SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 5, No. 1, May 2008, 67-76

Numerical Simulations for Investigating EMC Problems in Industrial Life

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Abstract: The complexity of current EMC problems and the necessity to solve them in an accurate, reliable and efficient way require various analysis techniques. Numerical simulations can be considered as one of the most powerful tools for performing EMC analysis. Computational electromagnetics is used within basic research for example at universities as well as during nearly all phases of a product or system development process occurring in industrial life. Especially here, several challenges result from the application of numerical simulations. The most important ones are described and discussed in this paper. An exemplary interference problem is presented demonstrating the relevance and impact of those challenges.

Keywords: EMC analysis, numerical simulation, industrial life, combined problems.

1 Introduction

The topic of EMC affects technical systems from different aspects, at an interdisciplinary level and during various phases of a project. Hence the scope of work within the area of EMC consists of a wide range of activities such as consulting and support during a project which might preferably be assigned to issues of management. Other tasks are in the areas of training and standardization which basically do not represent tasks specific for EMC but which nevertheless play an important role. And finally there are activities such as measurements or numerical simulations which are more or less on a technical and physical level.

An important activity in the area of EMC can be comprehended as EMC analysis. This means: description and investigation of a situation in which physical mechanisms might cause harmful electromagnetic interference. Hence EMC analysis can be considered as a general term for applying various approaches or methods in order to check, prove or assess whether and to what extent EMC is ensured in relation to an interference case. Very often EMC analysis is carried out by means of numerical simulations.

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2 EMC Analysis

2.1 Areas of EMC analysis

Carrying out EMC analysis does not represent an end in itself; it is rather a task within superior processes:

Development process: nowadays nearly every product or system under development contains a lot of electric and/or electronic components. This is a possible source of a variety of harmful interference situations inside the system as well as regarding the external electromagnetic environment in which the system has to operate. Those interference situations have to be considered and analyzed – preferably during each phase of the development process – since their neglect might drastically affect the quality of the product or system.

Planning process: large, extended and complex systems consist of a wide range of components with different electromagnetic features [1]. Typical examples are the infrastructures of a railway system or of an industrial plant with units for power supply, automations, drives, communication and control. The need to systematically plan a harmonic interaction of different sub-systems and components in terms of EMC often arises. One part of the whole planning or management process is analysis of the total interference situation. This might result in the performance of consequent measures in order to ensure undisturbed operation of the entire installation.

Assessment process: Besides EMC planning of complex systems, there is often the need to prove that the EMC of such a system is ensured under all potential normal, abnormal and failure modes and for all potential configurations of components building up the system. Such evidence is particularly required when a sub-system is inserted into an existing one – which might not be EMC designed – and when the operation of the system affects issues of personal safety. Especially for such assessments, EMC analysis plays an extremely important role and there are increased demands on the accuracy, plausibility and reliability of the analysis results.

2.2 Approaches for EMC analysis

There are different approaches to perform an EMC analysis. The actual approach – applied to a specific interference case under consideration – depends on various parameters such as the complexity of the problem or the requirements concerning the accuracy and reliability of the analysis results.

EMC analysis based on experience: not each analysis will be formally carried out by means of calculations. Being involved in EMC for a longer time might allow analysis and assessment of a particular situation to be based on experience gained in the course of previous projects.

EMC analysis based on the application of simple, technical arguments: even in the process of investigating interference cases which might exist between complex and extended systems, a lot of entries of the resulting interference matrix can be solved by means of simple technical arguments. They can, for example, be derived from a comparison between the emission characteristics of an interference source and the immunity features of an interference victim. In the case of a sufficient margin between those levels no harmful interference may be expected to occur.

EMC analysis based on the application of basic physical formulas: only a few practical problems can be investigated through analytical formulas due to the complex geometries that define the problems [2]. Anyway, in many cases it might be sufficient to model a situation in a simple way, in order to approximately determine the order of magnitude or for worst-case estimations. The interference source can be modelled for example by an infinite line or described by an elementary antenna whose radiation characteristics can be easily derived by simple formulas.

EMC analysis performed by means of numerical simulations: in case the above approaches have proven not sufficiently powerful and efficient in solving the interference problem, a more sophisticated approach has to be applied. In the frame of numerical simulations various methods can be used to transfer the actual interference situation into a physical model which can be described by a set of mathematical equations solved by various algorithms. Every numerical method involves an analytic simplification to the point where it is easy to apply the numerical method [2]. As a result, the relevant quantities can be derived such as electromagnetic field strengths, induced voltages, etc.

EMC analysis by means of tests and measurements: the above approaches which can be considered as being more theoretical cannot be applied in every case. This is the situation for example when there is no data available to characterize or model the situation or when data can be derived only approximately or with enormous effort. In other cases the systems under consideration are too complex to be modeled accurately in reasonable time and with reasonable resources. Then only investigation by tests or measurements can provide the required interference data with sufficient accuracy and reliability. Nevertheless, experiments are expensive, time consuming, sometimes hazardous, and do not usually allow flexible parameter variation.

It could be noted that these approaches should not to be considered independent of each other. For many problems the best strategy for a global solution would be to combine them to solve the problem as fast, accurately and economically as possible.

Further aspects to be considered result from the necessity of determining and assessing in which depth or to which extent an analysis has to be performed in order to provide results that can be considered sufficiently accurate and reliable. This is particularly important when issues of personal safety which might be adversely affected in case of harmful interference have to be taken into account. For this reason it might be helpful to introduce some formal analysis criteria [3].

3 EMC and numerical simulations

3.1 Spectrum of EMC problems

Nowadays, since electrical and electronic devices and components exist in nearly every system, a broad spectrum of potential interference situations exists that can be solved by numerical simulations. This is in particular an important situation in industrial life [4].

From a spatial point of view the spectrum of systems ranges from the inner of integrated circuits, to printed circuit boards and cubicles and further to large facilities such as plants or extended systems for high power transmission or railway infrastructures.

From an electromagnetic point of view phenomena have to be considered under various aspects, e.g., conducted and/or radiated, steady state or transient, and in the frequency range from DC to several tens of GHz.

Finally, from an application point of view systems might be considered in various fields, such as automotive or transportation systems, industrial or power installations or medical apparatus.

3.2 Spectrum of numerical simulation methods

Today a great variety of numerical methods for simulating EMC problems exists [2,5,6,7]. Regarding the formulation employed, they can be classified either as time- or frequency-domain methods. Alternatively, they can be divided between differential and integral methods. Most prominent among modern techniques is the class of Moment Methods (MoM) which are typically formulated in the frequency domain and are based on an integral equation approach. A further class of methods uses an approach based on differentiation of Maxwell's equations leading to Finite Difference (FD) methods. The FDTD (Finite-Difference Time-Domain) – and as a further type the Transmission-Line Method (TLM) – are typical differential time-domain approaches.

Each of these approaches has its particular advantages and the proper choice for the actual problem depends on the problem conditions, such as the necessity for considering nonlinearity or broadband analysis. Thus, it is important, before selecting a method, to determine in advance the objective of the model [5]. The program techniques are continuously developed to extend their capabilities and minimize the disadvantages.

The above methods are complemented by other approaches such as network analysis to simulate circuit problems. Basically it can be stated that during the past years the power of numerical methods has continuously improved and nearly every EMC interference case can be treated by means of such simulations. However, the chosen method might not have the capability to investigate all aspects of an interference case and several different methods might have to be applied. The remaining challenge often consists in finding the most appropriate and effective method to deal with an actual problem and to find a user-friendly implementation of the method.

When carrying out an EMC analysis of potential interference situations the following facts shall be kept in mind in order to achieve confidence in the analysis results [2], [6]:

- Analytical methods and the data used for the analysis shall be observed from a conservative viewpoint: worst-case conditions shall be assumed or the occurrence of possible interference conditions and mechanisms shall be enhanced during the analysis to assure that no potential EMC problem is ignored and a sufficient safety margin is considered.
- Analysis methodology shall be redundant: two independent and differing methods should be applied to identify any occurrence of any possible interference condition, at least when there is an initial indication of potential interference or when high reliability constraints exist.
- A phased approach shall be applied during the entire analysis: a number of passes through the analysis configurations, incorporating additional details and new information on each pass should be accomplished. In early analytical passes input data might likely be based on functional specification information or on estimations due to experience. More exact data of individual component equipment and of the environment or test data shall be incorporated as analytical input data become available during the project progress.

4 Situation of numerical simulations in industrial life

The situation and the conditions of work in industrial life are decisively determined by the fact that all activities therein are observed from an economic point of view. All these activities are aimed at ensuring and increasing the profit of a company. This goal indirectly applies to the field of performing numerical simulations as well. From that basic and overall condition a lot of challenges result.

Necessity for numerical simulations: the need for simulations cannot be planned in detail: depending on the project progress various interference problems might result. This can partly be controlled by means of EMC planning which is recommended in the case of complex and extended systems; but nonetheless, aspects might become obvious which were not considered originally due to the fact that nearly every project is a 'live' project with varying parameters, conditions, environmental issues, etc.

Type of numerical simulations: affiliated with the above point and mainly due to the fact of 'live' projects various aspects might become significant during an actual interference case. In general, however, there is no numerical method or computer program which allows investigation of all aspects of an interference case or of all phenomena. Normally, methods and programs have their specific field of application where they work most accurately, reliably and economically. Hence, in practice, it is necessary to establish a range of methods and programs enabling analysis of a wide range of EMC aspects.

Extent of numerical simulations: as a typical characteristic of 'live' projects interference cases of different complexity, severity and with a wide range of potential consequences onto the system operation or onto safety may occur. Hence there is no standard effort or working time to analyze an individual interference case. Depending on all the problem boundary conditions and requirements it could be possible to analyze and simulate a problem within minutes or it may need up to weeks or months. Linked to that is the issue of technical and personal resources which are to be handled in order to cover the needs of varying simulation capacity.

Time schedule for numerical simulations: a further consequence due to the situation of such projects follows from the time schedule of corresponding simulations. In contrast to simulations during a well organized planning phase sudden arising of problems must be investigated and solved as soon as possible and their simulation cannot be managed under a long term horizon. This means that the actual interference case has to be simplified as much as possible and needs to be as modest as technically justified in order to enable fast solution of the case.

Application to actual and practical problems: beside the area of research and development where mainly fundamental EMC problems are investigated or treated from a general point of view, particular conditions take place in most practical cases. This results in the need to determine actual and realistic parameters which characterize the interference case. The spectrum of such data ranges from purely geometrical data to model the case spatially, to material parameters which often deviate from ideal parameters, up to phenomena in the external electromagnetic environment which might affect the accuracy and reliability of simulations. In many cases the effort for identifying and determining significant parameters exceeds that needed for pure simulations.

Coordination of numerical simulations: due to the conditions concerning type, extent, time schedule and data of numerical simulations the situation might occur where simulations have to be performed within a group or by several project partners. This requires coordination with respect to the overall methodology, the common data basis, data interfaces, etc.

Results of numerical simulations: as far as interference consequences have been identified and investigated, they need results to work out measures to prevent harmful interference. Since such measures might represent a significant impact on the project conditions or the functionality of the system definite evidence must be present that they are necessary, adequate and sufficient – aspects which have to be derived on the basis of the simulations.

Assessment of measures: EMC issues and associated measures cannot be treated as being independent of the project configuration. The project boundary conditions have to be taken into account when working out suitable EMC measures based on the simulations. Their impact on other project issues has to be taken into account as well.

General electromagnetic problems: often specific electromagnetic problems arise during a project progress and they are not directly related to interference situations rather but to other effects resulting from currents, voltages or electromagnetic fields. Nonetheless they are often investigated within the framework of EMC simulations. This might be justified by the fact that EMC simulations use standard numerical procedures for solving electromagnetic problems and such procedures do not apply to the field of interference problems only.

5 Investigation of EMC problems

The need to deal with combined problems often arises from the fact that practical implementation of EMC measures does not solve the EMC problem only but might affect other technical aspects of the system under consideration. Hence additional problems arise as described in the following example:

High power systems, such as variable speed drive systems, static frequency converters, bus bars, etc., generate high field strengths which in many cases have to be attenuated by means of shielding measures. Significant eddy currents are induced due to physical mechanisms of shielding and they cause thermal losses and heat in the shield.

The bus bar system carries high AC currents with a significant contribution of high frequency phenomena and therefore it has to be shielded to reduce its radiation (see Fig. 1). The high AC currents (at rated frequency), however, induce eddy currents in the shielding and supporting structures and due to their arrangement some spots result where the temperature is relatively high. Such local hot spots could affect the long term mechanical stability of the entire structure (see Fig. 2).

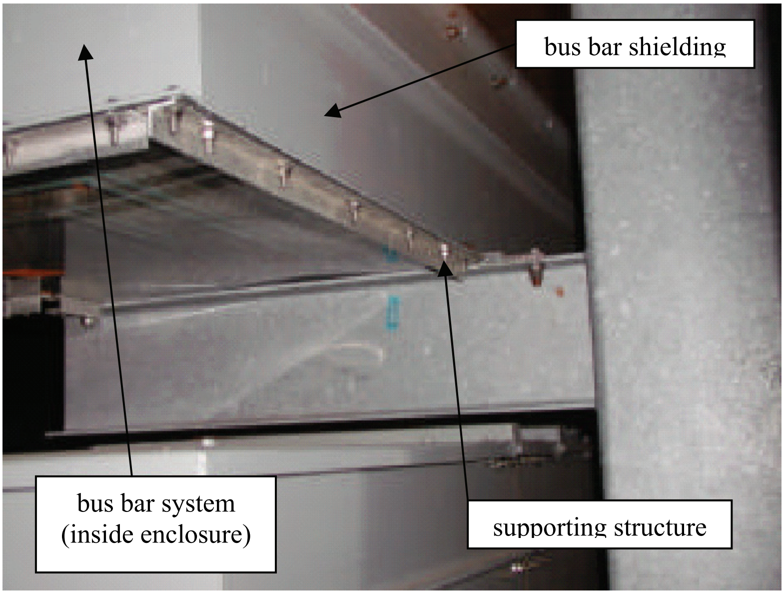

Fig. 1 – *Bus bar and supporting elements.*

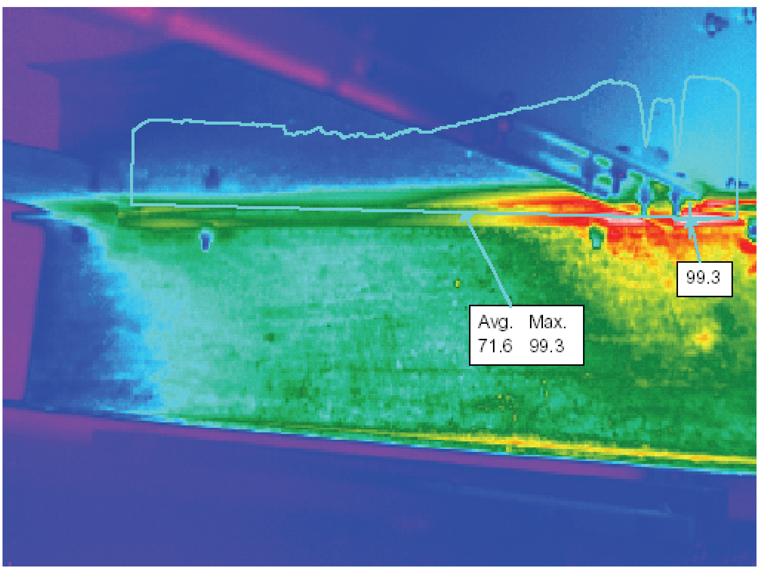

Fig. 2 – *Infrared representation showing thermal stress (temperature indicated in* °C).

In order to overcome this effect and to specify suitable measures, numerical simulations were performed (using FEM). The simulation model is given in Fig. 3. It also shows the distribution of the magnetic field caused by AC currents. The simulations clearly show some areas with relatively high field strength amplitudes causing high eddy currents in the metallic structures at certain spots.

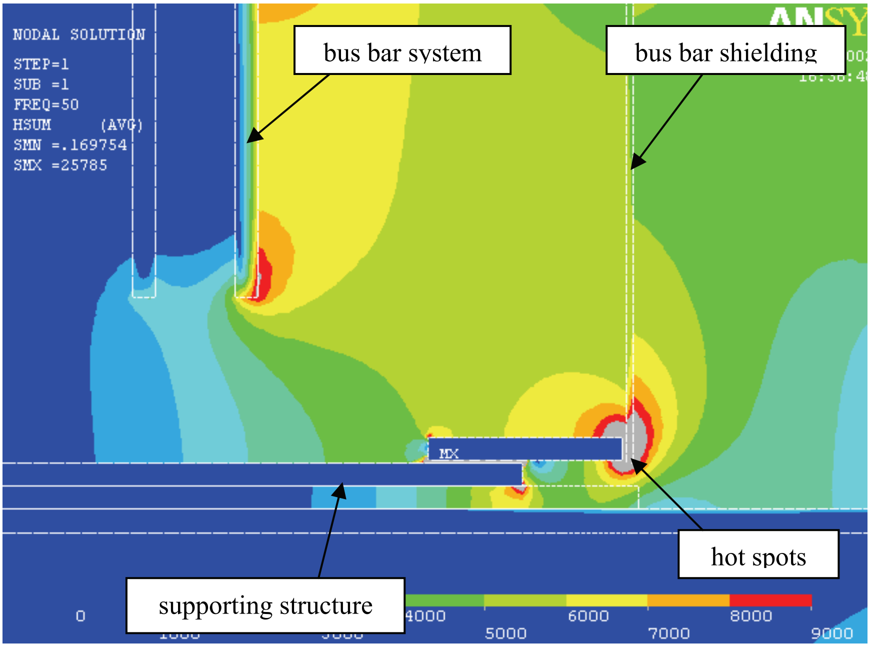

Fig. 3 – *Simulation model of a bus bar with supporting structure and the resulting magnetic field strength distribution.*

6 Conclusion

Numerical simulations represent a powerful method for investigating interference problems. Lately their capability has reached a degree which allows dealing with problems arising in practice during execution of commercial technical projects. Nevertheless various challenges are connected to the application of numerical simulations and utilization of simulation programs. A particular condition results from interactions between EMC issues and other technical aspects or boundary conditions of a system. Taking into account such interactions within programs is expected to lead to more powerful programs suitable for everyday industrial work.

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