ANALYSIS METHODS FOR ELECTRICALLY LARGE SYSTEMS FORM THE PARTICULAR TO THE GENERAL (FOR 417)

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Abstract: The present two pages are introductory remarks concerning the contributions of session Q. All the papers treat the topics of the German EMC research group FOR 417. The short summaries describe the main ideas and intentions of the single projects, putting emphasis on the expected scientific progress.

1 Introduction

In the last few years one could observe a tremendous increase of EM sources, in particular because of the rapid growth and extension in the fields of communication and information techniques. This development is accompanied by a raise of the susceptibility of more and more densely packed electronic devices. Therefore, in order to meet EMC requirements, one has thoroughly to analyse principally new systems with respect to their electromagnetic compatibility, up to several GHz. This shall become a major aspect of the present session: We want to provide tools on the basis of which one can examine electric and electronic systems from lower to high frequencies where the systems already become electrically large. It is our intension to start our investigation from concrete, existing facilities of our research laboratories and will then generalize the essential assumptions and system parameters, and also adopt our tools to become able to handle these new situations. In the following introductory remarks we will very briefly describe this idea for the projects (TP1-TP5) of our EMC research group FOR 417.

2 Electromagnetic emissions of pulsed arc and resistance welding installations (TP1)

In recent years, there is an increasing application of pulsating power for technological processes. Process power sources based on power electronic converters are used to generate and shape pulsating output voltage and current waveforms. To ensure a defined control of the different process periods the power sources must provide a high dynamic response. A number of technological processes e.g. plasma, electrical discharge machining (EDM), arc and resistance welding processes are characterised by high currents (capacitor discharge welding — up to 500 kA, resistance spot welding — up to 60 kA, shielding gas arc welding — up to 800 A), high rates of current change (EDM — up to 1 kA/s, tungsten inert gas welding — up to 20 A/s), high pulse frequencies (EDM — up to 100 kHz). Due to these parameters of the electrical magnitudes the power source, the output cable connection to the load as well as the technological process itself may represent sources of electromagnetic disturbances. In large fields of industry arc and resistance welding are widely used for joining processes. Here, occurring disturbances mainly arise from the power units of the welding equipment. Nowadays, switched-mode power supplies in half-bridge or full-bridge converter topologies are more and more used for welding applications. Whereas the power semiconductors the converters are built of (IGBTs, Power MOSFETs, fast-switching diodes) represent the main sources of high-frequency electromagnetic emissions, pulsating welding currents flowing in the output current loops generate intense time-varying magnetic fields in the vicinity of welding installations which have to be regarded concerning the admissibility of the exposure of the operators. Some results of investigations into the occurring magnetic field distributions based on measurement, calculation and simulation will be presented in this session. Furthermore, scientific progress is expected in the fields of mains supply disturbances influencing power quality (especially mains current harmonics and interharmonics resulting from the interaction of input rectifier and power pulsation) and conducted high-frequency emissions. Starting point of the investigations are industrially used arc and resistance welding inverters which are available in our laboratory facilities.

3 Power Quality in Distribution Power Systems with Symmetrical and Unsymmetrical Pulsed Loads (TP4)

Distribution power systems consist of electrical equipment which is developed with the main objective being to transport and distribute as much electrical power as possible through a 50 Hz (or 60 Hz) positive sequence component to the consumer. To fulfill this goal efficiently the components of this electrically complex system should be matched to each other and to the consumer loads at the aforementioned fundamental frequency.
However, especially in recent years, there has been a continuous proliferation of non-linear type loads, mainly due to the extensive use of power electronic control in all branches of industry and non-linear type generators — as we look at the growing number of renewables connected to the public power systems throughout the world. As a result, the power system is exposed to the new operational conditions and self-generates interferences, which not only decrease the efficiency of the energy transport within it, but badly affect its immunity.
The problem of distortion penetration due to the increasingly stronger presence of power electronic devices in distribution systems is especially important when devices with pulsed power are working in the system. Such devices like welding machines (TP1) demand high current pulses from the supply network. The current spectra draw by these devices depend on their operational conditions and are stochastically variable. These disturbances are then propagated within the supply system — in a

conducted way — reaching other parts of the system and causing e.g. overvoltages, which can lead to damages of the distribution system equipment or/and to bad tripping of the protection devices. This can truly affect the proper system operation and therefore should be analyzed with special care.

Generally, in the scope of this part of the project the models of the network elements will be developed to acquire the significant effects of those disturbances on the direct surroundings of its source. This description will provide the analysis of the pulsed power influence on other parts of the distribution system. By means of this tool it can also be possible to describe the process in mean of the BLT-Equation (TP3) in order to reach the optimal conformity between pulsed-power device (source) and the distribution system (sink).

4 Super Transmission-Line Theory (TP3)

Cabling in complex systems and wiring harnesses are essential elements which collect and transport electromagnetic energy to manifoldly connected electronic devices. Generally the cables are nonuniformly lead through the systems and are excited by internal or external sources having frequency spectra up to several GHz. Therefore, an effective theory to describe linear structures at arbitrary frequencies, including radiation and nonuniformities, of conductors is needed. We know that the Telegrapher equations represent an effective tool to model multiconductor lines at lower frequencies with dominating TEM modes. If we succeeded to cast Maxwell's equations into the form of the Telegrapher equations with modified and generalized, new line parameters (complex-valued, including radiation, etc.) then we could profit from the advantage to be able to use all already known solution procedures for the Telegrapher equations (e.g. product integral, etc.) and apply them to the new theory, the Super Transmission-Line theory. We have derived such a desired theory and will present it and some simple applications in this session. Undoubtedly, the benefit of this super transmission-line theory is the fast solution — even for complex wirings — of the corresponding equations. One can imagine to combine the new theory with existing full-wave numerical packages to a hybrid theory to treat linear structures together with their housings. Of course, we will also apply our theory to our laboratory facilities, however, in this case the classical transmission-line theory or lumped circuit models should be sufficient.

5 Modeling and simulation of 3D interconnection structures by using the method of partial elements (TP2)

Many interconnection structures, especially if they are relatively close to the circuit level, do neither fulfill the preconditions for the classical nor for the Super Transmission Line Theory. This is because conductors are led above a finite ground plane, transversal dimensions are not small in comparison to the longitudinal dimensions, cross sections of wires are arbitrary, often rectangular (traces on PCB's, busbars like used in power electronics), and non-linear loads in electronic devices have to be taken into account.

A powerful numerical tool to treat the above mentioned problems is the method of partial elements (PEEC) introduced by A. Ruehli in 1974. The circuit interpretation of PEEC permits to treat 3D full-wave models with a modified SPICE simulator and thus to use the non-linear models of electronic devices provided by a SPICE solver as loads for the linear PEEC models.

While the PEEC models are more general, the TL models are faster to calculate. Many interconnection structures consist of both, parts that can be analyzed with TL models and parts that have to be treated with PEEC models. Therefore, a hybrid method is desirable. We propose two approaches to it. Firstly, we link a PEEC model with a TL model so that a smooth transition between both models is ensured. This approach is usable if there are no other electromagnetic couplings between the joined parts. The second approach is more general. Based on the PEEC model for the entire system the requirements of the classical TL theory are observed. This leads to a reduction of the number of couplings and to thinning out the parameter matrices. Consequently, computing time can be saved.

Further, based on the PEEC analysis we derive a new possibility for a fast calculation of radiated and incident power in arbitrary wire systems in the frequency domain. This algorithm avoids time consuming field calculation and is also appropriate to include power considerations in the analysis and design for electromagnetic coupled systems.

A new modification of the PEEC method for an approximate modeling of the skin effect in wire-like 3D structures with arbitrary cross sections is presented in the paper of this session. This approach avoids the discretization of the wire cross section in a host of current filaments and is therefore very effective concerning the computing time. Moreover, the model can also be used for time domain calculations.

6 Test Sites for radiated EMC (TP5)

In the low frequency region, where practically all systems are small compared to the wavelength, electromagnetic disturbances propagate mainly along the wiring and radiation effects are of minor importance. Radiated emc testing is well established in the frequency range from 30 MHz up to 1 GHz (wavelength 10 m down to 30 cm) for emission testing, and 80 MHz up to 1 GHz (3.75 m to 30 cm) for susceptibility testing using open area test sites (OATS) or anechoic chambers (AC). At the lower ends of these frequency ranges, most systems can be considered to be electrically small, leading to a small directivity. Coming to higher frequencies, more and more systems become electrically large, especially those which include long cabling. As a consequence, systems generally have a larger directivity at higher frequencies. A high directivity automatically means that radiation patterns become more complicated (the internal structure becomes visible), and the directions of maximum emission and minimum susceptibility will have a stronger angular dependency in comparison to systems with lower directivity. Thus, the detection of the worst case becomes a serious task at high frequencies (for electrically large systems). Using the well established measuring procedures in OATS and AC will then lead to non-robust tests. Mode-stirred chambers (MSC), as electrically large systems, may overcome this problem. These chambers are shielded rooms operated in the (so-called) overmoded region. By changing the boundary conditions, a homogeneous field inside the chamber can be achieved in a statistical sense. Any information about the direction of the radiated wave and its polarization are lost (or meaningless). Therefore, the validity of the results may be increased in a MSC. On the other hand, new problems arise due to the fact that MSCs are high quality cavity resonators. Thus, transient effects have to be considered. In addition, a strong coupling of the MSC and the system under test may occur. In the middle between the two extremes — mode-stirred chambers and anechoic chambers — TEM cells or waveguides (e.g. GTEM cells) are used in EMC testing. In these cells, the field properties are similar to a radiated far field but the coupling of the system with the field generator has to be taken into consideration. The goal of TP5 is to compare anechoic chambers, GTEM cells and mode-stirred chambers with respect to their advantages and disadvantages for radiated emc testing. In the paper for this session the focus is on transient fields in a MSC.