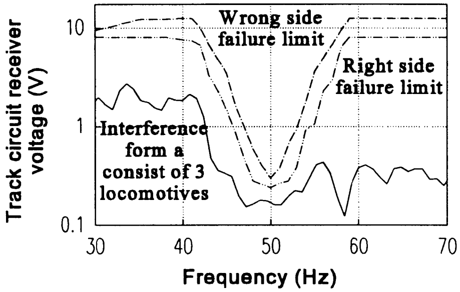

Figure 5 Measured interference after modification

4.2 Assessment during failure conditions

Once the locomotive has been proved compatible with the existing signalling system, interference during failure conditions must be assessed. The use of a FMECA is well known in engineering [3] and has been used in the signalling industry [4]. The general procedures are not always directly applicable and must be modified somewhat before they can be used in the assessment of EMC.

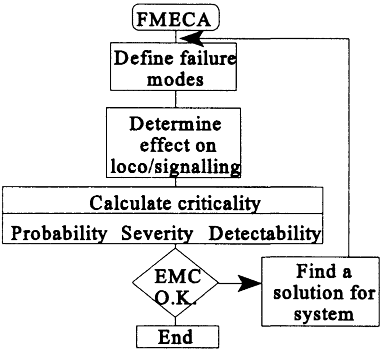

Figure 6 Procedure for performing a FMECA

As with the FMECA of signalling systems, the failure modes of subsystems and components of the locomotive must be defined, see Figure 6. These will include failures in the locomotive power electronic circuitry and the overhead traction system.

Following this, the effect of the failure on the interference current, and thus the signalling system, must be known. With this known the criticality of the failure can be calculated in terms of three dimensions namely: probability, severity and detectability. Every one of these dimensions is rated on a ten point scale [2].

4.2.1 Probability

This dimension states the possibility of a particular failure occurring. This should be done with a major contribution from the rolling stock department and the developer, because of their vast experience in this field.

4.2.2 Severity

The severity gives an indication of the interference effect of a failure on the signalling system. This can be assessed either by measurement or simulation [8] as described earlier.

4.2.3 Detectability

The third dimension is the detectability of the failure. Here the unavailability of any detecting functions is considered and also rated on a 10 point scale. The detecting function could be total power loss of the locomotive and indication to the driver etc. Certain failures might not be detected at all. An example of this being a reduction in the input filter capacitance of the locomotive.

4.2.4 Criticality

Once every defined failure has been rated accordingly, the product of the three

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ratings is calculated which gives the criticality rating of the failures. The criticality ratings are divided into three groups as shown in Appendix A.

5 EFFECTS ANALYSIS

In many cases it is difficult to assess the effect of a failure in the power electronic circuit of the locomotive, because most of the time the failure cannot be introduced physically, as the consequences of such an action can be very expensive and even dangerous. To overcome this, a combination of tests and simulation models can be used very effectively.

5.1 Tests

The measurements discussed previously, are mainly used to prove compatibility of the locomotive and the signalling system, under normal operating conditions. Fault conditions such as a faulty harmonic filter in the substation and a limited number of failures in the power electronic circuitry of the locomotive can also be tested.

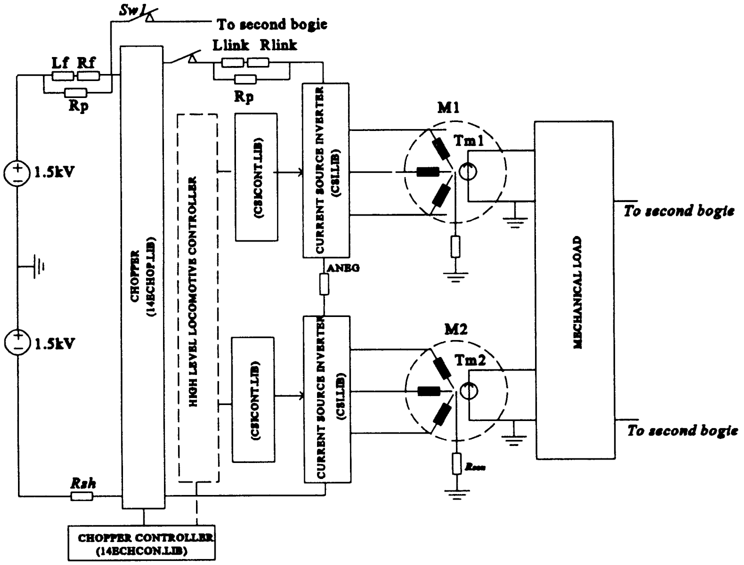

Figure 7 Locomotive simulation model in EMTP.

5.2 Modelling and Simulation

As was mentioned earlier, most of the failures in the power electronic circuitry of the locomotive cannot be tested because of the possible catastrophic consequences and the accompanying cost. For this reason, calibrated simulation models of the power electronic circuit of the locomotive are very useful [5,6], and can be used to simulate the failure conditions at a very reasonable cost [2]. A model developed for the locomotive is shown in Figure 7 and was implemented in modular form in the EMTP simulation program.

Usually these simulations are performed by the manufacturer of the locomotive [1], but in cases where this was not required in the specification of the locomotive, these have to be performed within Spoornet. The advantages of this is that the technological gap between the different railway disciplines can be bridged, and the compatibility levels can be optimised.

5.3 Calibration of simulation models

Before the simulation model mentioned above can be used in the assessment of electromagnetic compatibility the simulation results must be verified by experimental results. This is done during steady state as well as transient conditions [7].

5.4 Example fmeca - applying the model

5.4.1 Failure condition

The application of the simulation model can be demonstrated by the simulation of a transient condition. The case where the power connection to one of the bogies is disrupted during normal working conditions is investigated. A simulation was done for the case where the locomotive is operated with a d.c. link current of 800A, and the chopper frequency of 298Hz. Once steady state is reached the current to the second bogie is interrupted (Sw1 in Figure 7), and the simulation continues for a further period.

A moving window FFT [8] is then performed on the input current of the locomotive to determine the frequency spectrum as a function of time. From the simulation data the duration amplitude versus time for the 50Hz component curve can be constructed, as shown in Figure 8 together with the permissible limit for the 50Hz track circuit. As can be seen from the graph, the duration of the interference signal is more than that allowed for the 50HZ AC track circuit. It can therefore be concluded that tripping of a second bogie can present an interference problem.

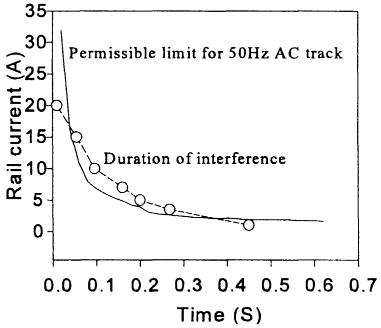

Figure 8 EMC assessment in terms of duration.

5.4.2 FMECA

If the FMECA is performed with respect to this failure, a criticality rating of 288 is obtained as shown in Table 1.

Failure mode	Effect	Criticality			
		P	S	D	Cr
Second bogie power loss	Transient with Possible WSF	8	9	4	288

Table 1 FMECA

According to the ratings in Appendix A this falls into the ALARP classification and therefore the risk should be assessed and the failure should be analysed and something should be done to reduce the criticality to as low as possible.

5.4.3 Risk assessment

The likelihood that one of the bogies trip, is considered quite possible and therefore rated with a value of 6. In determining the frequency of occurance, the number of this type of track ciruits installed on the route in relation to other types has to be taken into account. The expected usage of this type of locomotive as part of the total traffic on the route should also be taken into account. For locomotive considered here and the conditions in South Africa the frequency is then established as being unusual and therefore a value of 2 is allocated. The locomotive will mainly be used for freight and therefore the consequences is considered disastrous with a value of 40. Therefore

$$\text{Risk} = 6 \times 2 \times 40 = 480,$$

which is clasified as a very high risk (see Appendix A).

6 Possible solutions

This problem can be addressed in a number of ways. Of the more practical solutions are:

- trip the main circuit breaker in the case of power loss to one of the bogies
- introduce an operating rule - ie. Stop the train and progress slowly to next signal
- install a non-vital interference monitor (IMU)
- install a vital interference monitor (IMU)
- introduce a time delay on the track circuit.

Since the installation of a non-vital interference monitor is beneficial for the detection of other faults identified with the FMECA this solution is considered. The FMECA can be redone for the case discussed above as shown in Table 2.

The criticality has reduced, but still remain in the ALARP region. Reassessment of the risk gives a great improvement with a value of 22, thus a possible risk. Slugging of the track relay's was also considered, but was not selected due to the cost.

Failure mode	Effect	Criticality (non-vital IMU installed)			
		P	S	D	Cr
Second bogie power loss	Transient with Possible WSF	8	9	2	144

Table 2 FMECA

7 INTERNATIONAL STANDARDS

It is interesting to note that a draft specification (prEN50238) has been developed by CENELEC sub-committee 9XA and that the procedure described here is almost identical an will conform to all requirements when the final version is issued.

8 CONCLUSION

Many failures on the locomotive will not cause an interference problem on the signalling system, but some failures will. Measurement of the effect of these failures is in many cases not possible, and therefore calibrated simulation models becomes a cost effective alternative. It has been demonstrated that with use of simulation models, tests and measurement, FMECA and risk assessment, a procedure was developed which can be applied very cost effectively for the EMC assessment of rolling stock and signalling systems.

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Appendix A
SPOORNET RISK EVALUATION SYSTEM

LIKELIHOOD (PROBABILITY)	VALUE
Might well be expected (Happens often)	10
Quite possible	6
Unusual but possible	3
Only remotely possible ("Has happened somewhere")	1
Conceivable but very unlikely ("Hasn't happened yet")	0.5
Practically impossible ("One in a million")	0.2
Virtually impossible ("Approaches the impossible")	0.1

EXPOSURE (FREQUENCY) VALUE	
Continuous	10
Frequent (daily)	6
Occasional (weekly)	3
Unusual (monthly)	2
Rare (a few per year)	1
Very rare (yearly)	0.5
No exposure	0

CONSEQUENCES	VALUE
Catastrophic (many fatalities, or damage over R10m)	100
Disaster (a few fatalities, or damage over R10m)	40
Very serious (one fatality, or damage over R1m)	15
Serious (serious injury, or damage over R100 000)	7
Important (temporary disability, or damage over R10 000)	3
Noticeable (minor first aid, or damage over (R1000)	1

Risk Score	Risk Classification
Over 400	Very high risk: consider discontinuing operation/activity
200-400	High risk; immediate correction required
70-200	Substantial risk: correction needed
20- 70	Possible risk; attention indicated
Under 20	Risk perhaps acceptable as is

FMECA - CRITICALITY DEFENITION

Criticality	Rating	Description
Acceptable	1 to 120	Criticality is low enough and can be accepted
ALARP	120 - 500	The risk of this failure should be assessed and the failure analysed to determine if the criticality can be reduced to a value as low as reasonably possible
Unacceptable	> 500	The criticality is unacceptable and should be reduced.